

WoodEMA 2025

**WOOD FOR THE FUTURE:
INTEGRATING SUSTAINABILITY
ACROSS INDUSTRIES**

**Ohrid, North Macedonia
September 17th-19th 2025**





WoodEMA, i.a. – International Association for Economics and Management in Wood Processing and Furniture Manufacturing



Faculty of Design and Technology of Furniture and Interior



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Proceedings of Scientific Papers

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PREFACE

Dear colleagues, experts, and friends of the WoodEMA international association,

We are pleased to present the book of proceedings from the 18th WoodEMA international scientific conference „*Wood For The Future: Integrating Sustainability Across Industries*“, held in Ohrid, North Macedonia, from September 17 to 19, 2025.

The conference aimed to transfer knowledge and good practices from the field of economics and management of the forest-based sector. Topics under consideration and discussion are sustainability and circular economy in forest and wood-based sectors, economic, financial, and logistics perspectives. management, investment, and innovation, artificial intelligence and digital innovation, market trends, marketing, and customer engagement, policy, legal framework, and esg reporting, technological innovations in production and construction.

This year WoodEMA i.a. partnered with Faculty of Design and Technology of Furniture and Interior, Skopje, North Macedonia, International Balkan University, Skopje, North Macedonia, KI-PAR d.o.o., Strumica, North Macedonia and Mebel VI d.o.o.e.l. Vinica, North Macedonia to organize the conference event. We would like to thank them all for their cooperation and the opportunity to see good practices from the Bulgarian furniture industry.

After the review process, the conference book of proceedings includes 82 scientific articles authored by 138 scientists and experts representing 11 European countries. This book includes five main axes of scientific papers which introduce readers to interdisciplinary and various debates about conceptual ideas and approaches towards sustainable, innovative and productive forestry-based sector.

WoodEMA 2025 international conference was conceived as a space for debate and networking among academics, experts and professionals in the forestry and wood-based industries. We are grateful to all authors and conference participants who presented their analysis and points of view regarding important topics of the current market demands and competitiveness, sustainability, as well as new perspectives, innovative ideas and new approaches towards the successful and sustainable forest and wood-based sector.

We believe that the outcomes of the 18th International Scientific Conference WoodEMA 2025 and the book of proceedings will be valuable in future work to all scientists, teachers, experts, professional, and enthusiasts in the forest and wood-based sector.

Editors-in-chief,
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INVITED PAPERS

REGULATORY SANDBOXES IN THE FURNITURE INDUSTRY. CHALLENGES AND OPPORTUNITIES

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Abstract: This report analyses the potential of regulatory sandboxes as an instrument to stimulate innovation in the Bulgarian furniture industry, with a focus on testing smart furniture. Through the use of SWOT analysis, the strengths, weaknesses, opportunities, and threats associated with introducing regulatory laboratories in the furniture sector are identified. Through a case study analysis, regions in Bulgaria with different levels of potential for the pilot implementation of regulatory sandboxes are suggested.

Keywords: smart furniture, regulatory sandboxes, furniture industry, innovation

1. INTRODUCTION

Smart furniture is an innovative segment within the furniture industry that integrates digital technologies, automation, sensors, and connectivity. They not only transforms the traditional appearance and functions of furniture but also raises new regulatory issues related to cybersecurity, personal data protection, safety, sustainability, and certification. El-Gizawi et al. (2023) points out that intelligent office furniture equipped with sensors and IoT solutions significantly improves working conditions and functional comfort for employees, but at the same time requires standardisation and clear regulation for its full-scale implementation. Schwarz et al. (2021) analyzes how smart furniture and IoT in smart homes increase the level of automation but raises concerns related to security and privacy. Xu (2024) examines trends in smart furniture design, emphasizing that IoT solutions and user experience are key factors for their widespread integration. Smart furniture is tailored to individual users, combining technology with craftsmanship, hence Červený et al. (2022) note that the furniture industry still lags behind the Industry 2.0 level. Yet the authors argue that with proper planning and cooperation among small and medium-sized enterprises, the implementation of Industry 4.0 can significantly enhance the efficiency and sustainability of production. However, this may prove insufficient. Manufacturers in such an innovative segment could also face serious regulatory burdens related to product safety, compliance with environmental standards, and supply chain transparency.

The integration of AI systems, both in the manufacturing process and in the final product, further binds manufacturers and suppliers to the obligations in the Artificial Intelligence Act for safety, health protection, and fundamental rights. As explained in the Commission's notice the "Blue Guide" (2022) on the implementation of EU product rules, the general principle is that "more than one piece of Union harmonisation legislation may apply to a single product." Placing a product on the market or putting it into service may only occur when it complies with all applicable legislation of EU for harmonization (Art. 46 of the Artificial Intelligence Act). This poses a serious challenge for all actors across the value chain, as well as for regulatory and market surveillance and control authorities. It requires a different and flexible approach to regulation and support for innovation, increasingly linked to the possibility of testing products in controlled environments before they are implemented on the market. This aims to provide a

controlled experimentation and testing environment through which both manufacturers and regulators can gain knowledge, assess risks, and develop effective rules. In this respect, as part of the “smart regulation” concept, regulatory sandboxes are viewed as regulatory instruments for fostering innovation (G20 Survey) as they perform a “dual role”. On one hand, they support businesses in testing and implementing innovations in a real-world environment, and on the other hand, they provide a mechanism for regulatory learning and adaptation. They are described as “a limited form of regulatory waiver or flexibility, allowing firms to test new business models with reduced regulatory requirements” (Attrey et al., 2020). They are prescribed as „specific and structured experimental frameworks that enable the real-world testing of innovative technologies, products, services, or approaches for a limited period and in a limited part of a sector or area under regulatory supervision“ (EP, 2022). Regulatory sandboxes have a special place in the Artificial Intelligence Act as “measures to support innovation” and receive their legal definition (Art. 3, point 55) and regulatory framework (Arts. 57 and 58). Hence, ensuring that appropriate safeguards are in place. Regulatory sandboxes can be seen as a key instrument for promoting innovation in the furniture industry, particularly for smart furniture, where end products combine design, functionality, and digital technologies.

The main goal of the paper is to analyse the potential of regulatory sandboxes as an instrument for testing and assessing the compliance of smart furniture models and systems in Bulgaria, following the relevant regulatory framework. The authors hypothesise that regulatory sandboxes can support the transformation of the Bulgarian furniture industry by creating a controlled environment for testing and adapting smart technologies without breaching existing regulatory standards and with reduced risk for enterprises. The research methodology is based on a SWOT analysis to identify the strengths and threats associated with implementing regulatory sandboxes in the Bulgarian furniture industry, as well as a case study approach to determine suitable regions for the pilot application of regulatory sandboxes.

2. STATE OF THE ART

The furniture industry contributes over 3% of the added value in Bulgaria's industrial sector and employs more than 30,000 individuals, underscoring its economic significance (Ministry of economy and industry, 2024). Some examples of smart furniture in Bulgaria include the smart desks for schools under development by the Bulgarian Furniture Cluster. These desks come in three models for different student age groups and include tables for charging devices, integrating modern technology to improve the learning environment. The design firm ALL in Studio has implemented a smart home system in a two-story apartment in Sofia, allowing residents to control lighting, climate, and other features via smartphone, showing how smart furniture can enhance residential spaces. Ergonomic Furniture BG produces electric height-adjustable desks that support better posture and overall health. Profis BG develops smart solar benches equipped with solar panels, USB ports, wireless charging, environmental sensors, and LED lighting. However, the integration of smart technologies into furniture design and manufacturing in Bulgaria has not been analysed under the regulatory sandbox concept. Bulgaria has no prior experience in designing and managing experimental test environments such as regulatory sandboxes. In December 2024, the Library-Information and Research Parliamentary Centre at the National Assembly of the Republic of Bulgaria published a sociological study entitled “Regulatory Sandboxes as Part of Evidence-Based Legislative Policy” (Parliament.bg). The findings of the study indicate that a “significant gap in the

understanding of regulatory sandboxes and experimental clauses.” The main challenges and barriers to introducing experimental regulatory environments in Bulgaria include limited administrative and financial capacity, lack of coordination among institutions and the legal framework, regulatory complexity, and fragmentation of emerging technologies. Although the study does not specifically address the furniture industry, the identified barriers mostly affect SMEs and start-ups, which is directly relevant to furniture manufacturers, who represent the largest share of this sector in Bulgaria. Moreover, the study’s data show that more than two-thirds of civil servants, including municipal administration representatives, and 70% of business representatives indicate that the potential of regulatory sandboxes is of interest to them as a tool for fostering innovation. Given that, at present, the furniture industry is not a focus of regulatory experimentation (unlike financial instruments, automated credit algorithms, biometric systems, autonomous vehicles, and other frequently tested AI-based solutions), it can be assumed that it may still be too early to establish a regulatory sandbox specifically dedicated to smart furniture. Nevertheless, smart furniture is in constant, direct physical interaction with users. This interaction affects both the physical and digital environments of the user, an aspect explicitly highlighted in the definition of artificial intelligence under Article 3 of the Artificial Intelligence Act . Precisely because of this capacity to directly influence the surrounding environment and user behaviour, smart furniture deserves careful regulatory consideration. Testing within regulatory sandboxes, even on a cross-sectoral basis, is an appropriate mechanism for the early assessment of risks, regulatory compliance, and the need for legislative adaptation in view of ensuring safety, transparency, and trust in intelligent solutions integrated into everyday environments. In this respect, manufacturers can participate in cross-sectoral regulatory laboratories, drawing on the example of the cross-sectoral regulatory lab with a general purpose for innovation and the digital transformation of public administration called “Sperimentazione Italia”. “Sperimentazione Italia” is an Italian cross-sectoral regulatory sandbox, which allows start-ups, companies, universities, and research centres to test their innovative projects for a limited period through temporary exemptions from existing regulations.

3. SWOT ANALYSIS OF REGULATORY SANDBOXES IN THE FURNITURE INDUSTRY

Regulatory sandboxes provide a controlled environment for testing innovations without posing risks to core production, which is a key advantage for companies that cannot afford disruptions to their ongoing manufacturing processes. Bauknecht and Kubeczko (2024) view regulatory experiments as a tool for sustainable transformations that, through sandboxes and living labs, enable the testing of new products and regulations, accelerating innovation and regulatory learning. Baldini and Francis (2024) emphasize the role of AI regulatory sandboxes in supporting the introduction of innovations in line with the GDPR and the AI Act, highlighting the need for ethical principles and corporate responsibility. Olszewski (2024) stresses the importance of regulatory sandboxes for the safe testing of AI and the prevention of legal and ethical risks across all economic sectors. In this respect, the application of regulatory sandboxes in the furniture industry highlights several strengths (see Table 1) that justify their role as a key instrument for the accelerated implementation of innovations and digital transformation. A major advantage is the potential for significant cost reduction and shorter development time through virtual prototype testing and simulations. This enables manufacturers to identify defects and weaknesses at an early stage, minimising the need for costly physical prototypes. Sandboxes can support the collection of data on the interaction

between new technologies and existing processes, which facilitates strategic planning and the alignment of innovation policies with market trends. Last but not least, sandboxes promote sustainable manufacturing and the transition to a circular economy by creating conditions for experiments with recyclable materials and energy-efficient production processes.

Implementing sandboxes also involves several weaknesses. Data from the OECD (2023) show that establishing sandboxes often requires a high level of institutional capacity, legal flexibility, and political will. The substantial initial costs for building infrastructure, acquiring specialized software, and ensuring the necessary training and expert capacity are often unaffordable for companies that lack sufficient technological and financial resources. Moreover, despite the high precision of virtual simulations, sandboxes cannot always fully replicate all the real conditions of the production process. Another significant risk is related to technological maturity. Companies operating with outdated production systems or with a low degree of digitalization may face difficulties integrating solutions from test environments into their actual operations, which limits their potential benefits and slows down effective implementation.

Alongside the challenges, there are also significant opportunities for expanding the use of sandboxes in the furniture industry. Sandboxes can be established as a natural platform for the accelerated integration of new technologies such as AI, automation, robotics, IoT solutions, and digital twins. Thereby directly supporting the transition to Industry 4.0 and 5.0, where a new balance between automation and the role of the human factor is sought (Dallasega et al., 2020; Yordanova & Bertels, 2024). From a regulatory perspective, these environments enable flexible testing and faster certification of new products and processes within a controlled and adaptive legal framework, which reduces administrative burdens and supports compliance with applicable standards (Olszewski, 2024). Sandboxes allow furniture companies to experiment with environmentally friendly materials, energy-efficient processes, and designs compatible with modern regulations, such as Regulation (EU) 2024/1781.

Despite these positive prospects, the implementation of sandboxes in the furniture industry is associated with certain real threats that should not be underestimated. Often, the return on investment in sandbox solutions materializes in the long term, making it difficult to justify significant capital expenditures in the short term (OECD, 2023). There are concerns that within the EU, divergent practices and regulatory approaches to sandbox mechanisms may emerge, increasing the risk of heterogeneous national regimes and complicating the creation of a harmonized European framework for such innovation environments (Ranchordas & Vinci, 2024). There is a risk of disrupting the balance between measures that support innovation and the safeguards that protect the public interest and consumer rights (Leimüller and Schwarzer, 2020; Pop and Adomavicius, 2021). The potential for “misuse” of sandboxes is linked to the possible negative impact on consumer protection caused by reduced safeguards and requirements used by supervisory authorities to attract innovators which is particularly evident in the “race” for innovation in the fintech sector (Allen, 2020). Industry stakeholders are calling for greater clarity regarding the interaction between national and European regulatory sandboxes that could be used for AI technologies. K. Yordanova (2022) notes that “since the application of sandboxes is not uniform among EU countries, the EC’s proposal could create confusion in the market. It could also encourage AI developers to choose EU countries with less stringent sandbox regimes, at least for regulatory compliance purposes.” Another threat could be the resistance to change among the workforce, especially if workers are accustomed to traditional production practices and are sceptical about digitalization and automation. This requires targeted investment in reskilling and the development of new competencies to

overcome the shortage of qualified personnel capable of working with advanced simulation technologies and to ensure the successful integration of sandbox solutions into real production environments.

Table 1. SWOT analysis results

Strengths	Weaknesses
• Provide a controlled environment for the safe testing of innovations without posing risks to core production. • Allow for significant cost reduction and shorter development time through virtual testing and simulations. • Support the early detection of defects and weaknesses, minimising the need for physical prototypes. • Facilitate the optimisation of furniture design through computer-aided simulations and topological optimisation. • Stimulate creativity and personalisation through 3D modelling and AI tools. • Support collaboration between industry, academia, and public institutions. • Provide a flexible testing framework for ensuring compliance with standards and regulations.	• Require a high level of institutional capacity, legal flexibility, and political will. • Involve high initial costs for infrastructure, software, expert capacity, and training. • Sandboxes cannot always fully replicate real production conditions and market dynamics. • Companies with outdated technologies or a low level of digitalization may face difficulties in implementation.
Opportunities	Threats
• Accelerate the integration of AI, IoT, and digital twins, supporting the transition to Industry 4.0 and 5.0. • Enable faster certification and reduce administrative burdens. • Support sustainable production and the circular economy through experiments with recyclable materials and energy-efficient solutions. • Improve strategic planning by collecting data on the interaction between new technologies and existing processes. • Can facilitate access to national and European funding programmes for innovation.	• High initial investments and a risk of non-return, especially for SMEs. • Regulatory uncertainty and the absence of a harmonized European framework. • Risk of market inequality, as selected participants may benefit from more favourable conditions. • Possibility of a “race to the bottom” if rules differ across countries. • Potential misuse of more flexible regimes and a risk to consumer protection. Resistance from the workforce and a need for investment in reskilling.

In summary, regulatory sandboxes represent a strong potential instrument for accelerating digitalisation, innovation, and sustainability in the furniture industry. To fully realise this potential, careful resource management, active support for small and medium-sized enterprises, a consistent regulatory framework, and effective programmes for workforce training and adaptation are essential.

4. OPPORTUNITIES FOR INTRODUCING REGULATORY SANDBOXES IN SMART FURNITURE MANUFACTURING IN BULGARIA

In 2021, data from the National Statistical Institute indicated that Bulgaria had 1,970 enterprises involved in furniture manufacturing. These companies are distributed across 517 settlements. Seventy-eight percent of these enterprises are classified as small, with a turnover below 500,000 euros. Medium-sized enterprises dominate the sector, accounting for 65% of total turnover, while large enterprises (with a turnover exceeding 5 million euros) make up only 3% of all companies but generate over 40% of the total turnover. Using the elbow method and considering the average number of employees, export value in euros, and the number of settlements, three clusters of furniture enterprises in the country can be identified. For analysis purposes and given the specifics of regulatory sandboxes, it is useful to focus on clusters with medium or high potential. The 'medium potential' cluster includes 22 settlements with an average of 234 employees in the sector and an estimated export value of 656 euros. The 'high potential' cluster comprises 18 settlements where an average of 741 people are employed and exports reach 2,727 euros. Notable towns and settlements within these clusters include Sevlievo, Troyan, Plovdiv, Sliven, Pazardzhik, Targovishte, Ruse, Sofia, Velingrad, Petrich, Yambol, Blagoevgrad, Burgas, Lovech, Razlog, and Peshtera. For possible future pilot projects of regulatory sandboxes within Bulgaria's furniture industry, a brief comparative analysis was performed on these settlements based on criteria such as industrial activity, digitalisation levels and Industry 4.0 integration, availability of a qualified workforce, access to universities and research institutes, presence of small, medium, and large enterprises, and potential to attract funding and regulatory support. Three groups of settlements can be distinguished according to their high, medium, or low potential for the implementation of regulatory sandboxes.

Settlements with high potential for introducing regulatory sandboxes in the furniture industry

This group may include cities such as Ruse, Plovdiv, Sofia, Troyan, and Burgas. The furniture industry in Bulgaria is most developed in Ruse and Gabrovo, which together generate over 60% of the country's furniture exports. The region stands out for its concentration of enterprises and a qualified workforce (Stoenchev and Stefanova, 2020). Large companies in Ruse invest in modern technologies, while small and medium-sized enterprises offer innovative and customised solutions. Examples include Mebel Hit, Mebeli IDEA, and IKEA Bulgaria. Located on the Danube River, Ruse is an important logistics centre with easy access to external markets. The Angel Kanchev University of Ruse trains specialists in automation, industrial design, and materials science, and works closely with businesses through internships and research projects. The Ruse Chamber of Commerce and Industry participates in initiatives such as "Digital Twin" and "DTAM," which develop digital skills and support Industry 4.0. The share of university graduates (31%) is above the national average, and the municipality actively invests in infrastructure with EU support, creating a favourable environment for the adoption of new technologies (<https://ruse.egov.bg>).

Plovdiv is the second largest industrial centre in Bulgaria and an important hub for the furniture industry. The city hosts the Thrace Economic Zone, which includes six industrial areas, over 3 billion euros in investments, and more than 50,000 jobs. Both large international companies and SMEs operate here, producing furniture for the domestic market and export, from mass production to boutique solutions. Leading manufacturers include Ted Bed EAD, Mebeli Kopanarski, Tsvete, REDO EOOD, Mebelor, Essenza, and Mebeli Ela. Plovdiv benefits from a skilled workforce thanks to the local branch of the Technical University of Sofia, the Paisii Hilendarski University of Plovdiv, and vocational high schools for woodworking. The city is an active participant in EU programmes and Industry 4.0 initiatives and benefits from support by the EBRD and the EU Regional Development Fund. The international "Industry 4.0" forum and the example of Schneider Electric's "smart factory" confirm Plovdiv's strong potential for regulatory laboratories for testing digital product passports and sustainable production models.

Sofia is a leading economic and technological centre with developed infrastructure, a qualified workforce, and a strong presence of universities and research institutes. More than 50% of the working-age population holds a higher education degree, and many companies implement innovative solutions such as IoT, automation, and AI. The Technical University, Sofia University, the Bulgarian Academy of Sciences, and Sofia Tech Park provide a scientific base and testing environments for new technologies and smart furniture. The city has broad access to European funding (for example, "Horizon Europe") and strong connections with international investors. Leading manufacturers include Interior-I, Buldecor, Era Stil, Videnov, METRON, Emiliano Mebel, MONEMA, and Pirinski Bor. In Sofia, there are both established furniture companies and start-ups focused on high-tech design and customised production.

Troyan is a traditional centre for furniture manufacturing, with more than 30% of local enterprises operating in the sector. The town has strong traditions in woodworking and craftsmanship (ceramics, solid wood) with leading companies such as "ELIMEKS – Ivan Radevski" and "Hemus Troyan." The absence of a university is offset by Troyan's proximity to Veliko Tarnovo and Gabrovo, which ensures access to a skilled workforce. Troyan has potential for regulatory testing of sustainable materials and biodegradable furniture.

Burgas is an important economic and logistics centre with access to the Black Sea, a strong industrial base, and active digitalisation programmes. The furniture sector is dominated by small and medium-sized companies such as Mebeli Dreams, Danista, and Estilo, which are implementing new technologies and automation. Vocational high schools and local universities (Burgas Free University and Prof. Dr. Asen Zlatarov University) train specialists for the industry. The city offers access to funding through the Rural Development Programme, the Operational Programme for Innovation and Competitiveness, and Industry 4.0 programmes, while the "Industrial and Logistics Park – Burgas" supports investment and innovation.

Settlements with medium potential for introducing regulatory sandboxes in the furniture industry

This group includes Sevlievo, Sliven, Pazardzhik, Targovishte, and Yambol. These are cities with developed or developing industrial zones and furniture enterprises, with a lower level of digitalisation and no universities or research institutes to support technological innovation. In Sevlievo, large companies such as "Paralel EAD" and "Abanos" operate alongside many small and medium-sized custom furniture firms. Vocational schools train specialists, and the proximity to Veliko Tarnovo and Gabrovo provides access to research institutes. There is good industrial infrastructure and funding for innovation. In Sliven, an active sector operates with companies

such as “NACHEVI 90,” “Sezoni,” and “Nimis.” SMEs offer customised solutions. The “Barshen” industrial zone is developing investments. In Pazardzhik, companies such as “Colorado” (with three factories) and “Piponkov” are active. Firms are modernising production with automation and planning new lines. Vocational high schools and proximity to Plovdiv provide a skilled workforce and access to universities. In Targovishte, “Mebel-stil,” “Mebeli Zdravec,” and “Lito-sin” are located. The city is developing an industrial park with modern infrastructure. The lack of a university is offset by proximity to Shumen and Varna for cooperation with research institutes. In Yambol, companies such as “NOV DOM,” “SNEP,” and “KAN” operate. More than 400 firms employ 3,000 people. There is progress in digitalisation and a trained workforce, and the proximity to Sliven and Burgas facilitates access to universities.

Settlements with low potential for introducing regulatory sandboxes in the furniture industry

This group comprises cities such as Blagoevgrad, Velingrad, Petrich, Lovech, Razlog, and Peshtera, which have limited industrial capacity in the furniture sector and a lower concentration of enterprises engaged in export-oriented production. These cities could be included in future phases of expanding regulatory sandboxes. Blagoevgrad lacks an industrial zone for large-scale production despite the presence of companies like “Perfect Mebel” and “Mebel 2010.” Velingrad is focused on tourism, and furniture manufacturing activity is limited. Petrich is mainly centred on agriculture and trade, without a developed furniture sector. Lovech has traditions in woodworking, but the modern furniture industry remains underdeveloped. Razlog is oriented towards tourism and agriculture, with no significant furniture industry. Peshtera is known for shoe and beverage production, while the furniture sector holds minimal importance.

In conclusion, Ruse, Plovdiv, Sofia, Troyan, and Burgas are the most suitable cities for launching pilot regulatory sandboxes in the furniture industry due to their high concentration of enterprises, good infrastructure, and the presence of research institutions. They have industrial activity, research capacity, access to international markets, and opportunities for digitalisation. As an initial step, it is appropriate to launch a pilot regulatory sandbox in Ruse, using the support of industrial clusters and universities to test new regulations under real conditions. Sevlievo, Sliven, Pazardzhik, Targovishte, and Yambol have potential for future inclusion in the initiative, while Blagoevgrad, Velingrad, Petrich, Lovech, Razlog, and Peshtera are less suitable for the introduction of such sandboxes at this stage.

3. CONCLUSIONS

Regulatory sandboxes can serve as a vital tool for fostering innovation and digitalisation within the furniture industry, particularly during the shift to smart furniture and Industry 4.0 and 5.0. The SWOT analysis highlights the benefits of sandboxes as controlled environments for experimentation, which help reduce development costs and speed up the market introduction of new products. They enable companies to safely test automation and smart manufacturing in a protected setting, minimise investment risks, and stay compliant with an ever-changing regulatory landscape. However, challenges such as high initial costs, the need for institutional capacity, and legal clarity demand well-coordinated efforts among businesses, academia, and regulators. Key locations like Ruse, Plovdiv, Sofia, Troyan, and Burgas possess the industrial and scientific capabilities necessary for piloting regulatory sandboxes and laboratories. These

areas benefit from a skilled workforce, advanced industrial infrastructure, and access to funding and research resources.

In conclusion, to fully realise the potential of regulatory sandboxes, targeted planning, the creation of a clear legal framework, and the provision of mechanisms to support small and medium-sized enterprises are necessary. In this way, the furniture industry will be able to position itself as a competitive player in the European market, ready to meet the requirements for sustainable and technologically advanced production.

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TRENDS AND MAIN CHALLENGES IN THE WOOD INDUSTRY IN SLOVENIA

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Abstract: The wood industry is an important part of the Slovenian economy, but it faces various challenges due to constantly changing market conditions, legislative changes, technologies and environmental requirements. In order to remain competitive in the increasingly demanding global market, Slovenian wood and furniture companies need to monitor trends in the global economy, sector. The study analyses some economic and financial indicators in the Slovenian wood industry as well as trends such as sustainable development, technological progress, digitalisation, modern design and personalised products, which are crucial for the competitiveness and long-term growth of the Slovenian wood processing industry.

Keywords: *Slovenian wood industry, economic and financial indicators, trends*

1. INTRODUCTION

Market conditions are constantly changing, we are confronted with rapid technological development, legislation is changing and environmental requirements are becoming increasingly important. This has a direct impact on the activities of companies and the functioning of the entire economy. In Slovenia, the wood industry represents an important part of the Slovenian economy and, like other companies, faces various challenges that strongly influence its competitiveness and success. The wood industry, which includes the activities "Manufacture of wood and of products of wood and cork (except furniture), manufacture of straw and plaiting materials" (C16) and "Manufacture of furniture" (C31) (European Union, 2025), contributed about 1.7% to Slovenia's GDP in 2023, and around 3,500 companies operate in this sector, employing about 12,000 people (Statistical Office of the Republic of Slovenia, 2025). All this makes it one of the most important industrial sectors in Slovenia, which has experienced significant growth and development in recent years, while also making an important contribution to the transition to a low-carbon society, which is one of the key priorities for the development of the economic environment at European level (European Commission (EC), 2019). Like the entire industry, the wood industry must be well prepared for these challenges. One of the measures that can help it overcome these challenges is to monitor trends in the global economy, particularly in the wood industry.

In the study, we therefore examined some economic and financial indicators in the Slovenian wood industry in relation to modern development trends in the areas of sustainability, digitalisation and technological development. Tracking these trends is key to ensuring the competitiveness and long-term development of the Slovenian wood processing industry. The purpose of this paper is to present the situation in the Slovenian wood industry based on some economic indicators and to analyse possible measures to improve the situation.

2. MATERIALS AND METHODS

The research was based on the search and analysis of data from official statistical databases and reports (Likar & Valentinčič, 2024; Statistical Office of the Republic of Slovenia, 2025). Based on this data, we then calculated some key performance indicators of the Slovenian wood industry. An analysis of trade was also carried out, which includes an overview of the growth of exports and imports, the coverage of imports by exports and the calculation of the shares of trade by economic group. We also analysed all values over time, including growth or decline indices, including constant basis indices and chain indices. We have also calculated index points [%], which represent the absolute difference of the calculated indices.

In order to identify the main challenges facing the wood industry in Slovenia, we used the SWOT analysis, a strategic tool that allows us to develop a strategy by identifying and analysing the strengths, weaknesses, opportunities and threats (Shakoor Shahabi et al., 2018). The SWOT analysis consists of two key phases. In the first phase, we determine the criteria and create a SWOT matrix, while in the second phase, we create the best combinations of strategies by combining internal and external factors, paying particular attention to how we can utilise the strengths to take advantage of opportunities and overcome threats, and how we can reduce the weaknesses to take advantage of opportunities and prevent threats from occurring due to our weaknesses (Abdel-Basset et al., 2018; Sevkli et al., 2012). The assessment was conducted based on a review of relevant sources.

3. RESULTS

3.1. Economic indicators

In 2023, the war in Ukraine and the resulting sharp increase in energy prices made industrial activity in Slovenia very difficult, as the average value of industrial production in Slovenia in 2023 was 5.3% lower than in the previous year. This also applies to the wood processing industry, where the value of the industrial production index in C16 fell by 13.3% and in C31 by 10.2%. A downward trend in incoming orders was observed in all areas of manufacturing.

The wood industry has stepped up its operations over the past eight years. Revenue, net profit and value added per employee were at their highest in 2022. In 2023, both **revenue and expenditure** declined: net sales on the domestic market fell by 6.3% in C16 compared to the previous year and also by 2.6% in C31. Net sales on the foreign market fell by 9.6% in C16 compared to the previous year and by 11.8% in C31. Overall, net sales in the wood processing industry on the domestic market fell by 5.1% in 2023 compared to 2022, and they also fell by 10.0% on the foreign market. Total net sales in the wood processing industry fell by 7% in 2023. Both sectors have achieved positive results in the last 9 years, which is a good indicator of the good state of the wood industry.

The share of companies C16 and C31 in the manufacturing sector (C) fell slightly in 2023 compared to 2022 and amounts to 12.02%. The same applies to the **share of employees** in the wood industry, which also decreased in 2023 compared to the manufacturing industry (C) and amounted to 6.10%. Employment in the wood industry fell by 2.9% in 2023 compared to the previous year. In C16, employment fell by 1.1% and in C31 by 6.3% (Table 1).

Table 1: Overview of employment in the wood industry in Slovenia

	2018	2019	2020	2021	2022	2023
C16	7,001	7,320	7,301	7,695	8,053	7,966
C31	3,959	3,968	3,837	4,121	4,103	3,843
C16+C31	10,960	11,288	11,138	11,816	12,156	11,808

When calculating labour costs, we can see that the **average gross wage** in Slovenia in 2023, excluding inflation, was 9.7% higher than in the previous year. Compared to the salary for 2022, the average gross salary for 2023 was 9.4% higher in the private sector and 10.3% higher in the public sector. In the manufacturing sector (C), the average monthly gross salary increased by 9.92% compared to the previous year. Similar trends can also be observed in the wood processing industry, where the average salary in C16 was 7.91% higher and in C31 10.57% higher than in 2022 (Table 2). By comparison, the salary in the wood industry is almost 17% below the Slovenian average.

Table 2: Average annual gross salary for the period in Slovenia

	2018	2019	2020	2021	2022	2023	Index 23/22
Slovenia (in general)	1,969.69	1,969.69	1,969.69	1,969.69	2,023.57	2,220.80	109.75
C	1,658.76	1,719.59	1,771.79	1,881.38	2,000.27	2,198.67	109.92
C16	1,378.10	1,436.42	1,492.28	1,602.37	1,723.47	1,859.85	107.91
C31	1,340.86	1,419.63	1,479.94	1,571.47	1,636.97	1,810.02	110.57

Another important indicator pointing to a healthy core of the wood industry is **value added**, which has been growing since 2014 but fell by 4.5% in C16 and rose by 4.6% in C31 in 2023 compared to 2022. **Value added per employee** has also risen over the last 13 years. In 2023, it averaged EUR 50,021 in C16 (EUR 51,835 in 2022), which means that it fell by 3.5% compared to the previous year. In C31, on the other hand, it rose to EUR 41,230 in 2023 (EUR 36,909 in 2022), which corresponds to an increase of 11.7%. In the wood processing industry as a whole (C16 + C31), the average value added per employee reached EUR 47,160 in 2023 (EUR 46,797 in 2021), which is 0.8% more than in the previous year. In the Slovenian economy as a whole, value added per employee amounted to € 61,003 in 2023 (€ 55,688 in 2022) and € 59,441 in manufacturing (NACE C), 3% more than in the previous year.

In Slovenia, **foreign trade** in goods increased slightly in 2023, mainly due to exports, while imports remained at the same level. The value of trade with non-EU countries increased, while trade with EU members decreased. Since 2014, trade in goods has increased, with the exception of 2020, when there was a temporary decline in trade. In 2022, trade in goods was the highest since 2014. In 2023, trade in goods decreased slightly. By product area, Slovenia exported wood and furniture products worth 1,367 million euros in 2023, an increase of 11.29% compared to the previous year. It imported wood and furniture products worth EUR 938 million, which corresponds to an increase in imports of 7.94% compared to the previous year 2022. The most important export and import markets for wood and furniture products were the

European countries (Germany, Austria, Italy, Croatia) and, albeit to a lesser extent, China and the USA.

3.2. SWOT analysis

The Slovenian wood industry has numerous advantages that need to be preserved and strengthened, but also some weaknesses that require special attention in its further development. Of course, there are also opportunities and threats that it must take into account in its strategic planning (Table 3) (Kropivšek et al., 2023).

Table 3: SWOT matrix of the Slovenian wood processing industry (adapted from Kropivšek et al., 2023)

STRENGTHS	WEAKNESSES
- Availability of raw materials - Potential for the circular economy - Potential for added value in products - Connection/synergy with other industries - Impact on rural development and the preservation of tradition - Innovation and market potential - Potential for new jobs - (Established) market and customer trust	- Failure of certain value chains - Technological obsolescence and the amount of investment needed in technology - The amount of investment required in R&D and promotion - Poorer availability of (skilled) labour - Cost inefficiency - The complexity of product quality management - Poor management of supply logistics
OPPORTUNITIES	THREATS
- Recognition of wood as a strategic raw material - National/EU incentives - Development of a digital society - Environmental awareness of the market and customers - Purchasing power in the market (SLO, EU) - Legal opportunities (e.g. green public procurement; packaging waste management, etc.)	- Competition in search for market channels for high value-added products - Bureaucratic obstacles - Macropolitical and macroeconomic conditions - Changes in the market (emergence of competition, price increases, etc.) - Slow consumer shift (or no shift) toward sustainability - Legal risks (e.g. regarding pollution from production...)

A more detailed SWOT analysis shows that the most important **strengths** can certainly be seen in the environmental aspect of wood processing in ensuring sustainability in the functioning of society, including positive impacts on rural development and a wider (utilisation) use of wood, also in modern concepts of circular economy and cascading use. On the other hand, there are also some **weaknesses**. A major issue is technological obsolescence and the associated need for investment in (energy-efficient and advanced) technology. One of the main challenges is also the low availability of (skilled) labour, low productivity and cost inefficiency. Among the **opportunities**, the most important are those related to the supportive environment (e.g. government incentives, legal opportunities, development of a digital and green society), the utilisation of developed infrastructure and modern strategic directions at the state level. The main **threats** are mainly related to bureaucratic obstacles, regulatory changes and the legal environment in general.

An in-depth analysis leads us to the conclusion that the wood industry offers numerous opportunities that the sector must maximise in order to increase its success and ensure further growth and development. Most of these are related to the increased environmental awareness of customers and their purchasing power, as well as numerous government incentives for

investment in technology and the development of innovative products specifically for the wood industry, which currently occupies a favourable position in Slovenia's economic policy.

3.3. Trends and challenges

Over the past decade, the Slovenian wood industry has been increasingly integrated into the global trends of sustainable development and digital transformation. Its structure, orientation, and technological image are changing in parallel with global social and economic development. The introduction of numerous new digital technologies (Authority & Brodolini, 2023) while striving for climate neutrality offers numerous opportunities for the progress and expansion of the industry, which is based on available natural resources and has great potential for achieving the goals of the European Green Deal (European Commission (EC), 2019). As part of the twin transition, it is therefore necessary to consider all aspects for the further development of the Slovenian wood industry, including strategic, technological, design, and human resources, as well as political ones.

From a **political and strategic perspective**, the development of the industry is influenced by strategic EU documents such as Next Generation Europe, which lead to initiatives such as the New European Bauhaus (European Commission (EC), 2021b) and Ready for 55 (European Commission (EC), 2021a). In Slovenia, the wood processing industry was recognized in the Slovenian Industrial Strategy 2021–2030 as a strategic sector (MGRT, 2021), which represents an important milestone for the further development of the sector (MGRT, 2022). In recent years, the Slovenian wood industry has been achieving better results, thanks to a more systematic approach, planning, and financial support from the state (Ministry of Economy, 2023; Spirit Slovenia, 2022).

Timber construction is one of the most important trends in the **context of sustainable development**. Wood as a building material enables the reduction of CO₂ emissions, improves the energy efficiency of buildings and contributes to the decarbonisation of the construction sector. According to research by the European Barometer (EBS), the population in Slovenia has become highly sensitised to the effects of climate change in recent years (ARSO, 2024). The demand for timber construction materials is expected to increase, especially in the segment of larger and more complex buildings. This opens up new market opportunities and requires the development of new knowledge and competences in the construction and wood processing industry (MGRT, 2020).

At the same time, companies in the wood industry are **modernising and digitalising their processes**, which is essential for maintaining competitiveness, reducing costs and increasing quality. The digital transformation of the industry is taking place in the direction of smart factories and Industry 5.0. Technologies such as 3D printing, robotics, machine learning, big data, virtual and augmented reality, and artificial intelligence are taking centre stage (Asif et al., 2024). The use of artificial intelligence holds great potential for optimising production, reducing errors, improving product quality, and more efficient logistics management.

Modern consumers are increasingly looking for **personalised, innovative and aesthetically pleasing products**. This requires companies to be highly adaptable, have shorter production cycles, and respond quickly to changes in demand. Design is becoming a competitive advantage as it influences the perceived value of the product and the buyer's decision. In the furniture industry, quality and price, as well as delivery time and after-sales activities, are particularly important for purchasing decisions, both among end customers and

between companies (Oblak et al., 2017; Rwanda & Oetama, 2023). Therefore, the ability to customise production quickly is the key to success in the market.

Slovenia is an important **exporter** of wood products, which is reflected in positive financial results and growth in **value added** per employee, which has risen from €20,000 to more than €47,000 in the last 14 years. (Likar & Valentinčič, 2024), whereby, as we have seen in the previous chapters, the C16 sector is more successful than the C31.

All these trends increase the need for **new knowledge and expertise**. Education is also very important to strengthen various aspects of performance and to achieve higher value added (per employee (VA/e) as a measure of the return on an organisation's intellectual capital (Kaba et al., 2024; Ngwenya, 2013). The educational structure of employees in the industry has a strong influence on the performance of companies (measured by revenue and value added per employee), with the number of employees with tertiary education having a strong and positive influence, while the number of employees with primary education has a negative influence on the performance of wood companies (Kropivšek et al., 2024). This proves that investment in higher education is the key to increasing the productivity and financial success of companies in the long term, including in the wood sector.

Cooperation between companies, research institutions, and the state is also important, especially in the development of skills for the green and digital transitions. It is therefore necessary to modernise education programmes, include more practical training, promote lifelong learning and develop new business models based on leanness, efficiency and environmental responsibility. **The state** must also ensure faster implementation of European directives and provide financial support to companies that invest in sustainable and digital solutions.

4 CONCLUSIONS

The results of a quantitative analysis of the wood industry in Slovenia point to an improvement in the industry's key financial indicators in recent years. The industry is growing both in terms of revenue and the number of employees, as well as in terms of value added per employee and labour productivity. Trade is also increasing and shows a significant structural shift in destinations, whereby it is particularly important that the share of exports is increasing. The growth of the wood sector also has a positive impact on its external reputation, which affects development and investment potential, employment and investment in research, as well as even greater mutual co-operation between companies within and outside the sector.

The wood industry has numerous advantages that we must maintain and strengthen in our further development and, above all, it must utilise its opportunities. The latter are primarily related to the increased environmental awareness of customers and their purchasing power, which can be utilised, for example, through innovative products and highlighting the positive impact on the environment, including by replacing other materials with wood (e.g. in timber construction). To this end, we must take advantage of government incentives for investment in technology and the development of innovative products, as the wood industry in Slovenia is currently in a (very) favorable position in the economy and in the state's economic policy.

Slovenian wood processing companies must recognise and follow the most important global trends. These are sustainable development, digitalisation and automation. At the same time, they must also take into account consumer demands for modern design and personalised products, which means adapting to market needs. A stronger focus on timber construction is

also expected in the future. Companies must therefore continue to modernise their processes by using advanced production and information technologies in the transition to Industry 4.0 and 5.0, investing in the training of their employees and driving innovation in products, services, market strategies and business models. It is important that in the process of transformation and growth we do not overlook the small companies that make up the majority of companies in the wood sector (Goropečnik et al., 2024). These companies often produce exceptional, high-quality and unique products that contribute significantly to the diversity, competitiveness and public image of the wood industry.

In this regard, wood and furniture companies must continue to collaborate proactively with educational and research institutions and industry support organisations to promote further international growth of the sector.

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WOOD-BASED CIRCULAR BIOECONOMY AND ITS PROMOTION IN EUROPE

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Abstract: This paper focuses on the role of the bioeconomy and the wood sector in particular as a driver of competitiveness in the construction sector in the light of the EU's ambitious environmental and social goals. The paper highlights the need for greater recognition and support of this sector by EU countries and institutions. It presents carbon balance related knowledge in the field of building design and identifies ways in which the public sector can promote more construction based on bio-based/renewable materials. The aim is to assess the supporting tools and the (still untapped) potential of using wood in building construction from the perspective of implementing pro-environmental initiatives and strategies.

Keywords: wood sector, constructions, buildings, promotion, bioeconomy

1. INTRODUCTION

The *ability* of each generation of people to *sustain* the environment for life in a "certain" state is a subject of interest across the entire (not only) academic community. The initiatives we are working on are conceptually based on efforts to achieve sustainability. We understand the term sustainability as a concept of human endeavour leading society towards a paradigm based on prosperity of humankind that thrives socially and environmentally. Achieving sustainability is clearly an issue that the forest-based sector not only touches on, but is holistically involved in (Kaputa et al., 2024). The home domain of the forest-based industry is the bioeconomy – and as quoted by (Moravčík, Dzian, Paluš, & Parobek, 2024) this is essential to achieving a balance between society, the environment, and economic development processes. The bioeconomy comprises those parts of the economy that use renewable biological resources from land and sea, suggests crops, forests, fish, animals and microorganism to produce food, materials and energy (European Commission, 2018). (Global Bioeconomy Summit, 2015) defined the term as the knowledge-based production and utilization of biological resources, innovative biological processes and principles to *sustainably* provide goods and services across all economic sectors.

Global trends in the bioeconomy reflect a fundamental transformation of economic models – fossil capital being replaced by natural renewable capital in connection with the paradigm shift from a linear to a circular economy. The practical application of bioeconomics lies not only in the use of biomass as a source of energy or raw material for industry, but also in the creation of systems that support the regeneration of natural resources, reduce greenhouse gas emissions, and promote sustainable economic models. This approach has particularly significant potential in the construction industry, where it can lead to innovations in materials processing, improvements in the energy efficiency of buildings, the achievement of climate neutrality (Pánik and Jantová, 2019) and social responsibility, thereby linking the three fundamental dimensions of the bioeconomy into a single comprehensive framework (Goldhahn, Cabane, & Chanana, 2021). Regional strategies vary depending on the economic,

geographical, and political characteristics of individual regions. In countries with a developed bioeconomy, emphasis is placed on creating local value by supporting small and medium-sized enterprises that use locally available biomass. In other regions where natural resources are limited, attention is focused on importing technology and know-how, which also stimulates regional development and increases competitiveness. These differences require the adaptation of political and financial instruments to the specific needs of individual regions in order to effectively implement the principles of sustainable development (Gallo, 2022). An integral part of regional trends is the interconnection of the bioeconomy with digital transformation. Technological digitization and the rise of analytical tools enable the optimization of production chains and improved management of natural resources. This supports more effective planning and monitoring of environmental indicators, which is critical for evaluating the success of bioeconomy strategies. Digitization enables the creation of coordinated strategies between stakeholders at both the regional and global levels (Moravčík et al., 2019).

This article focuses on promoting the use of wooden buildings in selected countries of the European Union (EU). This market within the wood processing sector was chosen based on its importance in terms of added value, not only economic but also social and environmental. Regulations affecting the market for wood products are clearly outlined, for example, in the document "Taking a bird's eye view of EU wood-based policy" (Aggestam, Weiss, Elomina, & Pölzl, 2025). Various related policies may not be explicitly focused on wood, but the instruments introduced have an impact on wood production in forests and the use of wood in the processing chain. Ultimately, they also have an impact on the consumer market.

The construction industry produces more than a third of CO₂ emissions in the EU (Sharmina, Pappas, Scott, & Gallego-Schmid, 2023). EU documents suggest that increasing the use of wood as a building material contributes to meeting its carbon emission reduction targets. The drive to reduce these emissions within the single European market (area), as well as pressure on trading partners worldwide (e.g. through the CBAM instrument), reflect the targets set. The prioritization of carbon reduction has also been reflected in the marketing (and political) strategy of the wood-based sector. Wooden buildings store CO₂ and use less CO₂-intensive materials than concrete or steel, underscoring their contribution to the transition to a circular bioeconomy. Traditional wood-based construction is making a successful comeback in the world (Eriksson et al., 2018), not only in the construction of single-family homes, but also in non-residential buildings. This is true for many EU countries, but in Slovakia the potential of timber buildings is far from being fully exploited (Švajlenka & Pošiváková, 2023). These facts, together with a number of social and environmental benefits, makes the issue very topical.

2. ANALYSIS OF SUPPORTIVE POLICIES TO PROMOTE THE USE OF WOOD IN CONSTRUCTION

As part of ongoing efforts to decarbonise the construction sector, develop a circular economy and strengthen the regional bio-economy, policies and instruments aimed at promoting the use of wood as a sustainable building material are increasingly being implemented in European countries. In this context, wood is presented not only as an environmentally friendly alternative to traditional materials, but also as a strategic element for economic development, employment promotion and technological innovation.

By analysing selected examples from countries such as Austria, Germany, Slovenia, the Czech Republic, Spain, Switzerland, Finland and Sweden, it is possible to identify a variety of

public policy approaches that support the increased use of wood in public and private construction projects. These initiatives include legislative measures, public-private partnerships, public procurement programmes, supportive financing, training, as well as technological innovations including CLT (cross-laminated timber) or hybrid wood systems.

2.1. Austria

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Thanks to its systematic approach, it can be considered a European leader in the field of timber construction. The 33% share of timber construction in social housing is the result of a combination of supportive legislation, public procurement favouring timber construction, and technological innovations (such as the development of CLT). The education system, which ensures the qualification of specialists, also plays a role.

In 2021, the CO₂ Bonus was launched – a specialized subsidy mechanism aimed at supporting environmentally friendly construction methods using renewable materials as part of a package of measures under the Waldfonds administered by the Ministry of Agriculture, Regions and Tourism (Kommunalkredit Public Consulting, 2024). The program provides transparent and measurable support through subsidies linked to the amount of wood used in construction – residential buildings and public buildings (such as schools, community centres, and administrative buildings):

- in its basic form, €1 for every kilogram of wood used.
- when using insulation materials from renewable raw materials, the increase is to €1.10/kg.

The maximum amount of support is €200,000 for businesses and €500,000 for public or non-profit entities outside the competitive market (municipalities, schools), but no more than 50% of eligible construction costs in total. Projects must not use fossil fuels for heating

2.2. Czech Republic

In response to the unsustainable trend of high raw timber exports, the Czech Republic adopted a National Wood Policy, which aims to increase domestic wood processing while supporting the development of higher added value in the wood processing industry. One of the goals in the field of sustainable construction is to increase the share of wooden buildings in individual housing from the current 15% to 25%. The next step is to reach 20 % share of wood in the public procurement for buildings and their reconstructions for the Ministry of Agriculture and its subordinate organizations (gov.cz, 2024). In 2023, an initiative known as the Platform for Sustainable Wooden Buildings was established in the Czech Republic, bringing together key players from the fields of development, architecture, and construction with the aim of promoting the construction of multi-story wooden buildings. The platform is overseen by the Czech Green Building Council (CZGBC). The aim is also to amend fire safety standards so that wooden buildings can reach a height of up to 22.5 meters without the need for special permits or exemptions (CZGBC, 2025).

2.3. Finland

The Finnish government's Wood Building Programme (2016–2023), coordinated by the Finnish Ministry of the Environment, focused on increasing the use of wood in various areas of construction, particularly in urban development, public buildings, and large structures such as bridges and halls, but also on strengthening regional skills and promoting exports

2.4. Germany

Germany introduces amendment to climate protection law (Klimaschutzgesetz) in 2021. The law introduces annual emission budgets for individual sectors, which are required to contribute to the overall emission reduction target. Each sector is allocated a specific limit on the amount of CO₂ it can produce in a year. In addition to climate protection, there is also the dimension of fair distribution of responsibility between the current and future generations (The Federal Government of Germany, 2021). The „Charter for Wood 2.0“ has been established to increase contributions of sustainable forestry and wood use to climate change mitigation, value creation and resource efficiency (Purkus & Lüdtkke, 2020).

Table 1. Overview of subsidies to promote the use of structural timber in German regions

Region/city	Subsidy (€/kg)	Note
Bavaria (BayFHolz)	cca 0.50	Calculation based on €500 per tonne of carbon sequestered in structural timber.
Berlin	0.30 – 0.80	The official municipal subsidy programme "Berlin baut mit Holz", aimed at promoting wood construction.
Munich	2.00	Part of a large urban project - Prinz-Eugen-Park - the largest wooden housing estate in Germany.
Freiburg	1.00 – 1.20	The amount of the subsidy depends on the distance of origin of the material (up to 400 km = the highest subsidy).
Hamburg	0.80	The subsidy applies to non-residential buildings; the material must be from sustainable sources.

Sources: Bayerisches Staatsministerium, 2021; Berlin.de, 2019; Optoppen, 2024)

Several German states and cities have introduced specific subsidy schemes to promote timber construction. Unlike traditional subsidies linked to the total investment volume or built-up area, these programmes encourage green construction based on the precisely quantifiable amount of timber used or carbon sequestered (Table 1). Simply, the subsidy presents an amounts in Euro per kilogram of renewable carbon-storing building material used in the building over the long term.

Bavaria, one of the most active German regions in this area, is implementing a strategy based on public-private partnerships. The aim of these projects is not only to promote timber construction, but also to verify its technical and environmental advantages in practice.

2.5. Slovenia

Slovenia emphasises education and the development of professional skills as a tool for promoting timber construction. The system of environmentally preferred public procurement is widely used. This approach, known as 'Green Public Procurement' (GPP), means that when

purchasing goods, services and construction works, preference is given to solutions with a lower environmental impact throughout their entire life cycle (gov.si, 2022). GPP is mandatory in Slovenia for procurement in more than 20 categories of public contracts, including the design and construction of buildings.

2.6. Spain

In the Galicia region of Spain, legislation requires that at least 20% of the materials used in public buildings be wood, which, in addition to the environmental dimension, also has a regional economic dimension, as it supports the local forest/wood-based sector.

The key initiator of decarbonisation in the construction sector is the Mass Madera network, coordinated by the Institute for Advanced Architecture of Catalonia and financially supported by the Built by Nature foundation in 2023. The aim is to strengthen: i) the building of a network of experts and institutions; ii) the advocacy of policies in the field of timber construction; and iii) the development of knowledge and solutions in the field of sustainable architecture. The network focuses on removing barriers that hinder the adoption of solid wood in construction processes (IAAC, 2025). The initiative does not introduce direct financial subsidies linked to the weight of wood used, but is a tool for long-term influence on the regulatory environment and the speed of adoption of wood as the main building material in Spain

2.7. Sweden

In 2020, the Swedish government allocated approx. EUR 200 million to support projects focused on energy-efficient and sustainable buildings. These funds were provided through the European Investment Bank to Vasakronan, Sweden's largest real estate developer, to finance the construction and renovation of five properties with low energy consumption and minimal climate impact (buildings have obtained LEED Platinum or LEED Gold environmental certification) (EIB.org, 2020).

Among private projects, Stockholm Wood City stands out – described as the largest urban district in the world built mainly from wood (2,000 new apartments and 7,000 office spaces).

Table 2 Overview of support policies and initiatives to promote the use of wood in construction in selected countries

Country	Initiative / Policy	Tools and measures
Austria	CO ₂ Bonus (Waldfonds)	- Subsidy of €1–1.10/kg of wood - Max. €200,000–500,000 - Conditions for CO ₂ and energy
Czech Republic	National Wood Policy (2023)	- SWOT analysis of the sector - Interdepartmental cooperation - Integrated approach
Finland	Wood Building Programme (2016–2023)	- Target: 45% share of wood (2025) - Handbooks, databases, networking
Germany	BayFHolz + regional projects (e.g. Munich)	- Support of up to €2/kg (Munich), €0.5/kg (BayFHolz) - Pilot constructions, training
Slovenia	Green Public Procurement + education	- Mandatory GPP in 20+ categories - Material certification, training

Spain	Mass Madera + Galician legislation	- Financial support €180,000 - Legislation, public procurement, network of actors
Sweden	Strategic plan for timber construction	- SEK 2 billion from government, - Stockholm Wood City – financed by private sector
Switzerland	Wood Resources Policy, Think Earth Project	Research, legislation, public campaigns - Think Earth project, ETH Zurich

Source: own elaboration (based on the previous text sources)

3. CONCLUSIONS

An analysis of measures in European countries identified several recurring tools and principles. Among the most common are national or regional policies specifically aimed at promoting timber construction, whether in the form of a legislative framework (Spain/Galicia), technological support (Austria, Switzerland). One of the most effective and transparent tools for promoting sustainable construction is the introduction of financial support directly linked to the volume of environmentally friendly materials actually used in construction, based on the Austrian and German models. In the case of timber buildings, this specifically refers to the amount of structural timber incorporated into the building, which not only represents environmental value (bound carbon) but also provides an economic stimulus for the entire supply chain – from harvesting and processing to construction. Several EU countries still lack a mechanism that would specifically support timber construction in this way. In this context, the Austrian CO₂ Bonus, which is part of the state Waldfonds program, can be considered a model. This instrument provides a direct subsidy of €1 to €1.10 for each kilogram of renewable building material used, with the amount of the subsidy linked to the environmental value of the material – i.e. the amount of carbon sequestered. The common denominator is the integration of environmental and economic policy objectives, as well as the linking of innovation with industry and academia. Communication and raising awareness among the public and professionals about the benefits of timber construction is also an important element.

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SUSTAINABILITY AND CIRCULAR ECONOMY IN FOREST AND WOOD-BASED SECTORS

CIRCLE ECONOMY AND SUSTAINABILITY IN WOOD PRODUCTION SECTOR BASED ON RECYCLING (THE BULGARIAN EXPERIENCE)

Dimitar Blagoev

Abstract: The reuse of raw materials is an important goal for the managers of any modern and socially responsible enterprise. The reuse and recycling of raw materials is also at the heart of the concept of the circular economy. This reduces costs for companies and also leaves a smaller ecological footprint on nature. The timber and wood processing industry is particularly suited to the application of the circular economy concept. This would lead to the sustainable development of enterprises in the sector. This paper examines (studies) the state and experience of Bulgaria in recycling and reusing wood products. For this purpose, data from the National Statistical Institute on the recycling of wood and wood waste in the period 2004 to 2022 were used. Trends and developments in the field of recycling of wood production waste are investigated on the basis of the linear function. The data and trends are presented in natural units (tones) and also as a percentage (%) of the total wood production waste generated. Statistical methods of investigation (correlation) were used to establish the relationship between the generated wood production waste, its recycling and the total industrial production index of the country. In this way, specific findings on the degree of adoption of the principles of the circular economy by industrial enterprises in the country are made based on the degree of reuse and recycling of wood waste in the industrial production process.

Keywords: circular economy, recycling, wood production waste, disposal

1. INTRODUCTION

It is undeniable that the paradigms of modern economic models and theories have been transforming from linear to circular, and to a large extent to regenerative, over the past few decades. The reuse of raw materials and goods, sometimes not in the same direction, is the basis of the circular economy. However, there is still much to be desired in achieving higher rates of reuse of raw materials and resources worldwide. Almost all raw materials and resources are subject to reuse and recycling, but some have a much higher degree of recycling intensity than others. At the same time, other resources (including wood, as a natural resource) can be reused both biologically (e.g., soil nourishment) and technically (e.g., re-use in various types of products). Unlike wood, plastic, for example, can only be reused technically, as it has no natural biological nature, but is an artificially created material. The situation is similar with a number of other raw materials. The object of research in this study, however, is the wood resource, and the subject is the degree of its reuse in a technical aspect rather than in a biological aspect (since the biological aspect may be unregistered in many cases). For this purpose, statistical analysis techniques and technical analysis are used, referring to the available data of the National Statistical Institute (NSI) on the volume of collection and reuse of wood resources for a period of nearly 20 years. Based on this, specific findings and patterns in the application of the principles of the circular economy in the wood processing sector have been defined.

2. LITERATURE REVIEW ON THE TOPIC

Circular economy paradigm

The topic of climate change and the human impact on these changes has been of particular relevance over the past decade. Everything indicates that it will be of the same level of relevance in the next few decades. In this direction, concepts of the evolution of the economy from a purely linear model to a circular model and even a regenerative model are also developing. Geissdoerfer, Savaget, Bocken, and Hultink (2017) define the circular economy as a regenerative system in which the reduction of resources and waste, emissions and energy leakage is minimized by slowing down, closing and narrowing energy and material costs. This can be achieved through innovative design, maintenance, repair, reuse, remanufacturing, reconstruction and recycling. Circular economy paradigms are in contrast to the concept of a linear economy. According to the European Environment Information and Observation Network (2025), the linear economy is a traditional model of economy based on a "consumption - disposal of waste resources" approach, or in other words, based on the principles of the consumer society. The redesign of the industrial system of production and consumption around the circular patterns of resource and energy use that we observe in mature ecosystems is only one part of the rethinking of the direction in which the economic system should be transformed, using the principles and concepts of ecology and recycling.

The transition to a circular economy does not only mean adjustments aimed at reducing the negative and disruptive impacts of the linear economy. Rather, it is a systemic change that builds long-term sustainability, generates business and economic opportunities, and provides benefits for the environment and society.

The concept of a circular economy must distinguish between biological and technical cycles. Consumption occurs only in biological cycles, where food and biological materials (such as cotton or wood, for example) are intended to be returned to the system through processes such as composting and anaerobic digestion. These cycles regenerate living systems, such as soil, which provide renewable resources for the economy. Technical cycles recover products, components, and materials through strategies such as reuse, repair, remanufacture, or (as a last resort) recycling (Circular Economy Overview). Some materials can only participate in the technical cycles of the circular economy, but others (including wood) can participate in both technical and biological cycles.

Wood production sector recycling

Post-consumer waste wood is a valuable feedstock for energetic and material sector. Its volume has been increased together with the rapid urbanization and industrialization (Nguyen, Luedtke, Nopens and Krause, 2023). A study by Erlandsson and Sundquist (2014) in several Scandinavian countries shows that the construction sector generates a large part of the wood resource (waste) that is subject to recycling and reuse. Reuse takes the form of using the resource for the production of particleboard and as an insulation material. Similar findings were made by Staňková and Pipiška (2024) investigating the practices of enterprises in the V4 countries in recycling and reuse of wood. They say that some companies (Kronospan and Egger can be mentioned) are using recycled wood to make woodbased composites and 30% recycled wood in its particleboard. Husgafvel, Linkosalmi, Hughes, Kanerva, and Dahl (2018) also identify the importance of wood waste from construction for recycling and reuse. Referring to Vis et al. (2016) they also investigate the so-called cascading reuse of wood. Cascade use

of wood refers to the processing of wood into a product and the use of that product at least once again for either material or energy purposes. The majority of approaches to improve resource efficiency focus on three areas: 1) preventing wood leaving the material flow, 2) addressing the burning of virgin wood, residues and waste wood and 3) enabling and promoting the material use of wood (Vis et al., 2016). Today, the systematic wood cascading is still in its infancies and limited to the downcycling of wood, i.e. the degradation of material quality. New recycling technologies are needed, which maintain the material quality at the beginning of the cascade chain and mobilize yet unused resources (Risse, Weber-Blaschke, and Richter, 2019).

As can be seen from the literature review on the topic, the main waste that is recycled is from the construction sector, and the directions of reuse of the raw material are cascading and mainly for raw materials again related to the construction sector. The available data on the basis of which our study was carried out, however, are not differentiated by sectors of the economy and therefore our findings are common to the entire economy without differentiation by sectors.

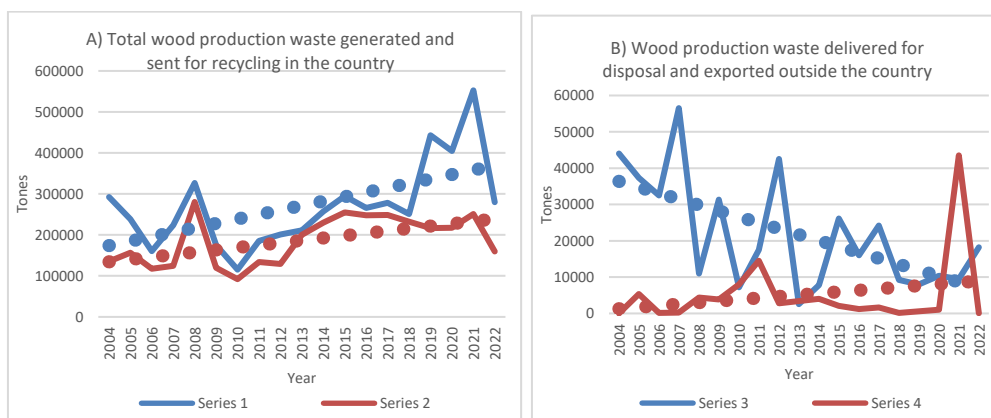
3. METHODOLOGY

For the purposes of this study, we will use the method of technical (comparative) analysis and trends for a certain period, using available statistical data for the following main economic indicators for a 19-year period. The goal is to obtain a complete (data) statistical series that will allow us to outline the relevant trend and short-term forecast for the degree of recycling and reuse of wood raw materials. Statistical methods such as correlation analysis are also used to establish the relationship between the generated wood production waste, recycled wood production waste and the general industrial production index. The goal is to determine whether the degree of reuse (recycling) of wood waste increases with an increase in industrial production. If this hypothesis is confirmed, it can be said that the economic sectors that generate and reuse wood have adopted the principles of the circular economy concept. Wood production waste in all industries is distinguished into three main groups: (1) Wood production waste submitted for recycling; (2) Wood production waste submitted for disposal; and (3) Wood production waste exported outside the country.

The main interest in this particular case is the first group of production waste (submitted for recycling), as the other two groups cover only part of the overall circular process and do not give us an idea of whether and when they complete the respective cycle of the circular economy.

4. RESULTS AND DISCUSSION

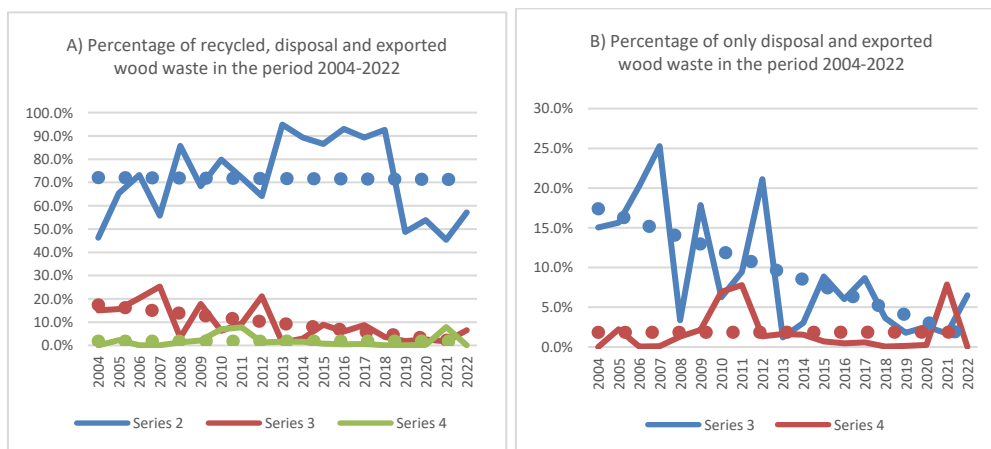
The literature review on the topic identified that one of the main sources of wood waste is the construction industry. This statement may also be relevant for Bulgaria, as the dynamics of waste generation from wood production coincides (to a large extent) with the dynamics of the real estate market and real estate construction. In the period 2006-2008 there was a significant increase in wood waste, but also in that which was sent for recycling. The global financial and economic crisis had an impact and in the period 2008-2010 there was a decline to levels before 2005-2006 (Figure 1). After this crisis there was a steady increase in both quantities until the beginning of the next crisis in 2020-2021 (Covid 19 Pandemic). However, it is observed that from 2018 to 2022 wood production waste is increasing significantly, while wood production waste submitted for recycling remains at relatively stable levels. That is, recycling is slowing down significantly.



Legend: Series 1 - Wood production waste; Series 2 - Wood production waste submitted for recycling; Series 3 - Wood production waste submitted for disposal; Series 4 - Exported wood production waste.

Figure 1 (A and B). Total wood production waste – generated, recycled, disposal and exported.

Data source: National Statistical Institute in Bulgaria



Legend: Series 2 – Recycled wood production waste; Series 3 - Submitted for disposal wood production waste; Series 4 - Exported wood production waste.

Figure 2 (A and B). Percentage of recycled, disposal and exported wood waste.

Data source: National Statistical Institute in Bulgaria

Two other facts presented in Figure 2 B can be positively assessed. For the entire, nearly 20-year period, there is a permanent and sustainable decrease in Wood production waste submitted for disposal. Exported wood production waste is of insignificant scale and is almost the same throughout the observed period.

In percentage terms, it can be said that the largest share of wood production waste is recycled. In the best years, about 90% of wood production waste is recyclable and a much smaller part (less than 10%) is sent for disposal and exported outside the country (less than 1%) (Figure 2).

Dependence between generation, recycling of wood production waste and the dynamics of the industrial production index.

Establishing the degree of adoption of the principles of the circular economy concept will be achieved by identifying the relationship between the levels of generation, recycling of wood waste and the dynamics of the industrial production index for the observed period.

The correlation analysis shows that the most significant correlation is between Wood production waste and Recycled wood production waste (correlation score – 0.644). Less significant is the correlation between Wood production waste and Industrial production index (correlation score – 0.293) and between Recycled wood production waste and Industrial production index (correlation score – 0.43). We can conclude that with the increase in industrial production in the country, there is no serious, statistically significant correlation for the increase in both Wood production waste and Recycled wood production waste. The only more significant correlation (which is logical) is between Wood production waste and Recycled wood production waste.

5. CONCLUSIONS

The following conclusions can be drawn from the study:

- Wood production waste is mainly obtained from the construction industry and it is precisely this waste that is subject to recycling and/or disposal;
- Wood production waste has two directions for utilization (recycling) – biological and technical. Both types are significant for implementing the principles of the circular economy, but technical recycling has a much greater economic effect. Biological recycling is more related to environmental protection. There, disposal of wood production waste before recycling is essential;
- In recent years, the gap between Wood production waste and Recycled wood production waste has been increasing. That is, the share of recycled wood production waste from the total generated wood production waste is decreasing. Although the principles of the circular economy are applied in the wood sector in Bulgarian economy, this process slows down its pace instead of accelerating and intensifying it.

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THE ROLE OF SUSTAINABLE FOREST MANAGEMENT IN THE TRANSITION TO A CIRCULAR ECONOMY

Katya Antonova

Abstract: Sustainable forest management is a key factor for a successful transition to a circular economy, ensuring efficient use of forest resources, minimizing waste and protecting ecosystems. In addition to being an important source of resources, forests play an essential role in carbon sequestration, biodiversity conservation and climate regulation.

The application of sustainability principles in the forestry sector is associated with innovative methods for optimal use of resources, extending the life cycle of wood products, as well as the possibility of their reuse.

At the heart of sustainable forest management in Bulgaria are the goals for a carbon-neutral economy, with innovation and digital transformation of the sector becoming increasingly important. The integration of new technologies, effective policies and sustainable practices will contribute to the protection of forest ecosystems by combining economic benefits with environmental responsibility.

Keywords: circular economy, forestry, new technologies, sustainability, environmental responsibility

1. INTRODUCTION

The challenges facing the world are related to achieving a balance between economic development, caring for the environment and caring for people's health and well-being. The topic of sustainability is becoming more and more significant and relevant in the conditions of modern development, which is characterized by the global environmental crisis and the lack of equitable provision of minimum livelihoods for the world's population (O'Neill et al., 2018). The need to achieve sustainability is also confirmed by the need for planned management of land use and natural resources (Esmail and Geneletti, 2018), as well as for their sustainable development (Perez-Gladish et al., 2021). In this sense, sustainable forest management is key to addressing global environmental challenges and the transition to a circular economy. Forest resources occupy a special place in the ecosystems of each country, providing renewable resources for the economy on the one hand, and on the other hand playing an essential role in carbon sequestration, biodiversity conservation, climate regulation and the maintenance of vital ecological processes. By implementing circular economy principles such as reuse, recycling, recovery of residual products and extending the life cycle of resources, sustainable forest management becomes a strategic goal. It is becoming increasingly important in addressing challenges such as climate change, forest fires, illegal logging and biodiversity loss, and for this purpose new management models are needed, based on innovative approaches, in which the technological solutions of Industry 5.0 are integrated.

The object of research in this paper is the forest sector in Bulgaria in the context of a circular economy, and the subject is the possibilities for its sustainable management.

The aim of the author of this article is to analyze the role of sustainable management of forests and the forest sector in the context of a circular economy, considering both the existing threats and opportunities, as well as the place of innovation in the process of sector transformation and to propose a conceptual model for sustainable management. Our main

thesis is that there are no integrated frameworks for creating policies for sustainable management of forest resources in the context of the circular economy.

2. ROLE OF SUSTAINABLE GOVERNANCE IN A CIRCULAR ECONOMY

In order to respond to the global challenges of sustainable development in recent decades, thinking has been directed towards the concept and model of the development of a circular economy (B. Geldermans, M. Tenpierik & P. Luscuere, 2019). They imply extending the life cycle of products so that when they reach the end of their life, the materials from which they are composed can be reused and waste disposal is minimized. The circular economy (CE) is considered a strategic solution to harmonize economic growth and environmental protection by reducing waste, harmful emissions and resource use. The concept is gaining popularity, claiming to have different influences in different areas (Korhonen et al., 2018). It is defined as a sustainable initiative that achieves a gradual shift from linear to circular policies and practices and generates economic, environmental and social value. Through policies for waste management, environmental protection, longer use of products and materials, and the regeneration of natural systems, the circular economy can be seen as an approach to achieve local, national and global sustainability (Rodriguez-Anton et al., 2019). It can also be defined as a tool for achieving the Sustainable Development Goals (SDGs), and in particular Goal 12 to ensure sustainable consumption and production patterns. Some studies have explored the relationship between the concept of the circular economy and the Sustainable Development Goals and prove that it is essential for the implementation of the SDGs (Schroeder et al., 2019; Rodrigue-z-Anton et al., 2019), as CE is closely linked to sustainable development and is an important part of the European agenda aiming to replace the use-disposal paradigm in various industries. The concept of CE describes an alternative model of the linear system of production and consumption, with the idea that products and materials are not thrown away, but remain in the economic cycle as secondary raw materials for as long as possible. In this way, raw resources, waste and out-of-the-box emissions will be minimized (Geissdoerfer et al., 2017). The main goal of the circular economy is to enable sustainable development, creating economic, environmental and social value not only for current but also for future generations (Morsetto, 2020).

The implementation of sustainable governance models, aligned with the principles of the circular economy are of strategic importance (Bradford, 2020; Schroeder et al., 2019; Guldman & Huulgaard, 2019; Tura et al., 2019), with the aim not only the use of closed loops and the use of renewable energy, but also the improvement of interconnections between participants, in which the actions of one participant have an impact on the other participants. To account for this impact, the selection must take into account the short-term and long-term consequences, as well as the impact of the entire value chain. Some of the main elements of the circular economy are presented in Figure 1.

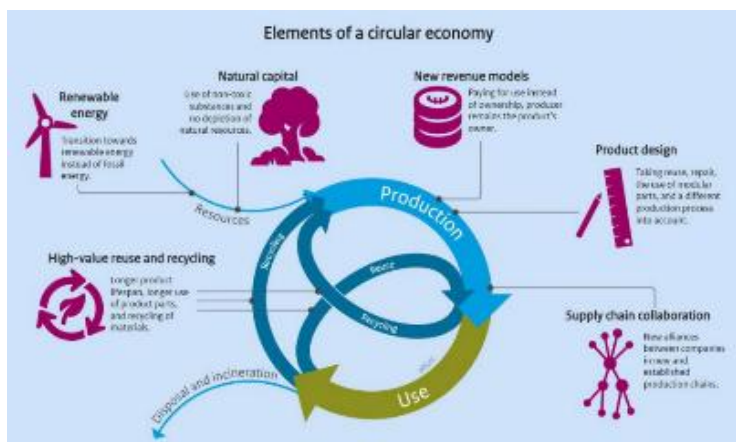


Fig. 1. Some of the elements of the circular economy

Source: <https://esg.asus.com/en/circular-economy/circular-economy-model>

Some benefits of the circular economy can be (European Parliament, 2023):

1. Protecting the environment, including biodiversity, reducing greenhouse gas emissions – by designing more efficient and sustainable products, reusing and recycling products, which in turn reduces the need for extraction of natural resources;
2. Reducing dependence on raw materials – as the population grows, the demand for raw materials also increases, and the possibility of recycling them reduces the risks associated with their procurement;
3. Resource efficiency – it is key to strengthening the competitiveness of the economy, creating the conditions for growth and creating new jobs;
4. Creating jobs and saving costs – resource efficiency is a key point in strengthening the competitiveness of the economy, designing products and materials in a way that implies reuse and recycling. Efficient use will stimulate innovation, and consumers will receive more sustainable and economical products and materials, which will save them costs and improve their quality of life.

The Circular Economy Action Plan (EC, 2023) proposes measures across the entire product lifecycle and aims to improve the economy, increase competitiveness, while protecting the environment and empowering consumers. The new Action Plan draws attention to resource-intensive sectors and focuses on design and manufacturing, where the raw materials used remain in the economy for as long as possible and are managed sustainably.

Globalization and technological development, the trends and challenges of the fourth and fifth industrial revolutions facing the modern economy require ensuring a balance between economic, environmental and social development. The concept of "sustainable management" is particularly relevant given the replacement of the goals perceived until the last century as "maximizing profits" and "maximizing shareholder value" with "increasing the value of all stakeholders" and "ensuring sustainable development". The popularity of the concept of "sustainability", as well as the interdependence of its components, is associated with the basic model known in the theory - three intersecting circles, symbolizing the three aspects of sustainability and the relationship between them: ecological - related to the state of natural equilibrium; economic - related to the ecological intensity of production; social - related to the economic and natural living conditions of the population, such as employment, education and

training, health, access to a "healthy" natural environment, responsible and shared management, etc. Sustainability is defined in many different ways (Meerow et al., 2019; Schiappacasse & Müller, 2018) and is used in a wide variety of research fields, such as environmental sciences, ecology, engineering, and psychology (Xue et al., 2018). Sustainability is about immediate and long-term integration, i.e. it is about striving to meet all sustainability requirements at the same time, seeking mutually reinforcing benefits. Sustainability is a property of a system that keeps it in a certain state over time, while sustainable development is a process that implies change or development. In other words, the concept of sustainable development does not take into account the final state of a system, but the process of change in the nature of the activities that are carried out and in which resources are used, investments are made, institutional changes are introduced. Achieving sustainability is a process that, in response to a change in internal and external environmental conditions, is able to establish a new equilibrium corresponding to these changes, both within a certain system and throughout the entire environment.

According to Tonev (2021), the concept of sustainable development is complemented by the concepts of green growth (economic growth that spares nature, ecosystems and non-renewable resources), green economy (economy that improves human well-being, reduces social inequality and environmental risks) and bioeconomy (a more innovative, resource-efficient and competitive society that equates food safety with the sustainable use of food and vegetables). renewable resources for industrial purposes, while ensuring environmental protection).

The integration of these concepts into a single policy for sustainable development implies that it is subordinated to a model for sustainable management of the forest sector.

3. SUSTAINABLE FOREST MANAGEMENT MODEL

In our opinion, the standard forest sector management process is no longer relevant. There is a need for a new working model for sustainable management, which is expressed in the need for a systematic approach in identifying strategic alternatives that will ensure long-term environmental, economic and social balance in the management of forest resources in Bulgaria. In our opinion, they are: (1) environmental sustainability; (2) economic sustainability; (3) social sustainability; (4) Innovation and new technologies (Fig. 1).

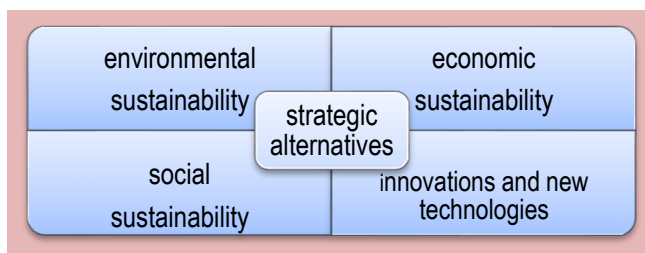


Fig. 1. Strategic alternatives for sustainable forest management

The proposed three strategic alternatives are logical and express the essence of the concept of "sustainability", and the fourth "innovation and new technologies", in our opinion, is important for the development of any sector, including the poor one. Advances in technology

and their application can be implemented and bring positive effects in production and management.

The proposed strategic alternatives open up significant opportunities, and the positive effects will manifest themselves in the following directions:

1. In the environmental aspect, renewable resources, increasing biodiversity, protecting the climate, soil, water, etc., can be ensured;
2. In the economic aspect, the implementation of the principles of the circular economy, the improvement of the value chain in the use of forest resources, the provision of balanced use of resources, the provision of economic incentives, etc. can be ensured;
3. Socially, social inclusion and equal access, people's health and well-being, as well as support for local communities and social responsibility can be ensured;
4. The introduction of innovations and new technologies in the management of forest resources would ensure the achievement of the requirements for circularity in the economy, digitalization of processes, the use of artificial intelligence technologies, etc., which would contribute to the sustainable extraction and processing of forest resources and to their sustainable management (see Fig. 2).



Fig. 2 Some areas of application of strategic alternatives

It is essential for sustainable management to take into account the influence of various external and internal environmental factors. They can be systematized into five groups:

1. Environmental factors – climate change (global warming, drought, natural disasters), plant diseases and pests, fire risk, soil erosion, reduction of biodiversity, geographical and relief features, etc.;
2. Economic factors – level of industrialization, trade in forest resources, capacity of forest farms, levels of urbanization, opportunities for financing the sector, opportunities for investment, migration and depopulation, tourist and recreational pressure, etc.;
3. Social factors – engagement and traditions of local communities, health and well-being, knowledge of sustainability and ecology, cultural and historical aspects, etc.
4. Political and institutional factors – political will and priorities, legislative and institutional framework, control and sanctions, etc.;
5. Technological factors – maintenance of forest infrastructure, implementation of new technological solutions in the production and management of forest resources, etc.

Based on the considerations made, our proposal for a model for sustainable management of the forest sector is as follows (see Fig. 3):

In our proposed model, the process of forest sector management and the transformation of this management into sustainable is outlined, and the following stages are considered:

First: Defining a policy, vision and mission for the development of the forest sector - if they are not well formulated, it is not possible to properly implement the strategy itself.

Second: The Sustainable Forest Management Strategy is an essential management tool and covers areas where long-term decisions are taken. In modern theory, management is understood as part of strategy, and strategic management can make the sector sustainable.

Third: Strategic alternatives represent choices. There are many options for such in the field of sustainable management of the forest sector, but in our opinion, those that we have included in the proposed model are fundamental for this management activity at the current stage of development, as they correspond to the three main pillars of sustainability, as well as to the development of technologies in the conditions of Industry 5.0.

Fourth: In the new economic conditions, improving quality is a sure indicator of success and in this regard, it is necessary to identify the appropriate measures and long-term planning. The assessment and analysis of the implementation of strategic alternatives sends the developments to the corrective actions. They are necessary in case the objectives set are not achieved and that the strategic alternatives chosen are inappropriate and the results obtained after the evaluation are unsatisfactory. Then it is necessary to return the developments to the beginning of the system and to evaluate the strategy. If the assessment turns out to be negative, it is necessary to set new goals, in accordance with them, develop a new strategy and identify new strategic alternatives.

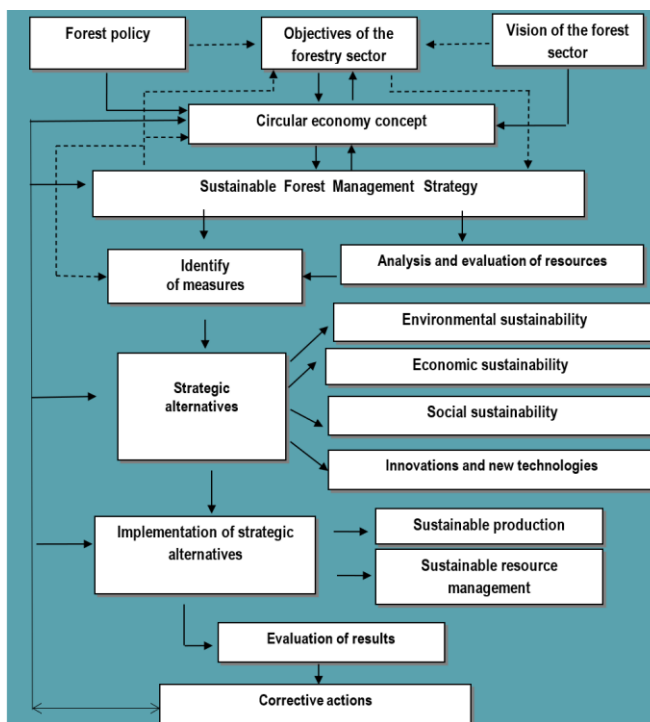


Figure 3. Sustainable Forest Management Model

Source: developed by the author

Fifth: At the heart of sustainable forest management, it is necessary to analyse changes in the internal and external environments so that decisions can be taken in critical situations, decisions that consider management from a strategic perspective and from the perspective of the forest sector as a single whole (system) with the elements and links of interdependence.

The development of a sustainable forest management model is a continuous process that is influenced by internal and external environmental factors. The dynamics of economic development presupposes constant research and analysis of development and the identification of new, more up-to-date strategic alternatives.

In conclusion, it can be said that the model for sustainable management of the forest sector, which we propose, is a set of elements and causal relationships between them. It can be used by different sectors. The proposed model is fundamental, because with a certain reorientation of some elements and strategic alternatives, it can be used for other strategic functions. Due to the interconnectedness of the individual management functions, it is necessary to implement and maintain a system for sustainable management of forest resources, which will ensure constant monitoring of activities, coordination and purposefulness of processes.

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ARCHITECTURAL PERSPECTIVES ON WOOD REUSE WITHIN CIRCULAR CONSTRUCTION IN NORTH MACEDONIA

Marija Miloshevska Janakieska, Manja Kitek Kuzman

Abstract: The reuse of wood in construction presents offers a sustainable solution for reducing waste and conserving resources, aligned with global efforts to mitigate the impacts of climate change. In North Macedonia, the construction sector is highly developed and holds a potential for the incorporation of reclaimed wood withing broader energy efficiency and circular construction practices. This approach aligns with the principles of the European Bauhaus initiative, which emphasizes sustainability, inclusivity, and aesthetic quality in design and construction.

This study explores the perspectives and practices of architects regarding the reuse of wood in construction, based on a survey of architectural professionals. It explores their attitudes, challenges, and motivations for using reclaimed wood, emphasizing circular construction principles. The findings highlight a shared perspective among respondents that both their profession and government entities fail to adequately support or promote wood reuse within the context of sustainable design. On the other hand, architects recognize the environmental benefits, unique aesthetics, historical value, and sustainability as primary drivers for reclaimed wood use.

The ecological benefits were identified as the most important aspect for reuse of wood products, followed by economic and technological factors. However, concerns about the long-term quality and maintenance of reclaimed wood products present significant barriers. This research sheds light on the challenges and opportunities surrounding reclaimed wood use in Macedonia, underscoring the need for stronger support mechanisms and greater awareness to advance circular construction practices. These findings provide valuable insights for architects, investors, and policymakers, identifying market opportunities and promoting eco-friendly building designs with reclaimed wood elements.

Keywords: architecture; building construction; circular construction; reused wood; North Macedonia, European Bauhaus initiative

1. INTRODUCTION

The application of reclaimed wooden elements in architecture and construction has become popular, especially because of its sustainable advantages. This practice is following the principles of circular bioeconomy such as efficient use of resources, decreasing the waste and carbon emissions [Nußholz et al., 2020]. Although reusing wood has some disadvantages, such as structural restrictions, health safety, and maintenance needs, the advantages are numerous.

A large part of the carbon emissions comes from the embodied energy in the building materials [Pomponi et al., 2016; Cabeza et al., 2014]. The circularity in the construction aims to close the material loops through recycling, reusing, and repurposing of the materials. Wood with its renewable nature, carbon storage potential and low embodied energy is especially valuable in this process.

The building sector in North Macedonia is revitalizing following a period of political and economic instability. Although almost 40% of the country is forested [Worldbank.org, 2020], the potential of using wood in sustainable building practices is still being explored.

The main aim of this study was to research the feasibility of reusing and recycling wood products in North Macedonia, based on collected data, and to identify the possible directions for future development in line with circular construction and cascade use principles.

2. METHODOLOGY

The methodology of this research is based on a survey questionnaire that was distributed among practicing architects through the Chamber of Certified Architects and Certified Engineers of the Republic of North Macedonia. The aim was to gather insights on the reuse of wood in building construction. The survey was conducted online, using 1KA, a free web survey software developed by the Centre for Social Informatics at the Faculty of Social Sciences, University of Ljubljana. The questionnaire consisted of four parts: a general questionnaire that reflected the profile of the respondents who participated in the survey: the industry sector, the company size, and the product type. A set of questions about the potential for wood products' reuse; a set of questions addressing doubts, motivations, and the potential to use and reuse wood products. Questions about material and construction choice made by investors and architects in their practice.

A total of 101 valid responses were received. Taking in account undeliverable emails due to outdated addresses or inactive firms, the response rate for the country was calculated accordingly. While the specific reasons for lower participation are not fully known, common contributing factors include limited interest in the survey topic or the perceived length of the questionnaire [Fan et al., 2010].

The statistical software JASP 0.16.4 was used for data analysis.

3. RESULTS AND DISCUSSION

According to the survey, the gender distribution among respondents was roughly equal. More than 80% of them were aged between 25 and 44 years. All respondents were certified architects, holding either a professional master's degree or a university degree.

88% of the architects reported that the investors typically use concrete for building construction (Figure 1). Brick is not so commonly used, which is understandable, since it doesn't have a horizontal load bearing capacity, and it is not recommended in seismic active regions. Wood and other materials are rarely selected as primary building materials.

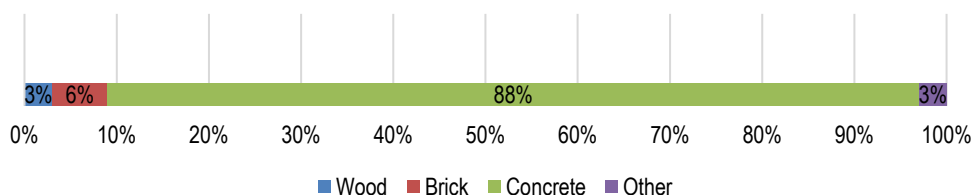


Figure 1. Investors' Choice of Material in Construction

The situation is different when it comes to architects' recommendations regarding the building materials (Figure 2). According to the answers, architects in North Macedonia are recommending concrete (42%), but also other materials (36%).

In North Macedonia, architects show a high level of confidence in wood as a building material, but various factors influence their perceptions, such as limited exposure or familiarity with contemporary wood technologies, misconceptions about the structural performance and durability, as well as regulatory limitations. Most of the architects agree or strongly agree (79%) that the ecological materials and construction methods applications are important for the investors (Figure 3).

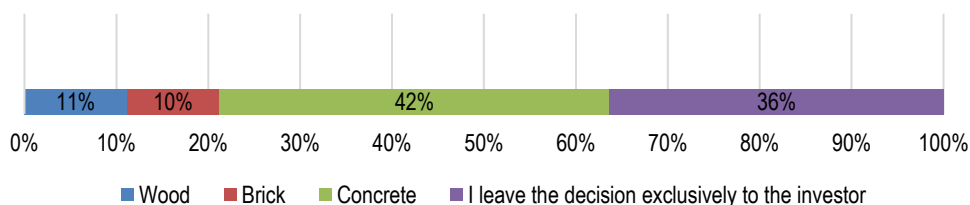


Figure 2. Construction Materials that are Recommended by Architects

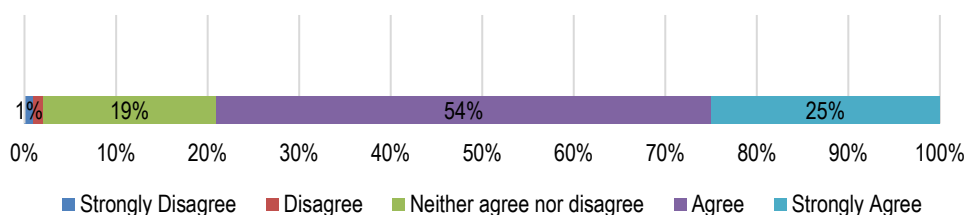


Figure 3: Perceived Importance of Ecological Materials and Construction Methods for Investors

Unfortunately, a low percentage of architects have experience with use of reclaimed wood (Figure 4).

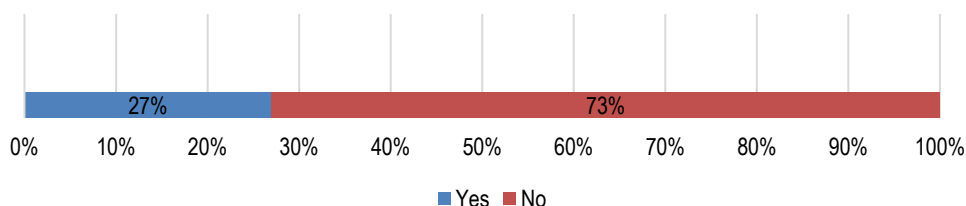


Figure 4: Architects' Experience with the Use of Reclaimed Wood

Among those surveyed, 68% of architects identified structural elements—such as beams and columns—as having the greatest potential for reuse, followed by doors with only 15% (Figure 5).

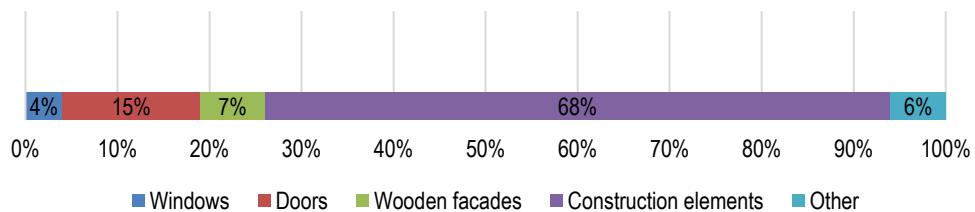


Figure 5: Perceived Reuse Potential of Various Wood Products

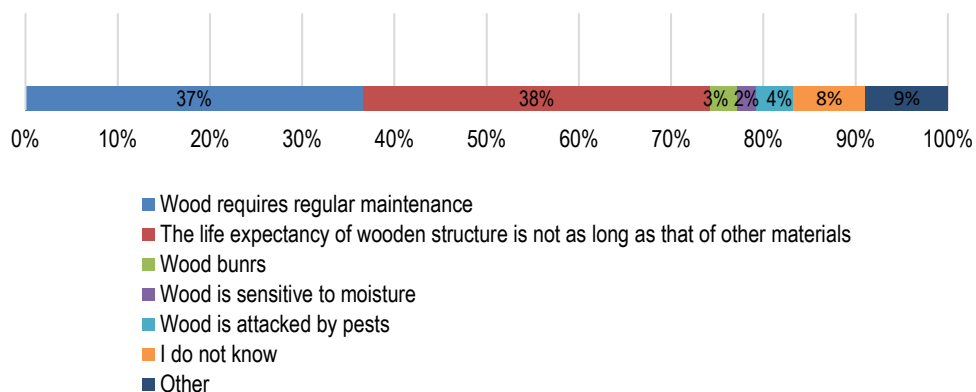


Figure 6: Doubts about the long-term quality of wood products

The concerns about the long-term quality of wood products are primarily due to the need for regular maintenance and the life expectancy of wooden structure (Figure 6).

Most of the respondents either agree or strongly agree that reclaimed wood has a lower value compared to other construction and demolition wastes, such as metals and plastics (Figure 7). They noted that reclaimed wood is reused less frequently than materials such as metal or plastic due to several factors. Reclaimed wood offers many benefits, from environmental characteristic to beautiful aesthetics, but it is not always easy to source, and the usage can be both labor-intensive and not affordable. Processing challenges, such as irregular sizes, embedded hardware, or degradation, further complicate its reuse. Moreover, the quality and durability of reclaimed wood vary depending on its previous use and condition, often requiring thorough inspection or testing. Regulatory constraints, including building codes and certification standards, may also restrict its application. Finally, regional availability, market demand, industry practices, and cultural attitudes can significantly influence the extent to which reclaimed wood is reused in construction and design.

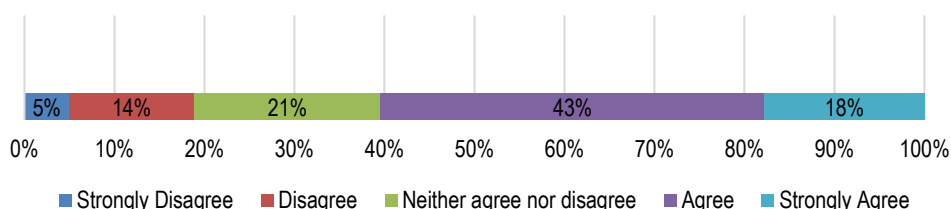


Figure 7: Reclaimed wood has a lower value compared to other construction and demolition waste

4. CONCLUSIONS

This study explores architects' perceptions on wood reuse in the construction sector in North Macedonia, highlighting its potential within circular bioeconomy practices and the broader vision of the New European Bauhaus.

Architects reported limited support from both professional and governmental institutions for reusing wood. Key challenges include limited availability, high costs, processing complexity, durability concerns, and regulatory limitations.

In North Macedonia, concrete is a dominant construction material, most often preferred by the investors for the structural elements in the buildings. Despite this fact, 79% of the architects agree that ecological material selection is important to investors—one of the highest rates among the surveyed countries.

Most architects reject the idea that reclaimed wood is of lower value. They appreciate the positive features of the reused wood, such as its sustainability, aesthetics, historic value, and craftsmanship appeal. The primary concerns include the need for regular maintenance and perceived shorter lifespan of wooden structures compared to other structures from concrete and steel.

In conclusion, this study emphasizes the need for stronger institutional support, targeted strategies to overcome common challenges, and greater awareness of the ecological and economic benefits of using reclaimed wood in construction. These actions could promote wider adoption of reclaimed wood and cascade use principles within circular construction practices in North Macedonia. Furthermore, the research offers valuable insights into the country's potential to advance circular construction within the broader framework of the circular bioeconomy.

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EXPLORING THE POTENTIAL OF DIGITIZATION IN ADVANCING THE CIRCULAR ECONOMY IN THE WOOD-BASED SECTOR

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Abstract: The transition to a circular economy in the wood-based sector requires the integration of digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), blockchain, and big data. These technologies have proven effective in optimizing production, minimizing waste, and enhancing supply chain transparency in sectors like automotive and construction. However, their adoption in the wood-based sector remains limited and underexplored. This review paper analyses current digital solutions that support circular economy principles in the wood-based sector. It examines existing research, case studies, and industry applications, highlighting key opportunities and challenges. The findings aim to enhance the understanding of how digitization can drive innovation, improve resource efficiency, and facilitate the transition toward a more sustainable and technologically advanced wood-based industry.

Keywords: Digitization, Circular Economy, Wood-Based Sector, Wood Processing, Digital Innovation, Sustainability, Industry 4.0.

1. INTRODUCTION

The global push for sustainability and stricter environmental regulations urges industries, including the wood sector, to improve resource management and efficiency. In this context, digital tools and Industry 4.0 technologies, such as digital twins, real-time analytics, and automation, are becoming increasingly essential (Legg et al., 2021; Goropečnik et al., 2024; Molinaro & Orzes, 2022).

While sectors like automotive and construction have advanced significantly in this area, the wood sector remains in its early stages. Research shows that digitalization boosts productivity, reduces resource consumption, and improves supply chain transparency (Müller et al., 2019). For example, Slovenian companies have demonstrated significant production improvements through digital adoption (Kropivšek & Grošelj, 2020). Additionally, AI and blockchain technologies enhance traceability, product quality, and compliance with sustainability standards (He & Turner, 2021). Sasaki (2025) notes that Industry 4.0 can even support carbon storage in harvested wood products, aligning digitalization with broader climate goals.

Croatia's National Development Plan (2023–2030) sets four priorities: promoting the digital and green transition, increasing productivity and climate resilience, boosting regional competitiveness, and supporting balanced development.

Despite the benefits, technical, financial, and organizational barriers remain. This paper examines how digitalization supports circular economy strategies, includes case studies, and provides recommendations for a sustainable transformation of the wood sector.

2. DIGITAL TECHNOLOGIES TRANSFORMING THE WOOD SECTOR

Integrating Industry 4.0 technologies is reshaping the wood sector by enhancing productivity, traceability, and sustainability. Real-time data, automation, and analytics improve responsiveness to market and environmental demands. IoT and smart sensors optimize kiln

drying and CNC machining by enabling real-time monitoring, reducing energy use, and enabling predictive maintenance (Dalenogare et al., 2018; Bersani et al., 2022). They also enhance traceability and quality control, ensuring certification compliance (Gharaibeh et al., 2024). AI and machine learning improve precision in sawmilling and furniture production by forecasting demand, detecting defects, and optimizing material use (Nasir et al., 2024; Mangla et al., 2022). Blockchain enhances transparency and traceability in supply chains, supporting certification and preventing illegal logging (He & Turner, 2021; Liu et al., 2023; Klarić et al., 2024). Pilot projects in Europe demonstrate its application in sustainable forest management. ERP systems improve digital coordination and sustainability by enabling real-time control and compliance (Vukman et al., 2024). Big data and cloud computing usually support production planning and strategic decision-making. Digital twins simulate real-time factory operations, helping detect inefficiencies (Timperi et al., 2024; Alshahrani, 2023). Aligned with Croatia's National Development Plan, the sector aims for resilience through digitalization, green technologies, energy efficiency, and circular economy practices. Together, these technologies drive the digital transformation of the wood sector, supporting sustainability and circular economy principles.

3. CIRCULAR ECONOMY STRATEGIES IN THE WOOD SECTOR

The concept of a circular economy emphasizes resource efficiency, waste reduction, and product longevity principles that are increasingly relevant to the wood sector. Digital technologies play a critical role in enabling these practices through advanced tracking, intelligent planning, and lifecycle monitoring.

3. 1. Material Reuse and Recycling

Digital tools have significantly improved the potential for material reuse in wood processing. IoT-based tracking systems enable real-time monitoring of wood products along the supply chain, ensuring compliance with quality and sustainability standards (Gharaibeh et al., 2024). At the same time, AI-powered sorting systems automate the classification of reclaimed wood, improving recycling efficiency and enabling higher-value reuse (Nasir et al., 2024). Blockchain enhances transparency in recycled wood supply chains, especially for applications where certification and origin tracking are critical (Liu et al., 2023; Klarić et al., 2024). Additionally, digital platforms support the resale and redistribution of reclaimed wood, reducing dependence on virgin raw materials (Singh et al., 2022).

3. 2. Product Lifecycle Extension

Extending the lifespan of wood products contributes directly to waste reduction and lower raw material consumption. Modular product design, facilitated by digital manufacturing and smart design tools, allows components to be disassembled, upgraded, or reused (Bravi et al., 2022). For instance, Scandinavian housing projects have successfully used BIM to recover and repurpose timber from demolished structures. Artificial intelligence can assist in monitoring the condition of wooden structures, predicting maintenance needs, and thus preventing premature

disposal (Okorie *et al.*, 2018). Life Cycle Assessment (LCA) tools also guide eco-design by evaluating environmental performance throughout the product's lifecycle (Kruhak *et al.*, 2023).

3. 3. Sustainable Forestry Management

Sustainable forestry represents the foundation of a circular wood economy. Industry 4.0 technologies, such as drones, remote sensing, and integrated digital platforms, are increasingly used for forest monitoring, planning, and carbon accounting. Sasaki (2025) highlights their role in enhancing carbon storage in harvested wood products and ensuring alignment with climate goals. Moreover, Beljan *et al.* (2023) emphasize the importance of forest management in carbon trading schemes, noting forests' economic and environmental value as carbon sinks. These approaches reflect the objectives of the EU's Green Deal, which promotes innovative technologies to support emission reduction and resilience in forest ecosystems. Together, these strategies demonstrate how digitalization can strengthen circular economy efforts across the entire wood value chain, from resource origin to end-of-life management, ultimately supporting a more sustainable and efficient industry.

4. LESSONS FROM OTHER INDUSTRIES

Implementing digital and circular economy strategies in other sectors offers valuable insights for the wood sector. Wood processing companies can identify transferable practices and avoid common pitfalls by studying successful applications in the automotive, textile, and construction industries.

4. 1. Automotive Industry

The automotive sector is among the pioneers in leveraging digitalization to support circularity. Digital twins allow manufacturers to monitor performance and simulate upgrades across the entire product lifecycle, improving maintenance and reducing waste (Molinaro & Orzes, 2022). Blockchain technologies trace components and ensure materials meet sustainability and ethical sourcing standards (He & Turner, 2021). Additionally, circular practices such as remanufacturing and component reuse are increasingly common, improving resource efficiency (Daemen and Hansson, 2022).

4. 2. Textile Industry

In the textile sector, digital platforms track material provenance and enable second-hand markets, supporting reuse and reducing textile waste (Ormazabal *et al.*, 2018). AI-based sorting systems help recover high-quality fibers from waste, while blockchain systems verify ethical sourcing and promote consumer trust (Faridi *et al.*, 2020; Hossain *et al.*, 2024). A similar strategy could be applied in the wood sector to facilitate reclaimed wood and upcycling initiatives. These innovations illustrate how digitalization can address sustainability challenges even in highly globalized and fast-moving industries.

4. 3 Construction Industry

Information Modeling (BIM) enhances the lifecycle management of buildings and materials (Baghalzadeh *et al.*, 2022). IoT-based sensors track material usage in real-time, improving efficiency and reducing waste (Gharaibeh *et al.*, 2024). Moreover, modular

construction methods promote the reuse and adaptation of prefabricated components, aligning the sector with circular economy principles (Jahan et al., 2022). Modular construction methods, which involve reusing and adapting prefabricated components, align seamlessly with circular economy principles. A study involving Dutch social housing organizations applying circular principles found that circular design pre-integrates lifespan considerations and future reuse potential, promoting sustainability (Çetin et al., 2022).

These cross-sectoral examples demonstrate that combining digital tools and circular strategies can generate substantial environmental and economic benefits. In the wood sector, adapting such practices as AI-driven material recovery, blockchain-based certification, and digital lifecycle monitoring could accelerate sustainable transformation while ensuring regulatory compliance in a rapidly evolving market.

5. BRIDGING THE GAP: DIGITALIZATION AND CIRCULAR ECONOMY IN WOOD PROCESSING

Despite the strong potential of digitalization to support circular economy goals in the wood sector, several challenges persist, including high initial investment costs that are especially burdensome for SMEs (Haddouche and Ilinca, 2022; Dalenogare et al., 2018). Concerns about data security and the lack of standardized frameworks for system interoperability further complicate adoption (Gharaibeh et al., 2024). Additionally, traditional resistance to change remains a significant barrier, requiring strong leadership, targeted education, and supportive policies to drive transformation (De Vass et al., 2023). A pronounced skills gap also limits progress, as effective digital and circular solutions implementation depends on specialized knowledge (Mangla et al., 2022). In Croatia, the wood sector focuses on low-value-added products. It demonstrates limited digitalization and ICT infrastructure progress, leading to a lag in adopting Industry 4.0 technologies such as automation and robotics. That ultimately reduces the sector's competitiveness in international markets. According to the DESI Index, Croatia remains below the EU average across indicators such as digital skills, infrastructure, business digitalization, and public services (Figure 1). To overcome these challenges and accelerate digital transformation, strategic action is essential. Government incentives and policy support are key in addressing financial barriers (Cláudio et al., 2024), while investment in workforce development and digital infrastructure is crucial for successful implementation (Haddouche and Ilinca, 2022). Integrating circular economy principles, such as using blockchain for traceable sourcing and AI for predictive maintenance, can enhance efficiency and reduce waste (Dragomir et al., 2023). Cross-sector collaboration further promotes innovation and knowledge transfer (Gharaibeh et al., 2024), while targeted research tailored to the wood sector's specific needs can ensure more effective digital solutions (Landscheidt and Kans, 2016). Strengthening digital skills and investing in R&D are fundamental steps toward building capacity and enabling a competitive, digitally driven economy (MINGO, 2023).

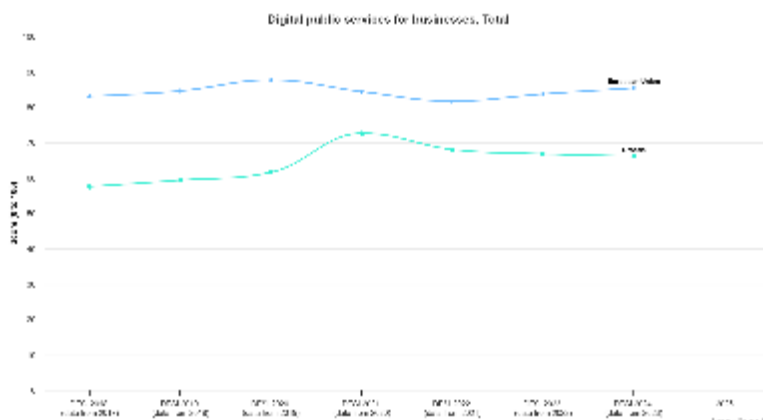


Figure 1. DESI Index for Croatia. (Source: eGovernment Benchmark Reports (2012-2024))

CONCLUSION

The convergence of digitalization and circular economy principles offers significant opportunities for the wood sector. By learning from industries like automotive, textile, and construction, wood manufacturers can adopt digital tools to boost sustainability, resource efficiency, and waste reduction. However, economic, technical, and regulatory barriers must be addressed through collaboration among industry, policymakers, and researchers. Forestry is also undergoing digital transformation. Technologies like drones, remote sensing, GIS, LiDAR, and AI are replacing traditional inventory methods. These tools enhance forest monitoring, support restoration, and improve sustainable forest management..

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A MODEL FOR QUANTIFYING POTENTIAL COST SAVINGS IN THE WOOD INDUSTRY FOR PRODUCTS UTILIZING RECYCLED MATERIALS

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Abstract: In response to the rising demand for sustainable goods made from recycled materials, manufacturing firms require increasingly precise and adaptable cost assessments to pinpoint potential savings. This study presents a methodology for quantifying cost reductions in the production of innovative items that integrate wood with plastic, rubber, or cement-based secondary materials. The proposed framework uses indexed indicators and machine-hour rates, facilitating dynamic adjustments to changes in raw material prices, energy consumption, and other influential factors, while also enabling optimal control of production costs. The proposed methodology yielded cost savings of 2.22 % in total production costs and 4.55 % in material costs. This approach bolsters the competitiveness of wood-focused manufacturing operations and broadens opportunities for further research into cost management strategies for sustainable and recycled materials.

Keywords: particleboard, cost calculation, cost savings, wood, plastic, cement,

1. INTRODUCTION

Over the past decade, the manufacturing sector has increasingly adapted to environmental regulations and societal pressures to reduce its carbon footprint, resulting in a marked rise in interest in sustainable production solutions and the circular economy (Shukla et al., 2024), (Alyousef et al., 2021). Simultaneously, there is growing demand for innovative, cost-competitive, and environmentally friendly products manufactured from secondary raw materials, particularly in sectors such as construction, furniture, and light industry (Lubguban et al., 2025). One of the most promising approaches in this area is the manufacture of composites that combine wood with recycled materials, such as thermoplastics (Zhou et al., 2024), waste tire rubber (Shaneei et al., 2024), cement fractions (Bajare et al., 2024), and fly ash (Saadeddine et al., 2022). These materials exhibit favorable mechanical strength, elasticity, and thermal and chemical resistance (Ayoob & Kavitha, 2021), while also enabling a significant reduction in the environmental impact of production (Tayançlı et al., 2021).

Although their technical potential is increasingly well documented (Keskisaari, 2017), the challenge remains how to effectively calculate and manage production costs when using recycled components, since input prices for these materials are often volatile and depend on local availability, seasonality, and processing quality (Harmaji et al., 2021). The instability of energy prices and the growing regulatory pressure on carbon emissions across the product life cycle also present significant challenges (Kolendo et al., 2024; Alyousef et al., 2021). Furthermore, quantifying the potential cost savings remains a crucial area of investigation (Osvaldová et al., 2023).

A solution to this challenge is the use of indexed cost indicators and machine-hour rates, which allow flexible and precise adjustment of cost calculations to prevailing raw-material and

energy market conditions (McHugh et al., 2020; Wang, Ashuri, 2016; 19. Hong et al., 2013). This approach enables dynamic control of manufacturing processes particularly for wood–plastic and wood–cement products, which place high demands on raw-material logistics and energy balance (Adamopoulos, 2013; Ghazali et al., 2015). However, there is currently no comprehensive methodology that integrates environmental and economic variables into a unified framework for cost management in the production of wood-based products with recycled components. Existing models are either too rigid or fail to account for the specific characteristics of composites made from secondary raw materials (Chen et al., 2021; Oti, 2015).

The aim of this study is to present a comprehensive and flexible methodology for quantifying and managing production costs of products combining wood with recycled materials such as plastic, rubber, and cement. The proposed framework enables manufacturers to track fluctuations in input prices using indexed metrics, adapt to energy intensity through machine-hour rates, reduce overall costs, and, most importantly, quantify total cost savings in relation to strengthening their products' ecological profile. Moreover, this study lays the foundation for future research on cost efficiency and competitiveness in sustainable manufacturing with recycled components

2. METHODOLOGY

This study examines two board types a standard three-layer P1-grade particleboard and a modified three-layer particleboard containing polymeric additives P1-grade (wood–plastic composite board). Both board variants were manufactured under laboratory conditions at the Technical University in Zvolen using conventional industrial technology and in compliance with standard requirements for P1-type particleboards intended for dry environments..

Production of Woodplastic Composite Particleboard

Woodplastic composite particleboard consisted of a traditional three-layer structure in which 10 wt% of the central core layer's wood particles were replaced by recycled plastic granulate. Three sources of post-consumer plastics were evaluated, each incorporated separately into individual board panels:

- **NNA (unpainted car bumpers):** polypropylene granulate
- **LNA (painted car bumpers):** polypropylene granulate
- **NAD (car fuel tanks):** polyethylene granulate

The wood particles for all layers were oven-dried to a moisture content of 2–3 wt%. Cold pre-pressing produced mats with dimensions 400 × 400 mm and a target thickness of 16 mm. Hot pressing was conducted at 180 °C under a maximum specific pressure of 2.5 MPa for 6 minutes, yielding boards that met all relevant density and mechanical property specification (Čabalová et al., 2025). A similar technological procedure is also employed in the production of composite boards incorporating rubber or cement additives.

2.1 Cost Determination

This section presents the methodology for comprehensively quantifying the cost structure of particleboard production, including the direct calculation of material and labor costs.

Based on the recommendations from theoretical sources (Král a kol., 2018; Coenenberg a kol., 2016; Potkány, Krajčirová, 2015; Hradecký a kol., 2008; Däumler, Grabe, 2002)) and

practical applications in the production of similar products, the following calculation formula structure was used:

Direct Material Cost – wood chips, sawdust
+ Direct Additional Material Cost – plastic/rubber/cement/additives/other
+ Direct Energy Cost
+ Production Overhead Costs
= Direct Production Costs
+ Administrative and Sales Overhead Costs
= Total Cost of Product
+ Profit Margin
= Sales Price Excluding VAT

To quantify Production Overhead Cost Surcharge (POS) and Administrative and Sales Overhead Surcharge (AaSOC), equations [1] and [2] were used podľa Král a et al., (2019); Martinovičová et al., (2019); Potkány, Krajčírová (2015); Osvaldová et al., (2023).

POS = Production Overhead Costs / Direct Wage Cost x 100 [%] [1]

AaSOC = Administrative and Sales Overhead Costs / Direct Production Costs x 100 [%] [2]

A relatively unknown concept in our context is the calculation of machine hour (MH) rates. The application of this methodological approach requires defining different cost groups and allocation bases for its implementation Wöltje (2016); Mumm (2015); Ostermann (2010); Osvaldová, Potkány (2025)

Direct Material Costs (wood chips)
+ Direct Additional Material Costs – plastic/rubber/other
+ Wage Cost Rate per Machine Hour
+ Energy Cost Rate per Machine Hour
+ Depreciation Cost Rate per Machine Hour
+ Rental Cost Rate per Machine Hour
= Total Production Costs
+ Other Overhead Costs
= Total Cost of Product
+ Profit Margin
= Sales Price Excluding VAT

Methodological procedure for quantifying proposed overhead cost items using overhead rate calculations:

- Wage Cost Rate: wage costs/planned time fund MH
- Energy Cost Rate: rated power of machines × Ø% of electrical capacity utilization × rate per unit of energy
- Calculated Depreciation Cost Rate: acquisition price of the technology/(lifetime/planned MH time fund)
- Calculated Interest Cost Rate: (equity × interest rate)/ planned time fund MH)
- Calculated Rental Cost Rate: rent / planned time fund MH
- Overhead Cost Markup: (other overhead costs)/(direct wage cost) × 100

2.2 Determination of Cost Savings

Indexing material costs allows adjustment of unit raw-material prices according to current price indices, thereby ensuring an accurate reflection of costs over time. The indices used (see Equation 3) represent price changes relative to a baseline level of 100 %.

Calculation of the Adjusted Unit Price

$$P_{t,i} = P_{0,i} \times \frac{I_{t,i}}{100} \quad [3]$$

$P_{0,i}$ – the base price of material i in the reference period (€/unit)

$I_{t,i}$ – the price index of material i at time t (base = 100)

Calculation of Total Material Costs

$$Mat. Cost_t = \sum_i Q_i \times P_{t,i} \quad [4]$$

Q_i – the quantity of material i consumed (in m³, kg, pieces, etc.)

Total material cost savings (i.e., total cost savings)

Material cost of the standard product – Material cost of the modified product [5]

Total cost of the standard product – Total cost of the modified product [6]

3. RESULTS

In this chapter, we present the methodological framework for applying both traditional and alternative markup calculations to the manufacture of a standard three-layer particleboard, including a variant containing 10 wt% plastic granulate. We examine the composition of material and overhead costs, assess the sensitivity of the final price to fluctuations in price indices, and compare different methods of overhead allocation to demonstrate the economic advantages of woodplastic composite particleboard.

Table 1. Indexation of material costs - woodplastic composite particleboard

Material	Quantity (Qi)	Unit price (Pt,i)	Material cost t (€/m ³)	Current index (It)	Adjusted unit price	Total material cost
Wood chips	<i>The exact quantities and ratios of material costs and also sales to unit are protected by the formulation</i>		55.94 €/m ³	1	55.94 €	55.94 €
Adhesive and additives			10.10 €/m ³	1	10.10 €	10.10 €
Plastic granulate (rubber granulate, other granulate)			1.65 €/m ³	1	1.65 €	1.65 €
Total	67.69 €/m³					

Table 1 presents the base prices of raw materials ($P_{t,i}$), their current price indices ($I_t = 1$), and the resulting adjusted unit prices used to calculate material costs per cubic meter of woodplastic composite particleboard. For wood chips (fractions 0.25–1 mm and 0.25–4 mm), the base price P_0 is €55.94/m³, which given an index of 1 remains €55.94/m³. Adhesive and additives are priced at €10.10/m³, and plastic granulate at €1.65/m³, also unchanged at an index of 1. This yields a total material cost of €67.69/m³. To preserve recipe confidentiality, the exact kilogram quantities per cubic meter are omitted. The methodology further demonstrates

that if the chips' price index were to rise from 1 to 1.10, their unit cost would increase from €55.94/m³ to €61.53/m³ (an increase of €5.59/m³), raising the total material cost to €73.28/m³.

Table 2. Conventional markup calculation for a standard particleboard

Calculation item – 3-layer standard particleboard	Calculation item (€/1 m ³)
Material Costs (chips. fraction 0.25–1 mm. 0.25–4 mm)	62.15
+ Material Costs (adhesive + additives)	10.10
+ Energy (water. electricity. gas)	28.07
= Direct Production Costs (excluding wage costs)	100.32
+ Production Overhead Costs (50%)	36.13
+ Administrative and Sales Overhead Costs (20%)	20.06
= Total Cost of Product	156.51
+ Profit Margin (15% ROC)	23.48
= Sales Price Excluding VAT	179.99

* The allocation base for manufacturing overhead (including labor costs) is the direct material costs

** The allocation base for other overhead is the direct production costs

Table 2 summarizes the cost structure and resulting quotation price for conventional particleboard, calculated using the markup method. Direct material costs for wood chips amounted to €62.15/m³, while adhesives and additives contributed an additional €10.10/m³. Energy costs of €28.07/m³ bring the direct production cost (excluding labor) to €100.32/m³. Manufacturing overhead, set at 50 % of these direct costs, was €36.13/m³, and administrative and sales overhead (20 %) was €20.06/m³, yielding total product costs of €156.51/m³. Applying a 15 % profit margin produces a pre-VAT quotation price of €179.99/m³. This model adheres to established theoretical formulas while preserving manufacturer confidentiality and provides a robust baseline for comparison with innovative variants.

Table 3. Conventional markup calculation for woodplastic composite particleboard

Calculation item – woodplastic composite particleboard	Calculation item (€/1 m ³)
Material Costs (chips. fraction 0.25–1 mm. 0.25–4 mm)	55.94
+ Material Costs (plastic. fraction 1–4 mm)	1.65
+ Material Costs (adhesive + additives)	10.10
+ Energy Costs (water. electricity. gas)	28.07
= Direct Production Costs (excluding wage costs)	95.76
+ Production Overhead Costs (50%) *	37.23
+ Administrative and Sales Overhead Costs (29.64%)	20.06
= Total Cost of Product	153.05
+ Profit Margin (15% ROC)	22.96
= Sales Price Excluding VAT	176.00

* The allocation base for manufacturing overhead (including labor costs) is the direct material costs

** The allocation base for other overhead is the direct production costs

When replacing 10 wt% of the wood chips with plastic granulate, the woodplastic composite particleboard (Table 3) shows lower material costs for wood chips (€55.94/m³) plus plastic granulate (€1.65/m³), while adhesives, additives, and energy costs remain unchanged. Direct production costs including energy amount to €95.76/m³. Manufacturing overhead rises to 55 % due to plastic handling, or €37.23/m³, and administrative and sales overhead remains €20.06/m³. Total product costs decrease to €153.05/m³, yielding a pre-VAT quotation price of €176.00/m³ with a 15 % profit margin. Compared to standard particleboard, this variant achieves material cost savings of €4.56/m³ (4.55 %) and total cost savings of €3.46/m³ (2.22 %), confirming the economic potential of incorporating 10 wt% plastic granulate. The same approach can quantify potential savings when adding rubber or cement to the composite board.

Table 4. Machine-hour rate calculation for woodplastic composite particleboard

Calculation item – woodplastic composite particleboard (panel dimensions 2800 × 2070 × 16 mm; also available in 10 mm and 18 mm thicknesses (t))	Altern. 1 t = 16 mm (€/1 m ³)	Altern. 2 t = 10 mm (€/1 m ³)	Altern.3 t = 18 mm (€/1 m ³)
Material Costs (chips. fraction 0.25–1 mm. 0.25–4 mm)	55.94	55.94	55.94
+ Material Costs (plastic. fraction 1–4 mm)	1.65	1.65	1.65
+ Material Costs (adhesive + additives)	10.10	10.1	10.1
+ Wage Cost Rate per Machine Hour 85.71 EUR/MH	9.71	12.86	9.00
+ Energy Cost Rate per Machine Hour 144 EUR/MH	16.32	21.60	15.12
+ Depreciation Cost Rate per Machine Hour 66.67 EUR/MH	7.56	10.00	7.00
+ Rental Cost Rate per Machine Hour 27.43 EUR/MH	3.11	4.11	2.88
= Total Production Costs	104.38	116.26	101.69
+ Other Overhead Costs (475.82%)	46.22	61.18	42.82
= Total Cost of Product	150.61	177.43	144.51
+ Profit Margin (15% ROC)	22.59	26.62	21.68
= Sales Price Excluding VAT	173.20	204.05	166.19

* The allocation base for other overhead costs is direct labor costs

Table 4 presents an alternative calculation based on machine-hour rates for the production of wood-plastic composite particleboard. The material components remain identical to the previous markup-based costing method. However, labor, energy, depreciation, and rental costs per machine hour (amounting to €36.70/m³), combined with other overhead expenses (475.82%), result in total production costs of €150.61/m³. After applying a 15% profit margin, the final offer price is €173.20/m³ excluding VAT only €2.80/m³ less than with the traditional markup method. This marginal difference highlights the homogeneity of input data and indicates that, in cases of standardized production, both costing methods are comparable. However, it has been shown that in cases of heterogeneous production (e.g., variations in thickness or component ratios), the alternative MHR method could provide a more accurate allocation of overhead costs and potentially reveal additional savings.

4. CONCLUSION AND DISCUSSION

The main objective of this work was to present a cost allocation methodology for the production of three-layer particleboard, using material price indexation and applying both the conventional markup-based costing approach and an alternative method based on machine-hour rates (MHR). The study also evaluated the economic impact of incorporating 10 wt% recycled plastic granulate. The applied methodology enabled a unified and systematic approach to determining the cost structure ranging from direct calculation of material and energy costs, through the computation of overhead markups and machine-hour rates, to price indexation and savings evaluation. Thanks to the modular nature of each step, the procedure can be adapted to various production scenarios and updated in accordance with current market prices and technical specifications. The implementation of a 10wt% share of plastic granulate into the three-layer particleboard resulted in measurable cost savings while maintaining a 15% profit margin. The traditional markup costing revealed a reduction in total costs from €156.51/m³ to €153.05/m³, representing a 2.22% saving (€3.46/m³) in total costs and a 4.55% saving (€4.56/m³) in direct material costs. The alternative calculation based on machine-hour rates confirmed the consistency of the results and enabled an even lower offer price of €173.20/m³ (i.e. €2.80/m³ less than the traditional method), highlighting the MHR method's capability to more accurately allocate overhead costs in heterogeneous production.

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CONCEPTUAL MODELS FOR ENHANCING SUSTAINABLE MANAGEMENT IN FORESTRY AND AGRICULTURAL SECTORS

Gergana Slavova, Tanya Georgieva

Abstract: Within the framework of the European Union's Common Agricultural Policy, an integrated, sustainable, and environmentally-conscious management approach for the agricultural and forestry sectors is established. Directly aligned with the EU's Green Deal, the challenges posed by climate change and increasing global temperatures necessitate a robust approach to resource management. This context underlines the need to develop conceptual models for sustainable management of both the forestry and agricultural sectors, encompassing economic, technological, ecological, and social aspects. The aim of this report is to propose such conceptual models, grounded in the principal concepts of sustainable management applicable to both areas. These models draw on not only existing publications but also on specific insights, viewpoints, and analyses directly related to these sectors in Bulgaria. The methodologies applied in this report include comparative analysis, extrapolation, deduction, induction, strategic review, and structured interviews. The recommendations, based on empirical findings, contribute to existing scientific theories and support academic discourse. They offer new perspectives particularly important for farmers and the forestry sector in Bulgaria, focusing on economic, political, and social parameters, as well as innovative practices for sustainable growth in both sectors.

Keywords: conceptual models, sustainable, integrated, management, concepts, development, forestry and agricultural sector

1. INTRODUCTION: FROM SUSTAINABLE DEVELOPMENT TO SUSTAINABLE MANAGEMENT

There are numerous reasons for the emergence of the concept of sustainable management. Among the most prominent are growing environmental pollution, the depletion of already scarce natural resources, adverse climate change, economic instability, social inequalities, and increasing international pressure for coordinated action. Within this context, sustainable management is established as a long-term approach that seeks to integrate economic, social, and environmental goals in a balanced manner. Moreover, it emphasizes the need for a long-term vision, active stakeholder engagement, and adherence to ethical principles, particularly intergenerational justice (World Commission on Environment and Development, 1987). Sustainable management encompasses the concrete processes, operational strategies, and institutional instruments used to translate the goals of sustainable development into practical outcomes (Billedeau & Moreno-Cruz, 2022). While sustainable development offers an overarching vision, sustainable management provides the applicable framework necessary to implement that vision within organizational and policy contexts. The concepts of sustainable management in agriculture and forestry align with this overarching framework—both rely on the integration of ecological, economic, and social goals to ensure long-term viability (Fraser, 2019; Mudacumura et al., 2006). A thorough understanding of their content, however, requires consideration of the sectoral specificities that shape them as both theoretical constructs and practical approaches. In this context, **the paper aims to propose** a structured approach to sustainable management in the agricultural and forestry sectors by integrating key dimensions of sustainability—economic, ecological and social. The focus is on aligning these dimensions with long-term planning and decision-making processes that reflect both sector-specific needs and broader sustainability goals. By drawing on theoretical

foundations and context-specific insights, the study contributes to a more coherent understanding of how sustainability can be translated into practical management strategies.

2. THEORETICAL DIMENSIONS AND SECTOR-SPECIFIC INTERPRETATIONS

Sustainable Farm Management (SFM) seeks equilibrium between what is extracted from the land and what is returned to it, minimizing disturbances to soil, crops, and animals. It involves integrated systems that reduce external inputs, enhance biodiversity, and strengthen the self-regenerative capacity of agroecosystems (Goewie et al., 2006). **Sustainable Forest Management (SFoM)** entails managing and utilizing forests in a way that maintains their productivity, regeneration capacity, and the long-term sustainability of forest ecosystems (Fraser, 2019). Forests are increasingly regarded as complex systems involving diverse stakeholders (Nocentini, 2001). The SFoM framework incorporates *three key dimensions* (Kniivilä et al., 2012): **Ecological stability** – ensuring soil fertility, preserving species diversity, and preventing forest degradation; **Economic viability** – sustainable yield and responsible resource use; **Social responsibility** – stakeholder participation in planning and implementing forest policies.

As management models, both sectors can be framed using *six analytical and managerial blocks*, each carrying conceptual and operational value: **Strategic Orientation (Focus)**: The dominant long-term managerial objective that defines the structure of management; **Instruments**: The practical tools and mechanisms for implementing strategies; **Time Horizon**: The strategic planning and control timeframe—how far into the future actions are planned and how outcomes are measured; **Risks**: Uncertainties and potential threats that may undermine sustainable outcomes; **Results**: The final positive or negative outcomes of management actions, expressed through economic, ecological, and social dimensions; **Feedback**: The continuous monitoring, analysis, and evaluation of outcomes, guiding future strategic decisions and improving performance. The selection of these six components reflects the inherent logic of the management process—progressing from strategic vision and orientation, through the use of implementation tools and time horizons, to risk assessment and impact evaluation.

2.1. Conceptual Basis for Sustainable Farm Management

Sustainable agricultural management represents a complex, balanced, and adaptive system (Pilarczyk et al., 2024). Achieving this form of management requires a systemic and integrated approach that connects three core dimensions—economic, ecological, and social sustainability. The **economic sustainability** of agriculture depends on a farm's ability to generate income, remain competitive in the market, and adapt to evolving market conditions. This includes effective resource use, product diversification, and reduced dependency on external inputs (Kniivilä et al., 2012). System flexibility enables farmers to respond to market and climate challenges while supporting short-term productivity (Gray, 1991). **Ecological sustainability** in agriculture focuses on preserving natural resources and maintaining ecosystem functions over time. It involves practices that protect soil fertility, reduce pollution, conserve water, and enhance biodiversity within agricultural landscapes. Sustainable land use planning, crop diversification, minimal use of chemical inputs, and organic farming are central to reducing the ecological footprint of agricultural activity. These practices not only mitigate negative environmental impacts but also improve the resilience and regenerative capacity of agroecosystems, particularly under the growing pressures of climate change (Bachev et al.,

2019). **Social sustainability** encompasses community engagement, access to knowledge and technologies, and the equitable distribution of benefits. Sustainable agricultural systems rely on active participation from local stakeholders, which enhances social legitimacy and long-term efficiency. Farmers' involvement in long-term planning fosters commitment, continuity, and fair allocation of resources.

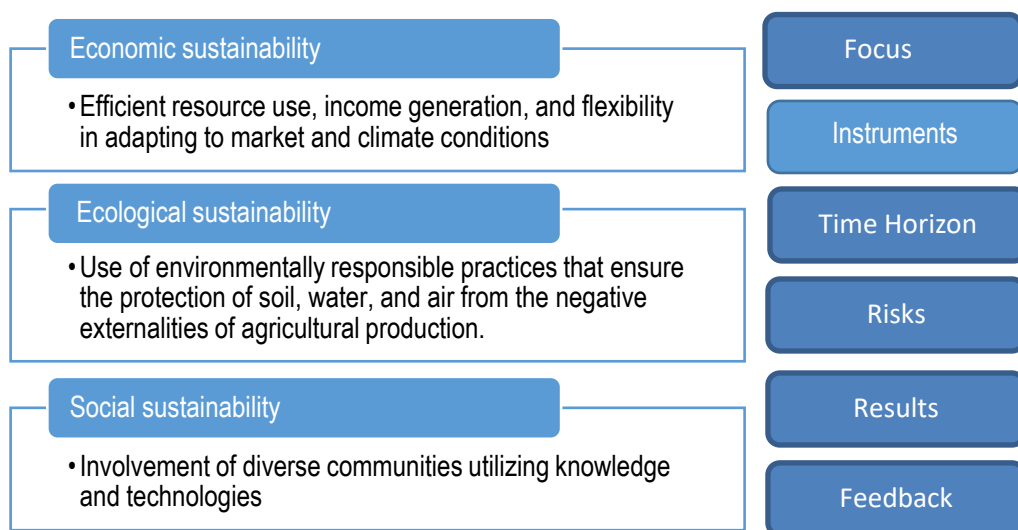


Figure 1. Conceptual Framework for Sustainable Farm Management in Bulgaria: Key Structural Blocks

Table 1. Structural Components and Associated Variables in the Conceptual Model for Sustainable Agricultural Management

Model Block	Variables	Related Dimension
Focus	- Farm income- Economic viability- Market flexibility- Short-term productivity- Increased competitiveness	Economic
Instruments	- Agroecological practices- Precision farming- Soil conservation- Crop rotation- Reduced chemical use- Organic farming	Ecological
Time Horizon	- Planning period: 1–5 years- Adaptability to market conditions- Flexibility to policy shifts- Implementation of short-term measures	Economic, Social
Risks	- Soil erosion- Biodiversity loss- Dependency on external inputs (e.g., imported fertilizers/seeds)- Vulnerability to climate change- Economic instability	Ecological, Economic
Results	- Food security- Employment- Innovation in sustainable practices- Enhanced system resilience- Social engagement and participation	Social, Economic, Ecological

Model Block	Variables	Related Dimension
Feedback	- Evaluation of economic, social, and ecological results; considers both positive and negative aspects of agricultural processes	Social, Economic, Ecological

Figure 1 illustrates the conceptual framework for sustainable farm management, outlining six core components that shape strategic and operational decisions. Table 1 complements the figure by presenting the key variables within each component and their alignment with the economic, ecological, and social dimensions of sustainability. Together, they offer a coherent view of the model's structure and applied relevance.

2.2. Conceptual Basis for Sustainable Forest Management

In **economic terms**, sustainable forest management (SFoM) aims to ensure long-term profitability through balanced timber harvesting, risk mitigation, and the enhancement of ecosystem service value (Peters, 2024). **Social sustainability** is promoted through equitable access to forest resources, fair benefit distribution, and inclusive decision-making processes (Cantarello et al., 2024; Friedman et al., 2020). **Ecological sustainability** represents the core dimension of forest management, focusing on biodiversity conservation, the preservation of natural habitats, and the continuity of ecosystem processes such as carbon sequestration and the hydrological cycle (Nocentini, 2001). Core management tools include close-to-nature silviculture, minimal intervention strategies, forest zoning, and natural regeneration.

Figure 2 presents the conceptual framework for sustainable forest management in Bulgaria, while Table 2 elaborates on its six structural components, their associated variables, and sustainability dimensions.

The framework highlights the three interrelated dimensions of sustainability in forest management, with a particular emphasis on ecological priorities. **Economic sustainability** involves efficient and profitable use of forest resources, including the restoration of harvested areas through reforestation and afforestation practices. **Ecological sustainability** is positioned as a central concern, focusing on the preservation of biodiversity, native plant and animal species, as well as the protection of soils, water bodies, and climatic conditions in forested regions across Bulgaria. **Social sustainability** is reflected in the meaningful involvement of local communities in forest stewardship, the promotion of employment within the forestry sector, and the protection of human rights.

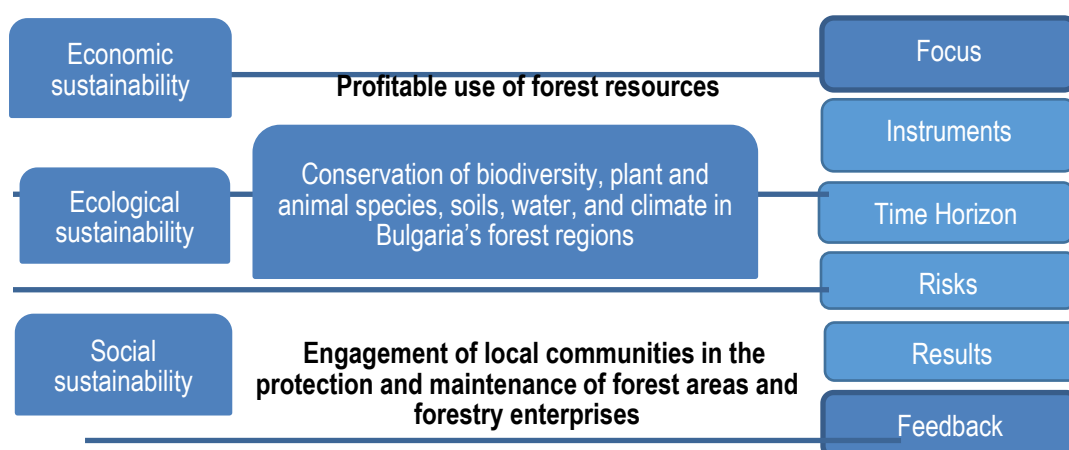


Figure 2. Conceptual Framework for Sustainable Forest Management in Bulgaria

Table 2. Structural Components and Associated Variables in the Conceptual Model for Sustainable Forest Management

Model Block	Variables	Related Dimension
Focus	- Long-term sustainability- Multifunctionality of forests- Ecosystem stability- Continuous low-intensity harvesting- Socially legitimate governance	Ecological, Economic, Social
Instruments	- Selective logging- Natural regeneration- Adaptive management- Buffer zones- Functional zoning- Habitat restoration	Ecological, Social
Time Horizon	- Planning horizon > 30 years- Forest age structure- Regeneration rates- Climate adaptation	Ecological, Economic
Risks	- Deforestation- Forest fires- Biodiversity loss- Habitat fragmentation- Social conflict over resources- Climate-induced stress	Ecological, Economic, Social
Results	- Carbon storage- Ecosystem services- Timber and non-timber products- Recreational value- Soil and water protection- Social engagement and identity	Ecological, Economic, Social
Feedback	- Evaluation of forest resource use and outcomes, encompassing economic, ecological, and social impacts	Ecological, Economic, Social

3. Strategic and Analytical Tools for Sustainable Farm and Forest Management

The assessment of the structural components of sustainable management in agriculture and forestry requires the application of a diverse set of analytical and strategic tools. These

include situational analysis, strategic planning methods, environmental and economic evaluation, diagnostic approaches, and scenario modeling. In both sectors, the evaluation of available resources relies on monitoring, observation, and systematic data collection. This encompasses the assessment of ecosystem services, stakeholder mapping, identification of environmental risks, and socio-economic needs. Economic analysis involves the estimation of costs associated with land and forest management practices, as well as revenues, profitability, and efficiency of operations. Strategic planning and governance are essential for setting and operationalizing economic, ecological, and social objectives. These may vary in scope—short-term or long-term, primary or complementary—and are shaped by regional and sector-specific priorities. A variety of strategic analysis instruments are applicable, including SWOT, STEEPLE, and PEST analyses, as well as scenario planning, factor analysis, Ishikawa diagrams, and other research-based methods using statistical and mathematical modeling tailored to the specifics of agricultural and forestry systems. The use of sustainability indicators is crucial for evaluating progress. Certifications such as FSC and PEFC (in forestry) or organic standards (in agriculture) serve as practical benchmarks. Functional zoning—whether in forests or farmland—supports more effective resource allocation and policy alignment by assigning specific uses and conservation goals to different management zones.

CONCLUSION

This paper outlines the conceptual foundations for developing models of sustainable management in the agricultural and forestry sectors. By identifying and organizing key structural components—such as strategic focus, instruments, planning horizon, risk, outcomes, and feedback—within ecological, economic, social, and technological dimensions, it offers an integrated framework for guiding future research and management practice. The proposed structure serves as a basis for evaluating current practices, formulating hypotheses, and selecting sustainability indicators. Moreover, the comparative perspective applied across both sectors reveals the potential for comparative alignment and cross-sectoral integration, especially in the context of sustainable territorial development and the need for synergistic responses under climate pressure and resource constraints.

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DEVELOPMENT OF LOCAL EXPOSURE MODEL OF TIMBER STRUCTURES IN THE CITY OF STRUMICA

Nadica Angova Kolevska

Abstract: Over the past 90 years, earthquake engineering has played a key role in mitigating seismic risks at national and local levels. Significant progress has been made in seismic design, seismic risk assessment, and understanding the seismic behavior of various building types. The vulnerability of existing structures has prompted collaboration between the scientific community and government institutions to develop methods to assess, mitigate, respond to, and recover from seismic events.

This paper highlights the need for an exposure model for Strumica, quantifying the existing stock of wooden buildings, taking into account its geographical distribution, structural characteristics, age, resilience, number of floors and structural costs. The model was developed using the Global Earthquake Model (GEM) building taxonomy, while the structural costs were obtained from the "Public Housing and Business Management Enterprise of North Macedonia". Field research conducted by the author collected data on the number of occupants in these buildings, revealing that wooden buildings constitute only 0.2% of the total stock in Strumica.

The methodology for the classification of structural typologies, with a focus on timber structures, can be adapted to other Macedonian cities with minor adjustments to the classification rules. The collection and organization of this data is essential to creating accurate exposure models - a key component in the calculation of seismic risk. In the medium and long term, this process improves technical capacity for risk management at both the local and regional levels, contributing to more resilient communities and improved disaster preparedness.

Keywords: seismic risk, vulnerability, exposure model, wooden buildings

1. INTRODUCTION

The seismic risk assessment process involves the interaction between three interdependent components: seismic hazard, exposure model for a specific building stock, and vulnerability model. The exposure model, as the second component necessary in the preparation of seismic risk assessment analyses, refers primarily to the elements that are at risk: the constructed buildings, their spatial distribution, their structural characteristics, the number of residents at risk in the analyzed pilot region, as well as the costs necessary to replace the buildings at risk. Despite the enormous importance of the seismic risk assessment process and its relative independence from the underlying hazard type, reliable information on elements at risk is often missing, incomplete, outdated or highly aggregated. This is particularly the case in developing countries where commonly used exposure data collection procedures

often cannot adequately deal with rapid urbanization and the greater spatio-temporal variability in urban areas (Wienland, и др., 2014).

Therefore, for the purposes of this paper, a classification of existing timber structures in the city of Strumica, North Macedonia, was carried out, using the building taxonomy developed by the Global Earthquake Model (GEM) (Brzev, et al., 2013). This taxonomy was firstly developed in 2012 as an initial version and afterwards updated as version 2.0 in 2013 (USGS Organization, 2013).

The main objective of this study is not to provide a detailed overview of the overall existing building stock in the city of Strumica that constitutes the city's exposure model largely developed by (Angova Kolevska & Vitanova, 2024), but to create a more relevant database of existing wooden structures in the city of Strumica, so far unprocessed, through a process of field collection and reconciliation of available data for each structure individually.

2. STUDY AREA

The city of Strumica, as one of the largest regional centers in the Southeastern part of the Republic of North Macedonia, covers an area of around 529,41 ha (Angova Kolevska & Vitanova, 2024) and a population of 49,995 inhabitants (Opshtina Strumica, n.d.) living in the city and the Municipality according to data from the last Housing and Population Census of the Macedonian Statistical Office in 2021 (Државен завод за статистика, 2021).

As a result of increasing rural-urban migration, the rural population in the Strumica region has halved in less than a decade. In contrast, the urban areas—dominated by the city of Strumica, which stands out compared to other cities in the Southeastern region - have experienced significant population growth. This shift has created a growing demand for housing and infrastructure development especially in the city.

The primary driver of this migration is the poor road infrastructure connecting the city with surrounding villages, which makes daily commuting and overall functioning increasingly difficult for rural residents. According to interviews conducted with local citizens, approximately 4,000 people travel daily between the villages and the city, underscoring the urgency and seriousness of the issue.

2.1 Seismicity

The Balkan Peninsula, where the Republic of North Macedonia and the city of Strumica are located, is characterized by a complex geological structure, high tectonic activity and anomalies in various geophysical fields (Сеизмолошка опсерваторија, 2024). Within this broader geotectonic framework, the Strumica Valley and the city of Strumica demonstrate special autochthonous seismic activity, at the same time remaining exposed to the seismic action of neighboring seismically active epicentral areas.

Of the total of 10 active seismic zones in our country, the Strumica Valley and the city of Strumica lie between two seismic zones: Zone 2: Kresna-Pehchevo-Vinica-Stip Gradsko and Zone 3: Valandovo-Gevgelija (Dumurdjanov, Milutinovic, & Salic, 2020).

3. GEM TAXONOMY SCHEME GEM BUILDING CLASSIFICATION OF EXISTING BUILDING STOCK

To create a relevant exposure model of the existing wooden structures in the city of Strumica, whose percentage of occurrence according to the field inspection and discussions with local experts in practice is 0.2%, building taxonomy strings in accordance with the GEM Building Taxonomy scheme (Brzev, et al., 2013) were created for each wooden structure individually. Even though the GEM Building Taxonomy v2.0 describes a building through 13 attributes - each associated with specific characteristics that can potentially affect seismic performance such as: direction, material of the lateral load-resisting system, height above ground, date of construction or retrofit, occupancy, building position within a block, plan shape, structural irregularities, exterior walls, roof, floor, and foundation system (Brzev, et al., 2013) the requirements of the OpenQuake engine program (GEM Global Earthquake model, n.d.) used for the final risk seismic risk analysis, in our study, required a more simplified taxonomy string as a mandatory attribute in the exposure model created by the author of the paper.

3.1 Exposure model data for timber structures in Strumica

For the purposes of this study, and in accordance with the guidelines provided by the OpenQuake engine program (GEM Global Earthquake model, n.d.), a building taxonomy string consisting of the following attributes: material of the lateral load-resisting system, height above ground, date of construction or ductility of structures and occupancy was created (*Table 1, column 5*).

In addition to the required building taxonomy string (*Table 1, column 5*), eight other exposure model data were necessary to develop a more reliable exposure model for the existing timber structures in the city.

Geographical location data (longitude and latitude) for each timber structure (*Table 1, column 3,4*), were provided from available available georeferenced rasters provided by the Real Estate Cadastre Agency, Strumica Regional Department. Information on the main construction material was collected through field inspections conducted by the author. The ductility level of each analyzed structure was estimated based on the year of construction, the proportion of informal construction, and the historical evolution of building codes and standards in North Macedonia (Yepes-Estrada, et al., 2023).

Structural replacement costs for the analyzed structures (*Table 1, column 7*), was determined using an Official template for determining the value of the building per m² prescribed in the Methodology for determining the value of the apartment (Official Gazette of RM, 2010).

The number of occupants during the day/night time - an essential attribute in the exposure model (*Table 1, column 8,9*), was determined through questionnaires conducted with local residents and community members.

Table 1 presents part of the resulting exposure model for the timber structures in the city of Strumica with all the attributes applied, previously explained above, while *Figure 1* visually illustrates the current state of the analyzed timber structures.

Table 1. Exposure model input data for timber structures in the city of Strumica

nb	id	lon	lat	taxonomy	num	struct.	day	night
1	5284	22.6457	41.437037	W_LFM-DUL_H3	1	135408	/	/
2	5325	22.652689	41.441237	W_LFM-DUL_H2	1	99138	1	/
3	5350	22.65258	41.43066	W_LFM-DUL_H2	1	44733	/	/
4	5402	22.65301	41.43303	W_LFM-DUL_H2	1	84630	1	/



Figure 1. Selected Timber structures in the city of Strumica (current state)

The results obtained from the visual inspection conducted on site (*Figure 1*) and interviews with the local residents show that in the city of Strumica there is a relatively small number of timber structures, about 0.2% of the total building stock in the city, compared to the reinforced concrete and masonry structures, the number of which is significantly larger. Timber structures are mostly located in the higher parts of the city and are in relatively poor condition, abandoned or demolished and almost no people live in them, except for occasional visitors.

In terms of the height of the buildings, the majority of the analyzed buildings are two or three stories above ground, with a notably high ground floor level.

In terms of the ductility of the buildings, which is closely related to the codes for aseismic design in our country (Yepes-Estrada, et al., 2023), the analyzed buildings were built in the period before 1948, more precisely in 1900, a period when the first regulations for seismic design had not yet been adopted in the former SFRY Yugoslavia, when we have an absence of seismic regulations, which is why they are classified as non-ductile structures (low ductility DUL).

4. CONCLUSION

The creation of relevant exposure models is a crucial component in defining and analyzing seismic risk. In correlation with seismic hazard analyses and appropriately chosen vulnerability models, exposure models enable the production of more relevant risk assessment analysis. These are often presented through average damage and loss maps as a final result in risk assessment, which not only support technical decision-making but also raise public awareness about natural disasters and the need for disaster prevention.

Throughout this study, only the timber structures located in the city of Strumica have been analyzed as a selected part of the city's exposure model. During the initial data collection phase for building attributes, simplified taxonomies were used, aligned with the taxonomy developed by the GEM (GEM Global Earthquake model, n.d.).

The primary focus of this research was to identify the most relevant characteristics of existing timber structures through visual field inspections and active collaboration with the relevant public institutions in the city of Strumica, in order to obtain the most reliable data possible.

The purpose of this study is not to provide a detailed analysis of the buildings, since such an analysis for the entire city/country would require decades of extensive research and significant financial resources. Instead, this study represents an expert technical assessment of the building stock, offering limited (due to possible subjectivity), but sufficiently reliable data. It is on the basis of the collected, selected and revised information on the construction fund that future directions and priorities can be determined for revising the existing ones and developing new long-term strategies for the prevention and mitigation of damages and losses caused by natural disasters that cannot always be avoided or prevented.

The final conclusions from this research will be possible after the development of a comprehensive exposure model of the city, largely composed of (Angova Kolevska & Vitanova, 2024) to which the results of this paper will be linked. Its application will enable the development of maps of average damages and average losses in the city of Strumica as a case study of this research.

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THE ROLE OF WOOD IN SUSTAINABLE ARCHITECTURAL DESIGN

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Abstract: During the past few decades sustainability has emerged as a leading concept in the contemporary architectural designs. Today, the architects are challenged not only to fulfil the form and function's requirements, but also to create health-benefiting designs with positive environmental impact. In this context, wooden materials have gain particular attention for their natural, renewable, recycling and low-carbon properties. This paper examines the versatile application of wood, as structural, surface and furnishing material, in context of sustainability. It presents various examples of wooden architecture worldwide, including the contemporary unconventional designs of high-rise buildings and flowing forms. Additionally, the application of wood in the interiors and its impact on indoor environments is considered. The findings highlight the technical, environmental and psychological potential of wood in the contemporary designs.

Keywords: sustainability, eco-friendly environments, natural material, wooden architecture, contemporary designs, wood products

1. INTRODUCTION

In the past few decades, sustainability has emerged as a leading concept in many fields, including architecture. The World Commission on Environment and Development defines sustainability as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*", (WCED, 1987). When related to architecture, this concept aims to minimize the environmental impact of the buildings throughout their lifecycle, by moderating the use of materials, resources and space. It prioritizes the well-being of the occupants, promoting healthier living environments, (Azubuike Chukwudi Okwandu et al., 2024).

The buildings sector play significant role in the global environmental domain, contributing significantly to resource consumptions, energy use and gas emissions. In 2022 the building sector (construction and operation) was responsible for 37% of the global carbon dioxide (CO₂) emissions, reaching new highs. Residential buildings accounted for 17% and non-residential buildings for 10% of this emissions, (UN Environment Programme, 2024). Moreover, a significant part of the building stock in Europe (75% of all buildings) is not designed as energy efficient and many still rely on fossil fuels (for heating and cooling) which are limited resources, that already running out, (World Economic Forum, 2021). It is necessary to consider the environmental footprint of the buildings since they play significant role in the global sustainable transformation. The implementation of sustainable practices in the field of architecture, whether in new or old buildings, can have environmental, economic and social benefits.

Lastly, incorporating environmentally friendly and natural materials like wood can play a significant role in promoting more sustainable architectural approach - enhancing environmental performance, elevating user's experience and adding to the aesthetic appeal of the design.

2. SUSTAINABLE ASPECTS OF WOOD

Wood is one of the oldest sustainable materials, used for centuries. No other material has been present in our everyday lives in such many shapes and ways as wood. It varies in colors, smells, textures, hues, which makes it particularly challenging for other materials to surpass these features. Moreover, wood possesses a range of characteristics that highlight its sustainable nature:

Renewable: as a natural material, wood can be renewed by planting new trees or forest management. The growth rate of the tree is related to the species and climate; for example, oak is slow growing and compact material, while pine wood is less compact and grows faster, (Christensen, 2023).

Reusable and recyclable: at the end of its use, wood can be reused or recycled. Material reuse is one of the highest waste management goals. Reusing or recycling wood usually requires less energy for production, compared to using new materials. Some wood-based products such as pallets, windows, doors, frame structures etc. are reused in the building sector. On the other hand, wood can be successfully recycled and turn into usable products such as building materials (plywood, fiberboard, wood-plastic composite), furniture, pulp for paper production etc. Even contaminated wood waste can be used for sawdust and shavings, when recovers from impurities. Additionally, wood waste can be transformed into fuel, which is a way for utilizing the non-recyclable material, (Christensen, 2023).

Biodegradable: Biodegradability of wood species vary considerably, with some studies indicating that certain hardwoods, such as red oak, has greater extends of decomposition compared to softwoods such as spruce and pine. Engineered wood products also show wide range of biodegradability, with plywood, particleboards and fiberboards showing lower extend of decomposition, (Wang et al., 2011).

Durable: when properly treated and maintained, wooden products and constructions can last for a long time. The lifespan of wooden structures is usually between 50 and 200 years; however, there are wooden historical buildings that have persisted for a longer period. Examples of this are the log-cabin churches in Europe which are over 200 years old, (Reinprecht, 2016).

Small environmental impact: regarding greenhouse gas emissions, wood stands out as better alternative, compared to other materials. Growing trees store CO₂ and it remains stored in the wood products for the duration of their usage. Additionally, the manufacture of wood products, such as glued-laminated timber and air-dried sawn timber, has lower emissions compared to other materials, (Miloshevska Janakievska et al., 2024).

Supports healthier living environments: wood has capacity to regulate humidity and can create pleasant indoor conditions and cozy atmosphere, (Alapieti et al., 2020).

Supports energy efficiency: since wood is a natural insulator, wooden buildings have good thermal performance and can help reduce energy consumption. Additionally, wood can be easily combined with other insulating materials and improve the overall energy-efficiency of the building. Among the wood-based materials, cross-laminated timber have many advantages including good thermal insulating properties, achieving energy savings of up to 40%, (Cabral and Blanchet, 2021).

Reduce energy consumption: wooden products usually need less energy to manufacture, compared to other materials like concrete and steel, (Alapieti et al., 2020).

3. WOOD IN ARCHITECTURE: FUNCTIONAL AND SUSTAINABLE DIMENSION

3.1. Wood as a structural component

As a structural building material, wood can play important role in supporting sustainable construction goals in several aspects:

- Technology: the performance of wood is closely related to its properties, environmental conditions and application. Technological innovations such as treatments can improve its durability and the development of cross-laminated timber enables broader application of the wood and capacity for constructing high-rise and more complex buildings.
- Economic: timber constructions provide time efficiency, especially through the possibilities to use prefabricated wooden components and capacity to reduce construction costs.
- Environmental: wood is a naturally renewable resource that requires significantly less energy to extract and process compared to conventional materials. At the end of building life-cycle it can be recycled or reused, (Lestari and Ikaputra, 2024).

Moreover, its potential to reduce the carbon footprint is a leading factor for many European initiatives that support the use of wood as a sustainable construction material. Scandinavian countries like Finland and Sweden have a long history of building with wood, primarily because of the forest abundance. The governmental program of Finland for carbon neutrality by 2035, aims to increase the use of wood in public buildings, which in 2020 represented only 15% of this category. Wood is mainly used for construction of single houses, with outgoing efforts to increase the number of multi-stories structures. In Stockholm there is a successfully built high-rise wooden building – Cedar House which comprises four buildings of 12 stories. Other European countries, such as Slovenia, Germany, England, Ireland, Spain, Portugal etc. have also increased the share of wooden structures and reconsider wood in their future perspectives, (Leszczyszyn et al., 2022).

Today's advancement in the construction sector provides great potential to design complex geometries with extraordinary free forms, using high-performance engineered wood products, such as: cross-laminated timber, glued-laminated timber, laminated veneer lumber, structural plywood etc. (Miloshevska Janakievska et al., 2024). An example of this is the Metropol Parasol in Seville, Spain, completed in 2011 (fig. 1). This is one of the biggest wooden structures from multi-glued laminated veneer lumber and a polyurethane coating. It defines a large public square, including a variety of markets, restaurants and walkways, (Cilento, 2012).



Figure 1. Complex wooden structure - Metropol Parasol in Seville, Spain, (Cilento, 2012)

3.2. Wood in building envelopes

Facades are vital element of the buildings, which impact the energy efficiency, quality of indoor space and define the first impression and its aesthetic appeal. In that context, they have significant role in developing sustainable building designs. Wooden facades can support sustainable goals by improving the energy performance of the building-offering natural thermal insulation and reducing the energy consumption for heating or cooling; they have low carbon footprint and offer durability-when properly managed, (Reinprecht, 2016) (Cabral and Blanchet, 2021). Some studies highlight the durability of a laminated wood profiles over solid wood, making them more sustainable solution for facade application, (Küçüktüvek et al., 2023).

Nowadays, building envelopes are incorporating innovative ways to improve living environments, using the potential of kinetics. A kinetic facade system includes movable components, responsive to the changing environmental conditions (such as sunlight, rain or wind) or the needs of the occupants. These flexible or foldable designs enable to optimize the natural light, regulate indoor temperature and support energy efficiency of the building, while enhancing its functionality; which represent important step towards sustainable architecture. The visually dynamic facades that can change through the day also contribute to the aesthetic appeal of the buildings, (Sharaidin, 2014).

The recreation house near Utrecht, Netherlands, which was built in 2014, is an example of architecture that combine wooden envelope with movable window shutters that opens up to the surrounding, fig. 2. The angle of these shutters can adjust, for effective control of both, sunlight and view, (Architizer Editors, n.d.).



Figure 2. Recreation house near Utrecht, Netherlands, (Architizer Editors, n.d.)

3.3. Wood in interior design

Wood has been fundamental material in interior design for centuries, bringing warmth, natural appearance and functional versatility, having both, functional and ornamental value. Studies have shown that wooden environments have mainly positive influence on the indoor quality, due to its antibacterial properties, moisture buffering and psychological effects, (Alapieti et al., 2020). The *antibacterial* mechanism of wood is not yet completely understood, though it's related to its hygroscopic behavior and the presence of wood extractives. It varies considerably among different tree species, with some studies highlighting the strong antibacterial properties of pine and spruce, attributed to wood components like lignin and volatile organic compounds, (Vainio-Kaila, 2017). The moisture buffering *capacity* of the surface materials or furnishing is particularly important for the indoor quality as it affects humidity levels and consequently affects the respiratory comfort, durability of materials and energy usage. The *hygroscopic nature* of wood helps to regulate the daily fluctuations of indoor

humidity without the need for increased ventilation. This property varies between wood species – the moisture permeability of softwoods is usually lower from the one of the hardwoods, (Alapieti et al., 2020). The *psychological effects* of wood is related to its natural appearance, often perceived as pleasant, warm and welcoming material that creates comfortable atmosphere, which enhance the mood of the occupants.

Sustainable wood use in interiors emphasizes the use of renewable and responsibly sourced materials such as reclaimed wood, which offers a unique character through its aged texture and distinct aesthetic that cannot be replicated. Repurposing the wood from old buildings (houses, barns, industrial buildings), not only reduces the waste and the need for new materials, but also extends the life-cycle of this valuable resource. It's usually repurposed from structural to decorative use and this transformation may involve some radical changes that affect its appearance or simple change in the function. Reclaimed wood is a versatile material that can create both modern and traditional designs, with a wide range of interiors applications (fig. 3), such as wall and ceiling panels, flooring, furniture, shelving, decorative elements, door and window frames etc. The selection of wood to reuse is influenced by various factors: physical qualities, presence of contaminants (paint, metal or rot), costs considerations and its size, (Solomon and Armster, 2019).



Figure 3. Interior design applications featuring reclaimed wood, (Solomon and Armster, 2019)

4. CONCLUSION

Wood is one of the oldest known materials, and it still continues to be an indispensable building component, offering many environmental and functional benefits. This paper outlines the exceptional versatility of wood from structural component to surface envelope or decorative feature, in supporting contemporary sustainable goals. As a structural material, wood play significant role in minimizing the carbon footprint, compared to other materials such as concrete and steel. Advances in engineered wood products like cross-laminated timber and glulam allow creating complex architectural masterpieces. When used as building envelope it contributes to the thermal performance of the building, enhancing energy-efficiency. Its natural renewability and possibility for recycling (reuse) reinforce its sustainable character even more. Lastly its thermal and hygroscopic properties, combined with aesthetic appeal improve the qualities of the indoor environments and occupants comfort.

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SMALL FOREST FARMS A PATH TO SUSTAINABILITY IN BULGARIA

Mihaela Mihailova, Petar Marinov

Abstract: This paper explores the potential of small forest farms in Bulgaria to contribute to sustainable agriculture through the adoption of agroforestry practices. Integrating trees into farming systems—via silvopasture, alley cropping, and forest farming—can enhance biodiversity, sequester carbon, and diversify farm incomes. Using a qualitative and spatial analysis of small farm specializations across Bulgaria's six planning regions, the study identifies compatibility with agroforestry. The study concludes that small forest farms, when supported by targeted policies, can become key drivers of climate resilience, sustainable land management, and rural development in Bulgaria.

Keywords: forest farms, sustainability, sustainable Agriculture

1. INTRODUCTION

Bulgaria's agricultural sector as part of EU pursuits sustainability and must reconcile with the socio-economic realities faced by small-scale farmers. Amidst the diverse strategies for sustainable agriculture, agroforestry — the integration of trees and shrubs into farming systems — emerges as a promising pathway, particularly for small forest farms. These farms, characterized by their multifunctional landscapes and diversified production systems, offer unique opportunities to enhance ecological resilience, promote biodiversity, and secure livelihoods. In the context of Bulgaria, where small farms represent a significant portion of agricultural holdings, the transition to agroforestry practices aligns with both environmental and economic objectives. The potential of small forest farms to contribute to sustainability is underscored by their ability to integrate traditional knowledge with modern ecological practices, fostering a harmonious relationship between agricultural productivity and environmental stewardship. This research article explores the role of small forest farms in Bulgaria's towards sustainable agriculture, examining the socio-economic benefits, environmental impacts, and policy frameworks that support or hinder their development. By analyzing case studies and current practices, this study aims to highlight the transformative potential of small forest farms as a viable model for sustainable rural development in Bulgaria.

Integrating tree plantations within small farms offers a pathway for soil conservation while potentially enhancing farm productivity. A key strategy for small farmers is the practice of intercropping, which allows for the simultaneous cultivation of trees and annual crops on the same plot of land. This approach can significantly reduce the costs associated with tree establishment and management, cutting them by half compared to traditional tree plantations Roshetko (2013). However, it is crucial to address the competition for resources such as light, which is a critical limiting factor for understorey crops (Roshetko 2013; Chesney, 2021). Farmers can mitigate these challenges through intensive branch pruning, which not only helps in shaping the trees but also reduces light interception, thereby extending the duration during which intercropping can be practiced (Newaj et al., 2012; Bertomeu et al., 2011). Despite potential reductions in understorey crop production due to competition, the overall benefits of improved tree survival and growth through annual crop management practices can enhance smallholder tree production (Mercer et. al 2014). Thus, incorporating tree plantations through

strategic intercropping, combined with effective pruning techniques, can provide a sustainable method for soil conservation while optimizing land use on small farms. Agroforestry offers multiple income opportunities through timber, fruit, nuts, and non-timber forest products, reducing financial risks and increasing resilience to market fluctuations that makes small-scale farms that rely on diversified income streams suitable for transition towards agroforestry.

Incorporating practices such as silvopasture, alley cropping, and forest farming into agroforestry systems offers a multitude of benefits that extend beyond timber production, enhancing overall agricultural productivity and ecological resilience. These agroforestry practices help in mitigating the impacts of agriculture on climate change and the environment by promoting carbon sequestration and improving soil carbon levels, which is crucial for long-term environmental sustainability (Sollen-Norrlin et al., 2020; Poudel et al. 2024). Silvopasture systems—integrating trees, forage crops, and livestock—are especially effective at modifying microclimatic conditions, which enhances biodiversity and promotes healthier ecosystems. This integration not only leads to improved water and soil quality but also contributes to the sequestration of atmospheric carbon and nitrogen, further underscoring their role in climate change mitigation (Poudel et al. 2024). This practices not only protects soil from erosion but also facilitates nutrient cycling, enhancing land productivity and resilience against environmental stresses (Elevitch et al. 2018). Therefore, the adoption of these agroforestry practices is crucial for creating a resilient agricultural landscape that supports both ecological and economic sustainability.

2. METHODOLOGY

This study employs a qualitative research design combined with a spatial and typological analysis of small farms across Bulgaria to assess their potential for transitioning into agroforestry systems. The methodology consists of three interlinked components:

2.1 Literature Review and Theoretical Framework

A comprehensive review of relevant scientific literature, policy documents, and case studies was conducted to establish the theoretical basis for agroforestry practices, with particular emphasis on silvopasture, alley cropping, and forest farming.

2.2. Farm Specialization Data Analysis

The study utilized official statistical data from Bulgaria's agricultural census and CAP-related documentation to categorize small farms based on their production specialization (e.g., mixed livestock, permanent crops, arable, or vineyards). The classification helped determine the compatibility of different farm types with agroforestry systems. The percentage share of small farms by specialization was analyzed to assess regional suitability for agroforestry adoption.

2.3. Regional Agroecological Potential Assessment

A region-by-region assessment was conducted, focusing on Bulgaria's six planning regions. For each region, dominant farm specializations were identified and cross-referenced with agroforestry-compatible systems. This assessment was based on key criteria such as existing land use (forest vs. agricultural land), crop and livestock types, and landscape features conducive to tree integration. Agroforestry potential was categorized qualitatively (e.g., high, moderate, or low) according to ecological compatibility and land-use synergies.

The combined methodological approach allows for an integrated understanding of how small forest farms in Bulgaria can be leveraged as catalysts for sustainable rural development.

3. RESULTS AND DISSCUSSION

The forested territory in Bulgaria ranges between 36,773 to 37,054 km², making up around 33.13% - 33.38% of the total land. Agricultural areas range between 60,524 to 60,780 km², accounting for approximately 54.53% - 54.76% of the total land. Given that agricultural land dominates over forested areas, small farmers could incorporate tree plantations within their farms for soil conservation, microclimate benefits, and additional revenue streams. Many small farms in Bulgaria face productivity challenges due to soil degradation, climate change, and market constraints. Practices such as silvopasture (integrating trees with livestock), alley cropping (tree rows combined with crops), and forest farming (non-timber products like mushrooms, herbs, and berries) could be viable. Given Bulgaria's participation in the Common Agricultural Policy (CAP), there are subsidies for afforestation, agroforestry, and biodiversity conservation. Small farms could benefit from EU Rural Development Program (RDP) measures, promoting afforestation and agroforestry systems. Agroforestry significantly enhances biodiversity, which plays a crucial role in maintaining ecological balance and supporting sustainability. By incorporating trees, shrubs, and other perennial vegetation into agricultural landscapes, agroforestry systems provide habitats for a wide variety of wildlife (Wilson, 2016). This enhanced biodiversity not only strengthens ecological health but also boosts essential ecosystem services that underpin sustainable income. This encourages a more resilient agricultural system that can adapt to and mitigate the impacts of climate change (Brown et al., 2018). Moreover, agroforestry supports global climate change mitigation by sequestering carbon and improving nutrient and water cycling. To fully capitalize on these benefits, it is essential to recognize and integrate agroforestry into agricultural greenhouse gas mitigation programs, which would not only enhance its environmental benefits but also support socio-economic development (Schoeneberger, 2008).

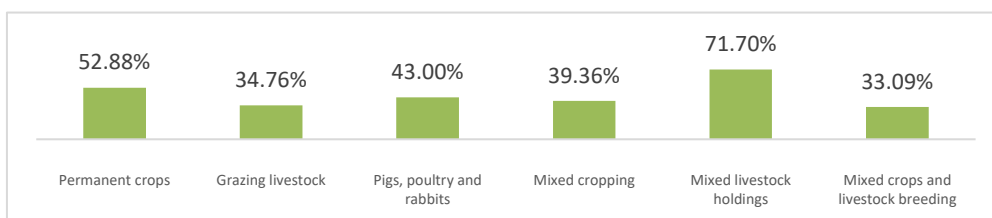
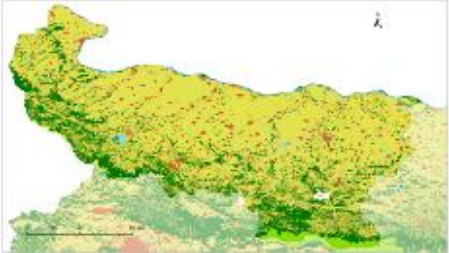
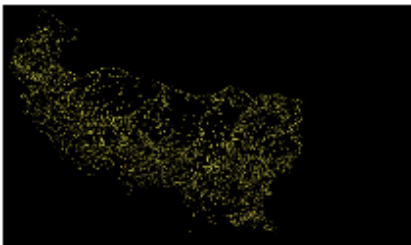


Fig 1. Small farms as % of all farms by specialization

In Bulgaria 36,95% of farms are small farms.

The transition to agroforestry presents varying levels of potential across different farm specializations, as evidenced by the distribution of small farms within these categories. Mixed livestock holdings, which represent 71.70% of all farms in this specialization, exhibit the highest potential for agroforestry. These farms are particularly suited for silvopasture systems, where trees provide shade, reduce heat stress for animals, and enhance pasture productivity. The integration of trees also offers secondary income streams through the production of fodder, fruits, or timber, while contributing to improved soil structure, erosion control, and water retention—factors essential for sustainable livestock management. Permanent crop farms, accounting for 52.88% of small farms, also demonstrate high potential for agroforestry. These farms, which typically cultivate orchards and vineyards, can benefit from diversifying with additional tree species, intercropping with nitrogen-fixing plants, or establishing hedgerows to

boost biodiversity. This diversification not only enhances ecological stability but also provides economic resilience against market fluctuations through multiple revenue streams. Farms specializing in pigs, poultry, and rabbits, comprising 43.00% of small farms, hold moderate to high potential for agroforestry. The integration of livestock into woodland systems allows for natural foraging and shelter, which mimics the animals' natural habitats and improves welfare. However, effective management is necessary to mitigate risks such as overgrazing and soil compaction, particularly with pigs. Mixed cropping farms, representing 39.36% of small farms, are well-positioned to adopt alley cropping techniques, where rows of trees are interspersed with annual crops. This approach can enhance soil fertility, increase biodiversity, and provide windbreaks to protect crops. Nonetheless, successful implementation requires careful planning to balance competition between trees and crops for light and nutrients. Grazing livestock farms, with 34.76% of small farms, offer moderate potential for agroforestry through the adoption of silvopasture practices. While integrating trees into extensive grazing systems can improve pasture productivity and animal welfare, challenges such as the need for protective fencing and managing large grazing areas may arise. Mixed crops and livestock breeding farms, which account for 33.09% of small farms, also exhibit moderate potential for agroforestry. These diversified farms can benefit from combining alley cropping with silvopasture, thereby supporting both crop productivity and livestock health. However, managing the complexities of such integrated systems requires careful coordination to optimize the benefits of agroforestry.

Map of regions of Bulgaria	Outline of forest bordering agricultural land in regions of Bulgaria
	
	

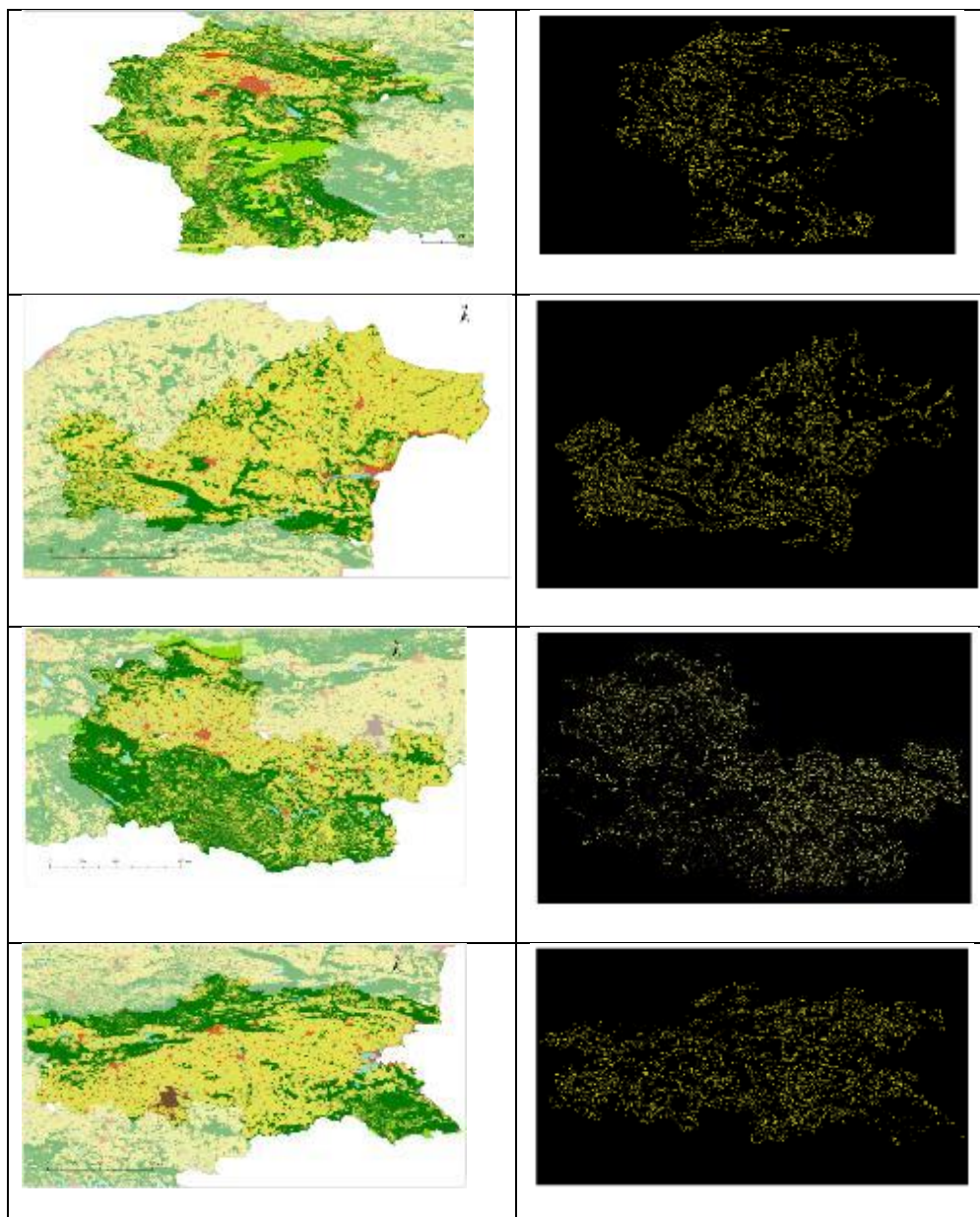


Fig 2. Map of regions of Bulgaria outline of forest bordering agricultural land in regions of Bulgaria

1. In Severozapaden Region the dominant specializations are: Mixed Permanent Crops (80.00%), Vineyards (68.94%), Grazing Livestock (71.02%), **Agroforestry Potential calculated: High** The high prevalence of mixed permanent crops and vineyards suggests strong compatibility with agroforestry systems such as silvopasture and alley cropping. The considerable proportion of grazing livestock (71.02%) further enhances the region's potential for silvopastoral systems, where trees provide shade and forage for animals.

2. In Severen Tsentralen Region the dominant specializations are: Grazing Livestock (79.23%), Pigs, Poultry, and Rabbits (78.02%) Sheep, Goats, and Other Grazing Livestock (50.15%) **Agroforestry Potential: Moderate to High** While the dominance of grazing livestock indicates potential for silvopasture, the significant presence of pig and poultry farms may limit the adaptability to tree-based systems. However, integrated systems combining forage crops and protective tree belts could enhance productivity and biodiversity.
3. Severoiztochen Region dominant specializations: Vineyards (78.57%), Grazing Livestock (73.07%), Pigs, Poultry, and Rabbits (77.06%), **Agroforestry Potential: High**. This region demonstrates a strong focus on perennial crops (vineyards) and livestock, both conducive to agroforestry. The integration of vineyards with windbreaks and shade trees could improve microclimatic conditions and soil health. Silvopastoral systems are also feasible due to the substantial presence of grazing livestock.
4. In Yugoiztochen Region the specializations are distributed: Grazing Livestock (73.33%), Vineyards (61.07%), Sheep, Goats, and Other Grazing Livestock (30.10%), **Agroforestry Potential: Moderate**. Although grazing livestock dominates, the relatively lower presence of mixed crops limits diversification opportunities. However, vineyards and livestock systems can be integrated through agroforestry practices like alley cropping and silvopasture.
5. Yugozapaden Region specializations: Vineyards (79.72%), Mixed Permanent Crops (73.81%), Fruit Trees (64.31%), **Agroforestry Potential: Very High**. The Yugozapaden region shows exceptional potential for agroforestry, given the dominance of vineyards, mixed permanent crops, and fruit trees. These systems align perfectly with agroforestry practices like forest farming and alley cropping, where trees can enhance soil fertility, reduce erosion, and diversify farm income.
6. In Yuzhen Tsentralen Region the specializations are distributed: Meat Cattle (52.48%), Milk Cattle (45.02%), Arable Crops and Grazing Livestock (41.76%), **Agroforestry Potential: Very High**. The combination of livestock farming and arable cropping presents strong opportunities for silvopastoral and agrosilvicultural systems. Integrating trees with livestock can improve animal welfare and productivity, while diversified cropping systems enhance resilience against climatic variability.

3. CONCLUSIONS

In conclusion, mixed livestock holdings and permanent crop farms present the greatest potential for agroforestry transitions due to their existing compatibility with practices such as silvopasture and intercropping. Farms specializing in pigs, poultry, rabbits, mixed cropping, and grazing livestock also show promise, contingent on effective management and strategic planning. The adaptability of small farms, coupled with their need for diversified income streams, positions them as prime candidates for agroforestry interventions, particularly in regions facing environmental degradation or climate-related challenges. Regions such as Yugozapaden and Yuzhen Tsentralen exhibit the highest potential for agroforestry due to their diversified agricultural practices and significant proportions of permanent crops and livestock. Severoiztochen and Severozapaden regions also offer strong opportunities, particularly through vineyard and livestock integration. Agroforestry in these regions can contribute to sustainable land management, increased farm resilience, and enhanced ecosystem services.

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SUSTAINABLE FAÇADE REDESIGN WITH ENGINEERED WOOD PRODUCTS: A CASE STUDY OF HOTEL MONTANA

Marija Miloshevska Janakieska

Abstract: In Europe, architectural practices are increasingly shifting toward sustainable and environmentally conscious designs, setting new standards for innovative contemporary materials and construction methods. Macedonia is following these European trends, incorporating innovative construction practices.

This paper studies the redesign of the facade of Hotel Montana in Krushevo, Macedonia, implementing engineered wood products (EWPs) in combination with other materials to achieve functional and aesthetically pleasing solutions. By integrating sustainability with architectural integrity, the study evaluates different EWP-based design solutions, focusing on their environmental, functional, structural and aesthetic characteristics. The paper provides a brief overview of historical and architectural context of the hotel, discusses the properties and advantages of EWPs in façade applications, and compares different redesign façade proposals.

Through a comparative analysis of material performance and architectural considerations, this study illustrates the potential of EWPs to achieve sustainable and innovative façade designs while respecting the architectural integrity of the building. The findings contribute to advancing sustainable practices in architectural façade design, emphasizing the role of engineered wood products in modern construction.

Keywords: engineered wood products (EWPs), façade design, façade materials, sustainable architecture, Hotel Montana

1. INTRODUCTION

Sustainable practices in architecture are necessary to address environmental changes. The building façade, as an envelope of the building plays a vital role in enhancing energy efficiency, reducing carbon footprint, and extending building lifespan [Aksamija, 2015]. By application of eco-friendly materials on the facade of the building, such as engineered wood products (EWPs), many sustainable aspects are improved, such as performance, durability, and aesthetic appearance [Murtezi, Miloshevska Janakieska, 2025].

The aim of this study is to explore sustainable redesign of a facade of a hotel using EWPs and complementary materials. Through a comparative analysis of design proposals, this study evaluates their environmental, structural, and visual benefits of the façade materials, and identifying the most suitable and sustainable solution with respect towards the hotel's architecture and identity.

Hotel Montana is located on a hilltop in Krushevo, North Macedonia (Figure 1). It is surrounded by a dense pine forest and offers panoramic views of the town and the mountains. Hotel Montana is an icon of the Yugoslav-era design [Koteski, 2022]. Although the hotel is older, its functional organization remains highly effective, with a spatial arrangement that aligns well with modern hotel standards.

The building's structural system is reinforced concrete frame structure, with columns and beams, providing overall stability and durability, and it is in a good condition. However, the existing external walls lack adequate thermal insulation, resulting in poor energy performance and highlighting the need for reconstruction. While each guest room features a private balcony, the absence of clear separation between them reduces privacy for occupants. Additionally, visible signs of wear and deterioration on the façade—caused by insufficient maintenance—further emphasize the necessity of renovation, not only to enhance the building's appearance but also to significantly improve its energy efficiency [Janakieska, 2024].

The façade redesign would enhance the hotel's overall appearance while carefully preserving its cultural and historical identity.



Figure 1. Photos from Hotel Montana – Existing Condition (private photos)

2. METHODOLOGY

The methodology of this study is structured in two main phases. The first phase focuses on comprehensive analysis, forming the foundation for the design process. It includes a landscape and urban context study, with detailed climate analysis (sun path, temperature, wind, humidity, precipitation, etc.), and assessment of the surrounding area (street types, traffic flow, access points, green spaces, and neighboring buildings' characteristics such as height, function, structure, and façade types). This part consisted of a site visit for documentation of the building, using both traditional and contemporary methods, such as drones and laser measuring devices.

In addition, referent examples from literature and contemporary architectural trends were reviewed, focusing on hotel design, façade systems, materials, and structural components. The development of the design idea was guided by structural, formal, and material considerations, along with sustainability principles and biophilic design patterns applicable to façade systems.

These analyses informed the second phase—design development—resulting in two alternative façade proposals. Each option was evaluated and compared to identify strengths and weaknesses, leading to the final conclusions. The analyses helped define the project's context, environmental conditions, and design direction.

3. RESULTS AND DISCUSSION

The first façade proposal features thermal insulation and façade plaster above it. The room terraces are divided by waterproof gypsum board partition walls with a metal structure. In between the partition walls that serve as a separator of the terraces, EWP's panels are placed

for decoration (Figure 2). These panels are made from wood plastic composites (WPCs). The design improves guest privacy while preserving the view and offers a cost-effective solution. The WPCs panels are protected in between the walls and contribute to the overall aesthetics of the facade.

The second proposal also includes façade thermal insulation but covered with a cladding element made of WPCs (Figure 3). The vertical elements on the terraces provide partial privacy for the guests, since they are situated at a certain distance. This also partially closes the panoramic view from the terraces. Since the wooden elements are dominating on the facade, the design is aligned with biophilia and reflects a calm and pleasant look for the viewers.



Figure 2. First Design Proposal, designed by Aid Kurpejovic, master's student from the Department of Architecture, International Balkan University



Figure 3. Second Design Proposal, designed by Fatih Sejfulla, master's student from the Department of Architecture, International Balkan University

For façade applications, the performance of Wood Plastic Composites (WPCs) depends on the selected polymers. Polymers like PMMA enhance transparency and UV resistance, PE adds flexibility and moisture resistance, and PVC offers durability and fire resistance. PP increases tensile strength and chemical resistance, while biopolymers such as PLA and PHA improve biodegradability, supporting more sustainable WPC solutions [Murtezi, Miloshevska Janakieska, 2025].

Table 1 shows a comparison of the two proposals for the redesign of the facade. The two proposed façade design solutions aim to improve the building's energy performance, aesthetic appeal, and alignment with sustainable design principles. Proposal 1 features a thermally insulated facade with plaster finish, glass terrace fences, and privacy partitions. Its strengths lie in energy efficiency, clear panoramic views, and enhanced privacy, though it offers limited wooden texture and requires more maintenance. Proposal 2 uses thermal insulation and WPC cladding for the entire facade, with terrace fences made from vertical WPC elements. This design emphasizes biophilic qualities, contextual integration, and sustainability, while also

improving energy performance. However, it provides less privacy for guests and partially obstructs the view from terraces.

While both solutions incorporate sustainable materials and improve the building's performance, Proposal 2 is the more balanced and future-oriented solution. It better integrates the building into its natural surroundings through biophilic design and offers a more durable, low-maintenance facade, which is crucial in the mountain climate of Krushevo. Despite its minor drawback in terrace privacy, the overall harmony with the environment and material resilience makes Proposal 2 the preferred choice.

Table 1. Comparison of the proposals for the façade of Hotel Montana in Krushevo

	Proposals for the facade of Hotel Montana in Krushevo	
	Proposal 1	Proposal 2
Description of the design	Facade is covered with thermo-insulation and façade plaster; Terraces are separated with waterproof gypsum board partition walls with a WPC cladding between them. The fences are made from glass.	Facade is covered with thermo-insulation and WPC façade cladding elements. The fences on the terraces are made from vertical slender WPC elements placed at a certain distance.
Advantages	Improved energy efficiency	Improved energy efficiency
	Enhanced privacy for the guests	Biophilic design
	Aesthetic appeal	Aesthetic appeal
	Use of sustainable materials	Use of sustainable materials
	Unobstructed panoramic view	Harmonizes with natural context
Disadvantages	Higher maintenance requirements	Partially obstructed terrace view
	Limited wooden texture on façade surface	Does not fully ensure terrace privacy
Aspects of Sustainability	Energy efficiency	Energy efficiency
	Sustainable materials	Sustainable materials
	Pleasant aesthetic	Biophilic design
		Contextual harmony

4. CONCLUSION

This study contributes to the growing body of knowledge on sustainable architecture by exploring design approaches that respond to environmental, cultural, and contextual challenges in the renovation of Hotel Montana in Krushevo. Through comprehensive analyses—ranging from climate and urban context to structural conditions and material performance—three façade design proposals were developed and evaluated. Each design integrates principles of sustainability, energy efficiency, and aesthetics, while also addressing guest comfort and privacy.

Among the proposals, the second solution, which employs wood-plastic composite (WPC) cladding and biophilic design strategies, stands out as the most balanced approach. It harmonizes the building with its natural surroundings, utilizes durable and sustainable

materials, and supports the long-term environmental goals of the renovation, despite offering slightly less terrace privacy.

This research also supports broader discussions on the adaptive reuse of historically and culturally significant buildings. It aligns with similar studies that emphasize the integration of sustainability in heritage architecture (e.g., Petrevska, 2016; Marinoski, 2012; Koteski, 2022), all of which underscore the importance of maintaining cultural identity while enhancing environmental performance. These studies reinforce the central finding of this paper: that sustainable renovation of historic buildings in tourism contexts is both feasible and valuable when approached with thoughtful design strategies that respect the past while addressing the future.

Ultimately, the study demonstrates that with careful planning and context-aware design, it is possible to revitalize older structures in a way that meets contemporary performance standards, supports sustainable tourism, and preserves local character.

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THE ROLE OF WOOD IN ALBANIAN TRADITIONAL RESIDENTIAL TOWERS: STRUCTURAL AND CULTURAL SIGNIFICANCE

Arbresha Ibrahim, Manja Kitek Kuzman, Dick Sandberg

Abstract: Albanian residential towers, which were constructed between the ninth and eighteenth centuries, are significant architectural and cultural landmarks in Kosovo, Albania, and North Macedonia. Despite being mostly composed of stone, wood was crucial to its utility, aesthetic refinement, and structural soundness. Despite its significance, little is known about the function of wood; most studies concentrate on the defensive characteristics of the towers and the general development of architecture. The choice, use, and development of wooden construction and decorative components in these structures are investigated in this research. Beams, flooring, ceilings, and stairs were among the structural elements that were made of wood, as were distinguishing elements like *telizi* (upper-floor wooden layers) and *divanhane* (wooden apertures). The "heart of the wood" was saved for the main support beams, and several wood species were carefully selected for their strength and longevity. Traditional workmanship increasingly gave way to contemporary materials as woodworking processes evolved to reflect socioeconomic shifts. This study emphasizes the role that wood had in the towers' longevity, insulation, and spatial organization using a historical-architectural perspective. Results show that traditional woodworking techniques were changed by modernization, sometimes compromising authenticity. Even though the goal of modern restoration is to save these buildings, it is sometimes difficult to replicate the original woodworking methods. This research advances our knowledge of the usage of materials in ancient architecture by examining this little-known side of Albanian tower building. It emphasizes how crucial it is to keep up traditional woodworking methods to preserve the traditional buildings' authenticity and cultural relevance.

Keywords: Albanian residential towers, woodworking, vernacular architecture, heritage preservation

1. INTRODUCTION

Albanian residential towers or *kullas*, are amongst the most typical expressions of traditional Albanian lifestyle in the mountains found in regions such as Albania, Kosovo, western part of North Macedonia, and elsewhere in the Balkan peninsula (Doli, 2001; Go2Albania, 2021). (Doli, 2001; Go2Albania, 2021). Between the ninth and nineteenth centuries, they stood as strongholds of domestic and defense life. Their long-standing architectural idiom is the product of the dominant culture, society, and economy of the period. Though primarily constructed of stone, wood played an essential role in their structure, spatial definition, and cultural identity. These towers are hybrid combinations of fortification and domesticity, the product of an evolution from original dwellings with Late Neolithic connections and centuries of building and tradition behind them. Their evolution was the product of tribal structure, customary law (particular the Kanun of Leke Dukagjini), and defensive exigency due to inter-tribal warfare or feuds. Wood, in this context, was more than an element of structure—it was an element of the spatial core of the *kulla*.

2. DEVELOPMENT AND TYPOLOGY OF TOWERS

The towers of Albania evolved during four phases (Go2Albania, 2021) (Fig. 1):

First phase (9th–19th century): Pre-19th-century towers were typically positioned on higher or strategic spots in order to achieve maximum surveillance and protection. Built with thick stone walls (up to 1 meter), they often reached 6–15 meters in height depending on the number of floors. Steeper-pitched roofs were accommodated with wooden trusses and stone tiles, which were the preferred choice. Interior heavily relied on wood—principal beams being carved from heartwood, while the rest of the wood used included floors, ceilings, doors, shutters, stairs, and decorative objects. Symbolical wooden features such as divanhane, telizi, qoshk, and krevetë represented localized culture and were developed according to both climatic and societal needs.

Second phase (1912–WWII): Moderate modernization marked this phase. Trusses got more refined, oil lights substituted torches, and interior arrangements enhanced. Twin towers with wooden bridges connecting them, which ensured privacy and security, also marked their entry during this phase. Innovative architectural features like chimneys and enhanced toilet arrangements demonstrated an adjustment to newer demands on lifestyles.

Third phase (1950s–1980s): Classic protective features like shutters and symbolic wood rooms like divanhane and qoshku were modified or eliminated. New materials (concrete, asbestos cement, aluminum, glass) joined the building palette. Stair positioning and window treatment transformed interior structure, and symbols of religiosity and paganism vanished. These transformations represented the shifting values under the influence of the state and fast-urbanizing society.

Fourth phase (2015–present): There was renewed interest in towers as a result of heritage tourism and cultural identity. Regionally, restoration and new constructions tried to replicate historic towers. However, most lacked material authenticity and often employed imitative or incompatible modern materials, which diminished the cultural and architectural value of the original towers.



Figure 1. Residential towers (Graphics in Watercolor: Maksim Mitrojorgji by Maksim Mitrojorgji and Joli Mitrojorgji (M. Mitrojorgji & J. Mitrojorgji, 2013)

3. THE ROLE OF WOOD IN SPATIAL AND STRUCTURAL LOGIC

Throughout all building periods of towers, wood played a dominant role in spatial arrangement and climatic comfort of the towers. It provided design flexibility, largely for interior uses where the utilisation of stone was impractical. Chestnut, oak, and pine were commonly used for beams, staircases, and flooring balanced building demands against local availability. The skilful preservation for heartwood utilised on principal beams is just such empirical experience for building materials passed down from one generation to the next. Wood was not only a structural necessity, but also an architectural identity. Significant architectural details like the *divanhane* (half-open reception rooms) and *telizi* (upper-storey lattices for lighting and ventilation) were primarily wooden components. They contributed to the enhanced versatility of the towers to environmental needs as well as to social needs, specifically providing comfort, insulation, and spatial flexibility within a defensive ring. Wooden balconies, inner galleries, shutters, and staircases enabled multi-level interaction with vertical mobility and vertical connection within the towers. Selection and direction of species of wood,—especially the heartwood of oak and pine,—were sensitive exercises in design of the environment. The heartwood with the built-in resistance to fungal growth and insects by possessing a larger proportion of extractive materials was reserved for the center structure uses. Ancient builders also showed an understanding of the anisotropic as well as hygroscopic nature of wood and designed correspondingly for movement during the seasons as well as for durability. These skills map onto contemporary expertise in *Engineered Wood Products in Contemporary Architecture* (2024), which acknowledges that historical uses of solid wood anticipated many of the virtues now attributed to engineered materials. The article highlights the architectural and environmental sensibilities of wood in spatial narrating—a practice Albanian towers invented long ago. Examples include the tactile, auditory, and visual characteristics of smooth bare wooden surfaces on kullas mirroring contemporary tactics on biophilic design for humanizing architecture through natural manifestation of materials (Janakieska, Kuzman, & Sandberg, 2024). Thus, the use of wood in such towers was not simply expedient but was closely related to climatic sophistication, symbolic tradition, and building culture. Preserving this knowledge is not only essential to the preservation of the towers themselves but to the transmission of sustainable design practice into the future - by respecting and evolving the vernacular wisdom of the past.

4. CHALLENGES IN PRESERVATION AND RESTORATION

Modernization has introduced some of the most serious threats to the towers' authenticity. Although there have been attempts which have managed to sustain the customary practices, most restoration work is plagued with quite a number of factors. One of the most serious is the use of modern materials in replacing the wood, which threatens both the thermal efficiency and aesthetic value of the structures. There is, in addition, the absence of skilled craftsmen capable to reproduce the customary systems of joinery and decorative ornament, which are essential in sustaining the architectural form of the towers. There is the added problem of limited availability of documentary and detailed architectural records, which makes restoring the towers accurately much more difficult. Despite these obstacles, regional governments, schools, and foreign organizations have begun taking specific, concrete action to address the issue. Their

work includes setting towers under heritage protection and offering training programs with the hope of cultivating the future generations of skilled laborers. To be most effective, however, there has to be an increased, long-term effort to maintain the wood-based vernacular knowhow that is the key to the sustainability and cultural relevance of the historic buildings being conserved.

5. CONCLUSION

Wood is not merely the building element of the Albanian residential towers, but it is the bearer of cultural heritage, environmental response, and architectural discourse, as well. As new forces as a tourism, modernity, and commodification challenge the authenticity of the towers, conserving traditional woodworking techniques becomes crucial- not only for ensuring their structural durability but also for sustaining them as living heritage.

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INTEGRATING SUSTAINABILITY INFORMATION THROUGH VALUE CHAIN DISCLOSURES: INSIGHTS FROM THE WOOD-BASED INDUSTRIES

Atanas Atanasov

Abstract: As sustainability increasingly shapes business strategy and stakeholder expectations, integrating sustainability information across the value chain has become essential. This paper examines the role of sustainability disclosures as a mechanism for integrating environmental, social, and governance (ESG) information within the wood-based industries in light of new reporting requirements. We analyze how value chain disclosures contribute to transparency, accountability, risk management, and sustainability performance. Companies that adopt a comprehensive approach to sustainability disclosure tend to demonstrate higher levels of stakeholder engagement and long-term strategic alignment with sustainability goals. However, challenges persist, including data fragmentation, limited supplier collaboration, and a lack of standardization in reporting formats.

The paper also highlights the challenges faced by wood-based industries in maintaining effective supply chain collaborations and the need for innovative solutions to overcome barriers to sustainability. It advocates for a holistic approach that encompasses product design, recycling technologies, and waste management strategies to maximize resource utilization and minimize waste. Overall, the paper provides valuable insights into how wood-based industries can integrate sustainability information through value chain disclosures to achieve long-term sustainability and competitive advantage.

Keywords: value chain disclosures, sustainability information, CSRD, CSDDD, wood-based industries

1. INTRODUCTION

Sustainability is increasingly vital for businesses, driven by rising global attention to environmental, social, and governance (ESG) factors. The wood-based industries, crucial for construction, furniture, and paper, face specific sustainability challenges and opportunities. Their significant impact on forestry management, biodiversity, and waste reduction makes them key to global sustainability efforts. However, complex supply chains often lead to fragmented data and inconsistent reporting (Hahn & Kühnen, 2013).

Deforestation and resource intensity are major concerns for wood-based industries, threatening biodiversity and climate stability (FAO, 2020). Growing regulatory pressure and consumer/investor demand for transparency are compelling these industries to adopt more sustainable practices. Transparency is essential for accountability and market access, as stakeholders seek assurance that companies are mitigating their environmental impact.

New EU regulations like the Corporate Sustainability Reporting Directive (CSRD) and the Directive on Corporate Sustainability Due Diligence (effective July 25, 2024) are further pushing companies to identify and address human rights and environmental impacts throughout their global value chains. For wood-based industries, integrating sustainability reporting across the value chain is crucial for enhancing ecological responsibility and demonstrating commitment to environmental and social governance. The aim of this paper is to explore the significance of sustainability disclosures as a critical mechanism for embedding ESG information across the value chain in the wood-based industries, particularly in light of emerging reporting requirements and regulatory frameworks. Our thesis is that integrating sustainability information through value chain disclosures can, on the one hand, increase transparency and

improve business competitiveness, including access to financing, and on the other hand, help to highlight and reveal the risks that businesses face in the value chain.

2. LITERATURE REVIEW

Integrating Environmental, Social, and Governance (ESG) factors into value chains is crucial for businesses seeking sustainable practices. ESG disclosures are vital for transparency, risk management, and continuous improvement, allowing stakeholders to assess sustainability efforts (Eccles et al., 2014; KPMG, 2020).

Initially focused narrowly on sustainable wood production, the forest sector's sustainability now encompasses economic, environmental, and social dimensions across the entire forest wood supply chain, though social aspects are often neglected in different studies (Santos et al., 2019). Accounting plays a key role in facilitating information flow within these supply chains, driven by globalization and increased scrutiny of corporate performance (Burritt & Schaltegger, 2014).

Existing EU legislation, including the Corporate Sustainability Reporting Directive (CSRD), European Sustainability Reporting Standards (ESRS), and Corporate Sustainability Due Diligence Directive (CSDDD), mandates comprehensive reporting on upstream and downstream value chain activities. This means large companies must disclose material information about their suppliers, distributors, and customers, assessing significant ESG impacts. The CSRD's "double materiality assessment" focuses on disclosing only the most relevant impacts, risks, and opportunities linked to value chain relationships.

While not directly mandated by CSRD, Small and Medium-sized Enterprises (SMEs), particularly those in the wood-based industries acting as suppliers or distributors, are increasingly impacted. They must provide data to larger companies for compliance, making adaptation to these new standards essential. Sustainability reports are pivotal for forestry companies, not just for compliance but for better management and stakeholder engagement. They guide strategic actions, emphasize ecological responsibility (Oleksich & Fominov, 2024), and require tailored approaches for specific environmental challenges (Ševčík et al., 2014). Critical success factors for supply chain sustainability in the wood industry include optimized production and improved waste management, highlighting the need for stakeholder collaboration (Paul et al., 2022; Boiral & Saizarbitoria, 2015). Adopting frameworks like GRI, ESRS, and CSRD enhances transparency and comparability (Malovrh et al., 2019), but comprehensive disclosure, including negative aspects, is crucial (Pizzi, 2018). Certification schemes like FSC and PEFC further reinforce sustainable management and marketability (Lombardo, 2024; Larsen et al., 2019). Despite the benefits of joining global value chains (GVCs) for economic transformation, managers in the Bulgarian furniture industry are hesitant due to perceived risks like dependency and delayed deliveries (Georgieva, 2024).

Ultimately, integrating sustainability reporting into the wood-based industries' value chains is critical for ecological responsibility and improved sustainable practices. This demands a multi-faceted approach involving stakeholder engagement, certification, and adapting reporting frameworks. Companies must understand their value chains to identify material impacts, risks, and opportunities, as disruptions can have significant financial implications. The proposed reduction in CSRD and CSDDD scope with the Omnibus package could limit transparency in complex value chains, hindering capital mobilization for sustainable transitions and creating a less transparent market (Accountancy Europe, 2025).

3. METHODOLOGY, RESULTS AND DISCUSSION

The sample for this study comprises four European companies within the "Building Products and Furnishings Industry" segment of the Sustainability Navigator database: Deceuninck (Belgium), Op Mobility (France), Kingspan (Ireland), and Rockwool (Denmark). The selected organizations represent the complete set of companies within this industry that have published a 2024 sustainability report in compliance with the CSRD and ESRS within the mentioned database. To ensure anonymity in the presentation of findings, each company has been assigned a randomized letter designation (e.g., Company A, Company B ...), preventing identification based on their initial listing.

Our analysis includes individual company assessments, a comparative summary, alignment tables, and recommendations. The CSRD mandates comprehensive transparency across value chains, while the ESRS provides detailed guidelines, specifically ESRS S2 (value chain workers) and environmental standards E2 (Pollution), E3 (Water and Marine Resources), and E5 (Circular Economy). Individual company analysis is detailed in Table 1.

Table 1. Individual Company Analysis

Criteria	Company A	Company B	Company C	Company D
Policies	Fair labor practices	Ethical labor practices	International labor standards	Health, safety, human rights, gender equity (S1)
Engagement Methods	Surveys and feedback channels	Regular training and communication	Technological platforms for real-time feedback	Well-defined engagement methods (S1)
Remediation Mechanisms	Clear grievance handling	Transparent, structured grievance processes	Swift and robust resolution	Effective grievance and remediation procedures (S1)
Actions Taken	Initiatives for improved conditions	Programs enhancing safety and rights	Extensive training and supplier support	Comprehensive ESG programs
Targets Set	Measurable labor condition improvements	Ambitious social and environmental goals	Specific and time-bound sustainability goals	Detailed and multi-dimensional ESG targets
Environmental Disclosures (E2-E5)	Not Disclosed	Not Disclosed	Not Disclosed	Extensive (E2: Pollution, E3: Water, E5: Circular Economy)
Value Chain Visualization	No	No	No	Yes

Source: Own elaboration based on the sustainability reports of the studied companies

A comparative summary of the four companies' 2024 Sustainability Reports reveals specific similarities and differences in their value chain disclosures. All companies demonstrated a universal commitment to ethical labor standards, and each clearly outlined mechanisms for worker engagement and grievance remediation. Furthermore, every company

disclosed defined targets, indicating an ongoing commitment to sustainability improvements. However, distinctions emerged in their approaches: engagement techniques differed, with Company A using traditional methods, Company B focusing on training, and Company C employing technology-driven approaches. Companies B and C also exhibited higher specificity and target ambition. Notably, Company D excelled in the scope of its reporting, integrating comprehensive environmental disclosures (E2: Pollution, E3: Water and Marine Resources, E5: Circular Economy) with social disclosures and value chain visualization.

The varying approaches to stakeholder engagement among the companies highlight different levels of maturity. Company A's reliance on traditional surveys contrasts with Company C's innovative, technology-driven feedback, which aligns with Boiral and Saizarbitoria's (2015) view that deep stakeholder involvement is crucial for achieving sustainability goals like biodiversity management. However, a notable weakness for Companies A, B, and C is the general absence of specific environmental disclosures (ESRS E2-E5). This is a significant gap given the wood-based industry's profound impact on deforestation, biodiversity, and resource intensity. As Ševčík et al. (2014) argue, the forestry sector needs adapted reporting protocols for its unique environmental externalities, a need largely unaddressed by these three companies.

A key finding is the strong focus on social disclosures (ESRS S2) across all firms. This likely reflects a response to regulatory pressures like the CSRD's mandate for detailed reporting on value chain workers. This observed shift is particularly interesting given Santos et al.'s (2019) earlier finding that social aspects have historically been the most neglected dimension in the forest wood supply chain, suggesting that new regulations are helping to correct this imbalance.

The information about the alignment of the disclosures by studied companies with CSRD and ESRS is presented in Table 2.

Table 2. Alignment with CSRD and ESRS

Criteria	Company A	Company B	Company C	Company D
Policies (S2-1)	V	V	V	Partial (via S1)
Engagement (S2-2)	Traditional	Training	Innovative Tech	Well-defined (via S1)
Remediation (S2-3)	V	V	V	V
Actions (S2-4)	V	V	V	Comprehensive ESG
Targets (S2-5)	Defined	Ambitious	Time-bound	Multi-dimensional
Environmental Disclosures (E2-E5)	X	X	X	V ; Extensive
Value Chain Visualization	X	X	X	V

Source: Own elaboration based on the sustainability reports of the studied companies

Table 2 reveals varying maturity levels in sustainability integration across the wood-based industries' value chain. Companies A, B, and C have established clear policies and remediation practices focused on social sustainability and labor conditions. Companies B and C particularly enhance their efforts with ambitious, time-bound targets addressing deforestation, biodiversity, and labor standards. Company C also leverages innovative technology to improve traceability and transparency in sustainable forestry. Company D excels by providing comprehensive

environmental disclosures and visual value chain mapping, representing a best practice for holistic sustainability management. Aligning with Burritt & Schaltegger (2014), this emphasizes accounting's strategic role in fostering transparency and accountability. Yet, Companies A, B, and C show gaps in environmental disclosures, limiting credibility and market competitiveness, in line with Pizzi (2018). Additionally, wood-based industries face ongoing challenges such as data fragmentation and limited supplier collaboration, hindering effective ESG integration and echoing Georgieva's (2024) concerns.

Based on our analysis for boosting value chain sustainability, companies, especially A, B, and C, need to expand environmental reporting on key factors (E2-E5) across their entire value chain. Adopting technology-driven feedback (like Company C) will significantly enhance sustainability management. Visual value chain mapping (like Company D) will improve transparency and stakeholder understanding. Finally, companies must prepare to align sustainability disclosures (CSRD) with financial indicators to clearly show financial impacts.

4. CONCLUSION

Integrating sustainability information across the value chain is a crucial and necessary transformation for the wood-based industries, primarily driven by new regulations like the Corporate Sustainability Reporting Directive (CSRD). This pushes companies to report on their entire upstream and downstream impact.

Our analysis shows an uneven response to these mandates. While there's a clear focus on social and labor-related disclosures, a concerning gap exists in reporting crucial environmental impacts, such as pollution, water resources, and the circular economy. This is particularly critical given the industry's direct link to natural resources and forestry. These findings highlight the importance of a holistic approach, where sustainability disclosures are integrated with broader corporate and financial strategies. Such integration not only mitigates environmental and social risks but also improves access to financing by offering investors more reliable information. Ultimately, these insights aim to deepen the understanding of how sustainability disclosures can foster sustainable practices within the wood-based industries, supporting a more responsible global economy.

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IMPACT OF TRANSPORT ON FORESTS – A CONCEPT FOR SUSTAINABLE DEVELOPMENT

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Abstract: The transport sector emits a significant amount of harmful emissions, which has a negative impact on both the environment, forests and human health. The development of transport infrastructure requires a serious land resource, the provision of which is very often associated with the felling and removal of large forest areas. The purpose of the study is to provide an overview and analysis of the challenges facing the transport sector and its impact on forests, as well as to achieve the goals of the European Green Deal for sustainable mobility and the principles of the circular economy. The main indicators are examined, through which the degree of impact of transport on forests is assessed. The prepared SWOT analysis objectifies the economic, social and environmental factors that significantly influence the concept of sustainable development. The main aspects of the concept of sustainable development are analyzed as a key priority for the implementation of the European Green Deal. The concept of sustainable development determines the need to select and promote strategies for the development of the transport and forestry sectors, consistent with economic development, environmental protection and improvement, as well as achieving biological balance on Earth. In conclusion, the main challenges to the development of an environmentally efficient economy are described, characterized by low levels of carbon emissions, rational use of resources, growth of green spaces, increase in forest areas, based on sustainable production in all sectors and a more sustainable lifestyle and transport mobility.

Keywords: transport, forests, sustainable development, concept, challenges

1. INTRODUCTION

Sustainable development is a public value that requires the definition of goals, strategies and plans for the development of each country and economy, with the aim of improving the environment and living conditions. One of the tasks for the sustainable development of the state is the construction of a transport system that meets the needs and requirements of society, both for transportation and for clean nature. Sustainable development determines the need to choose and promote strategies for economic development that are consistent with the protection and improvement of the environment, as well as achieving a biological balance on Earth. Transport has a significant impact on forests and can lead to serious environmental damage if not managed sustainably. The main external costs of environmental impacts related to transport are accidents, noise, air pollution and climate change. The development of transport infrastructure requires a serious land resource, the provision of which is very often associated with the felling and removal of large forest areas. The concept of sustainable development offers solutions that combine the needs of transport with the protection of forest ecosystems.

2. IMPACT OF TRANSPORT ON FORESTS

Transport in general, and especially road transport, negatively affects the environment by polluting and damaging the quality of atmospheric air in populated areas, changing the global climate, the landscape and agricultural land (construction of large transport

infrastructure projects), creating noise and waste.¹ The overall objective set in the Operational Programme "Transport Connectivity" is the development of a sustainable transport system. The transition to sustainable transport is part of the EU's strategic policy and is aimed at implementing three main strategies: reducing the need for passenger transport, transition to more sustainable means of transport, increasing the efficiency of vehicles and transport flow. The main priority in the strategic policy of all transport operational programmes aimed at the development of the transport sector in Bulgaria is related to reducing the need for passenger transport, thus contributing to the development of mobility by reducing the number of kilometres travelled. Another important strategic aspect is related to stimulating the use of more sustainable means of transport. The aim is to give priority to mobility that produces zero emissions for short distances, such as walking, cycling, trains and public transport for medium and long distances. A serious challenge is to take measures and implement investment decisions regarding vehicle technologies, as well as intelligent traffic management systems, thus aiming to increase the efficiency of transport. The general concept for the sustainable development of the transport sector in the EU shares the view that the development of transport and especially road transport can negatively affect the state of the environment. That is why effective investments in transport that can have a positive impact on forests are aimed at investments in railway infrastructure, in the development of sustainable public transport, such as metro, trams and low-emission buses, investments in electromobility, intelligent transport systems, etc. The quantitative characteristics of economic, social and environmental costs are determined on the basis of average estimates of external costs by transport mode for EU countries. They can be applied in the valuation of the costs and benefits of external effects and are presented in Table 1.

Table 1. Average estimates of external costs by transport mode for EU countries, INFRAS-IWW

Passenger (euro/1000 p/km)					
	Passenger car	Motorcycle	Bus	Railway	Airborne
Disasters	36	250	3,1	0,9	0,60
Noise	5,7	17	1,3	3,9	3,6
Air pollution	17,3	7,9	19,6	4,9	1,6
Climate change	15,9	13,8	8,9	5,3	35,2
Freight (euro/1000 tons/km)					
	LCV*	HGV**	Railway	Airborne	Water
Disasters	100	68	11,5		

¹ Integrated transport strategy for the period up to 2030,
<https://www.mtc.government.bg/bg/category/42/integrirana-transportna-strategiya-v-perioda-do-2030-g>

Noise	35,7	5,1	3,5	19,3	
Air pollution	131	32,4	4	2,6	9,7
Climate change	134	15,1	4,7	153	4,2
* Light commercial vehicles (vans with a gross weight of up to 3.5 tons)					
** Heavy goods vehicles (trucks with a gross weight of over 3.5 tons)					

Transport has a significant impact on forests, both directly and indirectly. The construction of transport infrastructure and all related activities have a negative impact on forest ecosystems. In this regard, the transport sector faces a number of challenges that are of particular importance for the concept of sustainable development. The degree of negative impact of transport on forests is assessed through several main indicators that cover both environmental and other aspects.

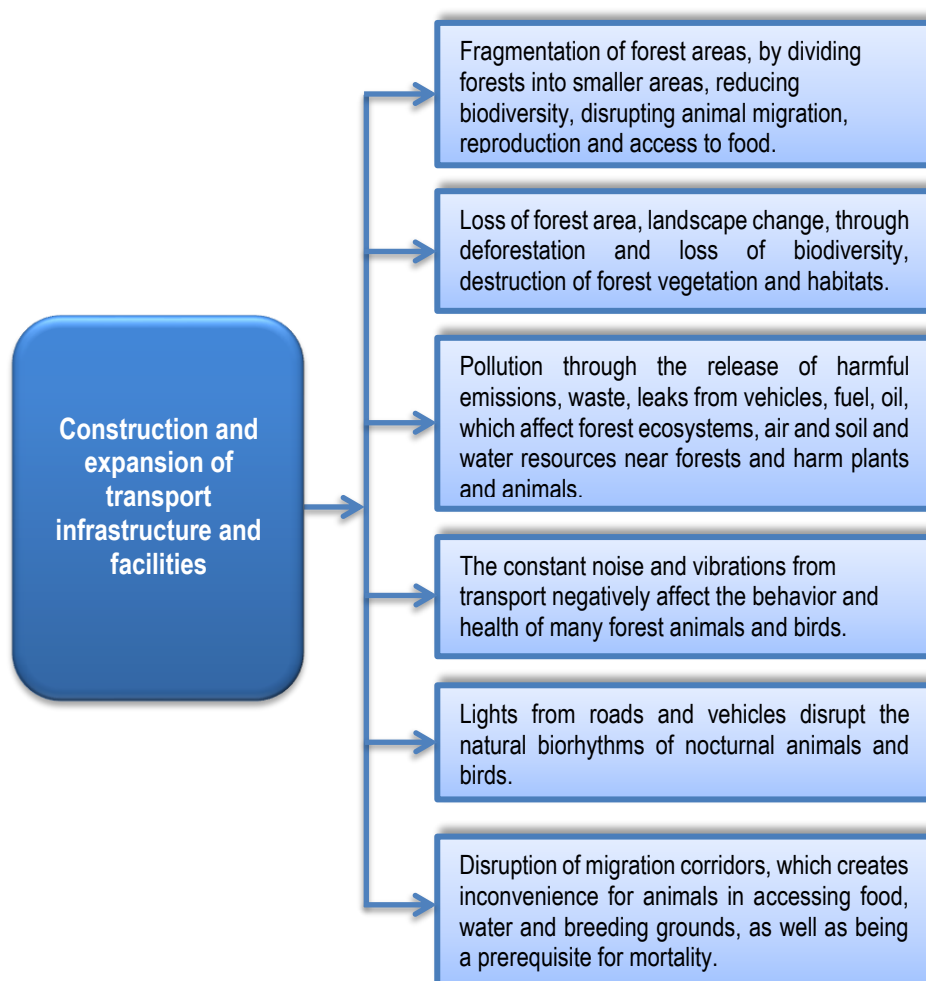


Figure 1.

3. SWOT ANALYSIS: IMPACT OF TRANSPORT ON FORESTS

The impact of transport on forests is a complex issue that has several main aspects that have an impact, both for environmental and strategic assessment. Through SWOT analysis (Tabl. 2), we present the economic, social and environmental factors that transport has on forests, considered as strengths, weaknesses, opportunities and threats.

Table 2. SWOT Analysis: Impact of Transport on Forests

Strengths • Improving access to forest resources for tourism and other economic activities. • Developing the local economy by expanding infrastructure and logistics activities. • Economic development of rural and forest areas. • Creating and securing jobs in the transport and forestry sectors. • Improved accessibility. • Facilitating access to sustainably harvested resources, without illegal logging. • More effective control of the various environmental protection services. • Promoting Eco-tourism through sustainable transport – electric buses, bicycle routes	Weaknesses • High costs for construction, expansion and maintenance of transport infrastructure in forest areas. • Illegal use of forest resources due to easier access. • Disruption of the traditional way of life of local communities. • Increase in road accidents near protected areas. • Fragmentation of forest ecosystems due to construction of roads and railways. • Pollution of air, soil and water from transport vehicles. • Reduction of biodiversity.
Opportunities • Development of sustainable transport. • Improvement of forestry, through easier access for machinery and workers, fire protection. • On tourist routes and development of eco-tourism; • Expansion of green infrastructure. • Reduction of biodiversity.	Threats • Uncontrolled exploitation of forest resources for commercial purposes. • Loss of biodiversity. • Conflicts between investors and local communities. • Increasing urbanization • Irreversible degradation of ecosystems. • Intensification of the effects of climate change through deforestation and increased greenhouse gas emissions.

4. CONCEPT OF SUSTAINABLE DEVELOPMENT IN TRANSPORT AND THE IMPACT ON FORESTS

Sustainable development of transport is associated with the need for constant modernization of both the transport infrastructure and the means of transport themselves. These are the main and particularly priority tasks, the implementation of which will contribute to the development of a modern and safe transport system. Sustainable development of the transport sector requires the use of cleaner fuels and energy in transport. This, in turn, requires effective organization of the use of individual modes of transport and achieving a balance between them. Economic and environmental priorities are the main elements of sustainable development of the transport sector. They require that all factors affecting both transport and the environment and human health be taken into account when making economic decisions.

Internet of Things (IoT) – The term "Internet of Things" is an emblem of the communication protocols and operating systems that allow the exchange of digitized data between objects (physical or virtual) equipped with sensors, telemetry tools, chips, or QR codes and applications, embedded in a computer, telephone or robot hardware. Provided the relevant interoperability conditions are met, about shared technical standards, miniature interconnected objects can play a useful role in work settings (tracking of components and products, employee monitoring, sales monitoring, access control), public spaces (urban traffic, public transport,

water supply, waste management) and private spaces (home automation, digital clothing, sports equipment). The application of IoT in smart cities is described in detail in (Čekerevac, Prigoda, & Bogavac, 2020). The implementation of the tasks set in the national strategy for sustainable development of transport requires significant investments in the development, modernization and maintenance of the transport infrastructure. Sustainable development as a concept seeks a balance between economic growth, environmental protection and social justice. In the context of transport and forests, this includes:

- Infrastructure planning with environmental assessment, for which purpose, before building roads, it is necessary to assess the environmental impact and select routes that minimize damage to forest areas.
- Use of environmentally friendly technologies, such as electric and hybrid vehicles, which reduce greenhouse gas emissions and improve energy efficiency.
- Green infrastructure, by building ecoducts, such as bridges for animals, tunnels and underpasses for species migration and planting green belts along roads.
- Afforestation of other terrains to compensate for cleared areas.
- Promotion of green tourism.
- Financing, by providing incentives and subsidies, for the use of sustainable transport solutions in forest areas, as well as using European and international funds to build sustainable transport infrastructure.
- Policies and legislation, by implementing strict environmental standards and controls, as well as promoting public transport and alternative forms of mobility.

This concept places sustainability at the heart of transport development, taking into account the need to protect forest ecosystems. Sustainable transport in forest areas is key to achieving a balance between economic development, social responsibility and environmental protection. These solutions (Tabl. 3) contribute to a comprehensive, applicable and long-term concept that not only minimizes the negative consequences of transport, but also creates positive opportunities for development compatible with nature.

Table 3. Measures and objectives affecting ecology and forest areas.

Measure	Purpose	Example
Construction of ecoducts	Maintaining migration routes	Viaducts over highways
Intelligent planning	Avoiding environmental damage	Biological diversity
Post-construction reforestation	Carbon footprint compensation	Planting trees and shrubs
Limited access	Protection of vulnerable forest areas	Electronic barriers, forest patrols

The expected benefits from the implementation of the above measures will lead to the preservation of biodiversity, reduction of emissions and the ecological footprint of transport, development of ecotourism, etc. The creation of a model for sustainable development of transport infrastructure, which minimizes the negative impact of transport on forests and contributes to the protection of biodiversity, is the basis of the concept of sustainable development of transport.

3. CONCLUSION

Sustainable transport management is key to forest conservation. Through strategic planning, innovation and the implementation of sustainable practices, it is possible to achieve harmony between the development of the transport network and the protection of forest ecosystems. Sustainable transport development is closely related to the idealization, development and implementation of a number of investment solutions aimed at increasing the efficiency and improving transport activities, both for individual transport companies and for society as a whole. Investment decisions lead to varying degrees to increasing transport safety and reducing the number of accidents, through the implementation of modern systems and technologies, and when making investment decisions, the impact of investment projects on the costs and benefits of external effects: noise, air pollution, climate change, soil and water pollution, nature, accompanying processes in land transport. Sustainable development in transport related to forest areas aims to minimize negative impacts on forest ecosystems, combined with improving access, mobility and economic activity in harmony with the protection of the natural environment. In order for transport not to pose a threat to forest conservation, careful planning, environmental assessments, and the application of sustainable practices in the construction and maintenance of transport infrastructure are necessary.

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ECONOMIC, FINANCIAL, AND LOGISTICS PERSPECTIVES

ECONOMIC CALCULATION OF HEALTH RISKS IN LONG-TERM STORAGE AND USE OF BIOMASS

Miloš Gejdoš, Marek Potkány

Abstract: This paper evaluates selected health and safety risks associated with biomass storage, focusing primarily on the production of PM_{2.5} and PM₁₀ dust particles and the release of phytopathogenic spores—both of which pose serious respiratory health threats to workers in biomass-utilizing plants and residents living nearby. The study thus assesses both occupational and environmental exposure. The analysis is based on data collected over the past two years, including both short-term and long-term dust measurements. Additionally, the paper aims to economically quantify these risks, particularly from the perspective of the burden they place on the health and social systems due to occupational and chronic respiratory diseases within the Slovak healthcare context. Using data from the Health Information Centre, the economic costs to the healthcare and social systems were calculated, providing a basis for risk assessment in enterprises operating with wood biomass.

Keywords: biomass, health risks, economic risks, biomass storage, wood chips, dust particles

1. INTRODUCTION

With the growing use of renewable energy sources, there is a corresponding increase in demand on their quality, transportation, and logistics, all of which are closely linked to storage and spatial requirements (Gejdoš & Hitka, 2024; Aboytes-Ojeda et al. 2022; Rafael et al. 2015). When biomass is used as a renewable energy source, most facilities are located close to the end users of the generated thermal or electrical energy, often directly within urban areas. The operation of such facilities is associated with several risks. Despite increasingly advanced technological solutions, there remains a partial impact on the surrounding environment and air quality, primarily due to emissions from biomass combustion. If the facility is situated in areas of intensive industrial activity or high traffic density, the negative impact can be even more significant.

In addition to emissions from combustion, other health and safety risks arise, particularly during the storage of large quantities of biomass (such as forest chips) in a single location. The most significant threats to human health are posed by fungal and mold activity within the chip piles, resulting from natural biological processes, and the inhalation of wood dust during chip handling (Pietryczuk, 2013; Barontini et al. 2014; Suchomel et al. 2014; Lieskovský & Gejdoš, 2023). These risks are especially pronounced outside the active heating season, when optimal logistics planning is more challenging. Long-term biomass storage can expose residents living in densely built-up areas near such facilities to elevated health risks. According to Barontini et al. (2014), the concentration of phytopathogenic spores in the air drops below critical levels within approximately 300 meters from the chip pile during handling.

Biological processes associated with natural biological degradation also cause heating of the inner layers of biomass, which is stored mainly in large-volume piles. These facts significantly increase the risk of fire, which can cause damage to property and human health. This risk is often further increased by incorrect location and spatial arrangement of wood chip storage in operations (Gejdoš, Lieskovský, 2024).

Not much attention has yet been paid to the assessment and quantification of the amount of dust particles that arise during various types of wood chip storage and handling. So far, attention has focused more on the process of wood chip production and the quantification of dustiness during it. However, relatively few works have been devoted to dustiness during the process of consumption and storage of woody biomass (Crook et al. 1991; Diehl, 1998). This is probably related to the instrumentation and time requirements of such research, while the results can be influenced by several other factors. An exception is the work where wood dust from chips was identified as the cause of an explosion, with consequences for human health and lives (Hedlund et al. 2014). In this type of biomass storage, dust particles together with fungal spores can create a dust mixture that can be dangerous for the health of operators working with biomass and can even form an incendiary and explosive mixture in case of contact with a heat source (Lulbadda-Waduge, Zigan, 2015).

The aim of the work is also the economic calculation of the mentioned risks (especially the burden of PM 2.5 and PM 10 dust particles and phytopathogens), especially from the perspective of the burden on the health and social system, due to the occurrence of occupational diseases and long-term respiratory diseases in the Slovak healthcare system. Based on data from the Health Information Center, economic costs for the health and social system were calculated, which can be used in the operating conditions of enterprises using wood biomass for the final calculation of risks.

2. METHODOLOGY

For the analysis of the environmental impacts of biomass storage, an urban-type heating plant located in the built-up area of the town of Hriňová, in the Banská Bystrica Self-Governing Region, was selected. Long-term measurements of particulate matter (PM) with diameters of 2.5 μm (PM_{2.5}) and 10 μm (PM₁₀) were conducted from May 29 to June 23, 2024. This period was deliberately chosen outside the heating season to eliminate the influence of biomass combustion emissions and to isolate dust particles generated exclusively from biomass storage and handling activities. Such long-term monitoring enables a more comprehensive analysis of air quality, considering the effects of operational activities, meteorological conditions, and storage practices.

According to the World Health Organization (WHO, 2021), the recommended average annual concentration limit for PM_{2.5} is 5 $\mu\text{g}/\text{m}^3$, and for PM₁₀, 15 $\mu\text{g}/\text{m}^3$. The recommended average daily concentrations should not exceed 15 $\mu\text{g}/\text{m}^3$ for PM_{2.5} and 45 $\mu\text{g}/\text{m}^3$ for PM₁₀. For the measurements, an AirNore device from Blue was used (Fig. 1).

At the selected facility, biomass samples were collected between 2019 and 2024 to analyze the presence of phytopathogens. For each sampling period, three samples were taken from the surface of the pile at different locations. All samples were subjected to microbial analysis for phytopathogenic presence at the accredited laboratory of the Regional Public Health Office in Poprad.

From an economic perspective, the potential impact of occupational diseases associated with biomass production and storage was also evaluated. The analysis focused primarily on allergic and immunodeficiency-related respiratory diseases, which may develop during the logistical processes of biomass production and handling. Specifically, data on patient visits to immunoallergology outpatient clinics and the number of hospitalized patients, regardless of age, were examined for the period 2013–2023 in the Banská Bystrica Self-Governing Region.

In addition, data on the number of reported occupational diseases in the relevant category were analyzed.

The economic assessment of these diseases was based on valid legislation (Act No. 437/2004 Coll.), databases from the National Health Information Centre (NCZI), and regulations issued by the Social Insurance Agency. Economic data from previous research were also incorporated (Gejdoš & Potkány, 2024).

For data processing and evaluation, standard software tools, including MS Excel and Statistica, were used.



Figure 1. Measuring equipment for PM_{2.5} and PM₁₀ on biomass storage

3. RESULTS

3.1. Particulate Matter analysis

Figure 2 evaluates long-term measurements of dust particle concentration in the operation of a municipal heating plant during the period outside the heating season.

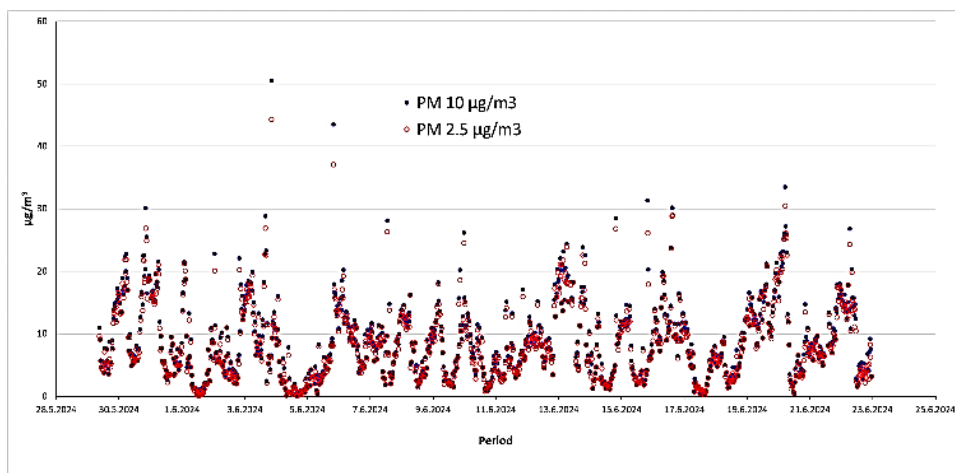


Figure 2. Time series of PM₁₀ and PM_{2.5} concentrations during the period of May–June 2024

There were relatively significant fluctuations in the concentration levels of particulate matter during the monitoring period. The average concentration of PM₁₀ particles was 8.8 µg/m³, with more than half of the recorded values falling between 4 and 12 µg/m³. A similar

average concentration and distribution of recorded values were observed for PM_{2.5} particles. During the monitoring period, the WHO-recommended daily limit for PM₁₀ was exceeded only once. However, the limit for PM_{2.5} was exceeded on several occasions, specifically in more than 14% of the recorded cases.

3.2. Fungi spores analysis

Table 1 presents the number of phytopathogenic spores considered hazardous to human health. The highest occurrence of these spores in colony forming unit per gram (CFU.g⁻¹) was recorded in 2023, while the lowest was observed in 2020. The most frequently identified genera were *Penicillium* and *Aspergillus*. Both are known to cause serious respiratory conditions, including respiratory and skin allergies, pulmonary diseases, and potentially even carcinogenic effects.

Table 1. Number of phytopathogen spores in analysed samples from the wood chip pile surface in the heating plant storage during the period 2019-2024 (in CFU.g⁻¹)

Year	Sample 1	Sample 2	Sample 3	Total
2019	110000	34000	7700	151700
2020	12000	5800	11000	28800
2021	12000	50	920000	932050
2022	46000	350000	3100000	3496000
2023	31007500	167650	43010850	74186000
2024	50000	26000	358350	434350

3.3. Burden of the health and social system

Table 2 presents the number of visits to immunology and allergology clinics, as well as the number of new patients requiring specific immunotherapy over the past ten years (2014–2023; data for 2024 are not yet available). Cases clearly unrelated to poor air quality—such as reactions to insect bites, sinusitis, or food allergies—were excluded from the total number of clinic visits. This filtered or "cleaned" number of cases is shown in the second column of Table 2. The data show that the number of new immunodeficient patients in the Banská Bystrica Self-Governing Region has consistently remained below 3,400 annually over the past eight years. Moreover, the incidence of immunodeficiency and allergic diseases potentially linked to poor air quality has shown a declining trend. In fact, 2023 recorded the lowest number of such cases in the last decade. This overall decrease may be attributed in part to increased investments in environmentally friendly technologies and emission-reduction measures in the region over the past ten years. These efforts likely contributed to a partial improvement in air quality. However, it is important to note that air quality is also influenced by other factors such as geography, meteorological conditions, and regional industrial activity. Therefore, a direct causal relationship between specific types of operations and health outcomes cannot be conclusively established. Nonetheless, the data suggest general trends that indicate a gradual improvement in air quality and associated health conditions in the region.

Table 2. Number of Cases in immunology and allergology treatment in the Banská Bystrica Self-Governing Region for the years 2013-2023 (NHIC, 2025)

Year	Nr. of visits to Immunology and Allergology Surgery	Nr. of specific diseases connected with air quality	Nr. of new patients with specific immunotherapy admitted to treatment
2014	125 129	110 395	3141
2015	132 715	83 505	3375
2016	127 396	94 650	3371
2017	125 866	84 715	3288
2018	124 106	84 011	3392
2019	124 467	82 853	3266
2020	113 430	77 455	3125
2021	110 514	73 153	3230
2022	120 431	75 303	3369
2023	109 178	68 496	3468

The average reimbursement for an extended and controlled examination at an immunoallergological outpatient clinic, according to the largest Slovak health insurance provider, is €10.72. Over the period 2014–2023, the total burden on the healthcare system due to poor air quality in the Banská Bystrica Self-Governing Region exceeded €9 million. In the most recent year analyzed, 2023, this burden amounted to over €734,000. A significant portion of these costs can be attributed to poor air quality, to which urban heating plants and large-scale biomass storage facilities also contribute.

Based on the identified risks associated with the production, storage, and use of biomass, the following diseases—classified according to the national system for occupational illnesses and health damage—were selected for analysis: 1. Allergic respiratory diseases; 2. Occupational dermatoses.

The economic values associated with these diseases were derived from Slovak legislation and are detailed in our previous study (Gejdoš & Potkány, 2024) (see Table 3).

Table 3. Registered diseases in the Slovak Republic in the agriculture, forestry, and wood processing sector in 2019-2023 and their economic value in €

Year/Dis.	2023	2022	2021	2020	2019	2018	Together	Costs in €
1	1				2	2	5	260,800
2				1	1		2	83,456
Together	1	0	0	1	3	2	7	344,256

Table 3 shows that over the past 7 years, the selected diseases with the greatest economic impact were allergic respiratory diseases, recognized occupational diseases in the forestry and timber sector. This fact is, of course, influenced mainly by increased dustiness in processing operations during the production of sawn timber and further mechanical processing

of wood. However, they also provide partial information for the area of production and use of biomass as a renewable energy source. At the same time, it is necessary to calculate the possible expenses of the employer (in case of severance pay or case of payment of damages) into the final prices of their performance, especially in the item increase or difference of overhead cost surcharge (ΔOCS). This relationship and general calculation formula were used in the study (Gejdoš, Potkány, 2024).

4. CONCLUSION AND DISCUSSION

The use of biomass as a renewable energy source offers undeniable advantages within the framework of national energy mix strategies. However, the direct and indirect impacts of biomass production, storage, and utilization on the health of residents and workers in associated facilities have been less thoroughly analyzed. In addition to the production of phytopathogens and molds, resulting from biological processes in stored biomass, air quality in the vicinity of storage sites is adversely affected not only by biomass combustion but also by its handling (including chipping, which sometimes occurs directly within heating plant premises). These activities significantly increase the concentration of solid particulate matter in the air, even outside the heating season, as confirmed by our study.

Demonstrating a direct correlation between air pollution and human health remains challenging, primarily because the health effects typically manifest over long-term exposure periods. Moreover, the process is influenced by a variety of additional factors, including meteorological and topographical conditions, proximity to other emission sources, traffic intensity, and local heating practices in family homes and apartment buildings. Current legislation primarily focuses on industrial-scale processes and does not adequately account for the negative exposure experienced by populations living near biomass-related operations. These operations often struggle with a shortage of qualified labor, as well as with both conscious and unconscious violations of safety protocols and regulatory guidelines. In many Slovak cities and municipalities, air quality parameters have consistently been classified as hazardous to health according to WHO standards, particularly during the heating season. Health risks associated with elevated concentrations of airborne particulate matter result in a long-term increase in visits to specialist clinics and place a considerable financial burden on the healthcare system. Furthermore, the incidence of occupational diseases imposes a strain on the social security system and represents a risk that should be financially quantified and reflected in the pricing of biomass-derived products (Gejdoš & Potkány, 2024).

Awareness among workers and residents regarding the health risks associated with biomass use and their potential consequences remains low. Residents are often unaware of the impact their heating practices have on air quality and lack information about the synergistic effects that occur when their activities interact with emissions from other biomass-burning facilities, industrial operations, transportation, and similar sources. Addressing these challenges requires not only improved public access to information and the promotion of civic responsibility, but also the implementation of appropriate legislation, enhanced support for regulatory and monitoring activities, and long-term analysis of health system data to better understand the causes and consequences of air quality-related health impacts.

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SUSTAINABLE PRACTICES IN THE FURNITURE MANUFACTURING PROCESS FOR MICRO, SMALL AND MEDIUM-SIZED ENTERPRISES (MSMEs)

Ivaylo Iliev

Abstract: The furniture manufacturing industry plays a pivotal role in the global economy, providing essential products for residential and commercial spaces. However, traditional manufacturing practices have often led to environmental challenges, including deforestation, high energy consumption, and significant waste generation. This article explores the integration of sustainable practices within furniture manufacturing MSMEs, focusing on sustainable raw material sourcing, energy-efficient production, waste reduction, innovative design, and corporate social responsibility. By embracing sustainability, MSMEs can enhance their competitiveness, contribute to environmental conservation, and meet the growing consumer demand for eco-friendly products.

Keywords: sustainability, furniture manufacturing, sustainable management, SMEs, corporate social responsibility

1. MSMEs GROWTH & SUSTAINABILITY IN FURNITURE MANUFACTURING

The furniture manufacturing industry plays a pivotal role in the global economy, providing essential products that furnish residential, commercial, and public spaces. This sector encompasses a wide range of activities, from design and production to distribution and retail. Small and medium-sized enterprises (MSMEs) are integral to this industry, contributing significantly to innovation, employment, and regional development. In Europe, for instance, MSMEs account for a substantial portion of the furniture manufacturing sector, highlighting their importance in economic growth and job creation.

However, traditional furniture manufacturing processes have often led to environmental challenges, including deforestation, pollution, and substantial waste generation. The extensive use of natural resources, particularly wood, has contributed to deforestation and biodiversity loss. Additionally, the industry has faced scrutiny over the use of chemicals such as formaldehyde in adhesives and finishes, which can off-gas volatile organic compounds (VOCs) harmful to human health and the environment. The production processes are also energy-intensive, relying heavily on fossil fuels, which contribute to greenhouse gas emissions and climate change. Moreover, the rise of "fast furniture"-affordable, mass-produced items designed for short-term use-has led to increased waste, with significant amounts of discarded furniture ending up in landfills.

Recognizing these challenges, there is a growing movement towards sustainable practices in furniture manufacturing. Sustainable furniture design aims to minimize environmental impact by considering the entire lifecycle of a product-from raw material extraction to end-of-life disposal. This approach emphasizes the use of renewable and recycled materials, energy-efficient production methods, and designs that facilitate repair, reuse, and recycling. For instance, sustainable furniture should be made from renewable and nontoxic materials, such as natural wood, bamboo, or recycled materials.

Furthermore, the concept of a circular economy is gaining traction within the industry. Unlike the traditional linear model of "take, make, dispose", a circular economy seeks to create

closed-loop systems where products and materials are continually repurposed, reducing the need for new resource extraction and minimizing waste. This model is particularly relevant for MSMEs, as it offers opportunities to innovate and differentiate themselves in the market.

2. SUSTAINABLE STRATEGIES IN FURNITURE MANUFACTURING

2.1. Sustainable Raw Material Sourcing

A central pillar of sustainable furniture production is the responsible sourcing of raw materials. MSMEs face unique challenges due to limited purchasing power and supply chain constraints. Nevertheless, sustainable wood certification systems such as FSC (Forest Stewardship Council) and PEFC (Programme for the Endorsement of Forest Certification) offer a viable route to ensuring ecological integrity and social responsibility in sourcing practices (Giannetti et al., 2015).

Incorporating recycled wood, bamboo, and fast-growing species into production can reduce pressure on natural forests. According to Sonnemann et al. (2018), material selection based on life cycle analysis can significantly lower environmental impacts in furniture products.

2.2 Energy Efficiency in Production

Energy-intensive processes such as cutting, drying, and finishing pose major sustainability challenges. Implementing energy-efficient machinery, optimizing production layouts, and recovering heat from drying processes are proven strategies to reduce energy consumption (Acquaye & Duffy, 2010). In a study of manufacturing SMEs, Thollander and Ottosson (2010) found that even simple energy audits can lead to efficiency improvements of up to 15%.

Investments in renewable energy, such as rooftop solar panels or biomass boilers, although capital-intensive initially, have shown positive returns for small manufacturers committed to long-term sustainability.

2.3 Waste Reduction and Circular Practices

Furniture manufacturing generates substantial wood and finishing waste. Integrating circular economy principles is crucial. Techniques such as lean manufacturing, modular production, and material recirculation can minimize waste generation (Braungart et al., 2007).

Waste wood can be reused for small parts or transformed into particle boards or biofuels. A study by Ghisellini, Cialani, and Ulgiati (2016) emphasizes that SMEs adopting closed-loop systems experience reduced material costs and enhanced environmental performance.

2.4 Eco-Design and Product Longevity

Sustainable design goes beyond aesthetics: it integrates functionality, durability, disassembly, and material recyclability. MSMEs can differentiate themselves through design strategies that prolong product life, encourage repair, and support end-of-life recyclability (Vezzoli & Manzini, 2008).

Life Cycle Thinking (LCT) should be embedded into the product development phase, guiding decisions on joinery methods, coatings, and packaging (Bocken et al., 2016). The adoption of Design for Environment (DfE) and Cradle-to-Cradle principles can yield products that are both environmentally sound and commercially competitive.

2.5 Corporate Social Responsibility and Market Differentiation

Beyond technical sustainability, MSMEs should embrace corporate social responsibility (CSR) to align business goals with societal expectations. Transparent communication of sustainable practices through labels and certifications builds trust and fosters consumer loyalty (Mont & Power, 2010).

Participation in local sustainability networks or partnerships with educational institutions for sustainable innovation can strengthen community ties and market positioning. Implementing sustainability messaging in the content strategy within the marketing activities is crucial toward building the brand. A strong marketing strategy recognizes such key changes within the target buyer persona and ideal customer of the business (Ilieva, 2024).

3. CHALLENGES AND OPPORTUNITIES FOR MSMEs: TURNING CONSTRAINTS INTO CATALYSTS

Micro, Small and Medium-Sized Enterprises (MSMEs) in the furniture industry face a unique set of structural and operational challenges in implementing sustainability measures. These include limited financial resources, lack of specialized staff, difficulties accessing certified materials, and constrained bargaining power in the supply chain. However, these limitations are not insurmountable. In fact, MSMEs possess intrinsic strengths that, if strategically leveraged, can transform them into agile leaders in sustainable manufacturing.

3.1. Challenges

Some of the key challenges MSMEs face include financial constraints, knowledge and skill gap, and supply chain dependence. High upfront investment costs for energy-efficient machinery, waste processing technologies, and certified raw materials can be prohibitive for small firms. Many MSMEs operate on tight margins, limiting their ability to self-finance green upgrades. The lack of internal expertise on sustainability standards, life cycle assessment (LCA), or eco-design frameworks hampers the ability to implement structured sustainability programs. MSMEs often depend on larger suppliers for raw materials and logistics, reducing their influence over environmental sourcing or transportation practices.

3.2. Opportunities and specific action items

Despite the challenges outlined above, micro, small, and medium-sized enterprises in the furniture manufacturing sector are uniquely positioned to benefit from sustainability-led transformation. Their relatively small size grants them organizational agility, which often translates into faster decision-making, experimentation, and responsiveness to market trends. Unlike large corporations, MSMEs can implement changes more rapidly without being hindered by rigid bureaucratic structures. For instance, small manufacturers can pilot the use of

alternative materials-such as recycled MDF, bamboo, or reclaimed wood-on select product lines, allowing them to test market acceptance while minimizing financial risk.

Another distinct advantage lies in the close relationships MSMEs maintain with their customers and communities. This proximity creates an opportunity to co-create sustainable product offerings that reflect local values and environmental concerns. By actively engaging customers in the design process or communicating the environmental story behind a product, such as the origin of the timber or the energy savings achieved during manufacturing, MSMEs can cultivate trust and enhance brand loyalty. Transparency, often more achievable for small enterprises, becomes a powerful tool for differentiation in a market increasingly driven by sustainability-conscious consumers.

Digitalization also presents substantial opportunities. Even basic digital tools-such as spreadsheets, cloud platforms, or open-source enterprise resource planning systems-can be employed to monitor resource use, track waste streams, and guide decisions on process optimization. More advanced technologies, including CAD software and CNC integration, enable precise material planning and significantly reduce production waste. In essence, digital transformation, often perceived as a challenge, can be a low-cost, high-impact lever for efficiency and sustainability in small-scale operations.

Access to external support mechanisms further strengthens the case for sustainable transformation. Numerous public and private programs offer grants, vouchers, and technical assistance specifically targeted at MSMEs undertaking green innovations. Initiatives funded by the European Union, such as the LIFE Programme or Horizon Europe, provide financial support for investments in energy-efficient equipment, renewable energy installations, and employee training in sustainable practices. Additionally, collaboration with universities and vocational institutions can facilitate knowledge transfer and innovation, whether through student-led audits, design projects, or applied research in eco-materials.

Collaborative strategies among MSMEs can also compensate for scale limitations. By joining industrial clusters or regional furniture associations, small firms gain access to shared infrastructure-such as waste treatment facilities, drying kilns, or centralized logistics-which would be prohibitively expensive to acquire individually. These partnerships not only reduce costs but also foster the development of circular economy practices, where one enterprise's waste becomes another's input, such as converting wood shavings into biomass fuel or reusing foam for protective packaging.

Market positioning is another significant area of opportunity. Sustainability is increasingly viewed as a key differentiator, particularly among environmentally conscious consumers in both domestic and international markets. Focusing on green marketing efforts can lead to increasing trust among consumers (Dimitrova, 2024). MSMEs that successfully integrate sustainability into their core operations can pursue eco-labels and certifications such as FSC Chain of Custody or ISO 14001, which enhance credibility and market access. In niche markets, especially online platforms focused on artisanal or eco-conscious goods, these credentials can provide a competitive edge and justify premium pricing.

Finally, the constraints that MSMEs face can themselves foster innovation. Limited resources often necessitate a "do more with less" mindset, which can drive creative design solutions. Modular and multifunctional furniture designs, for example, not only optimize material use but also respond to emerging consumer preferences for adaptable and space-saving products. Furthermore, initiatives such as product take-back schemes-where customers return

old furniture for repair, refurbishment, or recycling-enable MSMEs to build long-term relationships while closing the material loop and reducing environmental impact.

While the path to sustainability may present specific constraints for MSMEs, it is equally rich with opportunities. By leveraging their flexibility, local embeddedness, and capacity for innovation, small furniture manufacturers can act not only as adopters but also as leaders of sustainable practices in the industry. Their role is particularly critical in shaping a decentralized and inclusive transition towards circularity and environmental stewardship in the manufacturing sector.

Embracing sustainable practices in furniture manufacturing is imperative for environmental preservation and aligns with evolving consumer preferences for eco-friendly products. By integrating sustainable raw material sourcing, energy-efficient production methods, waste reduction strategies, and eco-friendly technologies, manufacturers can significantly diminish their environmental footprint. However, challenges such as resource scarcity, high initial investments, regulatory complexities, and shifting consumer perceptions must be addressed to ensure successful implementation of these practices. Overcoming these obstacles requires a concerted effort from industry stakeholders, policymakers, and consumers to foster a more sustainable and resilient furniture manufacturing sector. Ultimately, the transition to sustainable practices not only benefits the environment but also enhances corporate reputation and ensures long-term economic viability.

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FORESTRY LOGISTICS AND SUSTAINABILITY - ADAPTATION TO PRICE CHALLENGES

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Abstract: In the last decade or so, the problem of sustainability has escalated greatly in logistics, mainly due to raw material scarcity and increasing prices, most recently in forestry logistics. Yet, the understanding of how forestry logistics managers really perceive the rising costs of operations in the implementation of sustainability and how the perception influences their pricing strategies is still insufficient. The objective of this study is to consider forestry logistics managers' perceptions of price increases associated with the adoption of sustainability measures within the wood supply sector (from timber to finished products). The paper will further probe into the effects of such perceptions on pricing flexibility and competitiveness in the market. The objectives were accomplished with the help of structured questionnaires, filled in by 33 different logistics managers from all over the region, either already implementing sustainability initiatives within their forestry supply chains, or planning to. Subjects had to define four important pricing categories (Too Cheap, Cheap, Expensive and Too Expensive) and grade the intensity of their perceptions on a five-point scale. Data obtained from respondents were processed using the method of the „Price Sensitivity Meter“, leading to sharp optimal pricing points and acceptable price ranges. Initial findings identify a well-defined price range within which the additional sustainability costs can be balanced without compromising competitiveness. The results of the study present practical thoughts for organizations trying to successfully implement sustainability measures despite the scarcity of resources in forestry logistics.

Keywords: forest industry, logistics, Price Sensitivity Meter

1. INTRODUCTION

In recent years, the sustainability of logistics in the forestry sector has become an increasingly important factor contributing to competitiveness in the sector (Sun and Li, 2025). Increasing demands for environmental protection, social responsibility and economic efficiency are challenging managers to balance the costs of sustainable practices with operating costs and market expectations (Amirteimoori et al., 2025; Walter et al., 2025). Although the benefits of green investments have been widely discussed, few studies have explicitly focused on how these transportation costs affect pricing strategies in forest logistics and how managers perceive the boundaries between "acceptable" and "unacceptable" pricing policies. To meet sustainability requirements, many transport operators are adopting environmentally friendly practices (Atanasova, 2022; Dimitrakieva et al., 2022; Karadencheva, 2019) in logistics, from the use of electric or low-carbon vehicles to environmentally certified packaging (Yotsov et al., 2017). However, these measures lead to increased shipping costs, especially in the context of scarcity and rising wood prices (Calvano et al., 2025; Damaševičius and Maskeliūnas, 2025), which further increase the cost and influence the final price, making it necessary to introduce new approaches to optimise logistics processes. Changing market conditions make it necessary to investigate the perceptions of logistics managers on the increase in the cost of supply caused by the introduction of sustainable and environmentally friendly practices in the context of wood scarcity and to assess the effect on price elasticity (Eboli et al., 2025). The

results of such a study could help to develop pricing strategies that balance additional costs with market acceptability.

2. METHODOLOGY

A target group of logistics managers directly or indirectly involved in wood supply was formed for the purpose of the study. Participants included both companies already implementing sustainable and/or environmentally friendly practices and those planning their integration in the near future. The study was based on a purposive sample of 33 logistics managers involved in wood supply and having different experiences in implementing sustainable practices. This sample size meets business research methodological criteria by virtue of providing statistical reliability and allowing participants from whom there is variability, as the participants were drawn from organisations that are practising green strategies as well as planning their adoption. The variety of market segments and different degrees of sustainability in the sample pools limit the presence of systematic bias and confirm the validity of the results. For the purpose of the study, a specially adapted questionnaire combining the classical Van Westendorp approach (Price Sensitivity Meter - PSM) with an additional assessment of perceptual intensity on price levels was used. In the main part, respondents indicated four key price points - price they would define as too low, acceptably low, high, and too high (Kendall, 1986). Thus, not just a 'range' but a real perceived threshold of balance between value and sustainability emerges. Furthermore, for each of the extreme price categories ('too cheap' and 'too expensive'), participants rated how strongly they perceived the bias - whether the price was just a little low' or 'unacceptably low'. The additional step allows not just to define a range but also to assess the depth of perception - i.e. how strong the negative reaction to extreme prices is. The method makes it possible to calculate two strategic key points: the Indifference Price Point - the point at which the price is balanced, and the Optimal Price Point - where the risk of rejection due to a low or high price is lowest. The information derived from this mapping goes beyond the usual averages - it allows managers to build a finer price benchmark, especially in the context of ESG (Environment, Social, and Governance) requirements and the tension between sustainability and cost-effectiveness. The data were analysed using specialised statistical software (**XLSTAT**) (Lumivero, 2024) to calculate cumulative curves according to the PSM method. The intersections between the **"Too Cheap"/"Cheap"** and **"Expensive"/"Too Expensive"** curves define the optimal price at which managers believe the sustainability costs of scarcity and rising prices are balanced with market acceptability. An elasticity analysis has been carried out by processing the responses to the elasticity question and, accordingly, assessing how price increases affect demand. This will provide insight into the sensitivity of the market to such changes.

3. RESULTS

The price sensitivity of supply in forest logistics is a key factor in integrating sustainable practices in the sector. For this reason, it is essential to identify reference price points that clearly indicate the critical boundaries perceived by logistics managers as indicative of the quality and sustainability of wood services and products supplied. The analysis was carried out using Van Westendorp's price sensitivity meter (PSM) method, which also included an assessment of perception intensity for individual price categories.

3.1. Sample analysis and Box plot diagrams

Initially, the statistical characteristics and structure of the managers' responses are examined through summary statistics and visualisation with Box plot diagrams. The analysis helps to identify the individual groups for the four price categories, together with the box plot diagrams, show a clear structured perception of managers' prices under sustainable logistics practices.

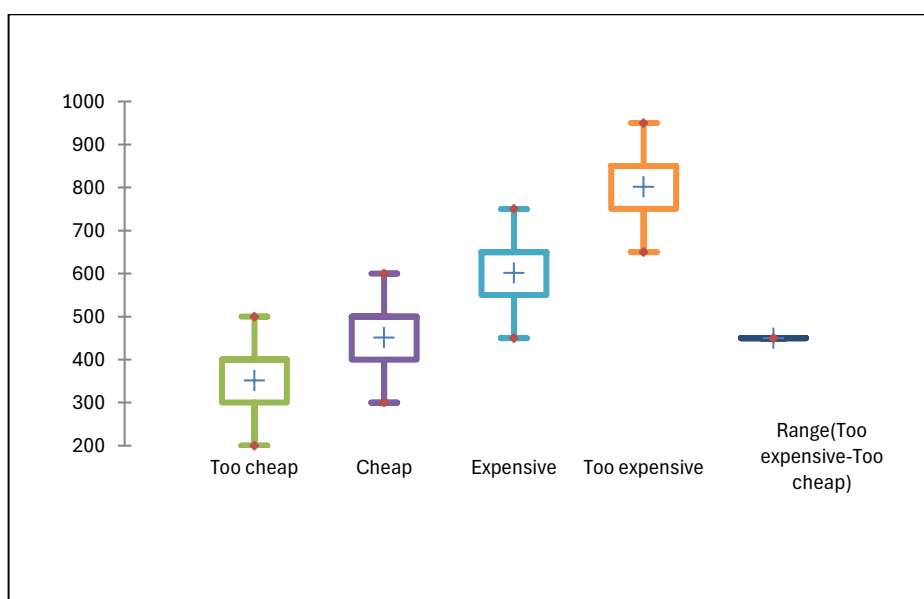


Figure 1. Box Plot

"Too Cheap" lies between 200 and 500 euros, the mean of which is 351 euros. The clusters, being close-packed around an interquartile range of 300-400 euros, point at a sharp lower bound below which sustainability is dubious. "Low-end" is €300-600 with an average price of €450. The small horizontal shift means that only larger values are realistic. "Expensive" encompasses the amount that ranges from 450 to 750 euros (mean 601.51 euros), with approximately mean values for the estimates, which indicates a conscious premium for sustainability. "Too Expensive" is between €650-950, and the median is €801. Although more widely spread, the limits are largely unchanged. With "Too Cheap" at 450€ and "Too Expensive" at 850€, we can assume stability and continuity of judgement - with this attitude, the price orientation in the industry gives you an indication that you are dealing with an already established standard.

3.2. Analysis of cumulative PSM-curves

The analysis was performed based on the calculated values visualised in Figure 2, where the cumulative curves obtained by the Price Sensitivity Meter method are presented. The data highlight two strategically significant price values. The Indifference Price Point at 550 EUR denotes a point of equilibrium between low and high price perceptions, signaling stability in market sentiment. On the other hand, the Optimal Price Point, calculated at €575, represents

the market's best accepted level at which the probability of price rejection due to inadequacy in the direction of too low or too high is minimal. The acceptable range of between €400 and €750 marks the limits within which a sustainable service remains competitive without compromising perceptions of value and reliability.

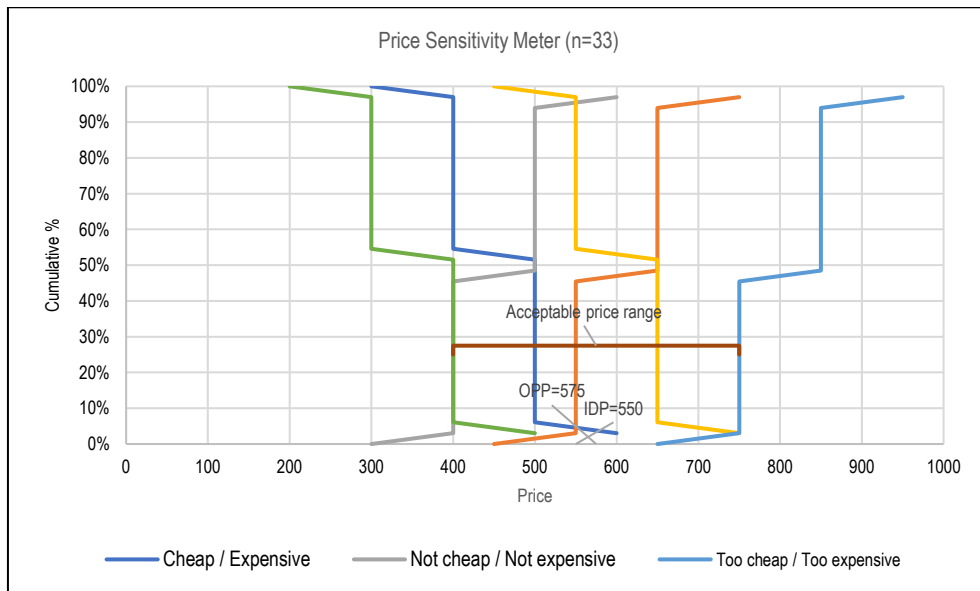


Figure 2. Price Sensitivity Meter (n=33)

The analysis is built on the calculations presented in Figure 2, where the cumulative curves from the Van Westendorp Price Sensitivity Meter (PSM) based on the opinions of 33 logistics managers are visualised. Through the “Too Cheap”, “Cheap”, “Expensive”, and “Too Expensive” curves, as well as the additional “Not Cheap” and “Not Expensive” curves, basic price benchmarks are derived, delineating the boundaries of perceived market rationality for sustainable logistics services. The Indifference Price Point (IDP) is positioned at 550 EUR, where the perceptions of “Cheap” and “Expensive” are balanced. This value reflects a balanced expectation of an adequate price that raises no doubt of either compromise in quality or high cost and represents a natural starting point for price positioning in the sustainable practices segment.

The Optimal Price Point (OPP) is found at €575, where the number of respondents perceiving the price as “Too Cheap” equals those who consider it “Too Expensive”. This is the value with the greatest potential for market acceptance, where the risk of refusal due to low or excessive price is minimal. The Acceptable Price Range, calculated by the intersection of “Too Cheap” with “Not Expensive” (lower bound) and “Too Expensive” with “Not Cheap” (upper bound), covers the range between €400 and €750. Below EUR 400, sustainability comes into question, while above EUR 750, a price threshold emerges, which the market finds difficult to justify, even in the context of environmental benefits.

The optimum “price curves for volume and revenue” also show a “maximum price that can be charged at EUR 500. At this price point, the market acceptance probability is 0.244 due to 8.04 units in the average number of transactions and a profit of EUR 4020, thus defining a strategic optimisation space in a more prudent pricing environment. The spread observed in the

distribution of individual probabilities θ between 0 and 0.7 indicates a number of heterogeneous market perceptions that support the requirement for pricing Flexibility to match the extent of sustainable commitment with firm's position within the supply chain. The PSM results present very clearly the best and fair price frontier where sustainable logistics services in the forestry sector are competitive. Results demonstrate the coherence of manager perceptions and reinforce the separatists argument for flexible pricing strategies for different sectors.

CONCLUSIONS AND RECOMMENDATIONS

The result indicates that the PSM approach is a valid approach for analysing perceived acceptable price levels in forest logistics services with the implementation of sustainable practices. This method allows for the determination of threshold price sensitivities and the creation of realistic, flexible pricing strategies in a resource-constrained, volatile market environment such as that in the industry.

The application of this methodology to logistics practice in the forestry sector is recommended in order to increase efficiency in assessing market responses to sustainable solutions. The method provides an opportunity to accurately balance the increasing costs associated with sustainability with market acceptability, thus contributing to a more sustainable and strategically sound positioning of logistics services in the face of price and resource volatility.

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FORESTRY, LOGISTICS AND ARTIFICIAL INTELLIGENCE IN THE CONTEXT OF NEW REGULATIONS

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Abstract: One major driver of efficiency in logistics within the forestry sector is the introduction of Artificial Intelligence (AI) applications. This is a sector that heavily relies on logistics for managing forests sustainably and then moving resources obtained from forests. AI technologies hold the promise to optimise these processes. New regulations related to AI should be taken into consideration. Several conditions must be met, including higher security, transparency, and protection of data and logistics in the forestry sector. This study aims to explore the challenges, opportunities, and readiness of logistics companies in the forestry sector to adopt new AI regulations. The study is constructed based on a Likert scale survey, which measures the level of difficulty faced by logistics companies in meeting the new requirements, as well as their readiness to meet these standards and the resource requirements necessary to adhere to them. It, therefore, shows that notwithstanding the undoubted benefits proven in AI deployment, logistics companies encountered sizable difficulties in harmonising the AI solutions with the new regulatory requirements. The challenges stem from the technological barrier, the need for specialised training, and the investment required for new infrastructure upgrades. The study distinguishes between different degrees of readiness to adopt change and the provision of resource support, primarily in the form of training and consulting, to facilitate the transition to compliance. The study also provides specific and practical guidance for businesses involved in forest logistics.

Keywords: forestry, logistics, artificial intelligence, regulations

1. NEW REGULATORY REQUIREMENTS

Logistics in the forestry sector is a strategic factor for the sustainable and efficient management of forest resources and their successful transportation to end users (Damaševičius and Maskeliūnas, 2025; Nunes, 2025; Sun and Li, 2025). In recent years, the integration of artificial intelligence (AI)-based technologies has begun to have an increasing impact on these processes (Malhotra and Kharub, 2025; Meng, 2025; Yetunde Adeoye et al., 2025, 2025), providing opportunities for precise optimisation of transport routes, automated demand forecasting and significantly improved management of inventories and supply chains.

In parallel with these technological changes, the European Union has introduced Regulation (EU) 2024/1689, which comes into force on 2 February 2025 (EUR-Lex, 2025). This regulation defines a new regulatory framework with stringent criteria for the security, transparency and protection of data processed and generated by AI systems. Analysis of existing studies highlights the dual impact of the combination of technological modernisation and new regulatory requirements - simultaneously opening up significant opportunities for efficiency improvements in the sector but also imposing significant challenges for logistics companies related to the need for additional resources, training (Atanasova and Yordanova, 2023; Kalinov and Karadencheva, 2023; Kanev, 2017; Karadencheva, 2019; Mednikarov et al., 2019) and infrastructure investments for compliance (Atanasova, 2022; Dimitrakieva et al.,

2022; Lutzkanova et al., 2022).. The purpose of this study is to provide an in-depth analysis of the readiness of logistics companies in the forestry sector to adapt to new artificial intelligence (AI) regulations. Specifically, the study aims to identify the main challenges companies face in meeting regulatory requirements for security, transparency and privacy. In addition, it will assess the overall readiness of companies to implement AI solutions that meet the standards of the new regulation, as well as identify the resource needs - including financial, training, and infrastructure investments - that mediate between regulatory conditions and technological capabilities for successful AI technology deployment.

2. METHODOLOGY

The research was conducted through an online-based survey covering a total of 13 logistics companies that are directly specialised and actively involved in the forestry sector. The total number of managers in decision-making positions participating in the survey was 32. The data were collected through a structured survey that contained three clearly defined thematic areas, each rated on a Likert scale of 1 to 5. An average was calculated for each of the thematic areas, and these formed the following three main factors for the analysis:

The first factor is Regulatory Compliance (X), which assesses the difficulty companies face in meeting new regulatory requirements related to security, transparency, and privacy when implementing AI technologies.

The second factor is resource capacity (M), which measures the extent to which companies identify a need for additional financial and human resources related to specific training and investment in infrastructure improvements to meet regulatory standards.

The third factor is technological capability (Y), which reflects the level of readiness of companies to implement AI solutions successfully, as well as the extent to which technological barriers may hinder achieving full compliance with regulations.

The analytical approach of this study involves several main stages. First, a preliminary assessment of the fit of the data to the mediation analysis was performed by testing the assumptions of normality of the distribution and the existence of significant correlations between the independent variable (regulatory compliance - X), the mediating variable (resource capacity - M) and the dependent variable (technological capability - Y).

The mediation model has been tested using XLSTAT's specialised mediation analysis module (Process Model 4), and two separate regression models have been defined:

Model 1: Resource capacity (M) is dependent on regulatory compatibility (X). Here, the significance of the relationship between these two variables is tested.

Model 2: Technological capability (Y) is dependent on both regulatory compatibility (X) and resource capacity (M). The purpose of this model is to identify how the two variables jointly affect technological capability.

A bootstrap procedure with a 95% confidence interval (CI) was applied to further test and confirm the mediation effect. This procedure allows a more precise and robust estimation of indirect effects between the variables under study.

In the final stage, the quality of the resulting regression models was assessed by analysing the coefficients of determination (R^2 and Adjusted R^2), performing an F-test for the overall significance of each model, and examining the p-values for the individual significance of each regression coefficient.

3. RESULTS

3.1. Analysis of variance (ANOVA)

From the presented results of the analysis of variance (ANOVA) for the model assessing technological capability (the presence of technological barriers and the prior readiness for AI implementation), the following can be seen:

Table 1. Computed against model $Y = \text{Mean}(Y)$

Source	DF	Sum of squares	Mean squares	F	Pr > F	p-value significance codes
Model	2	5,992	2,996	8,580	0,001	< 0.001
Error	29	10,126	0,349			
Corrected Total	31	16,117				

The model is statistically significant ($F(2,29) = 8.580$, $p = 0.001$), meaning that at least one of the variables considered ("Regulatory Compatibility" and "Resource Capacity") has a significant impact on technological capability.

In other words, the above factors reliably explain the variability in the level of technological readiness and the identified technological barriers in the implementation of AI solutions. Significance indicates a high level of confidence in the result ($p < 0.01$).

The presented model adequately describes the relationship between regulatory compatibility, resource capacity, and technological capability for AI deployment, allowing us to draw reasonable conclusions about the factors most significantly affecting companies' readiness to meet the new requirements of Regulation (EU) 2024/1689.

3.2. Analysis of the regression parameters of the model

Table 2 presents the parameters of the regression model estimating the technological capability (the presence of technological barriers and the overall pre-readiness for the implementation of AI solutions):

Table 2. Analysis of regression parameters of the model

Source	Value	Standard error	t	Pr > t	Lower bound (95%)	Upper bound (95%)	p-value significance codes
The Intercept	-0,281	0,922	-0,304	0,763	-2,166	1,605	not applicable
Regulatory Compatibility	0,597	0,210	2,844	0,008	0,168	1,027	meaningful
Resource capacity	0,387	0,244	1,587	0,123	-0,112	0,885	not applicable

The constant was not statistically significant ($p=0.763$), meaning that it did not independently affect the outcome. It has no practical interpretation in the context of the model. Regulatory compatibility has a significant positive effect on technological feasibility ($\beta = 0.597$, $p = 0.008$). This implies that the logistics companies studied that have less difficulty meeting regulatory requirements for security, transparency and data protection have a higher willingness to implement AI technologies and fewer technological barriers.

Resource capacity has a positive effect ($\beta=0.387$), but this effect does not reach statistical significance ($p=0.123$). This suggests that despite the positive trend, the need for additional resources for training and infrastructure improvements is not in itself a decisive factor for technological readiness, according to the model considered.

A key finding from the parameter analysis is that regulatory compliance is a significant factor influencing the technological readiness of companies in the forest sector to implement AI. On the other hand, while resource capacity plays a positive role, its influence remains insignificant when considered in isolation. This suggests that successfully addressing regulatory requirements should be a top priority for the forest sector firms surveyed.

3.3. Analysis of indirect effects (mediation)

Table 3 presents the results of the Bootstrap analysis, which measures the indirect effect of regulatory compliance (X) on technological capability (Y) through the mediator resource capacity (M):

Table 3: Indirect effects of X on Y

	Effect	Standard error (Bootstrap)	Lower bound (95%) (Bootstrap)	Upper bound (95%) (Bootstrap)	Significant
Resource capacity	0.136	0.077	0.008	0.308	Yes

The interpretation of the results obtained is that there is an indirect effect of 0.136, which is positive and statistically significant since the confidence interval (0.008 to 0.308) does not include zero (The effect is considered significant if zero is not included in the confidence interval). This implies that the relationship between regulatory compliance and the technological capability to implement AI solutions is partly mediated by the increase in companies' resource capacity.

In other words, companies that are more successful in meeting regulatory requirements for security, transparency, and data protection improve their resource capacity (financial and human resources, training, infrastructure investments), and it is this increase in resource capacity that, in turn, increases their technological readiness to adopt and deploy AI.

The results confirm the existence of partial mediation by resource capacity. This implies that in addition to the direct positive effect, regulatory compatibility indirectly improves firms' technological capabilities through the necessary provision of additional resources. The practical implication is that effective resource management (through training and infrastructure improvements) is a key mechanism that further strengthens the ability of companies to meet regulatory requirements and successfully implement AI technologies in their operations.

CONCLUSION

The study provides an in-depth, analytical examination of the impact of the new regulatory regime on the use of AI-based technologies in logistics within the forestry sector. An empirical study of managers directly involved in logistics in the forest sector reveals a significant positive

effect of regulatory compliance on their technological readiness to implement AI solutions. Accordingly, those demonstrating a higher degree of compliance with new security, transparency and privacy requirements were found to encounter fewer technological barriers and exhibit a higher readiness to integrate AI technologies successfully.

The analysis confirmed that resource capacity, including necessary financial and human resources, training, and infrastructure improvements, plays a partial mediating role. In addition to the direct positive effect, regulatory compatibility indirectly improves technological readiness by increasing resource endowment. This clearly demonstrates that the implementation of regulatory requirements cannot be considered in isolation from resource needs in the forest sector.

Practical recommendations arising from this study include prioritising management efforts to both implement the new regulations and simultaneously increase resource capacity. An integrated strategy will enable companies not only to adapt to the latest regulations but also to achieve greater competitiveness, efficiency and sustainability by introducing innovative AI solutions into their operations.

In summary, the alignment of logistics processes in the forest sector with the regulatory requirements of Regulation (EU) 2024/1689 is not only a prerequisite for companies' operations but also represents an opportunity to realise wider benefits from the application of AI, including cost optimisation, improved efficiency and better management of forest resources.

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ENSURING THE EXPORT POTENTIAL OF UKRAINE'S FORESTRY SECTOR UNDER THE CONDITIONS OF SUSTAINABLE DEVELOPMENT

Volodymyr Tsap, Oksana Tulai, Rostyslav Yatsukh

Abstract: The article explores the financial and economic dimensions of enhancing the export potential of Ukraine's forestry sector within the framework of sustainable development. It analyzes financing mechanisms, including state subsidies, investment programs, bank loans, and international financial support that contribute to the growth of export-oriented forestry enterprises. The study examines the role of tax regulation in creating a favorable environment for forest product exports, particularly regarding the tax burden, export duties, tax incentives, and compensatory mechanisms aimed at promoting sustainability in the sector. Special attention is given to the digitalization of financial management, which ensures transparency of financial flows, control over tax payments, and the reduction of shadow economy risks in forestry. The impact of international standards on financial transparency and environmental responsibility on the access of Ukrainian enterprises to foreign markets is assessed. Prospects for improving the financial and economic conditions for exporters in the context of European integration and global economic transformations are outlined.

Keywords: forestry, export, sustainable development, FSC/PEFC certification, financial support, EU, tax policy, environmental responsibility, green economy

1. INTRODUCTION

In the context of European integration and growing global challenges related to climate change and environmental protection, the sustainable development of Ukraine's forestry sector has gained strategic importance. Enhancing its export potential requires modernizing financial instruments, refining tax policy, digitalizing management systems, and aligning with international standards of transparency and environmental responsibility. This article aims to examine the financial and economic mechanisms that support the export capacity of Ukraine's forestry sector in accordance with sustainable development principles. Recent research highlights the increasing role of financial instruments in promoting sustainability in forestry. Scholars such as Gejdoš et al. (2024), Paluš et al. (2022), and Loučanová et al. (2021) argue that realizing export potential depends on adequate public funding, investment support, and the integration of digital technologies in sectoral governance.

2. FINANCIAL AND LEGAL FRAMEWORKS FOR SUSTAINABLE FOREST MANAGEMENT: THE EU AND UKRAINE

In the European Union, mechanisms to promote the sustainable development of the forestry sector are based on a combination of fiscal and non-fiscal instruments embedded at both supranational and national regulatory levels. In particular, the *EU Forest Strategy for 2030*, adopted by the European Commission on July 16, 2021, identifies forestry as a central element of the *European Green Deal*. This document emphasizes the necessity of financial support for sustainable forest management, the development of the wood-based bioeconomy, and enhanced transparency across timber supply chains. In contrast, while Ukraine has recognized the importance of sustainable development at the national level, its regulatory framework for supporting the forestry sector remains fragmented. Table 1 presents a comparative overview

of the regulatory frameworks governing forest management in Ukraine and the European Union, covering key aspects such as strategic planning, financial support, electronic timber accounting, certification, ESG reporting, and institutional coordination.

Table 1. Comparative overview of forest governance frameworks in the EU and Ukraine

Regulatory Aspect	European Union (EU)	Ukraine
Sustainable forest strategy	EU Forest Strategy 2030: support for bioeconomy, transparency	Draft Forest Strategy 2035: shift to sustainable, science-based use
Financial support	CAP, EAFRD: subsidies for sustainable forestry	Limited programs via State Forest Agency; pilot EIB projects
Green financing	Green Deal Investment Plan, LIFE funding	Environmental <i>Protection Fund</i> (not forest-specific)
E-timber tracking	FISE, EUTR IT systems	Environmental Protection Fund; forest support indirect
Timber legality & certification	EUTR (Reg. 995/2010), FSC/PEFC mandatory	Forest Code, voluntary FSC/PEFC, partial compliance
Deforestation regulation	EUDR (Reg. 2023/1115): strict due diligence from 2024	No equivalent; some alignment via roundwood export duties
ESG integration	EU Taxonomy, CSRD, SFDR: sustainability reporting mandatory	ESG draft laws under review; proposed sustainable finance fund
Institutional coordination	ESG draft laws under review; proposed sustainable finance fund	Forest Agency, Ministries of Environment & Economy; fragmented oversight
Tax & customs digitalization	Integration with customs and tax systems, <i>e-Customs</i>	STS not integrated with forestry control
Support for certification	Public schemes encourage FSC/PEFC & traceability	No direct subsidies for certification; coverage under 50%

At the national level, EU Member States implement targeted support programs that combine financial incentives with strict sustainability and compliance criteria. Fulfilling these requirements is essential for exporters seeking access to EU markets. In contrast, Ukraine's forestry sector continues to face systemic obstacles: limited transparency in financial flows, inadequate access to green financing, institutional weakness in implementing digital monitoring and certification, and insufficient ESG integration. The lack of a unified regulatory framework for sustainable forest finance constrains the sector's ability to modernize, attract investment, and align with international environmental and market standards.

3. RESEARCH RESULTS

3.1. Forestry Sector Financing as a Tool for Export Support

Financial support is crucial for unlocking the export potential of Ukraine's forestry sector, especially under the increasing pressure to comply with sustainable development and environmental standards. In Ukraine, forestry financing relies on a mix of public and private sources. State budget subsidies are allocated primarily to cover reforestation, forest protection, and maintenance, as stipulated by the Forest Code and environmental programs. However, the volume of public support remains limited and requires a shift toward performance-based funding. Investment programs led by the State Forest Resources Agency aim to modernize

forestry enterprises and improve the quality of exportable products. The Forest Management Strategy until 2035 emphasizes digital transformation and enhanced financial oversight. Access to bank loans remains limited but is gradually expanding, partly due to national programs that promote sustainable sector financing, including support from the National Bank of Ukraine. International financial institutions, particularly the European Investment Bank (EIB) and the World Bank, also play a key role. The ENPI FLEG II project, for example, strengthens institutional capacity and expands access to “green” financing for exporters certified under FSC and PEFC schemes. Additionally, private investment in high value-added wood processing—such as furniture, panels, and pellets—is increasing among companies targeting EU markets. These financial shifts are essential to boosting export revenues and reducing raw material exports. Table 2 summarizes the main financing sources, support instruments, and funding volumes between 2019 and 2024.

Table 2. Sources of Forestry Funding in Ukraine

Source of Funding	Form of Support	Purpose	Funding Volumes (million EUR/year)
State Budget of Ukraine	Budget subsidies for reforestation, forest protection, and conservation	Support of basic sector functions	2019 – 220; 2020 – 250; 2021 – 270; 2022 – 300; 2023 – 280; 2024 – 290
State Forest Resources Agency	Funding for enterprise modernization, digitalization, and technical re-equipment	Improvement of technological level and transparency	2019 – 45; 2020 – 50; 2021 – 60; 2022 – 75; 2023 – 80; 2024 – 85
Bank Loans	Loans for modernization and expansion of wood processing capacities	Financial sustainability of exporters	2019 – 95; 2020 – 100; 2021 – 110; 2022 – 130; 2023 – 145; 2024 – 150
International Financial Institutions (EIB, WB)	Grants, concessional loans, technical assistance, certification support	Enhancing competitiveness and compliance with EU standards	2019 – 80; 2020 – 85; 2021 – 90; 2022 – 110; 2023 – 120; 2024 – 125
Private Investors	Investments in deep wood processing, new equipment, export capacities	Increasing product value added and market expansion	2019 – 140; 2020 – 150; 2021 – 160; 2022 – 180; 2023 – 200; 2024 – 210

The analysis reveals that during 2019–2024, there was a steady increase in financial support for the forestry sector from the state, international organizations, and the private sector. However, the efficiency of resource utilization requires further improvement through the integration of digital management tools, transparent monitoring mechanisms, and a strategic shift towards the export of high value-added wood products. Thus, existing financial instruments provide a foundation for realizing the sector's export potential, but they need enhanced coordination, alignment with sustainable development goals, adaptation to EU requirements, and improved transparency in financial resource management.

3.2. Tax Regulation as a Stimulus for Export Activity

The tax system in Ukraine's forestry sector plays a key role in fostering the export of timber and processed wood products. Tax instruments are designed both to encourage business activity and to promote environmental responsibility. Ukrainian tax legislation offers several incentives and special tax regimes for forest product exporters. Notably, under the Tax Code

of Ukraine, timber exports are subject to a zero VAT rate, enhancing the international competitiveness of Ukrainian wood products (see Table 3).

Table 3. Comparative Tax Regulation of Forest Product Exports: Ukraine vs. the EU

Criterion	Ukraine	EU (general practice)	Comments / Examples
VAT rate on exports	0% (Art. 195.1.1 of the Tax Code of Ukraine)	0% (Directive 2006/112/EC)	Standard practice; promotes external trade
VAT on imported forest products	General rate – 20%	19–23% (country-specific)	Supports domestic producers
Export duties on roundwood	Suspended since 2022	Not applied	Export restrictions in the EU are rare
Corporate tax benefits (green)	Available (industrial parks, FSC projects)	Tax credits, accelerated depreciation	Austria, Sweden, Finland: sectoral incentives
Environmental tax relief	Available under local programs	Widely applied (emission reduction, certification)	Estonia, Finland: green investment support
Equipment depreciation	Accelerated (Sec. XX, TC)	Accelerated for low-carbon technologies	Encourages modernization
Customs policy	Exporter preferences, simplified zones	Unified EU customs regime	EU-Ukraine free trade zone effective since 2016

Tax regulation in Ukraine largely aligns with EU norms on VAT and export duties. However, green and institutional tax incentives remain fragmented and inconsistently applied. In contrast, EU countries offer systemic fiscal support for eco-friendly forestry investments - e.g., Austria promotes energy-efficient equipment, Sweden grants tax relief to FSC-certified producers, and Finland applies carbon tax credits. Ukraine's past export duties on raw timber, suspended under the EU-Ukraine Association Agreement, highlight the need to modernize domestic processing. Tax benefits for certified sustainable producers include accelerated depreciation, environmental tax exemptions, and priority in state aid, yet broader integration with EU sustainability standards and export policy is still lacking.

Table 4. Tax Payments by the Forestry Sector of Ukraine, 2019–2023 (million UAH)

Type of Taxes and Fees	2019	2020	2021	2022	2023 (Total)	2023 (With Benefits)	Tax Benefit (2023)
Value Added Tax (VAT)	3,200	3,100	3,400	3,800	4,200	3,780	420
Corporate Income Tax	850	900	950	1,100	1,250	1,125	125
Environmental Tax	120	130	140	160	180	162	18
Land Tax	90	95	100	110	115	103.5	11.5
Other Taxes and Fees	200	210	225	240	260	234	26
Total	4,460	4,435	4,815	5,410	6,005	5,404.5	600.5

The zero VAT rate on exports yields significant savings - around UAH 420 million in 2023 - by avoiding the standard 20% rate. Tax relief on profits and environmental charges, linked to green investments and FSC/PEFC certification, added another UAH 143 million, while local tax exemptions contributed UAH 27.5 million. In total, the forestry sector saved about UAH 600 million (10% of total tax liabilities), enabling reinvestment in modernization and export development. The impact of these incentives depends on strict compliance with certification and reporting standards. Effective tax policy thus strengthens the sector's financial capacity and should align with ESG principles and EU obligations.

3.3. Certification and Quality Standards of Forest Products: Challenges for Ukrainian Exporters

Access to EU markets increasingly requires Ukrainian forestry enterprises to comply with sustainability, transparency, and environmental responsibility standards. Certification under FSC or PEFC schemes is a de facto condition for market entry in the EU. Regulations such as EU No. 995/2010 (EUTR) and No. 2023/1115 (EUDR) demand documentation on legality, traceability, and deforestation risk, including geolocation and supply chain data.

In contrast, Ukraine's certification remains voluntary and only partially aligned with EU standards. Fewer than 50% of enterprises hold international certificates. The national electronic timber tracking system is not integrated with customs or tax platforms. Technical regulations are based on outdated GOST standards, lacking harmonization with ISO/EN norms, limiting EU market access. Addressing these gaps requires mandatory certification, harmonization of product standards with EU requirements, ESG reporting, and integration of digital monitoring systems. These reforms are essential for enhancing export competitiveness and aligning Ukraine's forestry sector with the EU's sustainable development framework.

4. DISCUSSION AND CONCLUSIONS

The conducted research has revealed that the sustainable development of Ukraine's forestry sector - particularly in the context of its export potential - is significantly constrained by institutional, financial, and regulatory factors. Unlike the European Union, where sustainable forest management is supported by integrated strategic instruments (EU Forest Strategy 2030, CAP Strategic Plans, Green Deal Investment Plan), Ukraine's regulatory framework remains fragmented and the scale of public support is insufficient.

Comparative analysis indicates that while ecological certification (FSC, PEFC) is a de facto requirement in the EU, and compliance with EUTR and EUDR is strictly enforced, certification in Ukraine remains voluntary with limited enforcement mechanisms. This hinders Ukrainian exporters' integration into global supply chains governed by high environmental standards and weakens the competitiveness of national forestry products in EU markets.

Although the forestry sector in Ukraine is financed through multiple sources - including the state budget, State Forest Agency investment programs, commercial bank loans, and international assistance (e.g., EIB, World Bank) - these mechanisms lack strategic alignment with sustainability goals, innovation incentives, and environmental certification. There is a clear need to expand green finance instruments and introduce targeted tax incentives for companies that adopt ESG and environmental standards.

To ensure sustainable development and export competitiveness of Ukraine's forestry sector, a systemic transition toward a new management model is essential. This model should integrate ecological responsibility, institutional transparency, and economic efficiency. Priority actions should include: harmonization of national legislation with EU regulations (EUTR, EUDR, ESG reporting); modernization of financial support mechanisms for exporters; strengthening digital traceability in logging and tax control systems; development of domestic wood processing capacity; and expansion of exports of high value-added products.

In our view, the implementation of these measures will enhance the sector's resilience to external challenges, ensure compliance with international partner requirements, and strengthen Ukraine's position in the global timber market.

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DIGITAL PLATFORMS FOR THE FINANCIAL AND ECONOMIC SUPPORT OF FORESTRY ENTERPRISES: THE EXPERIENCE OF UKRAINE

Olena Yatsukh, Irina Zhuravlova., Volodymyr Tsap

Abstract: This article explores the role of digital platforms in the financial and economic support of forestry enterprises in Ukraine. The study analyzes modern digital technologies, including FinTech solutions, blockchain, ERP systems, electronic payment services, and cloud technologies that enhance transparency in financial operations, automate accounting processes, optimize tax administration, and improve risk management. The article examines the practical implementation of digital platforms in financial management within Ukraine's forestry sector, covering public initiatives, private innovations, and international practices. Special attention is given to the potential of digitalization for attracting investments, efficient budget management, financial flow control, and increasing enterprise productivity. Key challenges identified include underdeveloped digital infrastructure, the need for improved legislative regulation, and insufficient digital literacy. The study also outlines the prospects for the development of digital financial technologies in the context of European integration and global digital economy trends, contributing to the sustainable development of the forestry industry..

Keywords: f digital platforms; forestry; financial and economic support; wood export; ERP systems; blockchain; investment; digitalization; budget management; FinTech in the forestry sector

1. INTRODUCTION

In the current context of economic transformation and the digitalization of all areas of economic activity, the implementation of digital financial and economic platforms has become a crucial component of the sustainable development of the forestry sector. In line with global trends, forestry enterprises are increasingly integrating innovative financial technologies to optimize internal processes, enhance transparency, and improve managerial efficiency. The aim of this article is to analyze modern digital solutions that provide financial and economic support to forestry enterprises in Ukraine and to assess their impact on productivity and the sustainable development of the sector.

2. Digitalization of the Export Potential of the Forestry Sector

The export of forest products remains an important source of foreign currency for Ukraine and a key driver of forestry sector activity. However, the export structure is still dominated by raw materials such as unprocessed timber and wood pellets, with limited value-added production, highlighting the sector's low financial efficiency. In 2023, major export destinations included Poland, Romania, Germany, China, Turkey, and Egypt, with over 60% of forest exports going to the EU. This underscores the need to meet EU standards for sustainability, transparency, and digital compliance. Digital tools—such as blockchain documentation, electronic certification, e-declarations, and online payment tracking—are essential for ensuring legal timber sourcing, reducing financial risks, and increasing trust from international partners. Export data for 2019–2024 (Figure 1) show volatility in physical versus monetary volumes, in contrast to the EU's steady growth (Figure 2). Key barriers to Ukraine's modernization include low processing depth, weak access to financial services, and limited digital infrastructure. Adoption of e-financial systems, digital trading platforms, and automated contracting tools is vital to improving transparency, speeding capital turnover, and attracting investment in high-value processing

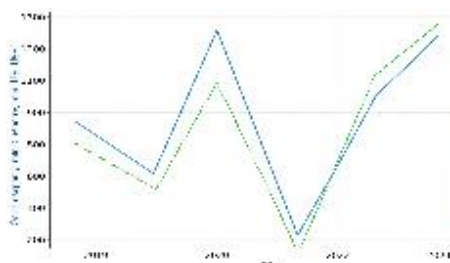


Fig. 1. Export of forest products from Ukraine: monetary and physical indicators

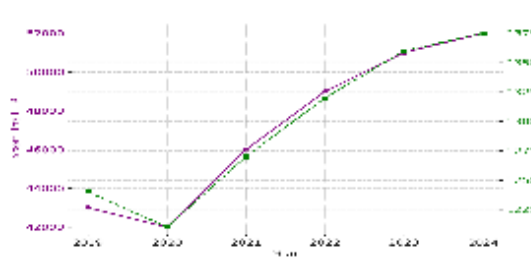


Fig. 2. Export of forest products to the EU: monetary (EUR million) and physical (thousand tonnes) indicators in 2019–2024

The graphs show that despite fluctuations in physical export volumes, foreign currency revenues remain stable or grow, likely due to better trade terms, a shift to value-added products, and external economic factors. This indicates rising export performance, supported by policies promoting processing and sustainable practices. Unlike Ukraine, the EU shows consistent growth in both volume and value, highlighting its strong position in global supply chains. Digitalization in forest product exports thus plays not only a regulatory role but also boosts financial efficiency, strengthens Ukraine's market position, and supports sustainable development goals.

3. RESEARCH RESULTS

3.1. Digital Technologies in Financial and Economic Management

The export of forest products has traditionally held a significant position in the structure of Ukraine's foreign economic activity. In 2023, revenues from timber exports accounted for over 15% of the total agri-raw material exports, highlighting the sector's high dependence on external demand. However, the export structure remains predominantly raw-material-based, with unprocessed timber, lumber, and pellets comprising the majority of export volume. This limits the potential for creating added value within the country. This model markedly contrasts with the approach adopted by European Union countries. In particular, countries such as Sweden, Finland, Austria, and Germany have structured the development of their forestry industries around principles of deep wood processing, environmental responsibility, and the widespread application of digital technologies across all stages of financial and economic operations.

Table 1. Comparative Characteristics of Digital Solutions in the Export Sector

Parameter / Country	Ukraine	European Union (e.g., Sweden, Austria, Finland)
Export Structure	60–70% – raw materials and primary wood products	70–80% – value-added products (CLT, LVL, biocomposites)
Level of Digitalization	Mainly timber accounting, partial e-documents	Full integration of ERP, CRM, digital certificates, IoT
Control Platforms	"Forest in a Smartphone", e-licenses, e-accounting	Unified digital supply chain from forest to buyer (EUDR, FLEGT)
Financial Instruments	Basic online banking, occasionally FinTech in foreign trade	Integrated digital modules for financial control and investment
Origin Certification	Paper-based + partial e-forms (some FSC)	Full digital integration: FSC, PEFC, blockchain-based supply chain control

The European Union implements an approach whereby all financial transactions related to timber exports are fully digitized and integrated into pan-European platforms, including the EU Customs Single Window, the European Union Deforestation Regulation (EUDR), FLEGT licensing, e-Invoicing, and e-Financing. In contrast, even the most advanced digital solutions in Ukraine—such as the “Electronic Forest” system or projects developed by the State Enterprise “Forestry Innovation and Analytical Centre” (LIAC)—are primarily focused on timber harvesting and transportation accounting rather than on comprehensive financial and export-related support. Ukraine’s lag in the digital transformation of financial support for forest product exports entails a number of risks: limited integration into high value-added global supply chains; constrained access to premium EU markets that demand digital transparency; insufficient trust from foreign investors due to weak financial flow control; and an inefficient tax base, resulting from unrecorded turnover associated with non-automated payment processes.

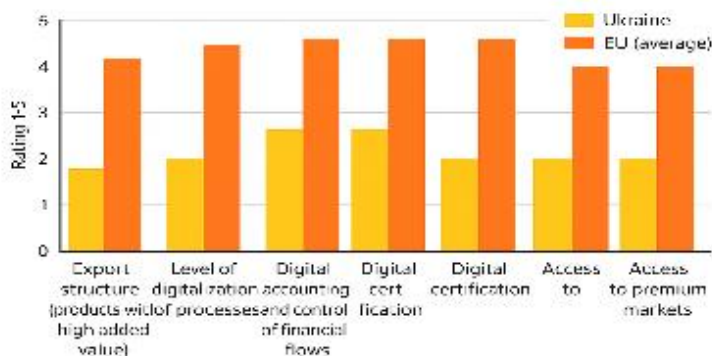


Figure 3. Comparison of digital financial and economic support for timber export between Ukraine and the EU by key parameters

The chart illustrates that Ukraine significantly lags behind EU countries in all key indicators of digital financial and economic support for timber export. The most pronounced gaps are observed in the areas of value-added processing, digital certification, and integrated financial services. This highlights the urgent need for accelerated digital transformation of the forestry sector to enhance its export efficiency and ensure compliance with European standards

3.2. Practice of Implementing Digital Platforms in the Forestry Sector

The implementation of digital platforms in the financial and economic support system of forestry enterprises in Ukraine is characterized by fragmentation and unevenness, both regionally and across different forms of ownership. At the national level, the State Forest Resources Agency of Ukraine plays a key role in the digitalization of the forestry sector, having initiated several digital solutions aimed at enhancing transparency, financial discipline, and managerial efficiency. One of the most large-scale projects is the integrated “Electronic Forest” system, which ensures electronic accounting of timber at the stages of harvesting, transportation, sale, and financial transactions. An additional tool for digital communication with the public and business sector is the mobile service “Forest in a Smartphone”, which provides open access to electronic logging tickets, as well as information on the origin and movement of

timber. These systems form the basis for digital financial monitoring; however, their functionality remains mostly limited to registration and inventory-related tasks.

Table 2. Electronic Modules of the "Electronic Forest" System

Electronic Module	Main Functions	Financial and Economic Significance
Electronic Timber Accounting (ETA)	Recording of timber harvesting, transportation, and sales operations	Creation of a reliable database for accounting and taxation
Electronic Logging Ticket	Digital authorization of logging with plot and volume verification	Legal fixation of logging volumes for budget planning and monitoring
Electronic Waybill (e-Waybill)	Control of timber transportation using GPS and QR codes	Reduction of smuggling risks and losses through automated control
Inventory Control System	Tracking warehouse stock and timber movement	Improved accuracy in financial planning and logistics optimization
Public Open Data Portal	Providing public access to data on logging volumes and sales	Ensuring transparency and anti-corruption control in financial operations
"Forest in a Smartphone"	Instant access to timber data, legality verification, and feedback submission	Strengthening public and partner trust; supporting digital financial reporting
BI Modules	Visualization of key financial and production indicators	Real-time financial management and strategic revenue planning

The implementation of digital modules within the "Electronic Forest" system has significantly reduced the volume of illegal timber circulation, enhanced the transparency of financial operations, and facilitated the legalization of the shadow segment of the forestry sector. According to preliminary estimates, the annual additional effect for the state budget from increased legal timber turnover and corresponding taxation may exceed UAH 2 billion. This demonstrates the high effectiveness of digitalization not only as an anti-corruption tool but also as a budget-enhancing mechanism. The main sources of financial gains include: reduction of illegal logging → increase in the volume of taxable legal timber; improved accounting accuracy → reduction in tax losses; logistics optimization → lower transportation costs → higher profits → increased tax revenues; transaction transparency → reduced corruption risks → increased budget inflows. Additional indirect benefits comprise: reduced inspection costs; decreased prevalence of corruption schemes; transparent reporting in international contracts → attraction of investors → inflows from VAT, corporate income tax, and customs duties.

Table 3. Estimated Economic Benefit to the State Budget from the Digitalization of the Forestry Sector

Parameter	Implementation		Difference	Note
	Before (pre-2016)	After (2023)		
Volume of timber sold, million m ³	~15	~18	+3	Partial legalization of the "shadow" market
Average price per 1 m ³ , UAH	950	1,400	—	Excluding VAT; reflects market price increase
Revenue from timber sales, billion UAH	14.25	25.2	+10.95	Not accounting for production or logistics costs
Corporate income tax rate	18%	18%	—	
Estimated additional budget revenues, UAH billion	~2.0	—	—	18% of the increased taxable profit

Estimated total fiscal benefit for the state budget of Ukraine: ≈ UAH 2 billion annually

In the field of financial management, state forestry enterprises in Ukraine are gradually introducing electronic document management, automated modules for accounting budgetary funds, and electronic treasury tools, including software systems such as M.E.Doc, "Kazna," and AIS "Local Budgets" modules. However, integration of these tools with digital export platforms, FinTech solutions, and analytical systems based on Big Data remains limited. In contrast, private logging and wood-processing companies are more likely to adopt comprehensive ERP systems (e.g., SAP Business One, BAS ERP) for internal financial control, supply chain management, cost calculation, and electronic accounting. Some of these companies also implement FinTech modules to integrate with banking APIs, manage risks, hedge currency fluctuations, and conduct digital contracting with international partners.

3.3. Digitalization as a Tool for Attracting Investment and Enhancing Budgetary Governance

Digital platforms play a key role in improving transparency, financial planning, and investor confidence in Ukraine's forestry sector. The integration of e-timber accounting, budget reporting, and ERP systems enables real-time tracking of expenditures, reduces misuse of funds, and enhances auditability. Automated financial tools streamline budgeting, reporting, and scenario analysis, supporting evidence-based decisions. Digital openness—through tools like blockchain certification, e-contracting, and public data access—strengthens the credibility of enterprises for foreign investors. Compared to traditional systems, digitalization significantly reduces transaction costs, improves fiscal discipline, and supports export operations. The use of integrated systems (e.g., M.E.Doc, Treasury.Online, BAS ERP) enhances financial control and reduces administrative burden. Empirical estimates show that digitalization yields over €2 billion in annual fiscal gains by formalizing timber flows, minimizing shadow operations, and increasing tax revenues. Overall, digital finance tools serve as strategic levers for attracting investment and improving budgetary governance.

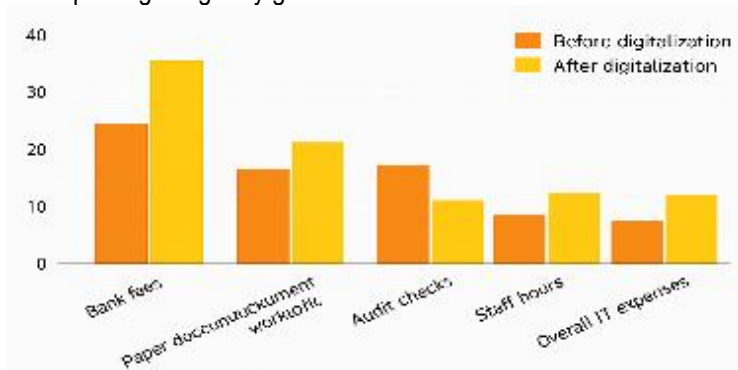


Fig. 4. Changes in the structure of transaction costs before and after digitalization

The results demonstrate a significant reduction in costs related to document management, banking services, and auditing, indicating the positive economic impact of digitalization and the optimization of operational activities.

5. DISCUSSION AND CONCLUSIONS

The study confirms that digital platforms are a vital driver of financial transformation in Ukraine's forestry sector, enabling automation, transparency, real-time financial analysis, and strategic planning. Their use significantly reduces transaction costs, lowers corruption risks, and improves investment appeal. Digitalization enhances integration into global supply chains through e-documentation, digital certificates, risk analytics, and online payments, particularly aligning with EU market standards. However, the full potential of these technologies is hindered by systemic barriers such as weak digital infrastructure in rural areas, lack of a unified regulatory framework, and limited digital competencies among forestry personnel.

Given Ukraine's EU integration goals, digital transformation must become a state priority. Recommended actions include developing national programs to modernize digital infrastructure, establishing financial reporting standards for the sector, and investing in workforce training to support ERP, CRM, BI, and FinTech adoption. Future research should focus on measuring digitalization efficiency across enterprise types, creating digital transformation indicators, and modeling the impact on financial and budgetary outcomes. Ultimately, digital platforms in forestry are not only operational tools but strategic enablers for modernization, competitiveness, and alignment with international standards

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COMPARATIVE ADVANTAGES OF SLOVAK FOREST PRODUCTS IN THE EU MARKET

Ján Parobek, Michal Dzian, Martina Nosáľová

Abstract: Slovakia's comparative advantages in the EU forest products market are primarily in industrial roundwood and primary wood processing products. These advantages are supported by abundant resources, competitive pricing, and efficient processing capabilities. The country's trade specialization evolves with the level of product processing, shifting from inter-industry to intra-industry as value is added. The paper deals with analysing the competitiveness of wood products trade with a focus on mechanical wood processing. It examines the time evolution of the Slovak Republic's competitiveness in timber and flat materials from 2004 to 2023 in the EU market of timber and flat materials, using selected competitiveness indicators.

Keywords: comparative advantages, sawmill industry, wood-based materials.

1. INTRODUCTION

Competition affects all sectors, including the timber processing sector, which, as Šupín (2011) points out, is inexhaustible if the principles of forest management are followed. As a consequence, individual changes require new strategies in order to gain long-term advantages and to face not only domestic, but also international competition due to globalisation (Sirgmetts et al., 2019; Zeng et al., 2025). The process of globalisation has gradually lowered trade barriers, resulting in a greater emphasis on promoting competitiveness in foreign trade (Bezrukova et al., 2024; PrykhodkoZozulia, 2021). Competitiveness and its identification has become a key area at the international level in efforts to promote exports as one of the important sources of growth for the domestic economy. This phenomenon is reflected in every sector of the national economy, including the wood processing and wood products industry (Cemil, 2020; Miličević et al., 2017; Paluš et al., 2015; Usoltceva et al., 2025). Thus, wood is now an important raw material not only for the processing but also for the energy industry worldwide. As history shows, wood has also been an important material for the development of society (Paluš, Maťová, Kaputa, 2012). Due to the increasing global demand for wood-based products, it is crucial that individual products are competitive in the market and that profits from the growing demand can be used efficiently.

The concept of competitiveness is quite complex. Wolff et al. (2007) argue that as a term it is used at different levels of aggregation (product level, business unit and firm level, industry sector, national or regional). The main difference between the competitiveness of firms and national economies lies in the differently defined objective. In the first case, enterprises consider the success in the competitive struggle, if not the growth in the market, at least the very survival of the company, while in the second sense, from the perspective of a national economy, the goal is the increase in the standard of living (Janský et al., 2014). The competitiveness of a country can be characterized as the extent to which it is possible, under

free and fair market conditions, to produce goods and services that meet the basic criteria set in international markets, while ensuring that the income of the country's population is maintained and increased in the long run.

According to Noor et al. (2008) the theory of competitiveness is based on comparative and competitive advantages, which are often linked but frequently confused, with the concept of comparative advantage being derived from traditional international trade theory. In general, it can be said that long-term competitiveness exceeds comparative advantage, however, no country can be competitive in every sector of the national economy.

2. METHODOLOGY FOR APPLYING COMPETITIVENESS ANALYSIS IN WOOD PROCESSING

The analysis of competitiveness in wood processing focuses on the mechanical wood processing sector. Separately, the time evolution of the competitiveness of the sawmilling industry and the production of wood-based materials, representing an aggregated group of products, including: veneers, plywood, fibreboard and particleboard, is analysed over time. The analysis itself, based on official data from FAOSTAT International Statistics (2025), applies the indicators TSI (Trade Specialization Index) for the period from 2004 to 2023 for the Slovak Republic (SR).

Trade Specialisation Index (TSI)

According to Balasso (1965), in a specific sector, a country can gain a market advantage by setting the index of trade specialization as the ratio of the net trade balance to the total trade balance of the analyzed wood product. This index is commonly referred to as the net trade index to indicate comparative advantage. It is calculated as:

$$TSI_j^A = \frac{X_j^A - M_j^A}{X_j^A + M_j^A} \quad (1)$$

Where:

X_j^A – export of product j (lumber and wood-based materials) from the Slovak Republic

M_j^A – import of product j (sawnwood and wood-based materials) from the Slovak Republic

The indicator for a given country ranges from -1, which is the case when there are no exports for product j ($X_j=0$), to 1, which is the case when there are no imports of product j ($M_j=0$). The analysis shows a comparative disadvantage when the calculated value is between -1 and 0 and a comparative advantage when the calculated value is between 0 and 1. If the calculated value is equal to 0, it means that exports and imports of a certain product are equal. More specifically, this index measures the degree of specialization of a country to export a certain product (Prasad 2004).

3. TITLE ANALYSIS OF THE COMPETITIVENESS OF THE SAWMILL INDUSTRY AND THE WOOD-BASED MATERIALS PRODUCTION

The competitiveness analysis of wood processing focused on the mechanical wood processing sector, particularly the sawmill industry and wood-based materials production. These represent an aggregated group of products, namely: veneers, plywood, fibreboard and particleboard. Using competitiveness indicators of TSI Trade Specialisation Index, we analysed the evolution over time of the competitiveness of coniferous and broadleaved sawnwood as well as wood-based materials over the ten-year period 2004-2023 for the Slovak Republic (see Table 1).

Table 2. Evolution of TSI Competitiveness Indices for the Sawmill Industry and Wood-based Materials Production for the Slovak Republic

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Coniferous Sawnwood	0.79	0.81	0.73	0.51	0.66	0.66	0.33	0.54	0.45	0.41
Broadleaved Sawnwood	0.80	0.73	0.74	0.69	0.71	0.38	0.64	0.38	0.26	0.25
Wood-based Materials	0.00	0.00	-0.10	-0.10	0.04	-0.19	-0.14	-0.22	-0.15	-0.18
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Coniferous Sawnwood	0.40	0.28	0.38	0.35	0.39	0.49	0.53	0.52	0.39	0.42
Broadleaved Sawnwood	0.35	0.70	0.71	0.66	0.68	0.39	0.41	0.45	0.40	0.42
Wood-based Materials	-0.12	0.01	0.03	0.11	0.15	0.17	0.10	0.12	0.23	0.28

Coniferous as well as broadleaved sawnwood both recorded their highest level of competitiveness in 2004, when the TSI trade specialisation index is closest to 1. This indicates the minimum imports of these commodities and a strong comparative advantage for the Slovak Republic. Throughout the analysed period, the TSI remained consistently positive, with coniferous sawnwood reaching its maximum value of 0.81 in 2005. This suggests that exports continued to exceed imports for both types of sawnwood. However, there was considerable variability: the lowest level of specialisation for coniferous sawnwood was observed in 2020 (0.53), while for broadleaved sawnwood it occurred in 2023 (0.42).

The situation is notably different for wood-based materials, which comprise a group of products – veneers, plywood, fibreboard and particleboard – characterised by a high variability in foreign trade. The TSI trade specialisation index fluctuates around a value of 0, ranging from -0.22 to 0.28, with zero indicating a balanced foreign trade balance and approximately equal volumes of exports and imports expressed in monetary units. On the other hand, the predominantly negative TSI values suggest a comparative disadvantage for the Slovak Republic in these materials.

This trend begins to shift after year 2015 with the highest TSI in 2023. The narrow range between competitive advantage and disadvantage in this category reflects the sensibility of the outcome to the specific indicator used. Other indicators, in contrast to the TSI, consider an industry to be competitive, albeit only very weakly, throughout the entire analyzed period. This

phenomenon is often due to the high variability in the production of the individual products included in the wood-based materials group. Based on the analysis, wood-based materials as a whole do not exhibit a clear comparative advantage for the Slovak Republic. Nevertheless, certain products within the group are showing signs of increasing competitiveness.

CONCLUSION

This paper has analysed the competitiveness of wood processing focusing on the mechanical wood processing sector. Using Trade Specialisation Index (TSI) indicators, the analysis of the sawmill industry and wood-based materials production over the period 2004–2023 identified a clear comparative advantage for the Slovak Republic in lumber. The market position of Slovakia and other Visegrad Four countries in the European Union market for sawnwood and wood-based materials was further analysed using the MS index for the years 2007 and 2012. In 2012, Slovakia's share of the EU market for sawnwood reached 2.12%, representing an increase of 0.53% over the previous five years. In contrast, Slovakia recorded the lowest market share among the V4 countries in the wood-based materials sector, with just 1.2% in 2012. This phenomenon points to a relatively strong position of foreign trade in sawnwood, but a considerably much weaker competitive advantage in the production of wood-based materials. Overall, the analysis confirms the current situation of a relatively high share of exports of wood-based products with lower added value (sawnwood) and thus a better position of the Slovak Republic on the EU markets. On the other hand, there is no effort to use raw materials domestically in order to maximise added value and thus support the national economy by using domestic renewable resources, as can be seen in some developed European countries. In contrast, in general the V4 countries as a whole (mainly due to Poland) exhibit the opposite trend to the Slovak Republic, where the overall share of wood-based materials in the EU market is higher than the share of sawnwood.

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CLUSTER ANALYSIS OF THE FURNITURE INDUSTRY AND AGRIBUSINESS IN BULGARIA: INNOVATION POTENTIAL, CHALLENGES, AND DEVELOPMENT OPPORTUNITIES

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Abstract: The report analyses the innovation potential of Bulgaria's furniture industry and agribusiness through a cluster approach, emphasizing regional disparities and challenges. The results indicate that the furniture industry suffers from low investment in innovation and limited digitization, while agribusiness faces low productivity and regional imbalances despite its steady growth. Leading regions (Ruse, Gabrovo, Dobrich, Yambol) demonstrate high economic activity and innovation development. National policies in the sector should focus on increasing investments in new technologies, promoting balanced regional development, and enhancing cluster coordination to improve competitiveness and sustainability in both sectors.

Keywords: furniture industry, agribusiness, cluster analysis, innovation potential

1. INTRODUCTION

The furniture industry and agribusiness are crucial to Bulgaria's economy, making a significant contribution to industrial output, regional development, and employment. The European furniture market is valued at over USD 192 billion (2024), with annual growth forecasts of 4.5% by 2031 (Europe Home Furniture Market Report, 2024). According to the Furniture Global Market Report (2024), this growth is driven by rising demand for sustainable furniture, digitalisation of production processes, and innovations in logistics. The furniture sector emphasises Augmented Reality (AR) technology, enabling customers to visualise furniture in real-time at home. Adoption of AR has increased online furniture sales by over 30% in three years, enhancing decision-making and customer satisfaction. Sustainable practices, including the use of recyclable materials and reducing carbon emissions during production, are key to maintaining long-term competitiveness. Over the past 15 years, the furniture industry in Bulgaria has experienced considerable transformation, marked by high levels of mechanisation, robotisation, and digitalisation of processes (Atanasov, 2022). Data from the National Statistical Institute of Bulgaria (NSI) shows that the furniture industry contributes over 3% to the industrial added value and provides employment for around 30,000 people, accounting for about 4% of total industrial employment (Statistical Yearbook 2024). In 2023, there was a 4% decline in production due to rising costs and reduced demand (BCCI, 2023). Furniture companies predominantly allocate funds towards machinery and equipment rather than R&D, software, patents, and other intangible assets. The industry continues to face challenges such as limited investment in innovation and a lack of cluster coordination. Barriers include restricted access to new markets and minimal collaboration with key suppliers, which hinder the growth of Bulgarian furniture companies (Biolcheva, 2017, p.126-127). Furthermore, the sector is largely composed of SMEs, which are highly labour-intensive and operate with fragmented supply chains. Despite potential improvements in production processes and competitiveness, digitisation remains limited. In Bulgaria, agribusiness accounts for 5% of national turnover and plays a vital role in exporting agricultural products (Branzova and Nestorov, 2023). According to NSI (2024), the sector's final output at basic prices totals BGN

9,440.6 million, with gross value added decreasing by 9.9% year-on-year to BGN 3,798.9 million, and net entrepreneurial income at BGN 889.1 million. The development of the agrarian sector and the formation of national competitive advantages rely on the innovative activity within the sectoral innovation system (Mileva and Georgieva, 2022). Due to low productivity, limited profitability, insufficient financial support, and low adaptability to change (Bashev and Koteva, 2021), over one-third of farms in Bulgaria show low competitiveness. Investments in sustainable agricultural practices could boost productivity and competitiveness (OECD, 2019). At the same time, precision agriculture technologies offer significant potential to optimise production. Agri-clusters are vital for increasing productivity and competitiveness by facilitating better coordination, knowledge sharing, and innovation adoption (Kabakchieva, 2019). However, the sector currently faces a lack of investment in innovation (Branzova and Dimitrova, 2023), regional disparities, an underdeveloped knowledge-sharing system, and insufficient coordination among farmers, institutions, and research entities. Additional challenges include climate and resource limitations (Kirchev, 2017), underdeveloped or absent cluster structures, and shortages of high-quality raw materials and resources. These issues further impede sustainable development and competitiveness.

The main goal of this paper is to identify preconditions influencing the innovation development of the furniture industry and agribusiness in Bulgaria, reveal regional disparities, and propose solutions to enhance their competitiveness. To achieve the research goal, cluster analysis is applied using standardized cluster indices to identify regions with high potential. The findings supplement existing literature by providing data for further formulation of suitable national policies aimed at sustainable development and improving the innovation potential of enterprises.

2. RESEARCH METHODOLOGY AND RESULTS

2.1. Methodology

The analysis applies clustering and the "elbow method" to determine the optimal number of clusters, alongside statistical techniques to enhance accuracy. Key indicators assessed include turnover, exports, and employment, using data from sources such as Orbis, Eurostat, FAO, and NSI. The visualization and further analysis were carried out with tools like RStudio and Power BI, providing detailed insights into sectoral and regional variations. Data from 2021, the most recent available, was used, covering turnover, employment, and exports. In 2021, furniture manufacturing, categorised under sector 31 of NACE Rev. 2, accounted for 0.3% of national enterprise turnover and 0.8% of employment. Agribusiness, including agriculture, food, and beverage production, made up 5% of turnover and employed 7% of the workforce.

2.2. Research results from furniture manufacturers' cluster analyses

In 2021, there are 1,970 enterprises in Bulgaria engaged in furniture manufacturing, distributed across 517 settlements. Despite their wide geographical distribution, six settlements lacked data on turnover or employment, hindering cluster analysis for these indicators. For cluster modeling, data from 511 settlements were used. Three clusters were identified. The first cluster encompasses 483 settlements with an average of 20 employees and EUR 37 exports. Despite its size, this group exhibits the lowest levels of employment and export valuation and is thus characterized as "low potential." The second cluster includes 22 settlements with an average of 234 employees and EUR 656 exports, deemed as having "medium potential." The

third cluster comprises six settlements with 741 employees and EUR 2,727 exports, identified as "high potential." To balance the groups, the SMOTE function in RStudio increased the number of units in clusters 2 and 3 to 342 and 243 settlements, respectively.

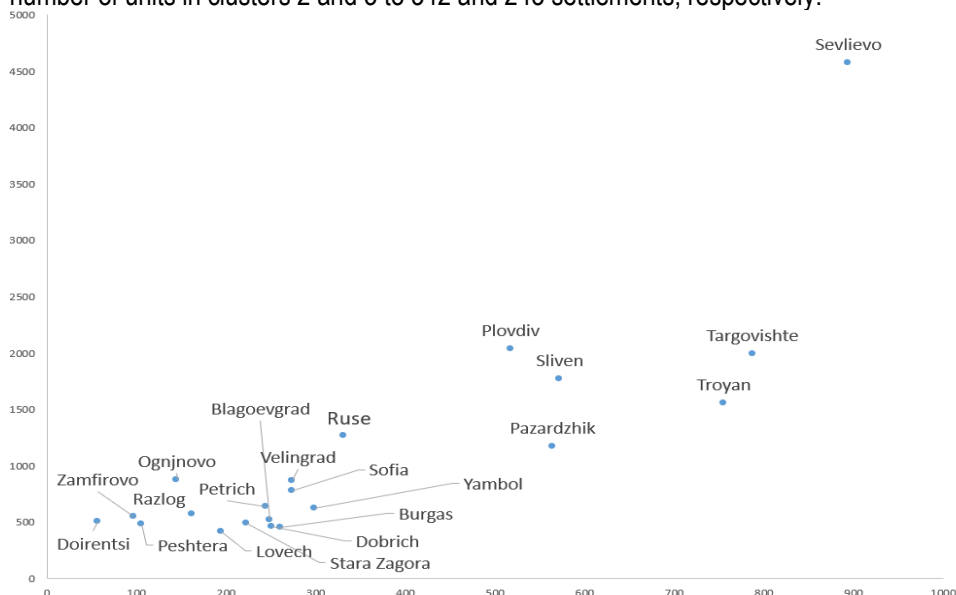


Figure 1. Settlements with Medium and High Innovation Potential

**Since there is more than one settlement in Sofia by postal code, the results are consolidated into one common unit "Sofia"*

Data analysis highlights clear differences in economic activity and competitiveness among the groups. The first cluster exhibits low economic participation and needs targeted policies for growth through infrastructure improvements and innovation. In contrast, the third cluster shows significant economic contributions, with high levels of exports and employment. Small enterprises (with turnover under EUR 500,000) make up 78% of all units but only generate 28% of total turnover. Medium-sized enterprises lead with a 65% share of turnover, while large enterprises (with turnover above EUR 5 million) comprise only 3% of units but account for over 40% of turnover. The Ruse and Gabrovo regions dominate, accounting for over 60% of total exports. Meanwhile, regions with low exports, such as Vidin and Silistra, have strong growth potential through integration into global supply chains and clustering. As shown in Figure 1, there is a strong link between cluster size and the average turnover of units, emphasizing the importance of clustering for boosting economic efficiency. The concentration of high-turnover enterprises in central regions like Ruse and Gabrovo highlights the role of clustering in economic efficiency. At the same time, low-export regions such as Vidin and Silistra present future growth opportunities through investments in infrastructure and global supply chain integration.

2.3. Research results from furniture manufacturers' cluster analyses

The agribusiness sector covered 14,358 enterprises across 2,433 settlements in Bulgaria. Data for 36 enterprises were missing, limiting cluster analysis to 2,397 settlements. Using the

"elbow method," three optimal clusters were identified. The first cluster includes 46 settlements characterized by an average of 136 employees and EUR 84,367 exports, identified as "high potential" (see Figure 2). The second cluster, classified as "medium potential," includes 220 settlements with an average of 9 employees and EUR 3,260 exports. The third and largest cluster, classified as "low potential," consists of 1,597 settlements with an average of three employees and EUR 591 exports. To balance clusters and enhance accuracy, the SMOTE function generated additional units, increasing the number of settlements in the first cluster to 1,365 and in the second to 1,542. Data indicate that micro-enterprises dominate agribusiness, with primary economic contributions coming from high-potential settlements. SVM and Naive Bayes models were used to verify categorization accuracy.

Table 1. Data from SVM and Naive Bayes Models

	Clusters	Precision	Sensitivity	F1	Area under the curve
Furniture industry					
SVM	3	0,95	1	0,9	88%
	2	0,98	1	0,9	
	1	1	0,5	0,7	
Naive Bayesian model	3	0,9	1	0,9	90,0%
	2	1	0,9	0,9	
	1	0,6	0,8	0,7	
Agribusiness					
SVM	1	0,9	0,4	0,6	88%
	2	0,9	0,9	0,9	
	3	0,9	1	0,9	
Naive Bayesian model	1	0,7	0,7	0,8	88%
	2	0,8	0,9	0,9	
	3	0,9	0,8	0,8	

The results, presented in Table 1, show high precision and sensitivity, particularly for the third cluster ("low potential"). However, the greatest challenge lies in accurately categorizing settlements in the first cluster. Models demonstrated satisfactory precision with F1 values between 0.6 and 0.9. Agribusiness demonstrates resilience with growth in turnover (+26%) and a significant increase in exports (+33%). Key regions with high potential include Dobrich and Yambol, which make substantial contributions to exports. High evaluations indicate a significant number of settlements in clusters with medium and high potential, with the population effect neutralized.

In summary, Sofia (the capital) has the highest index in the furniture sector (2.9), positioning it as a major center for innovation and economic activity in the sector. The regions of Smolyan and Yambol show good results in both sectors, highlighting their balanced economic profiles. At the same time, regions such as Dobrich and Razgrad have high indices only in agribusiness, emphasizing their specialization. On the other hand, over 70% of the regions do not achieve high indices, reflecting significant regional disparities. This underscores the need for targeted policies to stimulate economic activity in these regions. Special attention

should be given to regions like Vidin, Silistra, and Targovishte, which show potential for development through investments in infrastructure and innovation.

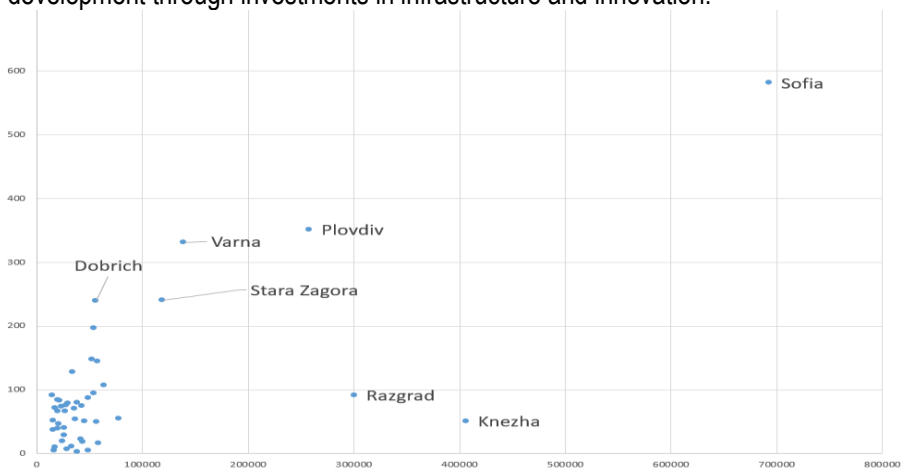


Figure 2. Populations with high innovation potential

3. CONCLUSIONS

Standardized aggregate indices were calculated for all regions based on the cluster analysis, revealing many settlements with medium and high potential, with population effects neutralized. Data indicate that Bulgaria's furniture industry is mainly concentrated in regions like Ruse and Gabrovo, demonstrating high economic efficiency and export capacity. Other regions lag in innovation and production capacity, emphasizing the need for modernization. Agribusiness exhibits a broader geographical distribution, with leading regions such as Dobrich and Yambol relying on sustainable practices and innovations. The main differences between the sectors include technology adoption levels, with the furniture industry requiring a stronger focus on digitization, while agribusiness shows steady growth through precision agricultural technologies. Regional disparities are more pronounced in the furniture sector, while agribusiness demonstrates better integration of innovations on a broader scale.

In conclusion, both sectors need increased innovation through targeted subsidies and incentives for R&D. Technologies such as augmented reality and suitable digital tools can boost the competitiveness of the furniture sector, while innovative agrotechnologies have the potential to enhance efficiency in agribusiness. Uneven regional development requires resource allocation and policy development focused on peripheral areas. Investments in infrastructure and logistics can support innovation in lagging regions like Targovishte, Silistra, and Vidin. Agribusiness must adjust to climate change with sustainable farming practices and optimization of water and soil resources. This will lessen the impact of natural constraints on productivity. Strengthening connections between furniture and agribusiness enterprises can encourage the exchange of experience and technologies. This involves organizing cluster initiatives that promote collaboration among SMEs. Bulgaria's furniture sector lags in digital transformation. Automation and digital management platforms can improve manufacturing processes and lower costs. Both sectors can boost their competitiveness through active participation in global supply chains, opening access to new markets and development prospects.

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INNOVATION POTENTIAL OF LOW-TECHNOLOGY SECTORS: THE CASE STUDY OF THE FORESTRY SECTOR AND AGRIBUSINESS IN BULGARIA

Teodora Marinova Georgieva, Daniela Ventsislavova Georgieva

Abstract: The success of implementing new technologies and utilising their full potential depends on numerous factors, primarily the innovation capacity of economic entities. Innovations are inherently sector-specific. Sectoral differentiation highlights how participants within technological chains and sectoral innovation systems collaborate to create, integrate, and implement technological, organisational, and market innovations. Analyses of sectoral innovation systems in low-technology sectors demonstrate the essence and significance of the innovation activities undertaken by these companies. Consequently, such analyses support the development of sector-based, innovation-oriented policies and measures that genuinely impact the economy. Creating impact mechanisms that emerge naturally from the transformative processes within specific sectors, rather than being externally imposed, can foster a healthier environment for the entire innovation ecosystem. Despite the relatively weak innovation dynamics in low-tech sectors, they remain crucial for national economies, competitiveness, and social impact. Therefore, it is essential to understand the mechanisms through which low-tech companies implement innovation activities and take appropriate steps to enhance their digital maturity and innovation readiness. This report 1) examines the unique characteristics of sectoral innovation systems in the forestry and agriculture sectors and 2) assesses the companies' potential to adopt new technological solutions. The 3) factors underpinning successful innovation activities are investigated to inform the design of targeted and well-justified national policies.

Keywords: innovation potential, low-tech sectors

1. INTRODUCTION

The recognition of innovation as a key factor for competitiveness since the middle of the last century has focused national policies on high-tech sectors as the intersection between intensive research and innovation potential. A number of public financial and non-financial support mechanisms and venture capitalists at national and international levels have identified high-tech solution providers as a priority in ensuring technological breakthroughs, developing technological leadership strategies and imposing technological standards. However, in recent years, a number of studies have proven the importance of low-tech activities (Hirsch-Kreinsen, 2006). Sectors such as forestry and agriculture, together with the furniture and food industries and their associated technological chains play a key role in at least several directions: the scope of application of high-tech developments, food security, sustainable development, quality of life, balanced development between economic spheres of activity and territories (Žemigala, 2018).

Based on a nationally representative study of the innovation potential in the field of low-tech sectors, this report aims to offer evidence of the presence of intensive innovation activity of economic agents in the field of agriculture, forestry and fisheries, to identify the specific features of their innovation potential, and to highlight the factors that support the manifestations of innovative behaviour.

2. METHODOLOGY

The present report is based on the understanding that the different stages of the innovation process, and transfer and diffusion of technological knowledge, are based on extensive interaction between various groups of stakeholders, depend on a number of internal and external factors, and in this sense represent a kind of innovation system. The methodology includes the implementation of a series of analytical procedures based on a broad information base, including desk research of scientific literature and legislative framework, statistical information, and qualitative and quantitative empirical data. This enables the research on innovation potential to reflect the specific characteristics of the sectoral context and the relevant business environment.

The report presents the results of a nationally representative survey, featuring a sample of more than 500 companies identified on a quota basis, representing various groups of business entities in the agriculture, forestry, and fisheries sectors, and located throughout the country. A standardised face-to-face structured questionnaire with indicators for assessing innovation potential was applied.

The sector of agriculture, forestry and fisheries was identified as a low-tech sector according to the classification criteria of OECD: R&D intensity measured by expenditure on R&D as a proportion of output. Following this approach, industries that spend more than 4.5% of sales on R&D are classified as high-tech; industries that spend between 1.0 and 4.5% of sales as medium-tech; and industries that spend less than 1% as low-tech. However, this term must be used with caution, as the initial classification primarily considers the manufacturing industry and data for the period 1991-1999. Nowadays, the concept of innovation has been further developed. Additionally, companies often combine existing technologies with modern ones, and innovation activity increasingly relies on close collaboration between high- and low-tech businesses (Hansen, 2015).

3. INNOVATION POTENTIAL OF LOW-TECHNOLOGY SECTORS

3.1. Innovation potential of business in the field of agriculture, forestry and fisheries

The success of implementing new technologies and utilising their full capacity depends on several factors, the primary one being the innovation potential of economic entities operating within the agricultural, forestry, and fisheries sectors. Innovation potential is determined by the understanding of the importance of innovation, the readiness to implement innovation, the available innovation capacity, and the innovation development practices applied by economic entities (natural and legal entities), which can be distinguished on the basis of geographical, sectoral or other signs. Innovation potential also depends on the regulatory and economic environment and on how economic entities position themselves in relation to it.

The agricultural, forestry, and fisheries sectors are part of the low-tech industries. The expectation is that, in comparative terms, the innovation potential of the agricultural sector will be lower compared to other sectors, also included in the group of low-tech industries. Companies in low-tech sectors do not innovate per se, or do so to a very limited extent. Indeed, the survey found that product innovation was limited to 7% of respondents when it came to launching new products and just over 19% when it came to product improvements. Almost 26% of the companies surveyed reported introducing marketing innovations, including engaging in

short supply chains, entering new markets, using new distribution channels, developing new advertising approaches, and developing a new brand.

Innovations in the agricultural, forestry, and fisheries sectors are initiated by factors external to the industry - primarily as a result of the development of science and technological progress in economic sectors, which form the inflows in the organisation of agricultural activities (Venckuvienea, 2014). Process innovations, the result of the application of technological solutions created in other industries, predominate. Such are most often associated with the use of new or improved machinery and equipment (just over 55%), new raw materials and materials (18%), packaging (7.5%) (Potters, 2009). A current direction for process innovation is the use of renewable energy sources. The most common is the installation of photovoltaic systems for solar energy (nearly 11% of respondents). The application of hydropower (2%), bioenergy (1.2%), wind energy (0.8%) and others lag far behind.

Innovative activity in the agricultural sector is expressed in the application of technological solutions new to the sector, but existing in other sectors (intersectoral diffusion), a new combination of or a new application of existing technologies (Hansen, 2015).

2.2. Factors enhancing successful innovation activity

Interaction, participation in innovation networks and technology transfer are key to the innovation activity of low-tech sectors due to the main specificity of the companies included in them – lack of potential for generating new technological knowledge (they do not have their own research units, they do not employ highly qualified personnel), but a highly developed absorption capacity for implementing innovative developments created outside them. However, the results of the conducted study indicate that the potential for interaction (inter-company, along the value chain, cooperation, with research units) remains unused (Zabala, 2025). Only 36% of respondents are members of a branch organization, and the cooperatives established in the country are rather isolated islands or exist in a latent phase. Nearly two-thirds of the respondents indicate that they are not members of any organization. In addition, less than 15% of companies in the sector maintain close contacts with research organizations, including the Bulgarian Academy of Sciences, the Agricultural Academy, the Forestry University, the Agricultural University and others.

Digitalization is one of the approaches to implementing process innovations (Gallegos, 2019). Precision agriculture (including forestry applications), fertilization automation, and the Internet of Things are some of the most common approaches to increasing productivity, optimizing costs, and improving the quality of end products (Parikoglou, 2024; Abad-Segura, 2024). Digitisation processes occur at varying intensities across different sub-sectors and types of businesses, primarily depending on access to skilled labour rather than financial resources (Gallegos, 2018).

Digitalisation implies qualification. Farms can only make their way with well-trained personnel. Eurostat data for Bulgaria outlines some main challenges in the introduction of high-tech solutions:

- low level of application of digital technologies by households and businesses
- low level of entrepreneurial and innovative activity
- innovative activity that is low-tech
- human resources that are insufficient purely physically, and at the same time unprepared for modern challenges

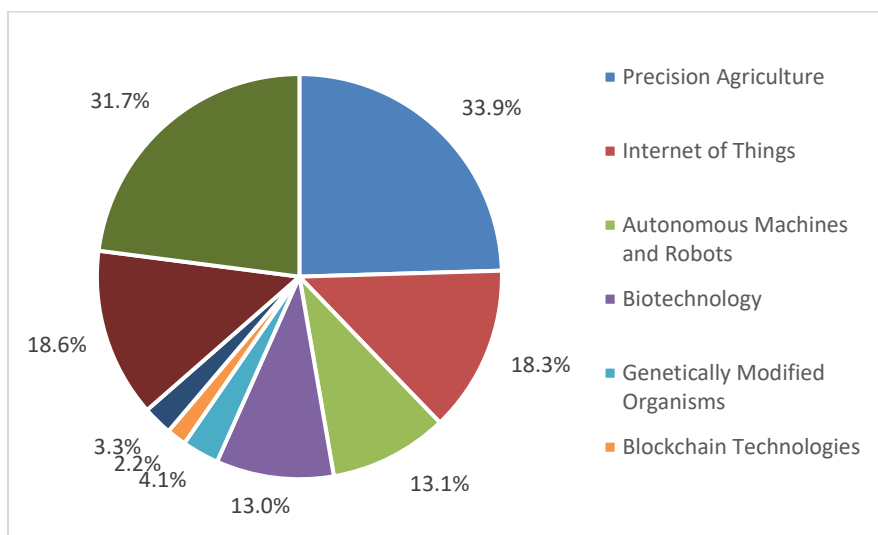


Figure 1. Application of digital technologies for automation of production processes

The decline in the population with a higher educational level is accompanied by deepening processes of dequalification. Against the background of the low share of the population with digital skills, the data show a lack of improvement in recent years in the indicator for the population with digital skills above the average level. At the same time, the number of enterprises providing training in the field of ICT decreased by 30%, and the total number of the population included in lifelong learning decreased by 20%.

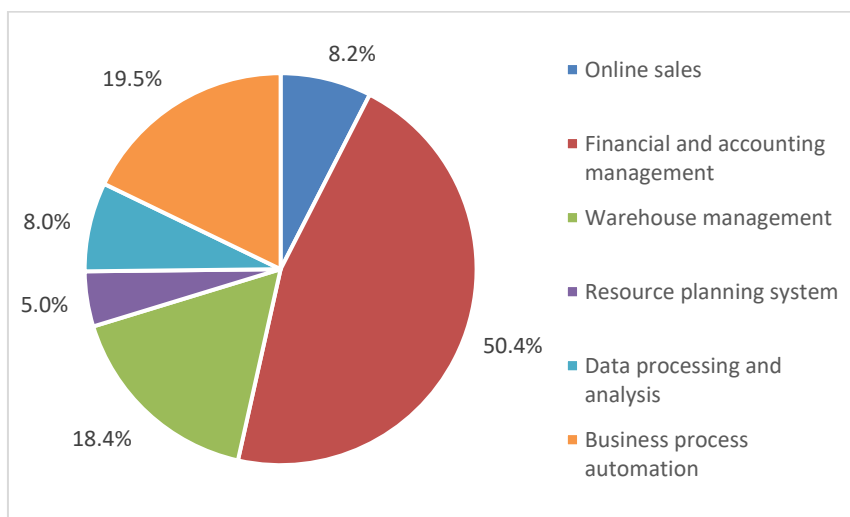


Figure 2. Application of digital technologies for automation of administrative processes

4. CONCLUSIONS

Medium- and low-tech activities are traditional for the country, with regard to their implementation, many years of know-how and experience have been created, they are based on existing data and naturally occurring interactions.

The orientation of innovation policies and priorities for economic development solely and exclusively towards high-tech activities (which are usually the ambitions of the state administration) creates conditions for a deepening discrepancy between existing potential and unrealistic goals. Without being tied to clear plans for restructuring the national economy, this leads to the orientation of efforts (human resources, financial resources, administrative capacity, public expectations) towards areas that cannot provide a sufficiently broad field for influencing the results of the functioning of the economy.

Despite the low level of investment in R&D and patent activity, these industries demonstrate potential for implementing know-how and new technologies created outside them, a high level of commitment along the technological chain and significant innovation activity when it comes to organizational and marketing innovations.

Traditional industries are a field for the application of technological developments with an external origin for the respective sector and thus they act as a driver of the research and innovation activity of other high-tech activities and knowledge-intensive services. In some cases, they have a saturated (in terms of institutional density) sectoral innovation ecosystem with a high intensity of interaction - factors that guarantee the rapid spread and diffusion of (un)protected and (un)codified new knowledge. By encouraging the innovation activity of traditional sectors, the effect of attracting innovative solutions created by other related economic activities is achieved. In this way, the intensity of interaction within the innovation system as a whole is increased in support of open innovations.

The conditions of the business environment are of key importance for the development of the innovation potential of traditional industries, which create less new knowledge and absorb more. The basic (transport and telecommunications) and top infrastructure (universities and research units) act as a conduit for the spread of existing and new technologies; the formal and informal environment (patent legislation, competition protection, tax breaks, imposed business practices). Sectoral development policies should be based on a thorough understanding of sectoral innovation systems, the capabilities and needs of the agents involved and their specific expertise in carrying out production activities and related interactions. This includes promoting national "champions" in sectors, as well as attracting such from outside.

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GEOGRAPHICAL CONCENTRATION AND GEOGRAPHICAL SUSTAINABILITY OF FURNITURE EXPORTS FROM BULGARIA

Nedialko Nestorov, Daniela Ventsislavova Georgieva

Abstract: The paper analyses the geographical concentration and sustainability of furniture exports from Bulgaria for the period 2015-2024. The focus of the research is on the main trading partners and the dynamics of foreign trade relationships. The methodology used is based on the application of geographical concentration (GCr) and geographical sustainability (GSr) indicators. The findings of the analysis indicate that a balanced structure, sustainability over time, and limited dependence on external shocks characterise the export of furniture from Bulgaria. Major trading partners account for approximately 51% of total exports, with 74% of them maintaining their positions in the top 5 over the entire analysed period.

Keywords: furniture trade, export concentration, trade stability

1. INTRODUCTION

The global furniture market is experiencing steady growth, with forecasts to reach \$1.04 trillion by 2029. The expansion of manufacturers' access to new markets globally, the development of online trade, and the adoption of innovative environmental practices are contributing to the sector's increasing competitiveness and sustainable development (Furniture Global Market Report, 2024). Europe plays a leading role in the global furniture industry in terms of production, consumption, and international trade. It is the second-largest furniture market in the world, valued at USD 262.03 billion in 2025 (Europe furniture market). In EU member states, along with the UK, Norway, Switzerland, and Iceland, around 75% of furniture trade is intra-regional (CSIL World Furniture Outlook). The woodworking and furniture industry in Bulgaria is considered a traditional sector, generating approximately 3% of GDP (NSI 2024). The Bulgarian furniture market is projected to reach USD 790.2 million by 2025, with an annual growth rate of 1.84% forecasted for 2029 (Statista). The sector is considered sustainable due to its strong market integration, dominant retail chains, and stable internal linkages (Research reports, furniture sector, forecasts). However, due to geopolitical and economic uncertainties, there is a decline in new building permits issued in 2024 compared to 2023 (NSI), reducing the demand for new furniture. Potential threats to the development of Bulgaria's furniture industry include legislative constraints, weak innovation and investment capacity, and a heavy dependence on a limited number of markets (Nikolova & Petrova, 2025, p. 253). Sustainable development is crucial for achieving competitiveness, as the European Green Policy mandates the introduction of sustainable design, repair and recycling options of goods, and the sharing of responsibility through a digital product passport. According to Sultanova & Naser (2025), export diversification helps reduce the environmental footprint in both developed and developing economies, with effects influenced by the specifics of the export structure and the energy mix utilised. Consequently, understanding the geographical distribution and sustainability of furniture exports is of critical importance. The main goal of the paper is to analyse the geographical structure, concentration, and sustainability of Bulgaria's furniture

exports from 2015 to 2024. This has been achieved through an assessment of dependencies on key trading partners and the degree of diversification, to minimise external trade risks and boost sector competitiveness.

2. RESEARCH METHODOLOGY

To clarify the status and trends of furniture exports from Bulgaria, the most recent foreign trade data published as of 1 July 2025 in the Eurostat foreign trade databases is considered. Furniture exports are classified mainly in the Combined Nomenclature sections of Chapter 94 Furniture; Bedding, etc. The occurrence of significant foreign trade events in recent years allows for a clear identification of the sustainability of trade partnerships. Consequently, the research period is set to cover the last ten years (2015–2024). As "an expression of the external sector of an economy, foreign trade is indicative of its openness, its participation in the international division of labour, its international trade specialisation and competitiveness" (Marinov, 2017). Therefore, in analyses of such topics, it is important to monitor the status and dynamics of a country's exports. The geographical structure is particularly important because "the development of foreign economic relations can be assessed from the location and structure of the main trading partners" (Panushev, 2017). In light of the stated objective to track the state and dynamics of Bulgaria's furniture exports, the following statistical methods have been employed: First, a description of export values and trends in their development is presented. For this purpose, the tools of descriptive statistics are utilised. Second, a detailed analysis of the geographical structure of foreign trade is conducted by examining two key parameters – geographical concentration and geographical sustainability.

In practice, when calculating the concentration of foreign trade, the Herfindahl-Hirschman Index – HHI (Hirschman, 1964) is often applied. In the study of Galabova and Nestorov, the authors discuss HHI's index shortcomings and suggest that "when examining the geographical distribution of foreign trade, the Geographical Concentration of the Export/Import rate (GCr) should be used" (see Galabova, Nestorov, 2018). It is calculated as a coefficient (or as a percentage), representing the relative share of the sum of the first three countries in the geographical distribution of exports or imports, with the total volume of transactions with all countries. Its mathematical expression is represented by the following formula:

$$GCr = \frac{\sum_{i=1}^5 topD}{\sum_{i=1}^n D}, \text{ where: } \quad (1),$$

GCr is the geographic concentration ratio of exports/imports;
D, the foreign trade transactions with *n* number of countries;
top - the members of the ranked order of transactions.

Galabova and Nestorov suggest that the coefficient of geographical concentration should be calculated for the top five countries - leading partners, and it can be calculated for each time period studied, for example, a year. Due to the advantages outlined by the authors regarding the proposed new coefficient, we accept to apply it for the current study. The interpretation of the indicator provides analytical and cognitive information on the degree of dependence of a country on its foreign trade partners and on their market conjuncture, political, social and

economic environment. The analysis of a country's foreign trade linkages is important to consider and includes their persistence over time. Resilience in an economy can be defined as "the ability of a system to maintain its basic quantitative and qualitative characteristics with relatively little change in a given parameter" (Voycheska, 2013). To measure the persistence of foreign trade transactions, Galabova and Nestorov propose a "geographic export/import persistence coefficient - GSr" (Galabova, Nestorov, 2018), which reflects changes in the structure over time. Its mathematical notation is expressed by the following formula:

$$GSr = \frac{\sum_{m=1}^5 \frac{C}{m}}{5}, \text{ where:} \quad (2)$$

GSr is the geographic export/import sustainability ratio;

C is the number of orders of the partner country in the top five places in the geographical structure by period;

M - the number of periods examined.

Foreign trade theory and practice argue that greater persistence over a long period is a favorable development scenario because it indicates relative stability and predictability

3. RESULTS AND DISCUSSIONS

The total furniture exports from Bulgaria for the period 2021–2024 – covering all goods under Chapter 94 "Furniture and parts thereof" – represent approximately 0.3% of the country's merchandise exports. With this export value, Bulgaria ranks 35th in the world in terms of furniture exports. The values for the individual years are graphically presented in Figure 1.

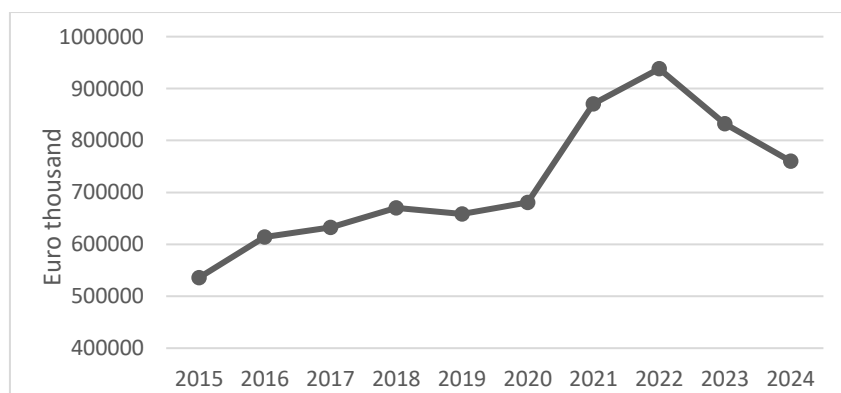


Figure 1. Value of furniture exports from Bulgaria in the period 2015-2024

Source: Eurostat data

The values show a clearly defined upward trend until 2022, when the trend reverses. From just over EUR 500 million in 2015, export revenues increased to over EUR 900 million in 2022. The following two years are marked by a decline, reaching around EUR 760 million in 2024. Due to the heterogeneity of the goods included in Chapter 94, the analysis continues by types of furniture. The goods with significant export value are from the following categories: 9403 – "Other furniture and parts thereof," 9401 – "Seating furniture," 9404 – "Bed springs and

mattress supports," and 9405 – "Lamps and lighting fittings and parts thereof" (see figure 2). The remaining goods in the furniture group have a negligible export value.

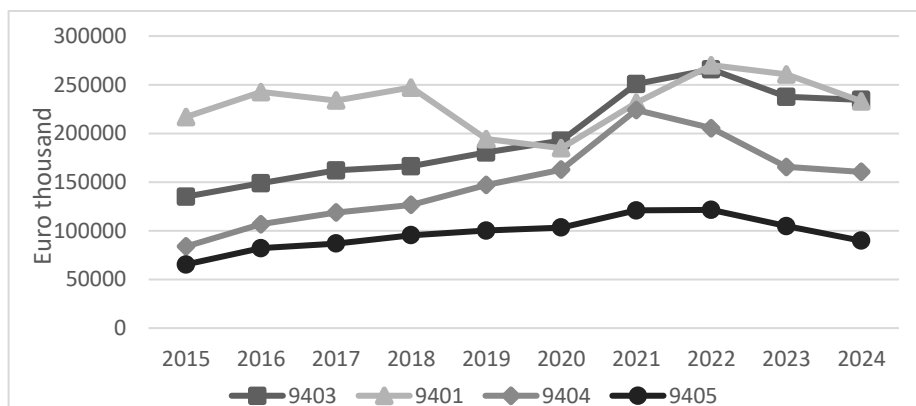


Figure 2. Value of furniture exports from Bulgaria, by Combined Nomenclature section, 2015-2024 Source: Eurostat data

The results of the calculations for the coefficients of geographical concentration and geographical sustainability are presented in Table 1.

Table 1. Results of the application of the geographic concentration and geographic stability coefficients for furniture exports from Bulgaria in the period 2015-2024

Commodity		GCr (2015-2024 average)	GSr (2015-2024)
9403	Other furniture and parts thereof	0,52	0,82
9401	Seating furniture	0,58	0,76
9404	Bed springs and mattress supports...	0,53	0,72
9405	Lamps and lighting fittings and parts thereof...	0,42	0,66

Source: Eurostat own calculations

The highest export value is recorded for the category "Other furniture and parts thereof," amounting to just over EUR 230 million in 2024. In recent years, the leading trade partners have been Romania (22%), Greece (13%), France (9%), Germany (7%), and the Netherlands (5%). Altogether, these five leading countries annually account for around 55% of the export transactions in this category. This value of the Geographical Concentration Coefficient indicates a balanced geographical structure. Throughout the observed period, in 82% of the cases, the same five countries remained the top partners. This coefficient demonstrates a stable geographical structure of exports for these goods. A similar trend is observed with Seating furniture. Transactions involving these items total nearly EUR 230 million in 2024. The top five trade partners collectively account for an average of 58% — Poland (19%), Romania (15%), Greece (10%), the Czech Republic (9%), and Germany (5%). The GCr again suggests a balanced market share among the leading five countries. Over the past decade, these countries have appeared among the top five in 76% of cases. The situation is comparable for Bed springs and mattress supports. In 2024, exports of these reached €160 million. The top five countries

together make up 53% of the exports, dominated by Romania (21%), Germany (13%), Italy (8%), Greece (7%), and Turkey (7%). A balanced geographical structure is also evident for these goods. Over the last ten years, these countries have been among the top five 72% of the time, signifying a stable export structure for this category of furniture. The scenario differs somewhat for Lamps and lighting fittings and parts thereof. Compared with other types of furniture, lighting exports are the smallest, amounting to €90 million in 2024. Established trading partners include Italy (15%), Romania (9%), Greece (8%), Germany (6%), and Slovakia (4%). The top five countries together account for 42% of exports. The similar GCr value suggests a balanced but somewhat near-diversified structure. These five countries have been in the top five 66% of the time over the past decade, again indicating a stable geographical export structure.

4. CONCLUSIONS

Overall, furniture exports from Bulgaria are characterised as balanced in terms of geographical concentration. As can be seen from the values of the geographical concentration ratio for the period 2025-2024, the top five trading partners account for around 51% for the different commodities. This does not indicate a high degree of concentration, as it is unfavourable because it shows a stronger dependence and linkage on fewer foreign trade partners and their terms of trade, and vice versa. At the same time, a balanced structure implies a greater degree of diversification. It is rather favourable because it reflects greater independence and a lack of strong interdependence. Moreover, it indicates less vulnerability of exports of these goods to external shocks and shocks that can substantially alter the geographical distribution of foreign trade.

Annex 1. List of full names of Combined Nomenclature headings

Code	Name
94	Furniture; bedding, mattresses, mattress supports, cushions and similar stuffed furnishings; luminaires and lighting fittings, not elsewhere specified or included; illuminated signs, illuminated nameplates and the like; prefabricated buildings
9401	Seats (other than those of heading 9402), whether or not convertible into beds, and parts thereof
9403	Other furniture and parts thereof
9404	Mattress supports; articles of bedding and similar furnishing (for example, mattresses, quilts, eiderdowns, cushions, pouffes and pillows) fitted with springs or stuffed or internally fitted with any material or of cellular rubber or plastics, whether or not covered
9405	Luminaires and lighting fittings including searchlights and spotlights and parts thereof, not elsewhere specified or included; illuminated signs, illuminated nameplates and the like, having a permanently fixed light source, and parts thereof not elsewhere specified or included:

Source: Commission implementing regulation (EU) 2024/2522.

In terms of sustainability over time, furniture exports from Bulgaria are characterised by the sustainability of foreign trade partners. On average, 74% of countries were always present in the top five, for the period 2015-2024 (highest in persistence in Other Furniture, and lowest in Lighting). When partners do not change significantly over the years, it can be argued that Bulgarian manufacturers have established themselves in the value chains. Transactions are not episodic, and the established foreign trade links are sustainable. Also, the establishment of long-lasting relationships with one group of trading partner countries shows that Bulgarian furniture is characterised by high competitiveness.

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EFFICIENCY ANALYSIS OF PELLET PRODUCING ENTERPRISES: A DATA ENVELOPMENT ANALYSIS (DEA) APPROACH TO BULGARIAN WOOD PROCESSING

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Abstract: The current study implements Data Envelopment Analysis (DEA) to estimate the efficiency of the Bulgarian pellet producing enterprises. The study examines the technical and scale efficiencies as well as the technological improvement of 45 enterprises for the period 2017-2022. The methodology includes radial DEA models and Malmquist Productivity Index (MPI). The index identifies whether factors of improvement are related to innovations and quality changes in the technologies being used or to the changes of enterprises' scale. The results provide insights for the future steps in the management of the enterprises which should be undertaken for their effectiveness. The study also profiles the benchmarks in the Bulgarian pellet industry and providing in this way a guide for the less-efficient enterprises to achieve better growth in the future.

Keywords: pellet producing enterprise, Data Envelopment Analysis, Malmquist Productivity Index, efficiency, productivity

1. INTRODUCTION

The increasing prices of oil and natural gas for many years have put the world in search of alternative energy sources. As Kuokkanen et al. (2009) point out, European legislative changes and signed international agreements fostered significantly pellets production in the European Union (EU) countries after the 2012. As Rodriguez (2022) reveals, the market potential of wood pellets is increasing after bigger United States (US) exports to EU. Wolf et al. (2006) defined three levels of pellet production costs according to combination of industrial enterprises related to wood supply chain. Kang et al. (2013) profoundly explained that the main drivers of the economic efficiency in wood pellet production are the material costs and capacity utilization. Pirraglia et al. (2010) revealed that the pellet production profitability can be sensitive to labor input. This research partly covers that of Uasuf and Becker (2011) who explained the comparatively low sensitivity of production cost levels to raw material's price levels due to other costs in the production lines. On the other side are Trømborg et al. (2013) who described the capital and labor like low important factors for gaining profitability. Same results are provided by Pergola et al. (2028), comparing different technologies of production. Some recent studies like that of Golonis et al. (2022) pay attention to the employment generated by the wood pellet production facility.

This study brings back the actuality of labor as a capacity maker and efficiency determinant for the wood pellets. Many studies in the last few years pay attention to the benefits of pellet production and utilization (Sarker et al., 2023; Rashedi et al., 2022; Mortadha et al., 2025) as biomass valorization alternative. Actually, the problem of the efficiency of pellet production in the recent years was somehow neglected in favor of biomass utilization efficiency (Rodino et al., 2024), sustainable energy from wood pellets (Topić Božić et al., 2024; Lee and

Hnu, 2025) and ecoefficiency of pellet production (Sperandio et al., 2024). Regarding Bulgaria, studies on the wood pellets are conducted on predominantly engineering basis (Tomov, 2024; Zlateva et al., 2024, 2025) mostly like energy efficiency and utilization (Murzova and Zlateva, 2023). Another direction of research comprises studies on wood pellet market (Sikkema et al., 2011; Glavonjić et al., 2015).

According to the analysis on the research level of the Bulgarian wood pellet production, can be concluded that there is a lack of research that considers efficiency of production. The current study aims to fill this research gap revealing the efficiency of Bulgarian wood pellet producers. This study will be very useful for every producer to make the right decisions for technological innovation and ongoing use of the main production factors.

2. MATERIALS AND METHODS

In the current study is used a non-parametric approach for efficiency estimation called Data Envelopment Analysis (DEA). DEA was developed by Charnes et al (1978) with initially so-called CCR (Constant Returns to Scale) model, that means the all DMUs function at the same scale of production. Otherwise, the BCC (Variable Returns to Scale) model (Banker et al., 1984) is applicable and estimate the so-called pure technical efficiency (PTE). Classical input-oriented CCR model has been applied in the present study as well as BCC according to the available data and the purpose of optimization of the production factors in wood pellet producing enterprises. Mathematical forms of the implemented DEA in the current study models are as follows:

$$\begin{aligned} \min \theta_o^t \text{ (to be explained)} \\ \sum_{j=1}^m \lambda_j x_{ij} \leq \theta x_{io} \quad (1) \\ \sum_{j=1}^s \lambda_j y_{rj} \geq y_{ro} \\ \sum_{j=1}^n \lambda_j = 1 \text{ for the variable returns to scale (BCC) model} \end{aligned}$$

where λ_j are individual scalars of each j -th DMU ($i=1,2,\dots$ is the number of the input; $j=1,2,\dots$ is the number of the DMU _{j} used as a benchmark; y_{ro} is the output of the benchmarked DMU₀; θx_{io} is the input oriented efficiency scores for the benchmarked DMU₀)
 x_{ij} are amounts of inputs of type i in DMU _{j} , x_{io} is the amount of i -th input of DMU₀ being benchmarked.

One of the alternatives to supplement DEA and add more value to the business is to determine the improvement of the analysed wood pellet producing enterprises (DMUs) in Bulgaria regarding the scale and technology and to implement the Malmquist Productivity Index (MPI). Malmquist (1953) investigates the comparison of factor productivity between two time periods according to the inputs needed for the comparative levels of production. Fare et al. (1992) prepared a model for the productivity changes of DMUs calculated though DEA. The models MPI implemented in the current study are following:

$$\begin{aligned} MI &= PTE * TC \quad (2) \\ PTE &= \frac{\theta_o^{t+1}(x_o^{t+1}; y_o^{t+1})}{\theta_o^t(x_o^t; y_o^t)} \quad (3) \\ TC &= \left(\frac{\theta_o^t(x_o^t; y_o^t) \theta_o^t(x_o^{t+1}; y_o^{t+1})}{\theta_o^{t+1}(x_o^t; y_o^t) \theta_o^{t+1}(x_o^{t+1}; y_o^{t+1})} \right)^{1/2} \quad (4) \end{aligned}$$

where: TC is technological changes, $\theta_o^t(x_o^{t+1}; y_o^{t+1})$ are the minimum DEA scores from the CCR model (1) with inputs of year 2022 and output of year 2017;

$\theta_0^{t+1}(x_o^t; y_o^t)$ are the minimum DEA scores from the CCR model (1) with inputs of year 2017 and output of year 2022;

$\theta_0^t(x_o^t; y_o^t)$ and $\theta_0^{t+1}(x_o^{t+1}; y_o^{t+1})$ are the minimum DEA scores for years 2017 and 2022, accordingly.

The DMUs in the current study are 45 wood pellets producers in Bulgaria for the period 2017-2022. The inputs are annual wages and fixed tangible assets available. The output is the annual profit generated by the wood pellets. All the inputs and outputs are data collected by the project survey dedicated to the labor and assets influence on the profit of the wood pellets producing enterprises.

3. RESULTS AND DISCUSSION

The annual changes of the implemented input and outputs for the DEA models are presented in the Figure 1.

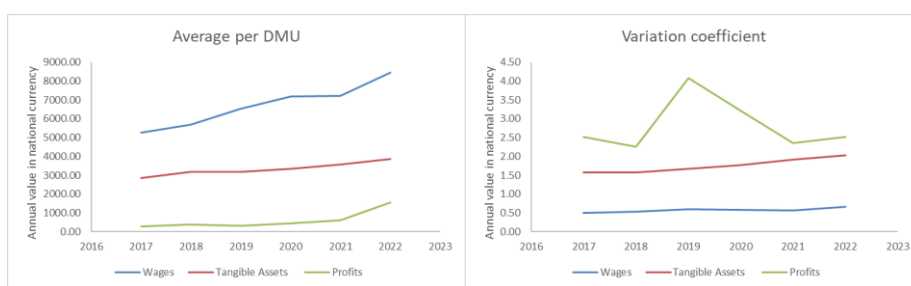


Figure 1. Averages and variation coefficients of the wages, fixed tangible assets and profits of the 45 Bulgarian wood pellets producers

The graphs in Figure 1 show an increase in the scale of wood pellet production in Bulgaria for the study period. The most significant increase is noted in the costs of wages. Comparing the variation with the change in inputs by year, it should be assumed that the studied companies are quite similar in the use of labor resources. This cannot be said to be true for the fixed tangible assets used. Profits are extremely variable between enterprises, which also shows the different direction of their use. As mentioned, some of them use these pellets in the applied circular economy within another, main production. Unlike profits, process management seems stable as a result of the stable time series and the weak variation of the used fixed assets and labor resources.

Results of the DEA with CCR, BCC and scale efficiencies time series are presented in the Figure 2.

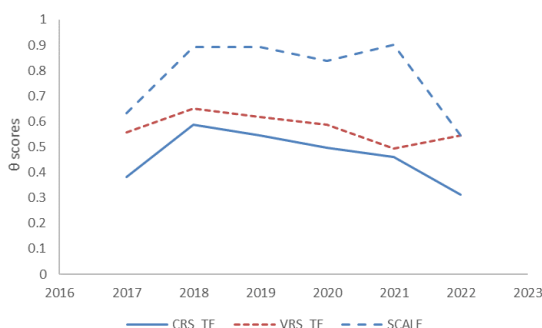


Figure 2. Results of model (1) along with the scale efficiency of the 45 Bulgarian wood pellet producers

The lines in Figure 2 reveal the dynamic nature of the efficiencies (CCR) during the period of research. Efficiency scores were constantly declining. The scale efficiency as a ratio of BCC/CCR varies significantly, which means that the capacity related decisions are crucial for the success of the pellet production. Comparing the lines in the two figures the capacity problems can be related to the costs for the wages. In the same time, PTE increased in 2022 when the wages and profits also increased. The problems with the declining efficiencies can explained through the Malmquist productivity Index. The results are summarized in the Table 1.

Table 1. Results of the models (2)-(4) for the Malmquist Productivity Index

Indicator	Value / Comment
Average MI	2.33 (Range: 0.0008 – 12.25)
Average TC	1.23 (Range: 0.0006 – 7.46)
Average PTE	1.55 (Range: 0.76 – 1.97)
Firms with MI growth > 1	24 out of 45 (53%)
Top performers (MI > 5)	Olimex Ltd., Pirin Pellet Ltd., Hightech Ltd.
Low performers (MI < 0.7)	BG Pellets Ltd., Pelleti Energia Ltd., Netkom Ltd.
Growth driver	Mostly Operational Efficiency (PTE > 1)
Efficiency improvements	Widespread: PTE > 1 for all but 2 firms
Notable insight	Some firms have strong TC despite low PTE, suggesting innovation-led growth rather than operational efficiency.

The summarized results in the Table 1 reveal that more than the half wood pellet producers have achieved total factor productivity improvement during the period of research. Despite the problems with the scale, the enterprises managed to improve the ability to produce more pellets. 82.22% of the enterprises relied on operational efficiency. Growth driver for some enterprises was the newly established equipment and machinery. These enterprises have the smaller share of 15.56% (enterprises with TC>1). Seven enterprises achieved good improvement through new technologies "Diaman" Ltd, "Eco Bio Calor" Ltd., "Eco Flame Comfort" Ltd., "Hedon" Ltd. "HK Peletek" Ltd. "Parvi May" JSC "Pirin Pellet" Ltd. and "Safari-

M" Ltd. They have very different FTE (?) to wages ratios, but have one thing in common – they have the biggest profits across the sample of the wood pellets producers.

4. CONCLUSIONS

The study conducted on 45 companies producing wood pellets in Bulgaria for the period 2017-2022, although limited in scope, due to the availability of only specific data, gives an idea of the generally accepted practices of running this business in the country. More than half (53%) of the analyzed Bulgarian wood pellet producers improved their total factor productivity between 2017 and 2022, indicating positive development. A large part of the companies is increasing their productivity with organizational optimizations. The companies that have emphasized mainly on technological development of productivity are those with the greatest profits. At this stage, it cannot be said that this is a proven dependence, but the results unequivocally show this. The results in the study show that the decisions made by enterprises during the study period increased productivity and improved over 50% of the organization in the companies, but market valorization was neglected, which led to high productivity with low efficiency.

This study was conducted within the existing limitations of the available data. In the future, this topic should be developed with additional studies covering material costs and other indicators that would be useful for the science and practice of the woodworking industry.

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THE STATE OF EXPORT AND IMPORT OF WOOD PRODUCTS AND FURNITURE IN THE REPUBLIC OF NORTH MACEDONIA: TRENDS AND STRATEGIES FOR GROWTH

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Ivana Antovska, Anastasija Temelkova

Abstract: The Republic of North Macedonia has a long-standing tradition in the production and international trade of wood products and furniture. This paper presents an analysis of the dynamics of wood and furniture import and export during the period from 2014 to 2023, based on data obtained from the Economic Chamber and the State Statistical Office of the Republic of North Macedonia. The data were classified according to the Standard International Trade Classification (SITC).

The results reveal a notable upward trend in exports — nearly five times for furniture and three times for wood products. A similar increasing trend is observed across all categories of imports.

The aim of this study is to provide a comprehensive assessment of external trade trends in the wood and furniture sector, with the objective of formulating strategic directions for enhancing export growth and market competitiveness.

Keywords: import, export, wood, wood products, furniture.

1. INTRODUCTION

The wood processing and furniture manufacturing industries represent significant segments of the industrial production in the Republic of North Macedonia. The country's rich forest resources and the availability of raw material provide favorable conditions for the development of a competitive wood processing industry, as well as the production of furniture and wood products for both domestic and foreign markets.

The wood industry consists of three main subsectors: primary wood processing (sawmill processing and hydrothermal treatment of the wood), production of wood semi-finished products (mainly solid wood panels and parquet blanks), and the industry for manufacturing furniture and wood products. Domestic softwood and hardwood species are used for the production of wood products, while exotic wood species (most commonly mahogany) are used in very limited quantities. In the last decade, there has been an expansion in the production of furniture made out of engineered wood products (particle boards and MDF), and current practices show that this type of furniture dominates the domestic market. For the production of this furniture, the industry utilizes modern technological lines and advanced production systems.

During the period from 2008 to 2012, the total export from the wood industry amounted to USD47431. Furniture exports accounted for 55% of the total wood industry export, while exports of wood and wood products made up 45% (Stankevik Šumanska et al., 2015). According to the authors, imports during the same period amounted to USD129316. The import of wood and wood products represented 55% of the total import value in the wood industry, while furniture accounted for 45%.

Over the past decade, international trade in furniture and wood products has experienced continuous growth. A significant factor contributing to this growth has been the country's accession to the World Trade Organization (WTO) and the signing of the free trade agreement with the European Union (CEFTA). According to Meloska et al. (2018), during the period from 2010 to 2017, the total furniture export reached USD7608801. The data in the cited paper is divided into categories: wooden bedroom furniture, wooden kitchen furniture, wooden office furniture, and other wooden furniture. The largest share of exports was in bedroom furniture (46.4%). Exports showed an increasing trend during the analyzed period, with an average annual growth rate (AAGR) of 4.87%. In terms of imports, the total value amounted to USD2941295, with the highest share attributed to other wooden furniture (60.7%).

2. METHODOLOGY

The methodological approach employed in this paper is entirely analytical. The research was conducted using a fully quantitative approach, based on the analysis of official data on the foreign trade of wood and furniture products in the Republic of North Macedonia for a period of ten years, from 2014 to 2023. The data were obtained from the State Statistical Office and the Economic Chamber of North Macedonia, as the primary institutions responsible for monitoring trade flows and economic indicators in the country.

The data analysis was carried out in two main categories: wood products and furniture. The objective of the analysis was to determine the dynamics of import and export, their annual value, and the changes occurring over the analyzed time period. The data are expressed in euros (€) and is classified according to the Standard International Trade Classification (SITC). The processing of data was performed using Microsoft Excel, employed as the primary tool for statistical analysis. The data were organized, and key indicators were calculated (average value for the analyzed period and average annual growth rate). The data are presented in tables, while graphs were created to visualize the values and identify the trends.

3. RESULTS AND DISCUSSION

3.1. Import of wood products and furniture

The import of wood products and furniture exhibits a stable increasing trend, with the highest recorded value in 2022. In 2023, a decline of 1.80% was observed, primarily due to a decrease in the import of wood and wood products. It is particularly noteworthy that the share of furniture in total imports has been continuously increasing, from 38.57% in 2014 to 50.40% in 2023. The average annual growth rate for imports was 7.24% for wood and wood products, 13.13% for furniture, and 9.82% overall.

It is also important to highlight that the import values for wood products and furniture did not experience a decline even during the global COVID-19 pandemic (from 2020 to 2022).

Table 1 presents the import data for the period from 2014 to 2023, while Figure 1 illustrates the import dynamics over the same period.

Table 1. Imports in the period from 2014 to 2023

Year	Wood and wood products		Furniture		Total	
	Value (€)	Share (%)	Value (€)	Share (%)	Value (€)	Total (%)
2014	55698	61.43	34965	38.57	90663	100.00
2015	62966	62.59	37628	37.41	100594	100.00
2016	67663	58.16	48674	41.84	116337	100.00
2017	77424	57.31	57666	42.69	135090	100.00
2018	81009	56.21	63110	43.79	144119	100.00
2019	83039	51.29	78868	48.71	161907	100.00
2020	85511	51.82	79510	48.18	165021	100.00
2021	98137	49.54	99940	50.46	198077	100.00
2022	112788	52.61	101601	47.39	214389	100.00
2023	104449	49.60	106142	50.40	210591	100.00
Avg.	82868	55.06	70810	44.94	153679	100.00
AAGR	7.24	/	13.13	/	9.82	/

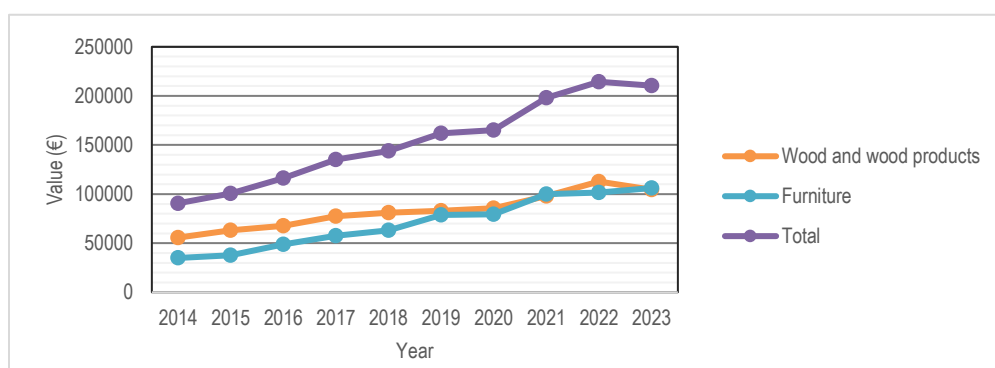


Figure 1. Import dynamics from 2014 to 2023

3.2. Export of wood products and furniture

During the analyzed period from 2014 to 2023, exports recorded significant growth, particularly in the furniture sector. Furniture export increased from EUR64261 in 2014 to EUR342458 in 2023 which represents more than a fivefold increase. The export of wood and wood products showed a slower, yet steady increase, from EUR4570 in 2014 to EUR12329 in 2023, or approximately a threefold increase. The average annual growth rate was 11.66% for wood and wood products, 20.43% for furniture, and 19.99% overall. The high average annual growth rate indicates strong export potential, especially in the furniture manufacturing sector.

Similar to imports, furniture exports did not experience a decline during the global COVID-19 pandemic (from 2020 to 2022).

Table 2 presents the export data for the period from 2014 to 2023, while Figure 2 displays the export dynamics during the same timeframe.

Table 2. Exports in the period from 2014 to 2023

Year	Wood and wood products		Furniture		Total	
	Value (€)	Share (%)	Value (€)	Share (%)	Value (€)	Share (%)
2014	4570	6.64	64261	93.36	68831	100.00
2015	5655	5.12	104721	94.88	110376	100.00
2016	7178	5.05	135080	94.95	142258	100.00
2017	6866	3.70	178629	96.30	185495	100.00
2018	8386	3.72	216880	96.28	225266	100.00
2019	10286	3.98	247919	96.02	258205	100.00
2020	6608	2.95	217070	97.05	223678	100.00
2021	7414	3.11	231224	96.89	238638	100.00
2022	13232	4.77	264157	95.23	277389	100.00
2023	12329	3.48	342458	96.52	354787	100.00
Avg.	8252	4.25	200240	95.75	208492	100.00
AAGR	11.66	/	20.43	/	19.99	/

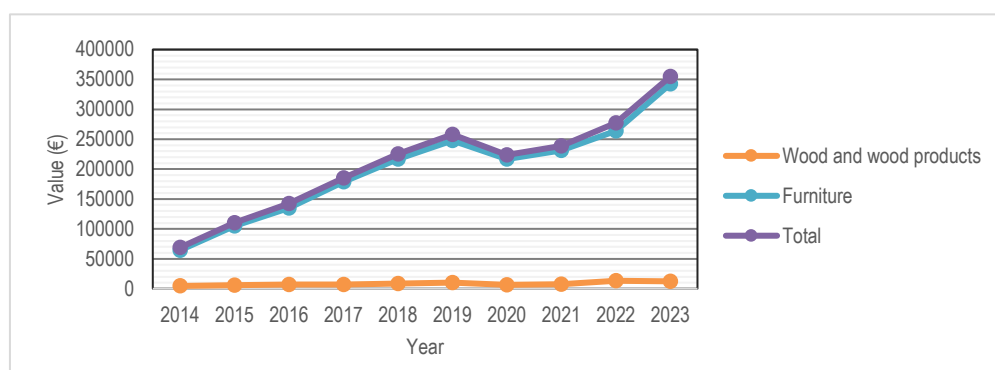


Figure 2. Export dynamics from 2014 to 2023

3.3. Trade balance of wood products and furniture

Despite the growth in exports, the trade balance for wood and wood products remains negative throughout all years of the analyzed period. In 2023, EUR104,449 worth of wood and wood products were imported, while exported only EUR12,329, indicating a high dependency on imported raw materials or semi-finished products, despite the country's abundant forest resources.

The majority of the trade value in the wood processing industry derives from the furniture manufacturing sector, where domestic companies demonstrate greater competitiveness. In contrast to wood products, furniture maintains a continuously positive trade balance. On

average, furniture exports were nearly three times higher than imports during the analyzed period.

The trade balance for wood and wood products from 2014 to 2023 is shown in Figure 3, while Figure 4 presents the trade balance for furniture over the same period.



Figure 3. Trade balance of wood and wood products from 2014 to 2023



Figure 4. Trade balance of furniture from 2014 to 2023

4. CONCLUSIONS

The analysis of import and export data for wood, wood products, and furniture in the Republic of North Macedonia for the period from 2014 to 2023 reveals a positive growth trend, particularly in the export of furniture, which increased more than five times.

The furniture manufacturing sector has achieved significant export results, which can be attributed to the continuous development and enhancement of production capacities, as well

as improved product designs that align with global trends and demonstrate competitiveness on the international market. The high average annual growth rate (20.43%) confirms that domestically produced furniture is successfully positioned in global markets.

In contrast, the wood and wood products sector records a negative trade balance. Despite the country's rich forest potential, there is an insufficient level of domestic production and processing of raw materials to reduce import dependency. In 2023, imports of wood and wood products amounted to EUR104449, while exports totaled only EUR12329. This represents an underutilization of the country's resource potential, especially considering that 35% of its territory is covered by forests.

The country possesses a realistic potential to strengthen its position in the trade of wood, wood products, and furniture. Systematic support is needed to reinforce production capacities and improve forest management. With a long-term vision and investments in capacity building, the industry can be transformed into an export-oriented economic branch with an increased share in the national trade balance.

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ASSESSMENT OF THE COMPETITIVENESS OF RETAIL OUTLETS OF COMPANIES IN THE FURNITURE INDUSTRY IN BULGARIA (BASED ON THE EXAMPLE OF 'MEBELI VIDENOV' AND IKEA)

Tsvetan Iliev, Lalka Borisova, Gergana Rashkova

Abstract: The aim of this study is to examine the possibilities of enterprises in the furniture retail sector to maintain their competitiveness, which would strengthen their market positions, attract more consumers and improve their financial performance. To this end, a comparative assessment of the competitiveness of two companies in the same line of business, viz. furniture and household goods retail trade in Bulgaria, was carried out. More particularly, this paper presents a model for assessing the point-of-sale competitiveness of both companies. It includes the most commonly applied indicators and criteria to measure the performance of companies and their ability to maintain competitive positions of their retail outlets. Based on the results of the assessment, conclusions were drawn and practical recommendations were made to increase the competitiveness of the companies.

Keywords: competitiveness, retail trade, competitiveness assessment model

INTRODUCTION

In a market economy, competition is especially important for the retail trade sector and its development. Retail business constantly interact trying to improve their operations in order to strengthen their market positions and generate more profit.

Essentially, competition is driving the market by creating incentives for more efficient management and better positioning of the enterprises on the market, especially when in the retail trade sector. Therefore, market research is considered a key factor for the development and implementation of a competitive corporate strategy.

Competitiveness assessment in retail trade aims to determine the most effective competitive strategy for an enterprise to consolidate its market position, gain a larger market share, and increase its profits.

In a free market environment, every company is subject to competitive pressure. Under such circumstances, competitiveness is instrumental in ensuring the effective performance of retail business activities. Therefore, the issue of its assessment is always relevant. It is especially pertinent in times of significant fluctuations of the external environmental factors - changes in government economic policies, shifts in supply chains, changes in the population's purchasing power, etc.

The subject of this study is the competitiveness of retail companies. Its object are the methods and indicators for assessing competitiveness at a retail outlet level.

The aim of this study is to examine the possibilities of enterprises in the furniture retail sector to maintain their competitiveness, which would strengthen their market positions, attract more consumers and improve their financial performance. To this end, a comparative assessment of the competitiveness of two companies in the same line of business, viz. furniture and household goods retail trade in Bulgaria, was carried out. More particularly, this paper

presents a model for assessing the point-of-sale competitiveness of both companies. It includes the most commonly applied indicators and criteria to measure the performance of companies and their ability to maintain competitive positions of their retail outlets. Based on the results of the assessment, conclusions were drawn and practical recommendations were made to increase the competitiveness of the companies.

The main research hypothesis tested in this paper is that the competitiveness of companies in the furniture retail sector depends on multiple factors, which influence to varying degrees their ability to compete effectively on the market.

1. METHODOLOGY FOR ASSESSING THE COMPETITIVENESS OF RETAIL OUTLETS

Since competitiveness is inherently multifaceted, it cannot be measured and analysed using a single indicator, criteria, or assessment method. To be objective and comprehensive, the assessment should be carried out using a system of indicators and applying various methods for measuring each indicator (Grabowska, S., Saniuk, S., 2022). Market competition occurs where multiple enterprises operate on the same market, hence the assessment of their competitiveness should be based on comparative analyses. This approach measures the level of competitiveness of a retail enterprise in relation to its competitors and determines whether it is less, equally, or more competitive in comparison.

A notable distinction of retail enterprises, in contrast to other market entities, is that they operate by means of retail outlets and warehouses in which their merchandise is sold directly to their customers and thus the characteristics of these enterprises are assessed directly by the consumers. This entails two aspects for assessing the competitiveness of retail enterprises (Abuzyarova, M., 2017):

- In terms of **the competitiveness of retail outlets** owned by the enterprise;
- In terms of **the competitiveness of the retail enterprise as an independent economic entity**.

The following criteria for selection of enterprises for comparative assessment of their competitiveness should be met:

- A competitor should be considered an enterprise in the same line of business regardless of whether it is a leader, a runner-up, or a peer competitor in the market segment;
- Retail outlets should be considered competitors if they are of the same type. Here, too, the competing retail outlet may be a leader, a runner-up, or a peer competitor point of sale.

The methodology for assessing the competitiveness of a retail outlet must meet specific requirements:

- It should include quantitative methods for measuring competitiveness;
- It should be based on a system of indicators;
- It should compile a general, comprehensive, and complex competitiveness indicator that can be used for comparing, supporting managerial decisions, making strategic decisions, etc.;
- It should allow comparisons across a wide range of competitors;
- It should be applicable both to the retail enterprise as a whole and to different types of retail outlets or warehouses;
- It should allow for algorithmization of the assessment process through a specific sequence of stages to arrive at a complex competitiveness assessment.

The competitiveness of retail establishments is related to the benefits and utility that consumers receive during the purchasing process. Consumers determine the utility based on the advantages they gain as a result of making the purchase, compared to the price they pay. (Владиминова, Й., 2005)

Customer utility is exceptionally important for retailers, because:

- It is important for a retailer to provide high value to their customers and to ensure that customers feel confident that their money is well-spent in making a purchase. This applies to all purchases, regardless of the amounts spent;
- Consumers have access to information about the prices of products offered by competing companies, which is why retailers are striving to set comparable and similar prices for the goods they offer;
- The competitiveness of a retail outlet depends on its distinctive characteristics and unique competitive advantages over the other market participants that offer greater utility to consumers;
- The utility-to-price ratio is essential and should be determined and analysed on an ongoing basis;
- The benefit-to-cost ratio should also be analysed in assessing the individual competitive advantages.

In commercial practice, mistakes are often made in selecting the characteristics of utility by including services that increase the perceived utility of goods, but which consumers do not find necessary and are not willing to pay a higher price for. Another common mistake is when a company guarantees the provision of additional services that, during the actual use of the products, are either not delivered or their delivery causes difficulties for consumers.

A comprehensive assessment of retail outlet competitiveness can be carried out through eleven stages. For the comparative analysis to be objective and to ensure comparability of characteristics and competitiveness indicators, it is necessary to select retail outlet(s) of the same kind and type as the one being assessed. The stages for assessing the competitiveness of retail outlets are as follows.

2. ASSESSMENT OF THE CURRENT COMPETITIVENESS OF MEBELI VIDENOV AND IKEA

The competitiveness of retail companies is assessed by determining the competitiveness of their individual retail outlets as well as an assessment of the overall competitiveness of the enterprise as an independent economic entity.

Both competitiveness indicators (for individual retail outlets and the enterprise as a whole) have specific relative weights and ratings on a scale from 1 to 5 (1 – very unfavourable; 2 – unfavourable; 3 – neutral; 4 – favourable; 5 – very favourable). The empirical data is first used to calculate the weighted indicators, which are then used to calculate an integral competitiveness indicator (Tsvetitskykh, A., Polukhin, I., Gromov, A., Chuvashova, M., 2023). This method has certain limitations since not all indicators can be accurately quantified because there is no publicly accessible information about them.

The analysis was carried out using data from the 2023 annual financial reports of MEBELI VIDENOV and IKEA, which operate in the retail furniture segment in Bulgaria.

MEBELI VIDENOV is a Bulgarian company with a 35-year history in the production and retail of furniture for homes, offices, and hotels. It sells over 90,000 pieces of furniture per month

through to its own logistics network. In addition to its operations in Bulgaria, the company is also active on the markets of Greece, Romania, North Macedonia, Albania, Hungary, and Moldova.¹

IKEA International Group (IKEA) is a multinational company specializing in home furnishings retail. The company was established in Sweden by Ingvar Kamprad in 1943. IKEA entered the Bulgarian market in 2011 with the opening of its store in Sofia through a franchise agreement with the House Market company, which runs five IKEA stores in Greece and one in Cyprus.²

In 2023, the product range of MEBELI VIDENOV included a total of 2,293 items, 120 of which were new. During the same period, IKEA offered 12,000 items in its product range, with 1,842 of them being new products. Based on this data, the novelty coefficient of the product range can be calculated as follows:

- For IKEA:

$$K_n = \frac{N}{T_n} = \frac{1\,842}{12\,000} = 0.153$$

- For MEBELI VIDENOV:

$$K_n = \frac{130}{2\,293} = 0.056$$

The values of the coefficient for the two companies lead to the conclusion that IKEA outperforms MEBELI VIDENOV in terms of the novelty of its product range, which gives it an advantage over its competitor. IKEA also outperforms MEBELI VIDENOV in terms of the breadth and depth of product categories, as it offers its customers a wide range of product categories, each of which includes a large number of items.

Due to existing limitations that do not allow for an accurate calculation of the product range saturation (namely, the lack of accessible data regarding the regulated or planned quantity of goods and services), only the total number of offered goods and services is taken into account. In 2023, IKEA offered 12,000 products and 4 services while its competitor MEBELI VIDENOV offered about 2,293 products and 4 services to its customers. In this regard, IKEA significantly outperforms MEBELI VIDENOV in terms of the total number of goods offered.

In 2023, MEBELI VIDENOV operated 44 retail outlets in over 40 cities and maintained a well-developed online store. In the same period, IKEA had 4 physical stores, two order and delivery centres, and also a well-developed online store. Retail outlets of both companies have parking facilities, with IKEA's parking areas being larger. In addition, their retail outlets offer various conveniences to its customers. For example, IKEA stores include a children's play area with supervision, a room for infant care and hygiene, a full-day restaurant, etc., while MEBELI VIDENOV outlets offer fewer such amenities.

Both companies are focused on the high quality of customer service in their retail locations. In 2023, the average number of employees at MEBELI VIDENOV was 852, compared to 408 at IKEA.

¹ For more details: https://videnov.bg/page/za-nas?_gl=1*1pr3xb*_up*MQ..*_gs*MQ..&gclid=EAlaIqobChMI14rfssKWjAMVS5toCR2AYCFOEAAYASAAEgKr2fD_BwE

² IKEA's sales in Bulgaria have grown with more than 10% for a year.
<https://www.mediapool.bg/prodazhbite-na-ikea-v-bulgaria-narasnali-s-nad-10-za-godina-news238712.html>

The product range and types of services offered by the two enterprises are not entirely comparable. The National Statistical Institute provides data on retail sales by product groups, but not for the entire market segment. Since there is no comprehensive and reliable information available on sales volume broken down by product range, their exact market share cannot be accurately determined. Therefore, in this case, it is considered appropriate to compare the companies' sales revenues and their dynamics. The assessment of the competitiveness of the retail outlets of the two companies is presented as weighted indicators in table 1.

Table 1. Assessment of the competitiveness of the retail outlets of IKEA and MEBELI VIDENOV

I. Product range characteristics	IKEA: $1.25 + 1.25 + 1.25 + 1.25 = 5.00$ MEBELI VIDENOV: $0.75 + 1.00 + 0.75 + 0.75 = 3.25$
II. Customer service characteristics	IKEA: $0.75 + 0.30 + 0.60 + 0.75 + 1.00 + 0.60 + 0.50 = 4.50$ MEBELI VIDENOV: $0.75 + 0.40 + 0.60 + 0.60 + 0.80 + 0.60 + 0.50 = 4.25$
III. Accessibility of goods and services	IKEA: $1.60 + 1.60 + 1.50 = 4.70$ MEBELI VIDENOV: $1.60 + 1.60 + 1.20 = 4.40$
IV. Retail outlet location	IKEA: $1.05 + 1.50 + 1.40 = 3.95$ MEBELI VIDENOV: $1.05 + 1.20 + 1.40 = 3.65$
V. Promotion means	IKEA: $1.40 + 1.20 + 1.40 = 4.00$ MEBELI VIDENOV: $1.75 + 1.20 + 1.75 = 4.35$

Source: Authors' calculations based on data from the 2023 financial statement of the companies.

Each retail outlet competitiveness indicator has a relative weight of 0.20 in the integral competitiveness assessment of the retail outlets of the two companies:

- For IKEA: $(0.20 \times 5.00) + (0.20 \times 4.50) + (0.20 \times 4.70) + (0.20 \times 3.95) + (0.20 \times 4.00) = 1.00 + 0.90 + 0.94 + 0.79 + 0.80 = 4.43$

- For MEBELI VIDENOV: $(0.20 \times 3.25) + (0.20 \times 4.25) + (0.20 \times 4.40) + (0.20 \times 3.65) + (0.20 \times 4.35) = 0.65 + 0.85 + 0.88 + 0.73 + 0.87 = 3.98$.

The results of the analysis lead to the conclusion that IKEA's retail outlets are more competitive than those of MEBELI VIDENOV due to the advantages represented by the indicator values presented above. This influences consumer preferences and their choice of a specific retailer.

CONCLUSION

In order to successfully enhance the competitiveness of a retail enterprise, it is essential that it be assessed. The assessment provides information about the enterprise's position in the competitive market, enables comparisons with past periods and other competitors, and supports the analysis of different alternative management approaches and decisions. Thus, it becomes a prerequisite for choosing a competitive development strategy. (OECD, 2021)

Competition in the furniture sector is extremely high, especially between local manufacturers and international chains. In Bulgaria, MEBELI VIDENOV and IKEA are two major players in this sector, although they employ different business models, pricing policies,

and strategies. The goal of this analysis is to compare the competitive advantages and disadvantages of the two companies, using real data on their market position, pricing policy, product quality, marketing, and customer satisfaction.

Based on the conducted research and the methodology presented above, the following key conclusions can be formulated. First, IKEA has a strong global presence, while MEBELI VIDENOV relies on the local market and personalized services. Second, IKEA is more accessible to the mass market, whereas MEBELI VIDENOV positions itself as a premium brand. Third, IKEA focuses on functionality, while MEBELI VIDENOV is concentrated on quality and a personalized approach. Fourth, IKEA invests in digital marketing, while MEBELI VIDENOV relies on direct, personal contact. Fifth, in terms of customer satisfaction, both companies have positive ratings, although they put a focus on different aspects. Sixth, IKEA dominates with global presence and low prices, but MEBELI VIDENOV offers higher quality and customized solutions. The choice between them depends on the customers' budget and preferences. Seventh, IKEA's retail outlets are more competitive than those of MEBELI VIDENOV due to the advantages represented by the indicator values discussed above. This also influences consumer preferences and their choice of a particular retailer.

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SELECTED ASPECTS OF THE TREE STANDS ECONOMIC USE DAMAGED BY HURRICANE (WINDFALLS) - THE REGIONAL FORESTRY CASE OF POLAND

Leszek Wanat, Władysław Kusiak, Łukasz Sarniak, Marek Wieruszewski

Abstract: The study discussed selected aspects of roundwood management in forest areas affected by intense hurricanes. The forest damage in selected units of the State Forests that occurred in Poland between 2002 and 2022 was analysed. The procedures for dealing with forest damage, their consequences, as well as potential options for managing wood harvested from hurricane-damaged trees were evaluated. Based on the results of the multiple case study assessment, as well as a diagnostic survey in forest districts, key conclusions and recommendations for forest policy were formulated.

Keywords: windfalls, post-hurricane roundwood, mesoeconomics, natural disasters, Poland

1. INTRODUCTION

Climate change is having an impact on forest ecosystems. Their consequence is damage, caused by various biotic and abiotic factors. Post-hurricane damage (so-called windfalls) is especially severe. When in Poland, on 4.07.2002, a hurricane destroyed trees in the Piska Forest (Puszcza Piska), it was thought that such a cataclysm would not be repeated soon. Not even 15 years had passed when another, much bigger disaster occurred in 2017 [4]. The question of the quality, value and usefulness of hurricane-damaged roundwood is thus rightly posed [2]. Wood harvested from wind-broken trees is exposed to cracking, but also to other damage. This prospect may result in a change in forest management strategies and the wood market structure [3]. An analysis of selected forest management aspects, including hurricane-damaged trees, therefore seems reasonable and necessary [10,11]. The need for rational programming of forestry policies in Poland, threatened in the future by further natural disasters.

2. MATERIAL AND METHODOLOGICAL BACKGROUND OF THE STUDY

The starting point in the research was an analysis of the hurricane consequences that occurred in Poland between 2002 and 2022. This background was used to evaluate selected aspects of wood management, which must also take into account the harvesting of windfalls. A multiple case study formula was applied to research in selected forest districts of Poland's state monopoly, State Forests. In the spatial scope, the post-hurricane area was selected in the following regions: Piska Forest / Puszcza Piska (2002), Tuchola Forest / Bory Tucholskie (2017) and the forests of northern and western Poland (2022). In the latter case, the multiple storms covered the area of several Regional State Forest Directorates of Szczecin and Szczecinek, as well as Pila and Poznan, and Gdansk, Olsztyn and Bialystok [8]. Secondary data, available in scientific literature and industry reports [4, 7], as well as photographic documentation, were used for the assessment [8]. Selected forest districts that liquidated the consequences of hurricanes were invited to the study. Three diagnostic survey techniques were

used: a written questionnaire, a formula of individual in-depth interviews with foresters working on the elimination of damage, as well as self-observation (a study visit to forest damage areas).

The procedure for the district forestry departments' work in situations of natural disasters (including hurricanes) was reviewed, as well as the method of inventorying damaged forest areas. The type of damaged trees, the process of harvesting damaged wood assortments (order, type), as well as the techniques and machinery used to harvest hurricane-damaged wood were analysed. Windfall wood harvesting plans and how they were classified were also assessed. Detailed studies were conducted in two forest districts: Gniezno and Szubin [4]. Those forest districts with the highest forest damage on 17.08.2017 were selected. In addition, a follow-up e-survey was conducted again in 9 selected forest districts after the 2022 hurricane.

3. THE POST-HURRICANE SITUATION IN THE FORESTS – THE CASE OF POLAND

The analysis of the effects of disasters caused by hurricanes was carried out using a multiple case study formula. The effects of three hurricanes that occurred in Poland between 2002 and 2022 were evaluated: (1) in the Pisz Forest (2002), (2) in Bory Tucholskie (2017), and (3) in western Poland (January and February 2022) [8, see: Figure 2 and 3].

3.1. Consequences of the hurricane in the Pisz Forest / Puszcza Piska in 2002

A strong hurricane in the Piska Forest on 4.07.2002 caused serious damage to more than 33,000 hectares (an area 130 km long and about 8-11 km wide). About 1.5 million cubic meters of wood were destroyed. The disaster area was divided into squares of 50-200 hectares. The damage elimination work, which lasted 2.5 years, was undertaken by 27 forest districts (from the regional directorates of Białystok and Olsztyn). Post-hurricane lying trees were removed first. Later, so-called 'scrap' trees (those trees broken by the hurricane) were cut down [Figure 3]. Finally, leaning trees with a pronounced, broken root system were removed [Figure 1]. Finally, mainly medium-sized roundwood (pulpwood and firewood) and good-quality sawn wood were harvested. Roundwood (pine) for the paper industry was sold at price discounts to wood-based chipboard producers in Świecie, Ostrołęka, Kwidzyn and Grójewo [8].

3.2. Consequences of the hurricane in the Tuchola Forest / Bory Tucholskie in 2017

The hurricane in 2017, caused a disaster much greater than in 2002. On 11 and 12.08.2017, a very strong storm traveled a route from Gdansk, through the Tuchola Forests, to the Oborniki Śląskie Forest District. The losses were huge, often difficult to estimate (difficult to access post-disaster areas) [1]. Aerial measurements were therefore used. A four-level scale was used to estimate damage: up to 20% (level IV), from 20% to 50% (level III), from 50% to 75% (level II), above 75% (level I). Post-disaster areas were divided into revirs (about 500 hectares). Measures were taken in two stages: cleaning up trees lining forest roads and creating conditions for the efficient elimination of damage.. A photo-optical scanner of the "Dralle" system was used to measure post-hurricane wood. This technique streamlined the damage estimation process. The stocking of large quantities of roundwood forced non-standard solutions. The organization of a central roundwood depot was dropped. Valuable roundwood grades were harvested first: sawnwood (large-dimensional WO), then logs (medium-dimensional SB2), and finally pulpwood (medium-dimensional SBA and S2AP/S4) [8].



Figure 1. Broken trees (so-called wood scrap) after the hurricane
Source: Own elaboration based on [author's photo by W. Kusiak, Poland 2022]



Figure 2. Permanently overturned trees with root parts after hurricane
Source: Own elaboration based on [author's photo by W. Kusiak, Poland 2022]

3.3. Consequences of the hurricane in north and western Poland in 2022

At the beginning of 2022, Poland was 'hit' successively by orkans Malik, Nadia, Dudley, with winds of 160 km/h, followed by Eunice and Franklin. The storm covered northwestern Poland. Forests in the area are managed by the Regional Directorates of State Forests in Szczecin and Szczecinek, as well as Pila, Poznan, Gdansk, Olsztyn and Bialystok [8]. Besides

trees, power lines, roads, and households were damaged. The most damage was caused by Eunice (more than 500 thousand cubic meters of damaged wood). Other forest districts 'lost' from 15 to 60 thousand cubic meters of raw wood. A total of 36% of the roundwood harvesting plan for 2022 (more than 1 million m³) was estimated as a result of the winter hurricanes [13]. Actually, it turned out that the hurricane forced the harvest of 4517 thousand m³ of roundwood. In individual regional directorates it was respectively: 1171 thousand m³ in Szczecin (30% of the 2022 annual plan), 1091 thousand m³ in Szczecinek (26%), 643 thousand m³ in Pila (34%), 225 thousand m³ in Poznań (11%), 108 thousand m³ in Gdańsk (7%), 219 thousand m³ in Toruń (9%), 833 thousand m³ in Olsztyn (28%), and 227 thousand m³ in Białystok (8%) [8].



Figure 3. Leaning trees after hurricane



Figure 4. Harvesting of broken trees

Source: Own elaboration based on [author's photo by W. Kusiak, Poland 2022]

4. SELECTED RESULTS AND DISCUSSION

The data was collected, aggregated and discussed (seven steps, marked 1-7). First, an assessment was made of the rules for handling post-hurricane damage in forest districts (1). The procedures were confirmed by only five forest districts (Bobolice, Bolewice, Ośno, Resko, Sarbia). The method of inventorying the damaged forest area was also analysed (2). Preliminary estimates were made based on a forest visual inspection. Only some forest districts performed aerial estimates. The results were verified based on after-assessment reports.

The proportion (%) of damaged trees was estimated according to the type of damage (3). They were estimated in four groups: trees knocked down by the wind with the root part (50-80%), broken trees (5-30%), trees bent by the wind (0-25%), as well as other damage, that is, trees tilted, twisted, torn, etc. (0-10%). The process of harvesting roundwood assortments was

also verified (4). Large-dimensional sortiments (so-called valuable wood, according to classes: WAO, WBO, WCO, WD) were harvested first; then medium-dimensional (according to classes: S2B, S2A and S2AP), and finally S4 (firewood).

Post-hurricane damage elimination methods were evaluated (5). Three methods were verified: traditional method (chainsaw and skidder tractor), mixed method (traditional method and multi-operational machine), and machine method (use of multi-operational machine: harvester, forwarder). In practice, it is difficult to apply a one-size-fits-all method. Thus, a method was chosen that was appropriate to the forest situation. Most often, the machine method was used (harvesters, in cooperation with forwards) [Figure 4], especially for larger damage. Individual damage was removed using chainsaws and skidder tractors (hand-machine technique). It was also determined which wood grades were harvested from post-hurricane areas (6). The largest amount - S2A grade wood (for the paper industry), and the smallest - S2B group (utility wood). Assessing the method of wood classification (7), it was noted that post-hurricane wood was classified according to standards, like typical wood raw material. Full information about the wood's source and quality defects is necessary [9]. Of course, the post-hurricane situation is economically difficult. However, it may pose a challenge for business activity, including alternative business activity, for example in the field of agroforestry [14].

5. CONCLUSIONS

Based on the comparative and descriptive analysis, the following conclusions and recommendations were formulated:

- 1) The development of clear procedures for dealing with post-hurricane forest damage is necessary due to the high probability of similar disasters in the future [5,12].
- 2) The following need to be assessed: methods of measuring damaged forest area, principles of harvesting post-hurricane timber, foresters' work techniques in the damage area, and the use of modern machinery and equipment [12].
- 3) It is necessary to determine an adequate market and economic use of lower quality (post-hurricane) roundwood [6,11].

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VARIATION OF CONIFEROUS SAWNWOOD MATERIAL EFFICIENCY ON THE CASE OF THE QUANTITY-DIMENSIONAL STRUCTURE OF ROOF TRUSSES: SELECTED ECONOMIC AND ECOLOGICAL ASPECTS

Marek Wieruszewski, Leszek Wanat, Władysław Kusiak, Łukasz Sarniak

Abstract: The study discusses selected aspects of the material efficiency of processing softwood into components of wood-based roof structures. The relationship between the cost of purchasing roundwood and the cost of producing 'roofing' wood materials has been taken into account. On the case of the wood market in Poland, the efficiency of the production process in a sawmill was evaluated. The potential dependence of efficiency on the quantitative and dimensional structure of sawn coniferous products was also verified. Finally, economic and environmental recommendations were formulated.

Keywords: roundwood, lumber, timber roof truss, production efficiency, wood market, mesoeconomics, Poland.

1. INTRODUCTION

Wood, as a natural material with anisotropic properties, is a basic component of roof constructions.. Two types of building, roof timber structures are used: carpentry trusses (residential construction and outbuildings with roof structures with spans of up to 12 meters) and engineered trusses (in so-called hall construction for structures with longer spans, up to 20 meters) [1]. When an average of 4 m³ of wood (per 100 m² area) of wood is used for carpentry structures, only 2.1 m³ of wood is used for engineering structures [6, 13]. Engineered roof trusses therefore need a limited amount of wood (which gives m 'advantage' over carpentry roof structures). They are produced not on the construction site, but in specialized factories.

The primary tree species used to make wood-based roof structures are Scots pine (*Pinus silvestris* L.), Norway spruce (*Picea Abies* L.), and European larch (*Larix decidua* Mill.). You can also, depending on your wood resources, make the roof structure from poplar (*Populus tremula* L.) or European oak (*Quercus* L.) wood. The usability of a particular wood material is determined by its physical, botanical and mechanical characteristics (including: diameter and length of the knot area, as well as: density, compressive and static bending strength [7, 13]. The productivity and efficiency of the sawmill process depends on the proper selection of wood materials.

2. MATERIAL AND METHODOLOGICAL BASIS OF THE STUDY

The aim of the study was to evaluate the material productivity and efficiency of the product, that is, wood for roof trusses. The efficiency was evaluated based on the variation of the quantitative and dimensional structure of coniferous wood components of roof trusses. Thus, an analysis of the structure of the wood materials that create the roof truss construction

was conducted. The origin of the roundwood (raw material) and the quality-dimensional structure were considered. The material productivity of sawing was determined, as well as the efficiency index of the product (for wood-based truss components).

Processing of raw wood. Round wood was prised on a horizontal band saw, and then the prism cutting was done on a multi-saw. This is how 100 x 75 mm sawn material was obtained, as well as side timber (100 x 25 mm non-board and edged board). The boards obtained from the prising, as well as during the second sawing, were used 100% for the production of pallets. The only by-product was sawdust and wood ash.

Material productivity and efficiency. The material yield index allows assessment of material consumption for obtaining a specific wood-based product. The following indicators can be determined: quantity material yield (W_i), quality material yield (W_j), sort material yield (W_s). The material yield index is calculated as the ratio of the volume of wood products obtained (with a given degree of processing [a] or with a given degree of processing and a given parameter / material feature [b]), to the volume of products determined in the previous stage of their industrial processing. Thus, the reference point remains: the material volume from which the wood product /sawn/ was obtained, as well as the previous, that is, preceding stage of processing (production).

Material efficiency of roundwood processing (E_p) is an indicator, expressed in natural units or as a percentage [5, 13]. It is defined as the sum of the commodity value (main lumber and other sawmill products, as well as wood chips and waste, obtained from a given raw material), related to the cost of purchasing roundwood necessary to produce them. This indicator is explained by the following formula:

$$E_p = \frac{\Sigma V_w * C_w + \Sigma V_z * C_z + \Sigma V_o * C_o}{\Sigma V_s * (C_s + T_r)} * 100 [\%]$$

where the individual components mean:[13]:

V_w - the volume of wood processing products (destined for the domestic market and export),

C_w - unit prices of wooden products,

V_z - thickness of woodchip raw material,

C_z - contractual, conversion price of woodchips,

V_o - thickness of wood waste and sawdust,

C_o - conversion price of wood waste and sawdust,

V_s - thickness of raw wood (roundwood),

C_s - contract price of raw wood (roundwood),

T_r – transport cost of raw wood (roundwood).

Technological efficiency thus refers to the basic criteria, namely: the cost of the wood raw material used (roundwood) for processing, as well as the production mix (wood 'finished' products) [3]. It is worth noting that the real raw wood (roundwood) cost increases with the distance from where it is harvested. Thus, there is a 'distance limit' to the purchase of wood, which determines the desirability (profitability) of production [4, 16]. Optimizing forest transportation is a current challenge for a wood-based, circular economy [11, 12].

In a study of the production efficiency of selected softwood products (for domestic and export markets), material yields and commodity efficiency of edged timber (board, logs) were analyzed. It is noted that for material productivity (W_p) of 55-59%, one achieves 85-165%

product efficiency. In the specific wood market (German and Dutch), which is a customer of edged timber, for material yield W_p of 59-64%, a product efficiency rate was obtained: 154-180% [13]. Product efficiency therefore depends on market specifics (including raw wood/roundwood prices and the exchange rate) [2, 8].

The productivity of pine construction sawn wood for the domestic market is shaped differently, and as a result, so is the product's efficiency. Reaching 44-50% material yield (for logs, beams, roof trusses), product efficiency of 134-158% can be achieved. An increase in the price of wood raw material therefore results to decreased of product efficiency [13, 14].

3. RESULTS AND DISCUSSION

Qualitative-quantitative analysis was carried out in a sample industrial sawmill that was purposely selected. The mass (volume) of large-size sawn pine wood processed in one year (2023) was calculated. This 'total mass' includes individual quality groups of large-size wood. The dominant group was the WCO class (both in the second and first wood thickness classes). By completing successive orders for wooden roof trusses, the sawmill optimizes orders in the forest (that is, in: National Forests) [9, 15]. Thus, round wood of the appropriate quality grade and thickness was ordered, so that after manipulation, logs of the necessary diameters were obtained (according to orders). 'Measure of optimization' was thus based on economic and environmental factors [10, 12]. It was to achieve the highest possible yield of main lumber through sawing, while maintaining the highest quality of roofing wood material.

The assessment of the wooden elements' contribution to the roof truss structure was carried out according to the author's scenario. Twenty randomly selected orders were verified. It is assumed that the wooden roof truss is made up of rafters, purlins, mayflies, wood masonry, shoulders (swords of wood), columns, braces, ties, ridge purlin and other wooden materials. Percentages were determined for these particular truss elements. The main part of the wooden roof structure is the rafter (about 56% of the total wood 'mass'). Next are purlin (16%) and wood masonry (11%), which support the rafters. Further estimated shares: wood mayflies (8%) and ticks (2%), which prevent the rafters from sliding apart under load, as well as wooden posts and swords (4%), which support purlins. The rest of the truss share (3%) is accounted for by other wooden elements included in the roof design.

The analysis was based on an assessment of the utilization rates of wood raw material (roundwood). The first of the assessed factors was the roundwood price. Comparatively, it was noted that the year 2021, the price of WCO pine raw material in the first thickness class, ranged from 240 PLN/m³ net in February, up to 278.5 PLN/m³ net in September [15, 17]. But as early as 2023, the average purchase price of round wood, i.e. WCO grade pine logs in the first thickness class, was 210 PLN/m³ net. Adequately to this indicator, the wood prices in the other quality and dimensional (thickness) classes also developed. It should be noted that a kind of 'equivalent' to the value (price) of large-size wood, is, of course, the price of finished pine wood assortments (products). Depending on the cross section and type of wood (assortment), these prices in 2023 (Q4), were in the range of 350-850 PLN/m³ [15].

The evaluation of Ep's products efficiency, by lumber cross-section, was carried out taking into account the length measure L (which also means taking into account the rate of change in the price of wood raw material). Also, the longer the roundwood, the higher the thickness grade of the longwood, and consequently the higher it's price. The Ep index was determined for the

section: thickness/width >200 mm, where $L < 6$ m (see Figure 1) and the section: thickness/width <200 mm, where $6 < L < 8$ m (see Figure 2).

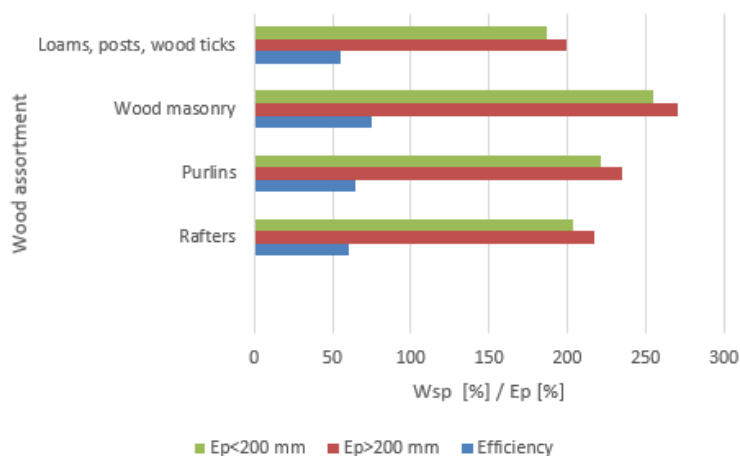


Figure 1. Products efficiency of softwood roof trusses up to 6 m in length: material yield coefficient Wsp (%) and efficiency Ep (%)

Source: Own elaboration based on [<https://www.drewno.pl/>; accessed on 03.02.2025] [15].

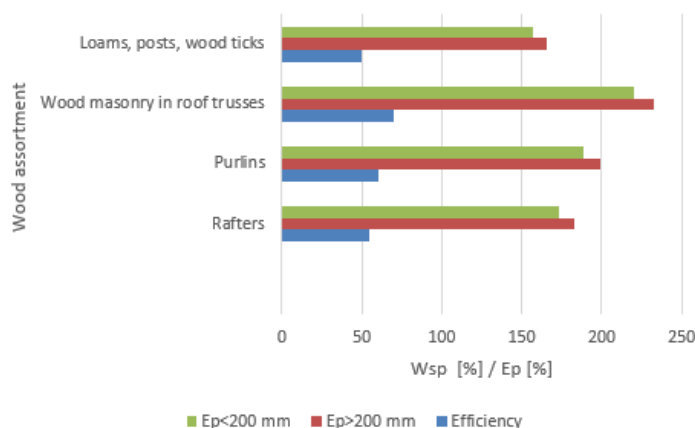


Figure 2. Products efficiency of softwood roof trusses over 6 m in length: material yield coefficient Wsp (%) and efficiency Ep (%)

Source: Own elaboration based on [<https://www.drewno.pl/>; accessed on 03.03.2025] [15].

It has been noted that production efficiency varies and depends on the thickness of the wood material. The indicator maintains a downward trend. Wood masonry and roof wood purlins have the highest efficiency. Why? Because the tested sawn wood has a square (or near-square) cross-section. The change in the length of the wooden component was also taken into account, in connection with the price change of roundwood. Then the efficiency decreases (especially compared to sawn wood with a length of less than 6 meters).

4. CONCLUSIONS

Based on the comparative and descriptive analysis, the following conclusions and recommendations were formulated:

- 1) The dominant class of large-size wood for sawmilling is the WCO class (93.1%). It is followed by the WBO class (4.53%), and the share of the others is only 2.37%. Each quality class was dominated by the second thickness class of roundwood.
- 2) Verifying the structure of the various wooden elements in the roof structure, the following proportions were found: rafter (55.61%), purlin (15.37%), wood masonry (10.6%) and wood mayflies (8.37%).
- 3) Material productivity factors include the quality of the wood raw material and the dimensions of the harvested roundwood sorts. If the roundwood is of better quality, then a higher price can be obtained for the finished wood materials ('sortiments').
- 4) Production costs of wooden roof structures can be optimized. For example, by selecting some sawn-wood components in the third quality class. The material efficiency of the remaining wood structural elements is then shaped according to the wood characteristics (raw-wood and material), cross-section and length.
- 5) Finally, it was noted that the material efficiency of sawmill production is approximately 55-64%. On this background, the product efficiency of softwood (dimensional lumber) in 2023, was 153-180% (European market). This efficiency determined for the Polish market, was 85-165%, respectively. Also, the average efficiency of the wood-based building material was 134-158%.

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ECONOMIC DILEMMAS OF QUANTITATIVE CHANGES IN THE PARTITION OF WOODY BIOMASS IN PELLET PRODUCTION - THE CASE OF POLAND

Marek Wieruszewski, Łukasz Sarniak, Władysław Kusiak, Leszek Wanat

Abstract: The study discusses selected aspects of quantitative potential changes in the wood biomass market, based on the case of wood pellet production. Currently, three sources of biomass are used for energy purposes: forest and wood-based waste, agricultural residues, and energy crops. Although the direction that will determine the biomass market is likely to be energy crops, research on forestry feedstock cannot be marginalized. Therefore, using the case of Poland, the current market for the supply and demand of wood pellets as wood-based biomass products was analysed. Finally, key conclusions and recommendations were formulated.

Keywords: mesoeconomics, bioenergy, biomass resource potential, energy security, wood pellets, European Union, Poland.

1. INTRODUCTION

Energy security and climate change mitigation are pillars of European energy policy. A key element in creating the renewable energy market in the European Union is biomass, which is expected to account for 56% of the green energy supply for the EU-27 [1]. The overall goal, aiming for a permanent increase in the share of renewable energy in the EU's energy balance, is highly controversial [14, 18]. What energy resource is being referred to? It's forest biomass. It represents the remains of felled trees, as well as the biological mass of wood from early forest thinning. However, the estimated bioenergy potential of forests varies (from 0.8 to 6.0 EJ/year). The long-term forecast to 2050 even puts the upper limit at 10.6 EJ/year [6, 9]. In EU countries, potential biomass resources include sewage sludge, municipal solid waste, wood processing residues, manure, and other agricultural wastes, among others.

Biomass can successfully 'participate' in circular economy programming [7]. Forest biomass, in the form of firewood, is commonly used to produce heat energy in rural areas. Firewood is readily available. It can be transported cheaply over short distances, and is competitively priced. One factor in the development of the biomass market is the growing demand for wood-based pellets. Wood pellets have become a popular renewable fuel. It is used for heating homes and apartments primarily in Canada, the US, Scandinavia, the UK, as well as in EU countries [12]. The traditional use of firewood, especially in rural areas, as well as significant wood resources, create natural conditions for the development of the wood pellet sector. Are these wood market developments correct? This question, given the significant forest resources, including biomass resources, also applies to the case of Poland.

The starting point for identifying and assessing the conditions for the contribution of woody biomass to the energy balance is not only an analysis of resource potential. It is also necessary to analyse the consequences of developing a wood-based energy market. In this context, there has been an attempt to identify the most important challenges and therefore dilemmas of development. The study used the results of previous research. The state of the art was verified, available secondary data was analysed. Comparative and descriptive analysis was applied.

Based on selected examples from the Polish market, the contribution of woody biomass, including pellets, to the development of the renewable energy market was assessed.

2. MATERIAL AND METHODOLOGICAL BACKGROUND

The analysis of the wood-based energy market segment, can be done from both the positive (opportunities) and negative (threats) perspectives [8]. One of the key products for this market is wood pellets. What use does it have? First, it is an excellent fuel for heating (thermal energy). It is also a good raw material for the production of green electricity. That is so-called clean, environmentally friendly biofuel.

When assessing energy potential, at least a medium-term or longer-term perspective (supply over 20-30 years) is taken into account. However, this is not always possible (and relevant to reality). This forecast depends, of course, on potential demand, mainly for wood chips and pellets. Looking ex post, between 2011 and 2020, there was an increase in the level of wood pellet production in Europe from 9.47 to 18.1 million tons. During the same period, there was an increase in the level of consumption of these resources worldwide from 12.5 to 39.8 million tons. It is expected that annual demand for wood pellets, could rise to about 25 million tons in Europe. This is due to the preferential policies followed by the EU. Institutional decisions seem to be driving much of the supply and demand.

Major European customers for wood pellets (demand market) include: UK, Italy, Denmark, Germany, Sweden, Belgium, France, Austria and Poland. On the other hand, the leading producers (supply market), and members of the EU (giving in parentheses the share of forests in the country's total area), include: Germany (32.8%), Lithuania (31.7%), Sweden (68.4%), France (31%), Austria (47.2%), Estonia (51.9%). In the case of Poland, there has been a significant increase in wood pellet production, up to 1 million tons between 2011 and 2021. So will the EU wood pellet market be a 'free market'? Not likely. Despite the EU's institutional pressures, the specific conditions of individual member states are likely to become the strongest regulator of the market. Thus, against the background of key conditions, secondary data was reviewed. Selected aspects of wood pellet market development were then discussed.

3. RESULTS AND DISCUSSION

By reviewing the results of studies available in the scientific literature and sector reports, the bioenergy market potential was assessed. A key creator of this market potential is the resources and production capacity of biomaterials, including pellets. The basis for bioenergy production in Europe is traditional and forage crops, that is: rapeseed, sugar and starch crops. Lignocellulosic energy crops are also growing in importance. So the resource potential in the green energy sector is changing. It is estimated that biomass potential will increase by 2030: for traditional food crops by an average of 7.3 EJ/year, and for lignocellulosic crops by an average of 15.3 EJ/year.

In Europe (EU27 countries), forested areas have increased by more than 22 million hectares since the beginning of the 21st century alone [3]. Despite the options in favor of energy crops, it is forestry and the wood-based sector that may determine the future design of the green energy sector. In terms of forest biomass, felling residues and tree bark are estimated to

remain unchanged in the short term (until 2030). However, the resources created from by-products of the wood industry should, over the same period, increase by about 30%.

3.1. The development trend of the wood-based pellet market

How are biomass resources for energy purposes assessed in research to date? First of all, the growing importance of growing so-called short-rotation (1-10 years) energy crops is indicated. These crops can also receive financial support under the EU Common Agricultural Policy [20]. Meanwhile, at the level of member countries, the potential supply of green energy resources is determined on the basis of internal energy demand trends. Conversion efficiency multipliers are used here. The starting point of the projections is the assumption that 11% of electricity generation in Europe is based on cogeneration of heat and electricity [3]. The actual share of wood pellets in the energy balance depends, of course, on changes in global demand (see Figure 1) [5].

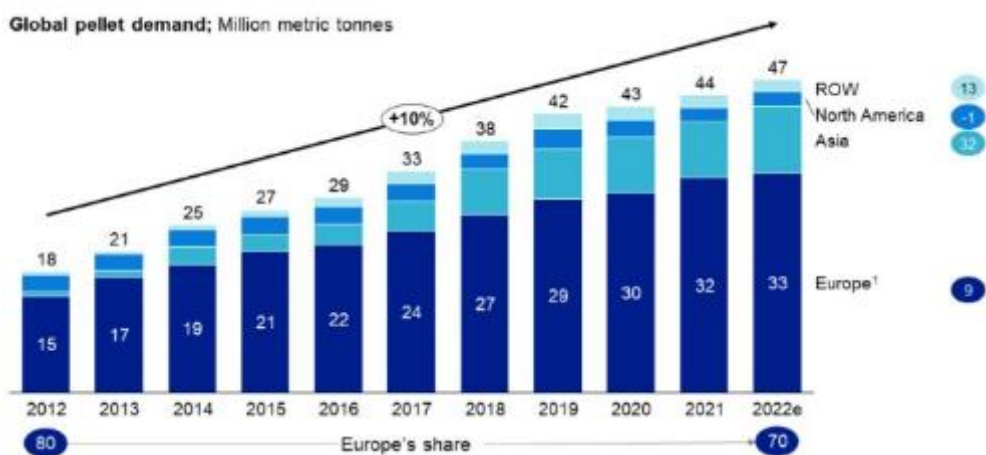


Figure 1. Europe on the back of global pellet demand (in millions of metric tonnes) [5].
 Source: European wood pellet market outlook 2023-2030 (accessed on 25.03.2025)

Under such conditions, it is estimated that the pursuit of the EU's energy target requires an increase in biomass supply to at least about 10 EJ in 2020 (in 2005 it was only 3.8 EJ) [3, 20]. This is an opportunity to develop the wood pellet sector. The growth of pellet trading is facilitated by quality assurance standards: the A1 certification system and the EN 14961-2 standard [5]. This allows the widespread use of pellets for residential heating (for heating boilers of the so-called 5th class) [17].

3.2. Production potential of wood-based pellets - the case of Poland

Poland reported a dynamic increase in pellet production after 2002 (about 90%). Regionally, production located in the Świętokrzyskie, Zachodniopomorskie and Wielkopolskie provinces dominated [11, 13]. Looking at the material (type of wood), the production of coniferous pellets (59%), mixed pellets (that is, coniferous-leaf pellets, 31%) and hardwood

pellets (10%) dominates [2]. This generic arrangement of pellet supply is primarily due to the species structure of Polish forests (coniferous species dominate) [13]. Also shown in Figure 3 are (comparatively), changes in pellet consumption in Poland (demand), as well as production dynamics in 2017-2022 [4, 21].

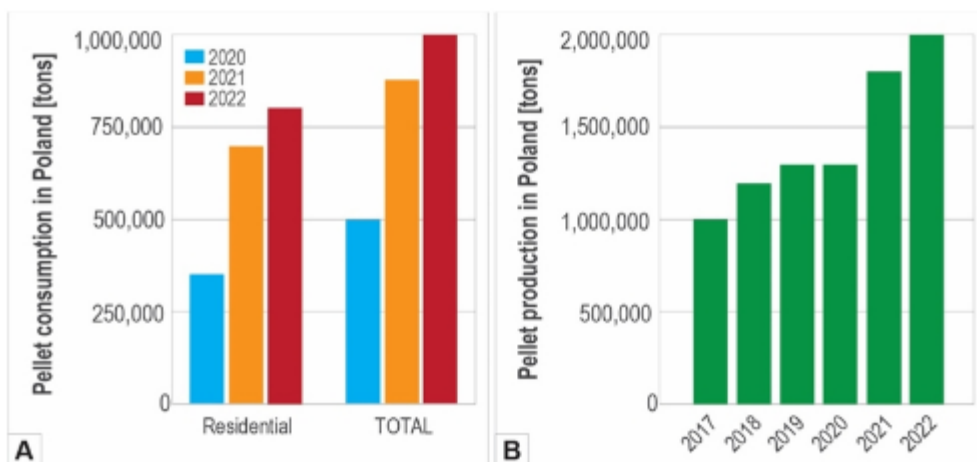


Figure 2. Changes in demand (A) for pellets (Polish consumption in 2020-2022) for heat/heating and total pellet supply/production (B) in Poland from 2017 to 2022 [4].

Source: Drobnia, A. et al. (2024).

Pellet producers in Poland apply quality standards under two certification systems. In the group of wood firms analyzed in the company's own research, 54% have the DIN-plus certification system (granted by the German Certification Institute). This system covers both the production process and the product itself. Meanwhile, 46% of companies have ENplus A1 certification (awarded by the European Pellet Association) [17]. This certificate specifies the requirements for wood pellets used in the production of thermal energy (heating). Certification is gradually becoming a widely used standard [10]. In the surveyed group of Polish enterprises, 42% of them produce wood pellets for export [17, 21].

What are the implications of regular growth in wood pellet production? The share of renewable energy for European Union members should reach 32% in 2030 [3]. Will this actually happen? Production of woody biomass, including pellets, will be particularly important for countries whose natural conditions do not allow them to increase the share of other renewable energy sources (including: hydropower, solar energy) in their energy mix. Poland has the resources to take advantage of this opportunity [15, 16, 19].

4. CONCLUSIONS

Based on the comparative and descriptive analysis, the following conclusions and recommendations were formulated:

- 4) The demand for wood biomass for energy purposes in the European Union is steadily increasing. It is estimated that in 2025 it will be an average of 10 EJ/year. This is an opportunity for the development of the wood pellet market in Europe and Poland.

- 5) It is assessed that the sourcing of energy biomass and its efficient use, will meet at least part of the demand for green energy. Biomass sources are diversified. Thus, forest biomass production should not increase significantly in the future. Instead, it is the integration of technology with the efficient use of production waste that is the opportunity for rational decarbonisation of energy supply.
- 6) Under current conditions, the demand for green energy will increase. Permanent scientific studies are therefore necessary. It is also a task to search for new biomass sources, new processing technologies, so as to connect the circular economy chain.

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OPTIMISATION OR INTEGRATION AND UNIFICATION? SPACE-FILLING PROGRAMMING CHALLENGES FOR TRANSPORT VEHICLES IN ROUNDWOOD LOGISTICS

Leszek Wanat, Władysław Kusiak, Łukasz Samiak

Abstract: The potential ability to optimise the filling space of transport vehicles is an important challenge for forest management. In the study, this transport capacity was verified based on the actual dimensions of the transported wood assortments. The analysis was based on the main conditions for wood transport in the logistics process. Opinions of entrepreneurs providing transport services for forestry in selected regions of Poland were used to verify the findings. The research was conducted using a diagnostic survey method (individual in-depth interview – IDI). It turned out that the level of filling of the cargo space of transport vehicles is a derivative of the dimensions of the transported wood assortments. Therefore, it is a matter of standardising the length of the harvested wood, which leads to maximising the filling of the cargo space and thus reducing forest transport costs.

Keywords: roundwood, forest economics, logistics, transport, cargo space, cost optimisation, wood dimension classification, Poland

1. INTRODUCTION

Optimising logistics processes is one of the key issues in forestry engineering. This applies in particular to the transport of roundwood. Therefore, logistics techniques that are not always obvious are needed at every stage of the supply chain [8]. The core regulations governing wood transport, including safety and related rules, are set out in Polish national legislation (acts). The transport of roundwood requires consideration of the actual weight, calculated as the result of multiplying the volume of the load by the standard density adopted for a given species of wood [2, 7]. The profitability of transporting raw wood materials depends on the volume of wood, which varies according to the conditions (season) of storing roundwood in the forest [5]. Previously, the effectiveness of roundwood transport in forests was verified based on selected technical and economic indicators [3, 6, 11]. However, this does not explain the complexity of the problem. Optimising cargo space requires the use of appropriate techniques, including adapting the vehicle to the dimensions of the transported roundwood, or vice versa. It is more efficient to use separate sets of transport vehicles for loading long wood (Figure 1) and another set for stacked wood (Figure 2) [4].

2. MATERIAL AND METHODOLOGICAL BACKGROUND OF THE STUDY

The starting point is the best possible distribution of roundwood loads in order to minimise empty transport space. The most important criteria for optimising the transport of roundwood harvested in the forest include: the type of raw wood material, the dimensions and other physical properties of the wood, and the organisation and logistics techniques [7].



Figure 1. Placement and transport of long roundwood cargo
Source: based on author's photo by W. Kusiak, Wielkopolska, Poland [4].



Figure 2. Placement and transport of stacked round wood
Source: based on author's photo by W. Kusiak, Wielkopolska, Poland [4]

The primary criterion determining the choice of roundwood transport is the type of wood assortment and its dimensions [1, 5]. Of course, other factors are not necessarily obvious. Therefore, taking other specific criteria into account, expert opinions of practitioners and forestry entrepreneurs were consulted. The research was conducted using a diagnostic survey method, employing the technique of individual in-depth interviews (IDI). Based on a targeted selection, wood transporters with at least 10 years of experience were invited to participate in the discussion. It was not possible to maintain the sample's representativeness, which is why an expert, qualitative selection was used. Individual interviews were conducted with 40 Polish entrepreneurs [4]. The responses were collected from five Polish regions (voivodeships): Lubuskie, Małopolskie, Pomorskie, Wielkopolskie, and Zachodniopomorskie. These regions have relatively high roundwood harvesting (adequate to the forest resource volume) and significant technical potential of forest transport businesses. The respondents' opinions were anonymised.

The following types of roundwood [4] were included in the study:

- large-size roundwood 'W': W0 and WK;
- medium-size roundwood 'S', including: stackable wood S2a (industrial), S2b (utility), S2AP (general purpose), S4 (firewood);
- small-sized roundwood 'M', including: M1 (industrial), M2 (firewood);
- wood residues 'M2E'.

The diagnostic survey got done using a custom questionnaire. The form had 20 questions, including 11 closed questions and 9 open questions. The interviews took place in 2022. The collected data were organised and aggregated. The most important responses were illustrated graphically. They were verified using the Chi-square test, assuming a significance level of $\alpha=0.05$ (using PQStat tools) [9]. The results were discussed.

3. SELECTED RESULTS AND DISCUSSION

Relatively the most frequently transported was roundwood of group S. This was confirmed by 51% (when indicating one type of wood) and 50% (when indicating more than one type of wood) of the responses received. The least frequently transported wood assortment was W0. This was indicated in 13% of responses (when selecting one assortment) and 8% of responses (when selecting more than one assortment). Roundwood loads were most often transported over distances of up to 50 km. Two-thirds of forest logistics businesses (66%) provided services on short routes (up to 100 km). Only 22% of businesses provided transport services on routes between 101 and 150 km, and 12% on longer routes (151-200 km). The greatest difficulty was the transport of wood residues (group M). In the WK assortment group, it was determined that the most frequently transported assortment was 3-4 m long logs (53%), while in the medium-sized roundwood group, it was 2.40 m long logs (44%). The least frequently transported items were: in group WK – logs with a length of 5–6 m, while in group S – logs with a length of 1.20 m (see Figure 3).

In response to the question: is it possible to indicate the optimal (for cargo space) length of wood logs, 45% of respondents considered logs with a length of 4-6 m to be the 'optimal load', while 43% considered logs with a length of 3-4 m to be the optimal cargo. Longer assortments, according to entrepreneurs, proved to be 'more user-friendly' and easier to transport. Similar results were recorded for large-size long roundwood and medium-size roundwood.

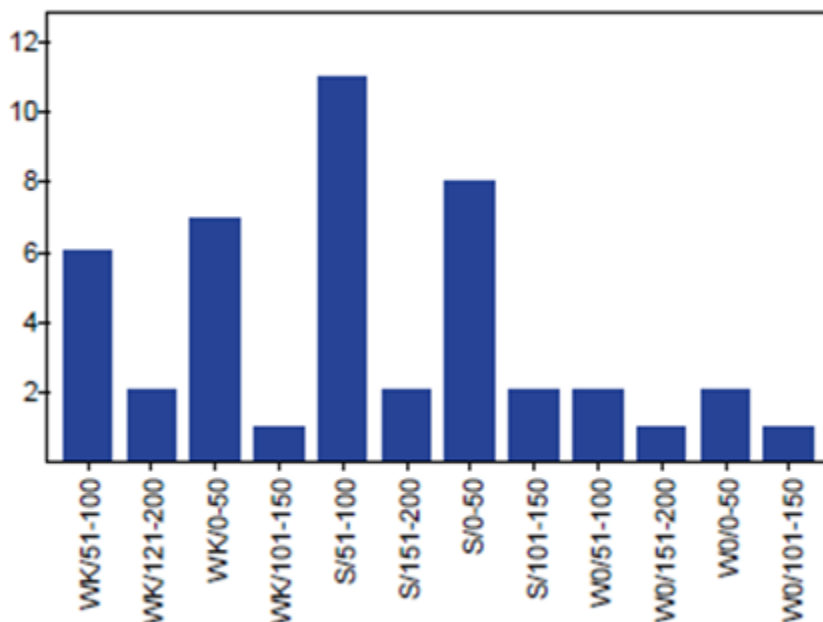


Figure 3. The relationship between the most frequently loaded assortment (number of observations on the y-axis) and the distance transported for roundwood / Source: [4].

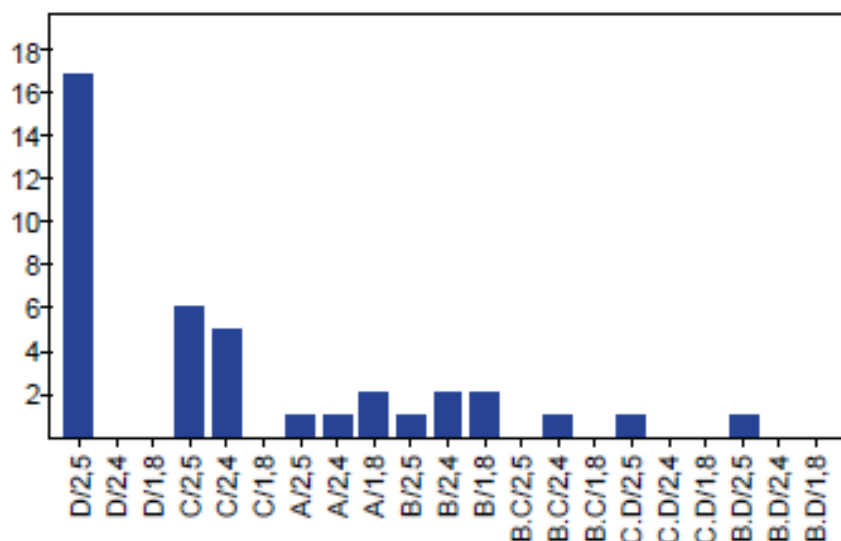


Figure 4. The relationship between the most frequently loaded length of roundwood assortment S (number of observations on the y-axis) and the length indicated in transport as optimal for group S (A=1.20 m, B=1.80 m, C=2.40 m, D=2.50 m) / Source: [4].

An interesting observation is illustrated in Figure 4. There was a significant statistical correlation between the analysed responses ($p=0.00258$). Forest transporters who most often transport 2.50 m long round logs considered this assortment to be the optimal way to fill the vehicle's cargo space [4].

When discussing the standardisation of pine wood transport (taking into account the length and thickness of roundwood), almost 52% of respondents chose the 1.8-3.0 m length range, and only 7% chose the 10-14 m range. In terms of roundwood thickness, 55% of operators indicated that the optimal range was 25–40 cm (55%). Only 20% of respondents considered the criterion of pine wood thickness to be irrelevant.

Transport operators strongly agreed (95%) that the length of logs determines the level of cargo space utilisation. It was considered necessary to standardise the length of roundwood harvested in the forest (77% for log transport and 80% for all assortments). This will facilitate the even arrangement of wood in the transport trailer, with the stanchions set at the same distance apart. Standardising the length of roundwood will significantly reduce loading time. The most commonly used vehicle for transporting round timber was a semi-trailer (73%), used for transporting both long wood and stacked wood. It was also found that roundwood loads are usually uniform (75% of carriers usually transport one assortment, while 25% transport a maximum of two assortments). When loading two length classes, the most common lengths were 2.40 m and 2.50 m (i.e. typical lengths of medium-sized stacked wood) were transported.

Reviewing the results might lead to the conclusion that the expected optimisation of roundwood assortment dimensions is difficult for practical reasons. There are also legal restrictions (permitted actual vehicle weight) and environmental restrictions (specifics of the roundwood harvesting site and transport) [10]. However, other barriers, especially those related to labour intensity, can be gradually eliminated by focusing on the safety of wood transport. Ultimately, it seems possible to achieve optimal utilisation of a vehicle's cargo space by applying not only institutionally defined legal regulations, but also taking advantage of the interests of entrepreneurs operating in market conditions.

5. CONCLUSIONS

Just to recap, it's actually possible to optimise the use of cargo space in wood transport vehicles. But how much space you can fill depends mostly on the size of the load you're carrying, like the wood assortments. It should be pointed out that:

- 7) The most frequently transported wood assortment was medium-sized stacked wood (group S).
- 8) The optimal solution would be to transport the longest (L) wood assortments in their respective classes. Satisfactory results can be achieved for the following lengths: $L=2.50$ m (for medium-sized stacked wood), $L=4-6$ m (for log wood), and $L=14$ m (for long wood).
- 9) To maximise the use of cargo space, the optimal thickness of transported wood assortments is indicated as 25-40 cm.
- 10) Standardising the length of transported wood (especially long roundwood) will facilitate even stacking of wood and reduce empty cargo space.

- 11) Forest transporters preferred single-length loads. When it was necessary to combine groups of medium-sized stacked wood assortments, the preferred lengths were 2.40 m and 2.50 m.
- 12) Despite the growing demand for wood-based energy resources, container transport was relatively rare.
- 13) Wood harvested in the forest (all assortment groups) was most often transported by wheeled vehicles: tractor units and pole semi-trailer.

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MULTINATIONL ENTERPRISES AND THE TIMBER VALUE CHAIN: INTEGRATING SUSTAINABILITY INTO GLOBAL BUSINESS STRATEGIES

Kaloyan Kolev

Abstract: This paper explores how MNEs in the global timber sector are embedding sustainability practices along their value chains. As the sustainability pressures arise timber companies' sustainability practices are shifting from green practice towards new business models blending profit and ecological sense. In our study we discovered successful MNEs embracing multilayer sustainability practices. Our study highlights some of the most critical drives for the change such as regulatory compliance risk reduction, expectation from the consumer regarding sustainability gain in the form of competitive advantage. From comparative cases of numerous world-wide timber stakeholders from North America, Europe and emerging economies we demonstrate how embracing sustainability agenda in business models can forestall environment degradations such as deforestation and meanwhile generate common value. We discovered that timber MNEs embracing the practice of traceability and reporting publicly on the supply structure attained desired environment performance steps and economic profitability. We recommend that timber MNEs have set out new benchmark standards of care shifting from the compliant position towards the leadership position on the sustainable management of the forests where everything this is reconfiguring the competitive maps. Our study contributes towards the new research on the way intensive and extensive world-wide industries reconcile economic progress and environment responsibility.

Keywords: timber sector, multinational enterprises, value chain

1. INTRODUCTION

Multinational enterprises (MNEs) are essential participants in the global timber production and supply chains, both as producers and consumers. The scale of their operations allows MNEs to influence production practices, including their sustainability parameters. This article analyzes how MNEs are implementing sustainability in their global value chains. This reorientation arises, on the one hand, under the pressure of increasing regulatory requirements, and on the other hand, it plays a role as a new source of competitive advantages over purely national or smaller firms in the timber sector. The study uses Jonah Dunning's eclectic OLI paradigm as a theoretical framework, while the conclusions are based on a comparative study of specific business practices of MNEs, including in a regional context.

2. MNE AND ECOLOGICAL CONTROVERSIES IN TIMBER PRODUCTION

Over the years, MNEs have always been associated with a predatory use of natural resources (Wilkins, 2001). In the timber sector, their scale activities usually cause massive deforestation of vast areas, supported by weak environmental regulations or corruption in developing economies. Deforestation has visible local effects such as the erosion of ecosystems, the reduction of biodiversity and water supplies (Dauvergne, 1997). Beyond the

environmental effects, MNEs also create problems for local communities (Adeola, 2001; Chilwalo, 2016). Practices such as forced displacement, the erosion of traditional values, labor exploitation and others have been documented in many developing countries and regions over the years.

The growing issues and public intolerance forced many countries to tighten their existing regulations or introduce new ones, including traceability and transparency requirements along the entire value chain (OECD, 2007; Neeff, T., et al., 2024). On the other hand, civil societies put companies' activities under constant monitoring and exposed their practices that are damaging to the environment and local communities (Schirmer, 2013). What was once considered an externalized cost is now a real business risk for MNEs. Companies face not only serious legal threats but also potential reputational damage. Consumer boycotts, negative media reports and information on social networks can irreparably damage MNEs brand's reputation, significantly reduce market share and lead to withdrawal of investors, limiting access to capital. Moreover, because of the global scale of operations even a single instance of unsustainable behavior within the global value chain can destroy MNE's reputation and its entire product portfolio. The growing pressure from governments and civil society completely changed the operating conditions of MNEs. Gradually, the costs of inaction have significantly exceeded those of implementing sustainable practices, forcing corporations to change their production practices.

3. SUSTAINABLE STRATEGY AS COMPETITIVE ADVANTAGE (OLI PARADIGM)

In addition to external pressure, there is another reason that motivates MNEs to undertake the change. Corporations can use the additional costs of implementing sustainable practices as a specific asset that increases their market competitiveness over the national counterparts (Porter & Linde, 1995; Li & Toppinen, 2011). The most appropriate way to explain this phenomenon is within the eclectic or OLI-paradigm. The framework was developed by John Dunning to explain why companies become multinational, how they choose the location and organize their overseas activities, how they decide what to internalize instead of using pure market transactions etc. When applied to the problem of sustainability, it explains very well how this cost burden turns into a source of strategic advantages and competitiveness (Dunning, 2008; p.95).

The starting point in the analysis is the so-called ownership (O) advantages. In general, these are companies' specific assets like technology, brand names etc., that are unavailable to small firms. But most important, O-advantages have the nature of public good. This means that they can be transferred abroad within the corporate structure without loss of value which makes international expansion possible. In the case of sustainability such advantages could become an investment in internal research centers for biotechnologies or genetics, specific certificates for sustainable sourcing or/and production, digital traceability platforms etc. that small businesses do not have the resources to acquire. Such assets could open an access to new sourcing operations sites and markets for final products. The attitude of consumers and investors to reward companies with good environmental performance makes the "green" brand identity a valuable asset, increasing the competitiveness of MNEs.

Location (L) advantages represent the specific benefits that MNE gains from the choice to invest and operate in a particular country or geographic area, such as access to resources, markets, specialized labor, or favorable regulatory regimes. Large timber multinationals

operate in many countries which allows them to position geographically different stages of their value chains in a pattern that strengthens their sustainability and serves their strategic goals. Therefore, MNEs' location decisions are not always cost driven. Furthermore, MNEs can be a catalyst of improvement of ecological standards in developing countries. Sometimes this is not an act of altruism, but rather a strategy to raise high environmental barriers that smaller competitors cannot overcome.

Table 1. OLI-paradigm and sustainability advantages for MNEs in the timber sector

Advantage type	How sustainability strengthens the advantages of MNEs	Competitive advantages over national firms
Ownership (O)	SFM Investment, R&D in bio-products, international certification, advanced traceability systems, establishing brand credibility for "green".	Access to significant capital for green investment; global brand name for certified products; enhanced R&D expertise for green technology.
Location (L)	Sourcing from certified forests in properly governed lands; "green" sales into customer markets; using host-country sustainability tax incentives or concessions.	Ability to diversify supplies from areas with varied sustainability performance; utilization of different regulatory regimes looking for maximum sustainable performance.
Internalization (I)	Vertical integration of forest management and processing; specific proprietary practices of sustainable production; in-house systems of diligence within the supply chain.	Improved value chain management ensuring sustainability criteria; minimized third-party non-compliance threats and transaction costs from suppliers; IP protection for eco-innovations.

The internalization (I) advantages represent the benefits that MNE can gain by conducting an activity itself within its own organizational boundaries rather than outsourcing or licensing it to an external party. Through internalization of important segments of added value chain MNE gains the ability to impose its own higher sustainability standards. For instance, if a paper company purchases pulp from various external suppliers, it can only partially guarantee environmental compliance. If the company uses only its own plantations, it may adopt specific programs for site recreation, biodiversity conservation, and the possibility of periodic third-party audits. Such approach eliminates the risk of unreliable external supplier and allows MNE to supply "in-house" assurance of environmental compliance and quality. Last but not least,

internalization can be used to limit the access of competitors to rare resources or plantations grown under high environmental standards, which increases the credibility and competitiveness of its brand.

4. SUSTAINABLE PRACTICES IN MNE TIMBER VALUE CHAINS (CASE EXAMPLES)

To uncover the characteristics of business practices that embed sustainability into value chains, the research analyzes operations of major timber sector MNEs in EU, North America and developing countries. The inquiry reveals that MNEs use four tools as a strategic instrument to improve their sustainability: certification, supply chain traceability, innovations in sustainable products, shareholders engagement.

Certification is the most common instrument of strategic transformation of global value chains. Examples in this regard are Stora Enso, UPM and Weyerhaeuser, which are implementing certification of their forests and supply chains (Stora Enso, 2022; UPM, 2024; Weyerhaeuser Co, 2024). Their implementation ensures compliance with strict environmental and social criteria and also guarantees the preservation of biodiversity, the responsible use of water resources, and the respectful treatment of local populations. Finnish companies Stora Enso and UPM are one step further. They have achieved almost full certification coverage of their production and supply chains, complemented by investments in ecological stewardship. With this strategic move, the companies have not only minimized regulatory risk but also responded to growing consumer demand for verifiable sustainability across the entire production cycle. In North America, Weyerhaeuser applies long term forest planning horizons within SFI and FSC certification. This decision allows sustainable timber supply while benefiting from ecosystem services such as carbon sequestration and water purification.

Digital traceability is the second tool that MNEs use to reduce the risk along the global value chain. Examples in this regard are Mondi, WestRock, and APP that possess robust Chain of Custody (CoC) and due diligence systems to trace the timber from forest to product (Mondi, 2025; Smurfit Westrock, 2024; Metsä Group, 2021). Modern equipment like satellite monitoring and GIS-based systems help verify and introduce accountability. APP and APRIL in Indonesia demonstrate a transition to reputational and market power. Zero-deforestation commitment, forest protection initiative, and electronic monitoring systems illustrate the shift from traditional deforestation towards leadership in disclosure. Suzano and Klabin in Brazil apply geolocation and plantation-only origin to trace illegality and forest conversion blocking point for entry into environmentally sensitive markets (Suzan, 2024). Traceability allows MNEs to supply certified low-risk products to ecologically sensitive consumers and authorities and improve their competitive power.

The innovations in sustainable products and processes are the third tools that are less commonly used due to their high cost. Some of the largest timber MNEs actively diversify their business models adopting or developing new ideas and technologies from bioeconomy and circular economy. Metsä Group, Sappi, and Arauco (Sappi, 2024; Arauco, 2024) developed products from renewable wood fiber sources in the form of bio composites, textiles, and biochemicals. These innovations diversify from traditional timber products and make companies less dependent while at the same time meets emerging needs in the building, clothing, and packaging. It also addresses the credibility and encourage the emergence of new sustainable businesses practices.

Environmental sustainability is closely related to social sustainability. MNEs in the timber sector now work more closely with local communities to build trust, avoid conflict, and create shared value. This shift goes beyond ethics. It is a strategic priority. Companies like Resolute Forest Products and Canfor in Canada (Canfor, 2022), as well as Suzano and APRIL in emerging markets (Suzano, 2024), are strong examples in this direction. Through support for education, healthcare, and long-term partnerships, help communities to become more resilient. Similarly, UPM and Smurfit Kappa include stakeholder voices in their managerial decision concerning forests and biodiversity. In regions with fragile ecosystems and contested rights on land like Indonesia and Brazil, partnerships are essential. They help companies balance their business goals with the real needs of local people and growing global expectations for responsibility and sustainability.

Although companies resort to the same tools in their efforts to embed sustainability in their global value chains, analysis of real business practices shows that there are some significant regional differences. European timber MNEs are pushing the circular bioeconomy forward through product innovation. These efforts are supported by well-defined regulatory frameworks and by ecologically aware customers. In contrast, North American companies employ certification, resource efficiency, and relations with local people in response to a mix of civil society influences and the law. Emerging market MNEs previously linked to forest degradation now go through a deep transition pushed by global pressure, reputational risk, and changing conditions in market access. Their reorientation shows a global convergence in sustainable forestry practice.

5. CONCLUSION

Timber MNEs are pioneers in incorporating sustainability into global value chains. Despite their exploitative and destructive forestry practices in the past, many of the companies adopted multi-layered green strategies as core business models. Through FDI in certified sourcing, supply-chain transparency, innovations and dialog with local communities, large timber firms reconcile environmental responsibility with profitability. Both external pressures and the OLI advantages that MNEs uniquely possess drive these strategies. Comparative evidence from North America, Europe and emerging markets shows that incorporating sustainability can buffer risk, meet consumer demand for eco-friendly products, and afford competitive differentiation. As a result, flagship timber MNEs are establishing new norms in the industry - assessing sustainable forestry not as a cost of doing business, but as a driver of leadership and competitiveness. Governments and policymakers should encourage this change by enforcing forest protection legislation and by rewarding sustainable timber FDI, which could be beneficial for local development and global sustainability agenda.

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MANAGEMENT, INVESTMENT, AND INNOVATION

ENVIRONMENTAL TAXES AS A MEANS OF SUPPORTING SUSTAINABLE DEVELOPMENT OF THE COUNTRY WITH A FOCUS ON THE FORESTRY INDUSTRY

Renata Nováková, Olena Plaksiuk, Eva Habiňáková

Abstract: The paper focuses on nature management as an objective process that takes place between society and nature and reflects the development, use, reproduction of natural resources, as well as the impact on nature, its transformation and protection in the interests of humanity. The forestry industry is part of the whole process and therefore it is necessary to focus from an economic point of view on areas such as: consumption, restoration, management and monitoring of resources in the forestry industry. Currently existing approaches to the use of natural resources cannot solve the issues of sustainable development. The main reasons are: the lack of a unified comprehensive approach and coordination in nature management, insufficient financing and stimulation of resource-saving measures, imperfection of the organizational and economic mechanism of nature management, instability of organizational management structures in this area of activity. Within the framework of the Concept of Sustainable Development, which includes the optimization and improvement of environmental policy, including with a focus on the forestry industry, the subject of our research will be how effective environmental taxation is in this area. In the article, we use secondary sources from available analyses and point out economic indicators related to taxation and sustainable development.

Keywords: environmental taxation, environmental taxes, eco-taxes, stimulation tools, sustainable development.

1. INTRODUCTION

The modern world faces numerous challenges related to environmental degradation, such as climate change, air, water and soil pollution, destruction of natural ecosystems and biodiversity. These problems require immediate and comprehensive measures to overcome them, since the quality of life of current and future generations depends on them. One of the effective tools aimed at stimulating sustainable development is environmental taxation. It is based on the "polluter pays" principle, which involves placing financial responsibility for negative environmental impacts on business entities and consumers. The introduction of environmental taxes allows not only to reduce the environmental burden, but also stimulates enterprises to implement environmentally friendly technologies, contributes to the development of a green economy and the formation of responsible environmental awareness in society.

2. KEY ISSUES OF ENVIRONMENTAL TAXATION AS A TOOL FOR STIMULATING SUSTAINABLE DEVELOPMENT

In the context of globalization and integration processes, it is relevant to study international experience in environmental taxation, which allows adapting best practices to national conditions and thereby increasing the effectiveness of national environmental policy. In EU countries, the issue of environmental taxation is of particular importance in the context of sustainable development, integration and globalization. Thus, the study of environmental taxation as a tool for stimulating sustainable development is extremely important and timely,

since it contributes to solving urgent environmental problems, ensures environmental and economic stability, and also improves the quality of life of the population. The purpose of the study is to analyze the effectiveness of environmental taxation as a tool for stimulating sustainable development, in particular its impact on the environmental state, economic activity and social aspects, as well as to develop recommendations for improving the environmental taxation system based on international experience.

2.1. The essence and development of environmental taxation

Environmental taxation is a system of payments (taxes and fees) imposed on legal entities and individuals to stimulate the rational use of natural resources, charging certain amounts in proportion to their negative impact on the environment [1].

The reform of the environmental tax system (ETR), which began in the 1990s in several EU countries, such as Sweden, Denmark, Finland and the Netherlands, raised concerns about the impact on employment, export volumes, income distribution and economic growth. The main objective of these reforms was to stimulate employment, with the main principle being to reduce taxes on labour. From 1 April 1999, environmental fiscal reforms were gradually introduced in all EU countries, with further steps being taken in 2000 and 2003. In Germany, the main objective of the environmental fiscal reform was to reduce energy consumption and harmful emissions, as well as to promote the development of new technologies and investment in innovation. The revenues from these taxes were used to reduce pension contributions. As a result of this ETR, a significant number of new jobs were created (about 250 thousand in 2003 alone), which amounted to 0.75% of the total number of jobs. Fig. 1 shows the chronology of the development of environmental taxes in the EU since the mid-20th century [2].

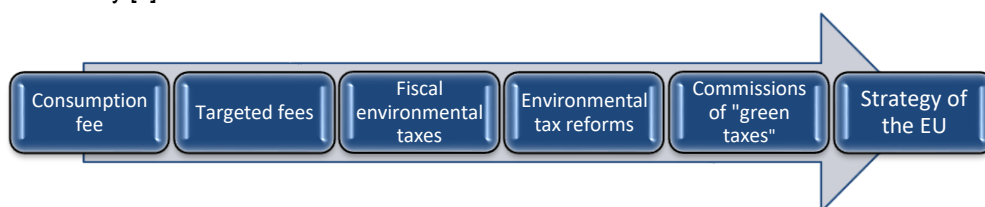


Figure 1. Chronology of the development of environmental taxes in the EU [2]

The effectiveness of environmental taxes depends on several factors, including the tax base, tax rates, the evolution of the tax system and overall tax policy. In the EU, environmental taxes are usually divided into four categories: energy taxes (ET), transport taxes (TT), pollution taxes (PT) and resource taxes (RT). The design of these taxes (e.g. rates, purpose, and scope) and their implementation differ between EU countries. Some countries focus on a narrower set of taxes, while others take a broader approach [2].

2.2. Main elements of the environmental taxation system

The main element of the environmental taxation system in most countries is the environmental tax, which is a national mandatory payment levied for [1]:

- emissions of pollutants into the atmosphere by stationary sources of pollution;
- discharges of pollutants into water bodies;

- waste disposal (except for some waste used as secondary raw materials);
- generation of radioactive waste (including already accumulated);
- temporary storage of radioactive waste by its producers beyond the period established by the terms of the license [3].

Environmental taxes are an important tool of state policy aimed at stimulating rational use of nature and reducing negative impact on the environment. The main types of environmental taxes are emission taxes, resource use taxes and product taxes [4, 8].

Studies conducted by European Union countries over many years show that the rate of the environmental tax on energy is lower than the labor norm, in addition to the positive impact on the greening of the energy complex; it will also contribute to employment. Recently, requests for research into the environmental aspects of the activities of business entities, in particular environmental taxes, have become relevant. Correction and innovation of existing tax distortions and the introduction of eco-taxes can contribute to the implementation of a "green" tax reform and improving the quality of the environment. [5, 9].

In many EU member states, environmental taxes are widespread, such as energy taxes (applied in Austria, Great Britain, Italy, the Netherlands, Slovenia, Sweden), which include taxation of electricity, coal, natural gas and fuel consumption, as well as a tax on mineral fuels (applied in countries such as Austria, Great Britain, Greece, Denmark, Ireland, Spain, Italy, Luxembourg, the Netherlands, Germany, Slovakia, France). The differences in the structure and methods of application of national environmental taxes are an important factor for the development of measures to harmonize environmental taxes in EU member states. Table 1 contains information on the main types of environmental taxes and charges applied by some EU states [5].

Table 1. Environmental taxes of EU countries

Country	Taxes
1. United Kingdom	– fuel tax; – excise tax on cars; – air passenger fees; – landfill tax; – climate change tax; – building materials tax.
2. Latvia	– air and water pollution tax; – waste tax; – mining tax; – environmentally harmful products tax.
3. Lithuania	– targeted fees for environmental pollution; – non-targeted taxes for the use of certain types of natural resources.
4. Germany	– environmental taxes (special tax for environmental financing, environmental protection tax); – a system of fees to maintain environmental quality (water pollution fee); – product fees (a surcharge on the price of a product whose production or consumption pollutes the environment); – quota trading.
5. Poland	– fees for air and water pollution, wastewater discharge, solid waste disposal, deforestation; – fees for products that do not meet environmental standards
6. Slovenia	– wastewater discharge fee; – carbon tax; – electricity production tax; – vehicle tax.
7. Czech Republic	– fee for atmospheric emissions; – fee for products using chlorofluorocarbons; – fee for water pollution; – fee for activities related to waste disposal; – tax on noise pollution (airports are taxed).

3. ENVIRONMENTAL TAXATION AS A MEANS OF FINANCING FORESTRY DEVELOPMENT

3.1 Opportunities and prospects of environmental taxation

In 2021, as part of the preparation of documents for the Recovery and Resilience Plan of the Slovak Republic, the most important social challenges, key economic problems and priorities in the forest sector were identified. The aim was to obtain investments to finance the investment debt in the infrastructure and equipment of the forest sector of the Slovak Republic in order to ensure sustainable and, in particular, environmentally friendly forestry in accordance with the government project "Value for Money". The need for investments and operating costs for measures in the areas of mechanical and technological equipment of the forest sector, water retention measures and the construction and reconstruction of the forest road network for a three-year period (2022-2024) was calculated at a total amount of EUR 176 million. Since these forestry measures were not included in the Recovery and Resilience Plan of the Slovak Republic, the above-mentioned priorities (including other measures) are partially implemented through the Rural Development Programme of the Slovak Republic for 2014-2022, and are also included in the Strategic Plan of the Common Cooperation Policy for 2023-2027 with an allocation of EUR 98.3 million. The budget for the implementation of the above-mentioned projects can be supplemented by funds from environmental taxation.

In the area of ensuring financing of the Forest Program of the Slovak Republic, an important instrument will be the National Forest Program of the Slovak Republic for the period 2025-2030 "FORESTS FOR SOCIETY" (NFP of the Slovak Republic), approved by the Government of the Slovak Republic on March 13, 2024, and its action plan, which the Government of the Slovak Republic will discuss by the end of 2024. The NFP of the Slovak Republic focuses on directing activities and investments to achieve a defined vision and global goals in the forest sector of the Slovak Republic [6].

Compensation for restrictions on forest land management in accordance with Section 61 of the Nature and Landscape Protection Act was paid to forest managers in the amount of EUR 7.49 million in 2023. The use of forest land for purposes other than forest functions is decided by the State Forest Administration. Forest land removal fees or compensation for the loss of unproductive functions are an economic instrument of the state aimed at protecting forest land. In 2023, the State Forest Administration bodies imposed forest land removal fees in the amount of EUR 0.75 million, of which 75% was paid. Financial penalties for violations of the Forest Act and Act No. 97/2013 Coll. on land communities, as amended, in 2023 the Land Tax of the Slovak Republic was assessed in the amount of 139.4 thousand euros, of which 64.0 thousand euros were paid, i.e. 46%. The economic efficiency indicators of the European Forest Accounts indicate that the current forest rent opportunities do not generate enough own resources to ensure all forest functions in the required volume. Therefore, the use and management of forests, as in other EU countries, cannot do without financial support from the state or support from European funds, which is reflected in the income generation account as a subsidy for production [6].

Over the past decade, the share of environmental taxes in Slovakia's tax base has been decreasing every year. In 2022, it was 2.4 percentage points lower than in 2013. In 2013, environmental taxes accounted for 8.1 percent of Slovakia's total tax revenues, while in 2022 it was only 5.7 percent. The share converted into GDP fell from 2.51 percent to 1.99 percent over the same period. In the latter figure, even a small difference represents a lot of money.

For example, in 2021, environmental taxes reached a share of 2.38 percent of GDP. If this ratio had been maintained in 2022, the state would have received 196 million euros more, or almost 2.4 billion euros. Instead, the share fell to 1.99 percent of GDP, which brought in revenues of 2.2 billion euros.

For the public, raising environmental taxes is more acceptable than raising VAT or property taxes, but companies have a different opinion. Roman Karlubik, vice president of the Slovak Chamber of Commerce and Industry and president of the Slovak Association of Chemical and Pharmaceutical Industries, opposes raising environmental taxes, pointing to the high tax burden that will not benefit either the business environment or the end consumer. According to him, it is doubtful whether such a measure will actually contribute to environmental protection, since it is unclear how the collected funds will be reinvested in greening the industry [7]. Slovakia's data also show that the largest share of environmental tax revenues is energy taxes - as much as 89.26 percent, which is one of the highest values in the European Union. Revenues from transport, collected in the form of registration fees, amount to 9.50 percent. The share of revenues from pollution, such as waste disposal or mining, is only 1.24 percent. Therefore, there is room for tax increases mainly in the latter category. From the perspective of the Ministry of Environment, increasing environmental taxes is not a priority, but rather tax preferences are provided by reducing VAT to those who take the environment into account in their production processes. [7].

3.2. Problems of implementing the environmental taxation system

The current state of environmental taxation indicates a gradual improvement of the taxation system in order to ensure sustainable development and preserve natural resources for future generations. Another problem is the definition of objects of taxation and methods of their assessment. For the effective functioning of the environmental tax system, it is necessary to clearly define which activities or products are subject to taxation, as well as to develop effective methods of assessing emissions or resource use. Another significant problem is the issue of administration and control over the payment of environmental taxes. Insufficient transparency and efficiency of the administration system can lead to tax evasion and violations of the law. To improve environmental taxation, the following measures are proposed to be implemented:

- expansion of objects of taxation: inclusion of new types of pollution and resources in the environmental taxation system, which will contribute to increasing the volume of fees and stimulating rational use of nature;
- increase in environmental tax rates: increase in rates for environmentally hazardous activities and emissions, which aims to reduce the negative impact on the environment and stimulate the implementation of clean technologies;
- development of the monitoring and control system;
- introduction of economic incentives;
- ensuring transparency and public participation: involving the public in the decision-making process regarding environmental taxation;
- international cooperation.

The study also found that environmental taxation has a significant economic impact; in particular, it contributes to the creation of new markets and increases the competitiveness of enterprises. An analysis of international experience showed that countries that actively use

environmental taxation achieve greater success in preserving the environment and developing a green economy.

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SUPPORT FOR SUSTAINABILITY IN AUDITING INTEGRATED MANAGEMENT SYSTEMS IN THE WOODEN INTERIOR DESIGN INDUSTRY

Alena Paulíková, Renata Nováková

Abstract: In industrial practice, we often meet combined audits of two or more management systems according to ISO, IATF or other standards, which are required by the organization itself, certification authorities, key customers or other stakeholders. In combined audits, when an audit is performed jointly on two or more management systems in one audited organization, the necessary emphasis is often not placed on sustainability when setting and fulfilling the requirements. From a sustainability perspective, it can be challenging to meet the common or specific requirements of integrated management systems while also preparing and maintaining accurate and up-to-date documented information. This article aims to present a holistic perspective on this special matter, offer insight, and demonstrate how sustainability can be supported in the industry of wooden interior design components used in the automotive design industry.

Keywords: audit, integrated management systems, automobile wooden interior, sustainability, automotive design industry

1. INTRODUCTION

Modern industry increasingly relies on combined audits to assess multiple management systems simultaneously, streamlining documentation, reducing redundancy, and providing a unified view of critical processes. At the same time, sustainability has shifted from ethical concern to strategic imperative, amplified by the SDGs and escalating societal expectations.

However, integrated management systems (IMS) audits often underemphasize sustainability when addressing system requirements — a gap that complicates efforts to maintain accurate documentation and compliance. This challenge becomes especially pronounced in product audits—for example, evaluating a wooden car interior demands rigorous scrutiny of material sourcing, environmental impact, performance, and regulatory compliance. The audit must therefore navigate not just the technical and aesthetic aspects of the product, but also its sustainability credentials across multiple standards.

This article addresses these intertwined challenges. It examines IMS theoretical foundations, core auditing principles, sustainability integration, and specific considerations for the wooden interior design industry.

2. PRINCIPLES AND PRACTICES OF AUDITING IMS

2.1 Overview of Auditing Principles as per ISO 19011

ISO 19011:2018 serves as a pivotal guidance document for organisations in establishing robust audit programmes and conducting effective audits of their existing MSs. The core of ISO 19011's guidance is built upon seven fundamental principles that ensure the effectiveness, reliability, and credibility of audit processes. ISO 19011 provides a universal framework for auditing, broadly applicable across various MSs, including those related to sustainability.

2.2 Specific Audit Requirements and Processes within IATF 16949

IATF 16949 mandates the development and implementation of a robust audit programme that explicitly includes three unique types of audits: system audits, manufacturing process audits, and product audits

- **System Audits:** Focus on the organisation's Quality Management System processes, addressing all elements of the IATF standard [Pauliková];
- **Manufacturing Process Audits:** Analyse the effectiveness and efficiency of all manufacturing processes, often employing customer-dictated approaches (e.g., CQI audits or Layered Process Audits);
- **Product Audits:** Concentrate on specific product characteristics to confirm that the measurement system, manufacturing process, and associated controls are capable of producing parts that consistently meet specifications [Russell].

Beyond quality, IATF 16949 places a strong emphasis on corporate responsibility. Certified organisations are required to define and implement policies covering anti-bribery, an employee code of conduct, and an ethics escalation (whistle-blower) policy. Auditors are tasked with verifying the active involvement of top management, adherence to customer-specific requirements (CSRs), the effectiveness of operational and proper document control, accurate recordkeeping, and robust supplier management practices [Compliance Quest; IPQC Co].

The "risk-based approach" inherent in ISO 19011, ISO 9001, ISO 14001 and IATF 16949 audits presents a strategic opportunity to embed sustainability considerations directly into the audit planning and execution phases. Furthermore, the explicit corporate responsibility requirements within IATF 16949 provide a direct auditable link to social and governance aspects of sustainability [Markulík].

3. INTEGRATING SUSTAINABILITY INTO MANAGEMENT SYSTEMS AND AUDITS

3.1 The Evolving Landscape of Sustainability and ESG in Industrial Practice

Sustainability has shifted from a secondary concern to a core business priority, driven by growing environmental and social challenges. In this context, Environmental, Social, and Governance (ESG) auditing plays a crucial role in assessing how effectively companies manage their responsibilities across these interconnected areas. The regulatory landscape is rapidly evolving, with examples like the European Union's Corporate Sustainability Reporting Directive (CSRD), which requires external assurance on ESG reports [Barral; Iris Carbon].

3.2 Strategies for Embedding Sustainability Objectives within IMS Frameworks

Selected MSs according to ISO standards, which are suitable for significant integration, support sustainable frameworks directly, e.g. ISO 9001, 14001, 20121, 26000, 45001, 50001. IMS offer a powerful framework for organisations to systematically address their environmental and social impacts (ESG reporting) while concurrently maintaining a focus on financial performance. For sustainable development and continuous performance improvement, it is paramount that IMS is deeply embedded across the entire organisation and integrated into all stakeholder relationships. A robust IMS framework can directly align with and support an organisation's ESG goals by streamlining processes, reducing duplication, and contributing to a lower carbon footprint.

For industries working with unconventional, sustainability-driven materials—such as wooden interior components in automobiles, this integration becomes especially complex. Wood, as a renewable but sensitive material, demands heightened attention to sourcing, lifecycle impacts, emissions, safety, and durability, all of which must be documented and auditable within the IMS. A robust framework not only streamlines such processes and reduces duplication but also supports ESG goals by enabling traceability and lowering the overall carbon footprint.

Effectively embedding sustainability within an IMS means translating overarching sustainability objectives into specific, actionable practices [ACCA Global]. This requires thorough gap analyses, detailed implementation plans, active involvement of employees and stakeholders, streamlined documentation, and comprehensive training [Olanab Consults].

3.3 Key Performance Indicators (KPIs) for Measuring and Monitoring Sustainability

Effective measurement of sustainability requires a careful selection of key metrics and a systematic approach to process improvements. KPIs are defined as priority ones crucial for achieving strategic objectives and indispensable for robust performance management. The suitable KPIs are listed in Table 1, [inspired by ACCA Global, Barral, Chovancová, Sheykin].

Table 1: Specific KPIs for Industrial Operations

Category	KPI	Unit	Relevance to Sustainability
Environmental	Energy Consumption	kWh/unit	Direct measure of resource efficiency and carbon footprint.
	GHG Emissions	tCO ₂ e	Key indicator of climate change impact from operations.
	Recycled Material Used	%	Reflects commitment to circular economy principles and resource conservation.
	Water Footprint	L/unit	Measures water efficiency and impact on local water resources.
	Waste Generated	kg/unit	Indicates efficiency of material use and effectiveness of waste management.
Social	Customer Satisfaction Score	°	Reflects product quality, ethical production practices, and the overall brand reputation.
	Employee Turnover Rate	-	Can indicate employee satisfaction and fair labour practices.
	Health & Safety Incident Rate	-	Reflects workplace safety and employee well-being.
	Suppliers with Sustainability Compliance	%	Measures ethical supply chain practices and responsible sourcing.
Governance (Operational)	% Defect Rate	-	Reflects quality control, reducing rework, waste, and resource consumption.
	% Material Utilisation Rate	-	Directly assesses efficiency of raw material use, reducing waste and costs.
	Production Lead Time	day	Indicates efficiency of production and supply chain, minimising resource holding.
	Sustainably Sourced Materials	%	Direct measure of adherence to responsible sourcing policies.

The integration of sustainability into IMS audits requires a fundamental shift from traditional compliance-focused auditing to a more holistic, risk-based approach that considers both quantitative and qualitative ESG factors across the entire value chain.

4. AUDITING IMS WITH A SUSTAINABILITY FOCUS

Auditing Integrated Management Systems (IMS) with a dedicated focus on sustainability—especially in the context of wooden interior design—presents a distinct set of challenges, but also offers valuable opportunities for innovation, improvement, and long-term value creation.

4.1 Challenges in Auditing Sustainability Data and Documented Information

- **Documentation Overload vs. Granularity:** While IMS aims for "lean documentation," sustainability auditing often requires detailed documentation, which can lead to overload [Olanab Consults];
- **Inconsistent Data Quality and Lack of Standardisation:** A primary hurdle is the inconsistent quality and reliability of ESG data, which can be scattered, qualitative, and challenging to quantify.
- **Qualitative Complexities and Greenwashing:** The subjective nature of qualitative ESG factors poses a significant challenge, with companies potentially misrepresenting their practices (greenwashing);
- **Resource Constraints and Expertise Gaps:** Implementing comprehensive sustainability auditing requires significant investment and specialised expertise among auditors.
- **Supply Chain Complexity:** Global supply chains make it difficult to collect and verify comprehensive ESG data, especially for sub-tier suppliers.

4.2 Opportunities and Best Practices for Enhanced Sustainability Auditing

- **Adopting a Risk-Based Approach:** The risk-based approach, central to ISO 19011 and IATF 16949, can be strategically leveraged to identify and prioritise material ESG risks and opportunities.
- **Continuous Improvement Framework:** The inherent continuous improvement (PDCA) cycle within IMS provides a structured approach for organisations to regularly review their sustainability performance [Olanab Consults; Visualogyx];
- **Developing Auditor Competence:** Auditors need a multifaceted skillset that extends beyond traditional financial auditing to include business acumen with a sustainability focus, industry understanding, knowledge of environmental regulations, and critical thinking to identify greenwashing. Training programmes for IMS auditors should integrate sustainability aspects, ISO 14001 and ESG principles.
- **Enhancing Data Quality and Transparency:** This includes robust data collection systems, materiality assessment, third-party verification, and disclosure of methodologies [Nováková];
- **Leveraging Integrated Systems for Holistic View:** IMS provides a unified framework to streamline processes and address environmental and social impacts alongside quality and safety [Visualogyx];

- **Leveraging Technology:** Advanced technology solutions, including AI-driven tools, scan revolutionise sustainability reporting and auditing by enhancing data collection, monitoring, and analysis processes;
- **Standardised Frameworks and Certifications:** Utilising recognised sustainability reporting frameworks (e.g., GRI, SASB, TCFD) and industry-specific certifications (e.g., FSC, PEFC, level®, Declare, EPDs) provides structure and comparability for sustainability data.

5. CONCLUSION

While Integrated Management Systems (IMS) offer clear benefits in operational efficiency and cost reduction, this study highlights a persistent gap in how sustainability—particularly ESG considerations—is addressed in combined audits. This shortfall is especially critical in the wooden interior design sector of the automotive industry, where material choices, such as wood, introduce specific sustainability challenges related to sourcing, lifecycle impact, and indoor environmental quality.

Despite the availability of recognized standards and certifications (e.g., FSC, PEFC, LCA), auditing these aspects remains complex due to fragmented data, qualitative criteria, and intricate supply chains. To address these challenges, audits must evolve beyond procedural checks to support deeper, systemic sustainability integration.

Key recommendations include:

- a) Enhancing auditor expertise in sustainability and ESG;
- b) Embedding sustainability into audit programs using a risk-based approach.;
- c) Promoting continuous improvement through holistic integration;
- d) Strengthening data verification and traceability mechanisms.

Ultimately, realising the full potential of IMS in the wooden interior design industry depends on the development of sector-specific auditing competencies. Auditors must be equipped not only with knowledge of relevant standards, but also with a nuanced understanding of material sustainability, stakeholder expectations, and long-term environmental performance.

Greater collaboration between designers, suppliers, and auditors is essential to bridge knowledge gaps and foster shared accountability. By embedding sustainability deeper into audit logic and practice, the industry can better align operational goals with global environmental and social imperatives.

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INNOVATION ACTIVITY IN WOOD-BASED INDUSTRY – EUROPEAN UNION AND CROATIAN PERSPECTIVE

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Abstract This research explores innovation activity within the wood-based sector, comparing trends, challenges, and policy frameworks between the European Union (EU) and Croatia. The wood industry, a key component of the bioeconomy, faces growing pressure to adopt sustainable and competitive innovation strategies. Using data from the Community Innovation Survey (CIS), this study examines innovation drivers and the role of public policy in fostering technological advancements and value-added product development. Through a comparative analysis, it assesses how Croatia aligns with broader EU innovation trends. Findings reveal both convergence and divergence in innovation performance, highlighting the need for targeted support mechanisms, enhanced collaboration, and increased investment in research and development. The study offers recommendations to strengthen innovation capacity and international competitiveness in the Croatian wood-based sector.

Keywords: wood based industry; innovation; European Union; Croatia

1. INTRODUCTION

Innovation can be a complete novelty or an improvement and advancement of an existing solution. It most often arises as a result of research and development activities. It is legally protected as intellectual property, which means that it can be placed on the market as a product. For this reason, innovation is an important wheel in driving the economy, the economy and entrepreneurial success. For this reason, the European Union is investing in stronger connections between member states in the common field of innovation and cooperation on green and digital transformation. Innovation is a look into the future, and preparation for future challenges is preparation for the survival and prosperity of society (Innovation Platform, 2022). Since organizations often cooperate with each other, it can sometimes be difficult to understand the impacts of innovation on our society as a whole. However, innovation is much more than companies' attempts to achieve a competitive advantage. Innovation is truly the fundamental reason for modern existence. Although innovation can have some unintended consequences, change is inevitable and in most cases innovation creates positive changes. From a societal perspective, the fundamental results of innovation are economic growth, increased well-being and communication, access to education and environmental sustainability (Kylliäinen, 2019).

The wood industry, whose innovation potential will be discussed in more detail later in the paper, is increasingly recognizing the importance of innovation. According to Sales (2001), technical innovations in wood processing in the second half of the twentieth century focused on optimizing the use of wood from temperate and boreal forests, responding to more sophisticated market segments. This especially meant keeping up with the growing competition from other materials, such as plastics, metals and concrete. As a result, the wood industry is now in a position to deliver high-quality products, such as standardized sawn timber of constant,

guaranteed quality, composite panels, glued and laminated timber and engineered wood products. In some particularly important application sectors, such as construction, advances in structural bonding techniques have allowed wood to improve its image to the point where it can compete with concrete and steel. The development of new technologies often led to a redistribution of market shares within the sector. For example, wood-based panels made of particles or fibres have partly replaced traditional plywood markets, as well as solid wood elements in certain furniture sectors. Similarly, medium-density fibreboard (MDF) has replaced traditional particleboard - and even solid wood - in many furniture applications.

Like all manufacturing industries, the wood sector has experienced major technological upheavals in recent decades. It may seem that there has been too little innovation in some areas, where wood has lost significant market shares (industrial joinery, tool handles, everyday office items, etc.). For example, in joinery (windows), wood supplied more than 80 percent of the European market 20 years ago. This share has now decreased to 30 percent as wood has been replaced by plastics and aluminium. On the other hand, wood has gained a new place in certain traditional sectors thanks to the good industrialization of products, the adaptation of assembly techniques to reduce the duration of construction processes, a good quality-price ratio, and recognized quality and efficiency (parquet and other floor coverings, cladding, outdoor furniture, etc.) (Loučanová et. al, 2017; Breuer et al., 2025). In addition, wood is increasingly used in the production of new composites that have become available on the market in the last 20 years: medium-density fiberboard, oriented strand board and laminated veneer lumber, as well as their various derivatives.

The aim of this paper is to analyze innovation activities in the wood industry sector and to analyze the contribution of public policies to the advancement of technological development and the creation of product innovations and innovative business processes.

2. INNOVATION AND INNOVATIVENESS

Innovation and technology are the driving force behind human progress, improving the quality of life, ensuring economic growth and creating the foundations for a sustainable future. Historically, innovation has led to drastic changes in society, from reducing working hours and increasing life expectancy, to creating new forms of work and education. However, today's global challenges, such as climate change, an aging population and limited natural resources, require an even stronger reliance on innovation to enable the transition to greener, more resilient and digitalized economies (DS Smith, 2023).

The difference between innovation and innovativeness is that innovation is the result of creating something new or an improved product or service. Innovativeness is the potential to be creative, ready for change. It generates new ideas or solutions and turns them into innovations.

In addition to the above definitions, it would be important to mention the "Oslo Manual", which provides guidelines for collecting and interpreting data on innovation. The Manual was jointly published by the OECD and Eurostat with the aim of collecting data and reporting using a common vocabulary, agreed principles and practical conventions. According to the Oslo Manual (OECD, 2018), an innovation is defined as a new or improved product or process (or their combination) that is significantly different from the unit's previous products or processes and which is made available to potential users (product) or put into use by the unit (process).

On the other hand, innovativeness means the ability and tendency of an organization to continuously develop and apply such innovations. Along with the definitions, there are 4 types of innovation in the company - product innovation, process innovation, business innovation (organizational innovation and marketing innovation). The authors (Tuncel et al., 2019) emphasize two key forces that drive innovation: market demands (market-pull) and technological progress (technology-push). Successful innovations often result from a combination of both approaches. Examples from the Turkish furniture industry show that innovations often arise as a response to specific problems in production, but also as a result of a conscious modernization of the business model.

One of the most important tools for monitoring innovation activities in the European Union is the Community Innovation Survey (CIS) – a standardized survey conducted by Eurostat in cooperation with national statistical offices, based on the methodology defined in the Oslo Manual. The CIS is conducted every two years and provides internationally comparable statistics on innovation in enterprises, including Croatia.

The Innovation Survey was first launched in the 1990s and became a regular biennial data collection starting with CIS4 (2004) in EU Member States, EFTA countries and EU candidate countries. Since its launch, the survey has been based on the methodology set out in the Oslo Manuals – international standards for the conceptualisation and collection of innovation data. The first Oslo Manual was published in 1992. It has been revised three times to take account of experience and to broaden its measurement framework – in 1997, 2005 and 2018.

In the CIS 2016 it is mentioned that in order to ensure comparability across countries, Eurostat, in close cooperation with EU Member States and other countries, has developed a standard core questionnaire for each CIS round, with an accompanying set of definitions and methodological recommendations. Most countries follow the proposed filtering used in the Harmonised Survey. In some cases, questions on basic economic information are included at the beginning of the national survey. The items related to "Turnover" and "Average number of employees" are obtained from national statistical business registers or from other surveys (Eurostat, 2020).

The New European Innovation Agenda (NEIA), adopted by the European Commission in July 2022, is a comprehensive strategic framework for strengthening the innovation potential of the European Union, with a particular emphasis on so-called "deep-tech" innovations. These are innovations that result from cutting-edge scientific and technological research and have the potential to transform industry and society as a whole. NEIA is structured into five key areas of action (flagship areas): financing the growth of high-tech companies, creating space for experimentation and innovative public procurement, strengthening innovation ecosystems and reducing the innovation gap, developing talent and improving innovation policies.

3. MATERIALS AND METHODS

In this research secondary data from the Eurostat database were used. The used data was a result of a survey on innovations in companies known as the Community Innovation Survey (CIS). The downloaded data refer to several aspects of innovation activities in the member states.

The indicators analyzed are the following: Innovation activity; In-house research / development (&); External R&D; Income from innovation and Types of innovation.

The data are presented at an aggregated level by countries, years and activities with an emphasis on activities C 16 – Wood processing and C 31- Furniture manufacturing (according to the NACE classification). The analysis covers data from 2016 to 2022, with a note that no data is available for certain indicators. Data are collected in even years. Excel was used for data analysis.

The data were cleaned of empty lines and headers, and systematized according to defined indicators for analysis. and interpreted in accordance with the recommended Eurostat definitions.

4. RESULTS AND DISCUSSION

As shown in table 1, between 2016 and 2022, the total number of innovative companies in both the EU-27 and Croatia fluctuated, with Croatia's share of EU totals remaining consistently low, between 0.6% and 1.1%. In each observed year, Croatia's relative participation was slightly higher in manufacturing sectors (NACE C), particularly in subsectors C16 (wood processing) and C31 (furniture). Notably, in 2020, Croatia recorded its highest share of EU companies in C16 at 2.4%, indicating a stronger presence in this niche industry. Despite an overall decline in absolute numbers in 2022, the proportional representation in these subsectors remained above the Croatian average. This suggests that Croatia, while small in overall volume, maintains a relatively specialized innovation presence in specific manufacturing sectors within the EU.

Table 1. Innovation activity EU and Croatia – all NACE, manufacturing, wood processing and furniture manufacturing

		EU -27 (No. Companies)	Croatia (No. Companies)	share of CRO in EU (in %)
2016	all economic activities	270,273	2211	0,8
	C	141,655	1091	0,8
	C 16	4,291	66	1,5
	C 31	4,662	58	1,2
2018	all economic activities	190,848	1480	0,8
	C	100,262	757	0,8
	C 16	2,701	48	1,8
	C 31	3,138	43	1,4
2020	all economic activities	385,852	4148	1,1
	C	177,462	1954	1,1
	C 16	6,349	151	2,4
	C 31	6,114	97	1,6
2022	all economic activities	172,599	1088	0,6
	C	86,301	492	0,6
	C 16	1,620	26	1,6
	C 31	2,528	32	1,3

Further more, the total number of companies conducting in-house R&D in Croatia increased from 902 (2016) to 1,302 (2020), then decreased to 943 (2022), which indicates increased R&D activity in the crisis period and subsequent stabilization. Croatia's share in the EU in this area was the highest in 2020 — 0.78%, which is also the highest level of share during the observed period. Croatia consistently had above-average shares in specialized sectors: in 2016, it contributed 0.94% in C16 and 1.04% in C31, which is significantly higher than its average share in all economic activities. Data for sectors C, C16 and C31 in 2020 and 2022 are not available for the EU, so it is not possible to calculate Croatia's share in those years, although Croatian figures are shown. Overall, the data suggest that Croatia has a relatively stronger position in the sectors of the traditional processing industry when it comes to its own research and development, despite the small absolute volume. Croatia has an above-average share in contractual R&D in relation to the total size of the economy, especially in 2016 (1.05%) and 2020 (1.00%), which shows continuous involvement in external research and development engagement.

External sources of knowledge play a significant role in wood based industry (sector C31), as evidenced by the country's notable share of EU companies engaged in contract R&D—2.86% in 2020 and 2.26% in 2022. In the sector C16 - wood processing, Croatia maintains a stable but smaller share, ranging from 0.69% to 1.60%, with the highest value recorded in 2018. The total number of Croatian firms using contract R&D varies, but decreases after 2020: from 671 firms in 2020 to 551 in 2022, which may indicate a decline in external R&D investment after the pandemic.

In 2016 The furniture sector (C31) consistently shows a higher percentage of turnover from innovation, with countries like Spain (51%), France (42%), and Belgium (40%) standing out. In contrast, C16 generally shows low innovation intensity, with Slovakia as a rare exception (92%), although its absolute turnover is relatively small. Croatia demonstrates a strong innovation contribution in furniture manufacturing (32%), above the European average, while its wood processing sector shows a moderate 7%. Several countries (e.g., Lithuania, Luxembourg, Netherlands, Slovenia) lack available data, limiting full regional comparison.

Table 2. Total turnover and turnover from innovation 2018-2022

	2018	EU-27	Croatia	share of CRO in EU (in %)
C	Turnover from innovation	1,214,512,329	2,867,977	0,24
	new to the firm	785,528,965	1,755,586	0,22
	new to the market	428,983,362	1,112,391	0,26
C 16	Turnover from innovation	7,074,713	133,380	1,89
	new to the firm	4,195,205	129,322	3,08
	new to the market	2,879,510	4,058	0,14
C 31	Turnover from innovation	10,868,310	93,099	0,86
	new to the firm	7,719,618	65,915	0,85
	new to the market	3,148,696	27,184	0,86

	2020	EU-27	Croatia	share of CRO in EU (in %)
C	Turnover from innovation	993,079,211	3,291,681	0,33
	new to the firm	611,756,847	2,589,369	0,42
	new to the market	379,652,842	702,312	0,18
C 16	Turnover from innovation	6,176,100	252,699	4,09
	new to the firm	4,071,573	233,114	5,73
	new to the market	2,080,814	19,585	0,94
C 31	Turnover from innovation	7,593,613	134,727	1,77
	new to the firm	4,775,049	110,817	2,32
	new to the market	2,798,563	23,910	0,85
	2022	EU-27	Croatia	share of CRO in EU (in %)
C	Turnover from innovation	1,578,314,576	3,410,202	0,22
	new to the firm	1,063,916,936	2,779,614	0,26
	new to the market	514,397,640	630,587	0,12
C 16	Turnover from innovation	7,516,363	105,597	1,4
	new to the firm	5,034,972	99,601	1,98
	new to the market	2,490,966	5,996	0,24
C 31	Turnover from innovation	10,443,055	155,914	1,49
	new to the firm	6,831,670	131,044	1,92
	new to the market	3,744,280	24,871	0,66

Table 2 shows the turnover from innovation in Croatia compared to the EU-27 in sectors C (manufacturing overall), C16 (wood processing), and C31 (furniture manufacturing) for the years 2018, 2020, and 2022. Croatia's overall share in EU manufacturing innovation turnover (sector C) remains low, between 0.22% and 0.33%, but its contribution is relatively higher in C16 and C31, especially in 2020. In C16, Croatia reached a peak share of 4.09% in 2020, driven primarily by innovations "new to the firm" (5.73%), while in C31, it recorded 1.77%, showing a consistent innovation presence. Across all years, Croatia's turnover from "new to the firm" innovations is significantly higher than for "new to the market", indicating a tendency toward adopting existing innovations rather than developing original ones. Although Croatia's absolute figures are small, its relative impact in niche manufacturing sectors is notable, particularly when benchmarked against the EU average.

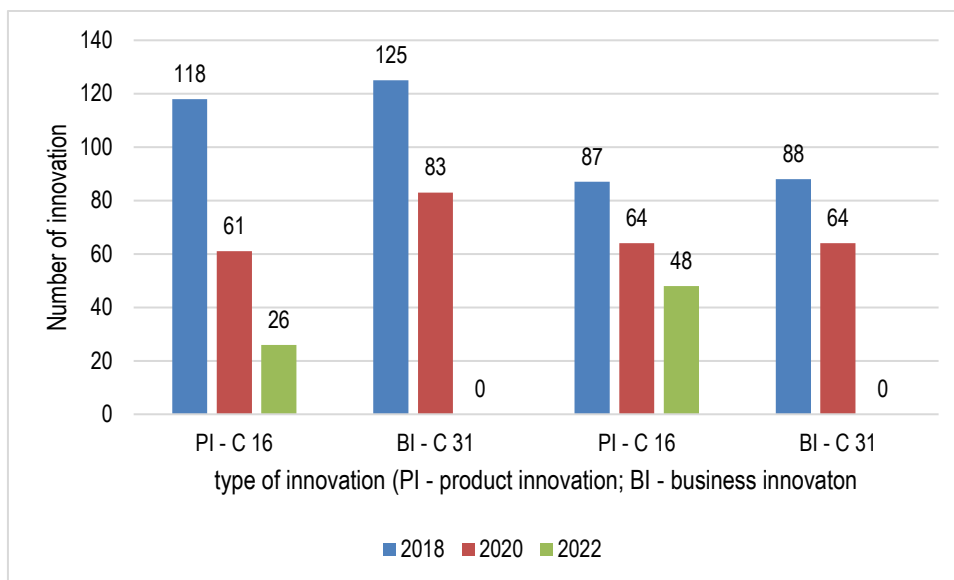


Figure 1. Types of innovation -2018-2020-2022

A figure 1 presents the number of product (PI) and business innovations (BI) in Croatia's C16 (wood processing) and C31 (furniture manufacturing) sectors for the years 2018, 2020, and 2022. In both sectors, 2018 was the peak year, with the highest recorded number of innovations — notably over 120 business innovations in C31. By 2020, the number of innovations decreased across all categories but remained relatively strong, especially in business innovations in C31 (around 85). In 2022, there was a sharp decline in product innovations in C16, dropping to about 25, and no data shown for business innovations, suggesting either a lack of activity or missing data. Overall, the trend indicates a steady decline in innovation activity, particularly after 2018, with business innovation in the furniture sector showing the greatest resilience.

5. CONCLUSIONS

Innovation activity in the Croatian wood industry shows a continuous presence, with a particular emphasis on the wood processing (C16) and furniture manufacturing (C31) sectors. Although the absolute number of innovative companies in Croatia is relatively small, their relative share in the context of the European Union is particularly pronounced in these traditional industries. The C31 sector shows a stable and above-average level of innovation, especially in the area of contract research and development (contract R&D), where Croatia achieved a share of as much as 2.86% at the EU level in 2020. The C16 sector also recorded a peak in innovation revenue in 2020, with a share of 4.09% compared to the EU, largely due to innovations that are “new to the company”. In general, Croatian companies in the wood industry more often adopt and adapt existing innovations than develop those that are “new to the market”, which indicates a reliance on knowledge transfer rather than on the development of their own solutions. In the period from 2018 to 2022, there is a decline in the total number of

innovations, especially in manufacturing innovations within the C16 sector, which may indicate the need for stronger institutional and financial support for research and development activities. Contract R&D continues to play an important role, but the number of companies using such services decreases after 2020, potentially as a result of post-pandemic restructuring. On the other hand, the furniture manufacturing sector (C31) shows greater resilience to change and maintains a higher level of business innovation compared to the wood processing sector. Therefore, it is necessary to design a more systematic and targeted public policy that would encourage innovation, especially in those areas where Croatia already shows competitive advantages. Despite limited resources, the Croatian wood industry shows real potential for strengthening innovation capacity through strategic investments, cross-sectoral cooperation and more active knowledge transfer.

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ELECTROMOBILITY AS KEY FACTOR IN THE SUSTAINABLE MODERNISATION OF WOOD PROCESSING ENTERPRISES

Patrik Richnák

Abstract: Electromobility is increasingly becoming an integral part of sustainable development strategies in industrial sectors. In the context of the wood processing industry, which is characterised by high material intensity and intensive logistics operations, the implementation of electromobility represents a significant step towards reducing the carbon footprint and industrial modernisation. This article examines electromobility as a key factor in the sustainable transformation of wood processing enterprises, targeting the potential for reducing environmental impact. The article includes a questionnaire survey of 49 wood processing enterprises in Slovakia. The aim of the survey was to map the current state of electromobility adoption, including the phase of implementation, the main factors influencing its adoption, priority areas for its development, the added value in the supply chain, the main barriers to adoption, and the preferred models of cooperation between stakeholders.

Keywords: Electromobility, Electric Vehicles, Sustainable Transport, Wood Processing Industry

1. INTRODUCTION

An important challenge for the future is focusing on sustainability in life and business. Sustainability issues are highly topical and important for organisations' current and future development and competitiveness (Fidlerová et al., 2022).

The wood processing sector uniquely intersects with renewable natural resources, yet the life cycle emissions reveal complexity: while wood products can serve as carbon sinks, the carbon neutrality of bioenergy or wood fuel remains under scrutiny because combustion emits more CO₂ per energy unit than fossil fuels, and forest regrowth to recapture this carbon is temporally protracted (Sterman et al., 2022; Fehrenbach et al., 2022). Consequently, electromobility adoption should be coupled with sustainable forestry management and efficient supply chains to maximise overall decarbonisation benefits.

In wood processing enterprises, electrification extends beyond transport to machinery and process energy demand. Modern industrial equipment integrating electric and renewable energy sources supports sustainable production while reducing fossil fuel dependency. China's forestry and wood industry exemplify rapid industrial modernisation through state-of-the-art equipment and consolidation of sustainable trade practices, achieving leadership in medium-density fibreboard and plywood production with increased energy efficiency (Barbu & Tudor, 2021).

Electromobility primarily refers to the use of electric-powered vehicles and equipment, substituting traditionally fossil-fueled machinery. In wood processing, electrification of transport and machinery reduces direct greenhouse gas (GHG) emissions and air pollutants, thereby aligning with global climate commitments. Notably, transitioning logistics fleets (including trucks and forklifts) to electric models contributes substantially to lowering operational emissions while improving local air quality in industrial zones (Rapson & Muehlegger, 2021).

Modern wood processing enterprises increasingly adopt Green Supply Chain Management (GSCM) practices that incorporate lifecycle assessments, green logistics, and reverse logistics, facilitating sustainable production and distribution. Electromobility complements several GSCM pillars - namely, green transportation and manufacturing - by enabling lower-emission logistics operations and electrification of factory inline equipment (Karunakaran et al., 2023; Labaran & Masood, 2023).

The economics of electromobility, including EV adoption in industrial fleets, depend heavily on policies that bridge private incentives and societal benefits. Effective approaches advocate for regionally tailored incentives, subsidisation that adapts over time, and electricity pricing aligned with social marginal costs (Rapson & Muehlegger, 2021).

Shifts toward electromobility in wood processing require policy instruments that foster infrastructure deployment, standardisation of charging protocols, and integration of renewable energy in manufacturing and logistics sectors (Kraemer et al., 2023).

2. CHARACTERISTICS OF THE RESEARCH SAMPLE

The survey sample (N = 49) delineates a well-differentiated structure of Slovakia's wood-processing sector. Engineered-wood manufacturers, producing plywood, OSB and glulam - formed the largest cohort with 16 enterprises, which translates to 32.7 % of all respondents. Classic sawmills accounted for 14 enterprises (28.6 %), while pulp and paper plants represented 12 enterprises (24.5 %). Integrated enterprises that combine harvesting, processing and distribution were the smallest segment, yet still significant at 14.3 % (7 enterprises).

An examination of employment classes indicates a pronounced predominance of medium-sized enterprises: 61.2 % of respondents (n = 30) report staffing levels between 50 and 249 employees. Large enterprises employing more than 250 persons comprise 20.4 % (n = 10). Small enterprises (10 – 49 employees) constitute 12.2 % (6 enterprises), whereas micro-enterprises with a staff of up to nine represent just 6.1 % (3 enterprises).

The geographical distribution is significantly shifted towards central and western Slovakia. The Nitra Region was the highest share of respondents (30.6 %; n = 15), followed by Banská Bystrica Region (22.4 %; n = 11) and Žilina Region (20.4 %; n = 10). Trenčín Region (8.2 %; n = 4) and Trnava Region (6.1 %; n = 3) presented moderate representation, whereas Bratislava Region contributes the one respondent (2.0 %). The Prešov Region accounts for 10.2 % (n = 5), and no surveyed enterprises operate in Košice Region.

With respect to environmental governance, the dataset reveals near-universal engagement in formal sustainability schemes. ISO 14001 certification is most prevalent, held by 46.9 % of enterprises (n = 23). Approximately one-third (30.6 %; n = 15) maintain multiple sustainability certifications including carbon footprint verification. Forest Stewardship Council (FSC) or Programme for the Endorsement of Forest Certification (PEFC) are present in 22.4 % of cases (n = 11). Notably, no enterprise reported an absence of certification, underscoring the sector's strong commitment to environmental standards.

3. RESEARCH RESULTS

The following sections analyse six key survey dimensions, each accompanied by a contingency table showing the distribution of responses by business size (percentages are expressed as a share of the total sample, N = 49).

The data indicate that electrification efforts in Slovakia's wood processing sector remain mostly exploratory or pilot-scale. As shown in Table 1, nearly one third of enterprises (32.7 %) already run pilot projects, whereas 30.6 % are still performing feasibility studies. Full-scale integration is observable in 16.3 % of the sample, driven mainly by medium-sized and large enterprises in Slovakia.

Table 1. Stage of Electromobility Implementation

Stage	Micro	Small	Medium-sized	Large
No consideration	4.1 %	4.1 %	10.2 %	2.0 %
Initial assessment / feasibility	2.0 %	4.1 %	20.4 %	4.1 %
Pilot project / partial electrification	0.0 %	4.1 %	20.4 %	8.2 %
Comprehensive integration	0.0 %	0.0 %	10.2 %	6.1 %
Total	6.1 %	12.3 %	61.2 %	20.4 %

Regulatory compliance clearly dominates among the main drivers for adopting electromobility, cited by 40.8 % of respondents; almost one third of all medium-sized enterprises (24.5 %) and over half of large enterprises (12.2 %) fall into this category. Brand image considerations come second (34.7 %), followed by lower maintenance complexity (14.3 %) and noise reduction (10.2 %).

Table 2. Primary Driver of Adoption

Adoption driver	Micro	Small	Medium-sized	Large
Noise reduction	2.0 %	2.0 %	6.1 %	0.0 %
Regulatory compliance	0.0 %	4.1 %	24.5 %	12.2 %
Brand image	4.1 %	4.1 %	20.4 %	6.1 %
Lower maintenance	0.0 %	2.0 %	10.2 %	2.0 %
Total	6.1 %	12.3 %	61.2 %	20.4 %

Internal material handling / warehousing is a priority area for Electromobility in business operations (38.8 %), with medium-sized enterprises again leading (24.5 %). Inbound raw-material logistics attracts 24.5 %, while finished-product distribution (22.4 %) and administrative fleets (14.3 %) are comparatively lower priorities.

Table 3. Priority Operational Area for Electromobility

Area	Micro	Small	Medium-sized	Large
Internal material handling / warehousing	2.0 %	4.1 %	24.5 %	8.2 %
Raw-material transport	0.0 %	4.1 %	16.3 %	4.1 %
Finished-product distribution	2.0 %	2.0 %	12.2 %	6.1 %
Administrative / service fleet	2.0 %	2.0 %	8.2 %	2.0 %
Total	6.1 %	12.3 %	61.2 %	20.4 %

From a supply-chain perspective, enhanced traceability is identified as the key benefit by 57.1 % of respondents, with medium-sized and large enterprises jointly contributing 46.9 %. Reductions in lead times (14.3 %), elimination of weather disruptions (14.3 %), and packaging standardisation (14.3 %) are viewed as secondary benefits.

Table 4. Supply-chain Value Added

Benefit	Micro	Small	Medium-sized	Large
Reduced lead times	0.0 %	2.0 %	8.2 %	4.1 %
Traceability & transparency	4.1 %	6.1 %	34.7 %	12.2 %
Elimination of weather disruptions	0.0 %	2.0 %	10.2 %	2.0 %
Packaging standardisation	2.0 %	2.0 %	8.2 %	2.0 %
Total	6.1 %	12.3 %	61.2 %	20.4 %

The most significant barrier to the adoption of electromobility in the wood processing enterprises surveyed in Slovakia is the high initial capital costs (40.8 %), which disproportionately affect medium-sized and large enterprises. Insufficient charging infrastructure ranks second (26.5 %), followed by limited vehicle availability (20.4 %) and uncertainty regarding long-term reliability (12.2 %).

Table 5. Dominant Barrier to Adoption

Barrier	Micro	Small	Medium-sized	Large
Insufficient charging infrastructure	2.0 %	4.1 %	16.3 %	4.1 %
High initial capital cost	2.0 %	4.1 %	24.5 %	10.2 %
Limited vehicle availability	2.0 %	2.0 %	12.2 %	4.1 %
Uncertainty of long-term reliability	0.0 %	2.0 %	8.2 %	2.0 %
Total	6.1 %	12.3 %	61.2 %	20.4 %

Electromobility is widely viewed as a systemic challenge best addressed through broad alliances. A majority of enterprises (55.1 %) favour multi-stakeholder partnerships that combine energy utilities and technology providers. Vertical integration with EV manufacturers attracts

22.4 %, whereas reliance on single-provider charging contracts (14.3 %) or full operational independence (8.2 %) are markedly less popular.

Table 6. Preferred Stakeholder-collaboration Model

Collaboration model	Micro	Small	Medium-sized	Large
Vertical integration with EV manufacturers	0.0 %	2.0 %	14.3 %	6.1 %
Multi-stakeholder partnership	4.1 %	6.1 %	30.6 %	14.3 %
Exclusive single-provider contract	2.0 %	2.0 %	10.2 %	0.0 %
Operational independence	0.0 %	2.0 %	6.1 %	0.0 %
Total	6.1 %	12.3 %	61.2 %	20.4 %

4. CONCLUSIONS

Electromobility is a growing trend in the context of environmental, economic, and social sustainability. In wood processing enterprises that use traditional manufacturing processes and conventional combustion engines for logistics and transport activities, electric vehicles and electrified handling equipment offer innovative solutions with the potential to reduce emissions, improve energy efficiency, and increase overall competitiveness.

The Slovak wood processing sector is environmentally advanced, with all surveyed companies holding sustainability certificates, yet its transition to electromobility is still in its early stages. Most of the enterprises surveyed are still in the feasibility or pilot phase, with only a minority having completed full electrification within their businesses. The implementation of electromobility in wood processing enterprises in Slovakia is mainly driven by stricter regulations and efforts to maintain the brand image, but it is slowed down by high initial capital costs, insufficient charging infrastructure, limited choice of heavy electric vehicles, and concerns about reliability.

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THE ROLE OF AGILITY IN ACHIEVING THE SUSTAINABILITY AND INVESTMENT CAPABILITY OF WOOD PROCESSING COMPANIES

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Abstract: The aim of the article was to analyse the role of business agility in integrating sustainability across industries with focus on wood processing companies in Slovakia. The agility depends on the optimal combination of partial business capabilities, and it can determine the current and continued effectiveness and performance of company. In the article, we research long-term activities and investment management of companies and find the connections between the level of corporate agility and investment capability. The results describe relevant conclusions considering actual status and trends of the ability of companies to adapt to market changes in effective ways with a focus on sustainability and competitiveness. Based on the results of the Business Agility Institute survey and the analysis of data collected from selected wood processing companies, we defined the greatest barriers for the implementation and continuous application of business agility principles as well as determinants of insufficient agile development conditioned by specific factors in wood processing industry of Slovakia.

Keywords: business agility, sustainability, investment, wood processing sector, Slovakia.

1. INTRODUCTION

Over the last few decades, organisations have been narrowing their attention on “core business”. This approach may have worked well in more predictable times. But for some, it came at a cost. They have become less agile and flexible, less resilient and adaptable towards market, technology and other changes, and also less capable of innovating. So, the short-term pursuit of efficiency has undermined their long-term sustainability (Coemans). Agility and sustainability of companies are key concepts in modern management that help companies respond quickly to changes while creating value for society and the environment in the long term. At the same time, agile companies are able to implement sustainable innovations faster, thereby increasing their long-term competitiveness and positive impact on society.

The concept of the agile enterprise was born in the manufacturing area. The concept originated in the 1990s and emphasized the ability of manufacturing firms to rapidly change their production processes and adapt to changes in demand, technology, and competition (Nagel, 1992). In general, business agility refers to an organization's ability to quickly adapt to changes in both external and internal environments, respond effectively to new challenges, and simultaneously seize opportunities through flexible decision-making, team collaboration, and continuous improvement. In the context of growing environmental and social challenges, there is an increasing emphasis on the need to link agility with the principles of sustainability. Sustainability focuses on ensuring long-term balance between economic growth, environmental protection, and social justice (Elkington, 1997). According to Goswami and Mansi (2022), agility is *“the capacity of the organization to respond to changes by altering the hierarchical structure, process, and procedure, culture followed, making technological advancements, following sustainable practices, and widening the organizational network”*.

Agile companies possess several characteristics that are favorable for the implementation of sustainable strategies. These include, for example, the ability to respond quickly to legislative changes in the area of ESG (Environmental, Social, Governance), to introduce ecological innovations, and to involve stakeholders more effectively in decision-making processes. As Rigby et al. (2020) point out, agility can serve as a tool to accelerate transformational change in favor of sustainable development, especially in turbulent and unpredictable environments. In the case of wood processing companies, this approach is particularly relevant, as the industry faces increasing environmental requirements, pressure to certify the origin of raw materials (e.g., FSC), as well as expectations regarding waste reduction and carbon footprint minimization. Agile wood processing companies are capable of flexibly adapting production processes, implementing technologies to use wood resources more efficiently, and responding to changing demand for environmentally friendly products. A high level of adaptability is also crucial in ensuring supply chain transparency and meeting the requirements of domestic and international partners for responsible and sustainable business practices. Achieving agility in finance requires compliance processes and reporting to blend with the trust that allows innovation, partnerships and collaboration to thrive; successful organisations have achieved an agile ethos and culture, whilst also defining boundaries for budgets, procurement and contractual relationships (Agile Business Consortium).

The connection between agility and sustainability is strong because agile approaches enable organizations to respond flexibly to changing environmental and social demands, thereby supporting long-term resilience, innovation potential, and responsible business practices aligned with the principles of sustainable development. Moreover, in the long term, integrating business agility with sustainability supports not only the resilience and competitiveness of organizations but also their ability to create positive value for society and the planet.

Slovakia with a value of 279.2 m³ exceeds the average hectare of wood stocks of all European regions (Green Report, 2021), up to 17.1% more carbon is stored in them than in 1990 (Green Report, 2020). Slovakia is the 13th most forested among 43 European states and has a higher forest cover than the average of Europe (34.8%), EU-28 (38.3%), and all regions, except for Northern Europe (Forest Europe, 2020). The contribution of the forestry and wood-processing sector to the Slovak GDP of 2.61% far exceeds the average contribution of all European regions, and in the ranking of individual countries, it is the fourth highest after Latvia (4.5%), Estonia (4.26%), and Finland (4.22%), as stated in Green Report (2021). The wood-processing industry in Slovakia is in a difficult situation, but there are possibilities for better investment management and the potential for a positive impact on the performance of companies (Merková, Drábek, Jelačić, 2015). Wood industry generates positive values of the EVA indicator with upward trend, which shows the good performance important in terms of future national economic policy in Slovakia as well as in terms of potential domestic and foreign investors (Rajnoha and Kánová, 2022). According to several economic indicators, productivity growth and wages, the paper sector appears to be a sector with potential for the Slovak economy (Kánová et al., 2024).

Despite the industry's strengths in terms of forest cover, wood stocks, carbon stocks, and contribution to Slovak GDP, the industry is undercapitalized and has created high investment debt over many years. The importance of the wood processing sector in Slovakia was the main motivation for our research.

The aim of the article was to analyse the role of business agility in integrating sustainability across industries with focus on wood processing industry (WPI) in Slovakia. The agility depends on the optimal combination of partial business capabilities, and it can determine the current and continued effectiveness and performance of company.

2. MATERIAL AND METHODS

In the article, we research business agility and find the connections between the level of and investment capability. Source data were collected from EU Eurostat database, Business Agility Institute and Agile Business Consortium. For analysis we have selected indicators of expenditure to research and development at the sectoral level. Due to the different sizes of values and the inadequacy of comparison in absolute terms, we calculated the percentage share of R&D in gross fixed capital formation.

Sectors of Slovak economy categorized according to NACE classification were following:

C – Manufacturing

C16 – Manufacture of wood and of products of wood and cork (Wood)

C17 – Manufacture of paper and paper products (Pulp and Paper)

C31-32 – Manufacture of furniture, other manufacture (Furniture).

Categories of indicator Gross fixed capital formation by industry and by asset (flows) according to Eurostat database analysed in the paper were:

N11G Total fixed assets (gross)

N1171G Research and development, gross

Statistical tool t-test was used to compare the means of two groups to determine if the difference between them is significant. Levene test was used to test homogeneity of variances.

3. RESULTS AND DISCUSSION

The results describe relevant conclusions considering actual status and trends of the ability of companies to adapt to market changes in effective ways with a focus on sustainability and competitiveness. We defined the greatest barriers for the implementation and continuous application of business agility principles as well as determinants of insufficient agile development conditioned by specific factors in wood processing industry of Slovakia.

Time series and linear trend of R&D share as % of total investment in given sector during 10-year period 2015-2024 is presented in Fig. 1. We can positively assess the growing trend in each of the WPI sectors, the most significant growth in the C17 furniture sector, which has also surpassed the aggregated group C-Manufacturing during the last 2 years. Descriptive statistics of mentioned indicator is described in Table 1. Slovak industry invested to R&D with the average 5.69% and an even higher median at 6.07% of total investment and this aggregated group exceeds each wood processing industry. The highest average R&D investment share among wood processing reached the furniture industry 3.52% with a lower median value 3.08%.

Separate WPI sectors lag in research and development is particularly evidenced by the median presented in Box Plot (Fig. 2). Almost no R&D is in wood sector and pulp & paper sector. Statistical results of t-test in Table 2 showed significant differences ($p < 0.05$) between

the mean of C-Manufacturing and all individual WPI sectors. However, the Levene test did not show homogeneity of variances of individual variables, we will not consider these statistical results relevant.

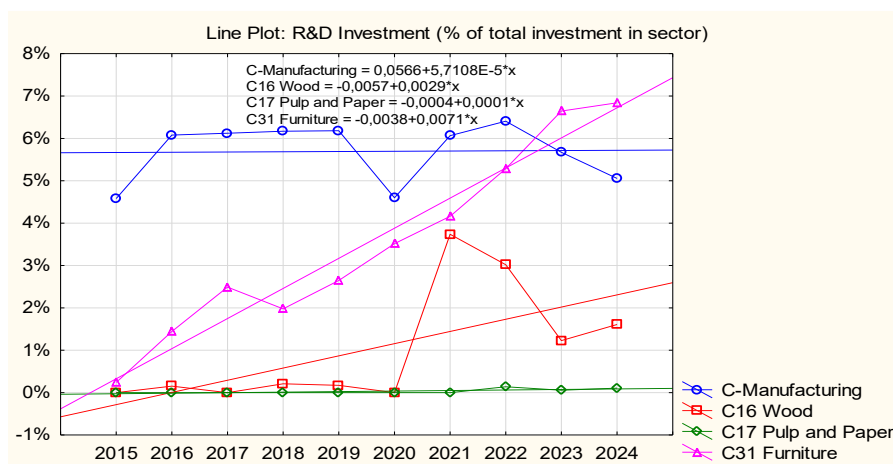


Figure 1. Line Plot: R&D Investment in WPI sectors in Slovakia (Source: own, Data: Eurostat)

Table 1. Descriptive statistics: R&D Investment in WPI sectors in Slovakia
 Source: own, Data: Eurostat

Descriptive statistics: R&D Investment share as % of total investment in a sector							
Group	Valid N	Mean	Median	Minimum	Maximum	Variance	Std.Dev.
C-Manufacturing	10	5.69%	6.07%	4.58%	6.41%	0.00%	0.69%
C16 Wood	10	1.01%	0.19%	0.00%	3.74%	0.02%	1.38%
C17 Pulp and Paper	10	0.03%	0.00%	0.00%	0.14%	0.00%	0.05%
C31 Furniture	10	3.52%	3.08%	0.24%	6.84%	0.05%	2.20%

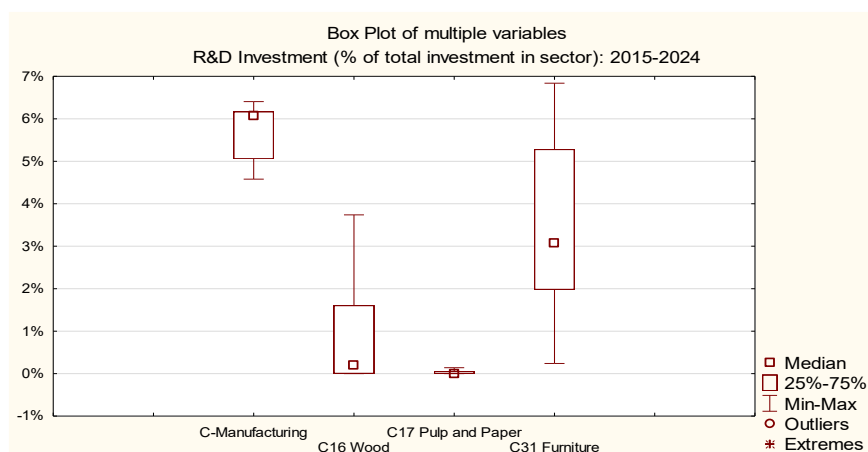


Figure 2. Box Plot: R&D Investment in WPI sectors in Slovakia (Source: own, Data: Eurostat)

Table 2. Statistical results for T-test: C-Manufacturing vs. WPI in Slovakia

Source: own processing

T-test for Independent Samples: C-Manufacturing vs. WPI sectors													
Group	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	Variances	Levene F(1,df)	df Levene	p Levene
C vs. C16	5.69%	1.01%	9.618	18	0.000	10	10	0.69%	1.38%	0.052	4.493	18	0.048
C vs. C17	5.69%	0.03%	25.867	18	0.000	10	10	0.69%	0.05%	0.000	25.106	18	0.000
C vs. C31	5.69%	3.52%	2.973	18	0.008	10	10	0.69%	2.20%	0.002	9.585	18	0.006

According to Business Agility Institute report (2018) „*all business agility journeys have their own challenges*“. These challenges often stem from deeply rooted organizational cultures, resistance to change, lack of leadership support, insufficient agile expertise, and the difficulty of aligning agile practices with existing business models, especially in traditional or heavily regulated industries. Table 3 provides an overview of the three perceived challenges to agility between 2018 and 2024, illustrating temporal trends and highlighting both persistent and emerging challenges in the implementation of agile practices across organizations.

Table 3. The main challenges of implementing agility and agile development of WPI

Source: Own processing according to Business Agility reports (2018-2024)

2018	2019	2020	2021	2022	2023	2024
▪ Leadership ▪ Lack of buy-in ▪ Inappropriate org. design	▪ Leadership ▪ Change management ▪ Culture	▪ Leadership style ▪ Agile mindset ▪ Silos	▪ Resistance to change ▪ Leadership ▪ Difficulty scalling	▪ Resistance to change ▪ Leadership ▪ Unsuitable practices	▪ Leadership ▪ Resist to change ▪ Mindset	▪ Outlanded leadership ▪ Mindset ▪ Lack of direction goal

The leadership is the most perceived challenge to business agility adoption that most organizations face. The role of leader in organization is crucial because the leader sets the tone for entire organization. Leaders should strive to be aware of how they are modeling the new culture and agile mindset and be mindful of their leadership style to ensure that it is consistent with the goals that the business agility journey is trying to achieve (Business agility report, 2019). In 2024, the second challenge is perceived the influencing fixed or traditional mindset. This challenge often stems from a narrow perception that agility is confined to IT and limits its broader adoption across organization. New in 2024, many organizations report that unclear, contradictory or missing transformation goals were significantly hindering their efforts towards business agility. This means: change fatigue, conflicting priorities, insufficient time given for change initiatives, and lack of clarity on the benefits. Ultimately leading to disengaged staff, wasted funds, and significant delays (Business agility report, 2024, p.26).

While the wood processing industry has significant potential to benefit from agile principles – especially in the context of sustainability, innovation, and responsiveness to market demands – several barriers continue to hinder the successful implementation of agility in this sector. The wood manufacturing industry must comply with various regulations, including environmental laws (air and water quality, emissions, waste disposal), and occupational health

and safety standards to ensure worker protection. International regulations also apply, covering trade, import/export, and sustainability. Companies are required to monitor compliance and keep accurate records. Additionally, many pursue certification to show adherence to industry standards, enhance transparency, and demonstrate commitment to sustainability and responsible business practices (Damini).

Many wood-processing companies lack advanced technologies such as IoT systems, smart sensors, or integrated ERP platforms. Without access to real-time data and automation, it becomes difficult to apply key agile principles such as continuous improvement, feedback loops, and flexibility (Gaspar et al., 2023). A typical sign of Slovak firms is indifference and aversion of using new and unfamiliar tools because they do not understand or do not trust those. If the company does not trust them, it does not expect possible future effects, especially improving performance. So, the firms use old customary manners without the need of change or innovations (Rajnoha et al., 2018). Traditional hierarchical structures and standardized workflows dominate many companies in this sector. However, organisations that prioritise business agility, differ from hierarchical organisations in their flexibility (Agile Business Consortium). These rigid environments resist rapid decision-making, experimentation, and team autonomy, all of which are critical for agile transformation (Bessant et al., 2000). Strict environmental standards (e.g., FSC certification), occupational safety regulations, and complex administrative requirements drain resources and distract organizations from innovation efforts. While essential, these requirements create a tension between compliance and adaptability (Hassan and Grobbelaar, 2023).

In a VUCA world (volatility, uncertainty, complexity and ambiguity), especially because of the complexity, the impact of change is often unpredictable, which is one of the reasons why agile businesses induce relatively small changes to the system and are very open to feedback to test assumptions and learn (Coesmans).

4. CONCLUSION

Although business agility can significantly enhance innovation, sustainability, and responsiveness in the wood processing sector, factors mentioned in the article obstruct its effective implementation. Substitute problem is seems that many organizations still view agility as a method rather than a systemic change to the way business operates. Business agility is not just about a specific methodology or achieving a definitive goal. It is an approach of continuous improvement and adaptation. By embracing business agility, companies are setting themselves up for long-term success, regardless of the uncertain future. Diversity of thought, skills, and strategy is essential for resilience. Dynamic focus allows businesses to safely adapt to changing conditions while remaining aligned with established goals and targeted performance.

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INCREASING OF THE PERFORMANCE OF SLOVAK WOOD PROCESSING COMPANIES ON THE PLATFORM OF QUALITY MANAGEMENT SYSTEMS

Pavol Gejdoš

Abstract: The article deals with the possibilities of increasing the performance of Slovak wood processing enterprises on the platform of quality management systems. Quality management systems, through their methods, tools and concepts, enable wood processing industry enterprises to effectively manage their costs, increase their performance and customer satisfaction. Therefore, it is important that wood processing industry enterprises in Slovakia also use this potential to an increased extent and thereby gain a competitive advantage in a demanding market environment.

Keywords: quality, performance, quality management technics, wood processing industry

1. INTRODUCTION

In today's highly competitive business environment, most manufacturing and non-manufacturing organizations face constantly increasing demands for the quality of products, processes, and services. Emphasis on effective quality management has become a key prerequisite for long-term sustainability, profitability, and the ability of companies to adapt to dynamically changing market requirements. In this context, quality management tools (e.g., control charts, cause-and-effect analysis, statistical quality control methods, benchmarking, or continuous improvement methods) play a crucial role in optimizing internal processes, reducing nonconformities, and increasing customer satisfaction.

Several empirical studies by authors such as Marcysiak (2021), Liu et al. (2021), and Ghicajanu (2019) suggest that the systematic use of these tools can have a positive impact on an organization's competitiveness and performance—not only in terms of production quality, but also from the perspective of economic indicators such as profitability, labor productivity, cost efficiency, and the rate of complaints. Nevertheless, there are significant differences in the level of quality tool implementation and their impact on business performance across various sectors and companies. These differences may be related to company size, ownership type, industry affiliation, the level of managerial capacity, as well as the degree of quality-oriented organizational culture.

The aim of this article is to analyze the impact of using quality management tools on the performance of companies in the wood-processing industry and to identify the factors that influenced their decision to implement these tools. It also examines the main benefits resulting from the implementation of such tools. The research is based on quantitative data collected through a questionnaire survey conducted among companies of various sizes between March 2025 and May 2025. The results contribute to a better understanding of the role of quality in strategic business management and provide recommendations for more effective implementation of quality tools in order to strengthen their competitive advantage.

2. METHODOLOGY

The Six Sigma method represents a systematic and data-driven approach focused on improving process quality by identifying and eliminating the causes of defects, variability, and inefficiencies. It is based on the DMAIC methodology (Define – Measure – Analyze – Improve – Control), which enables companies to manage improvement projects in a logical and analytical sequence (Herlambang, 2020). The main goal of Six Sigma is to achieve process outputs with minimal variability and defects—ideally fewer than 3.4 defects per million opportunities, which represents the “six sigma” level in statistical terms. Thus, Six Sigma is an effective tool of strategic quality management that can significantly contribute to the long-term performance and competitiveness of companies.

In the context of business performance, the implementation of Six Sigma has the potential to deliver multidimensional benefits. First and foremost, it leads to improved quality of products and services, which is reflected in reduced nonconformities, complaints, and returns. At the same time, it contributes to increased efficiency of internal processes by helping to identify and eliminate non-value-adding activities (Singh and Rathi, 2019). Six Sigma supports enhanced customer satisfaction through a consistent focus on their needs and expectations (Voice of the Customer). Together, these factors help improve a company's financial indicators, such as profitability, return on investment, labor productivity, and overall cost efficiency.

Empirical research authors (Raval et al., 2020, Winatie et al., 2020) shows that Six Sigma has a particularly favorable impact in large, process-oriented organizations. However, with the growing emphasis on quality and optimization, it is increasingly being applied in small and medium-sized enterprises, as well as in service and administrative sectors.

Total Quality Management (TQM) represents a comprehensive approach to organizational management focused on continuous quality improvement across all areas of a company's operations. TQM provides a holistic framework for quality management that integrates technical, process, and social aspects of business activities. (Nenadal et al., 2018) It is based on principles such as customer orientation, process approach, continuous improvement, employee involvement, and fact-based decision-making. The essence of TQM lies in creating a corporate culture in which every member of the organization actively contributes to improving the quality of products, services, and internal processes (Nguyen et al. 2018).

In terms of its impact on business performance, TQM is considered one of the most significant approaches in modern quality management. The implementation of TQM contributes to increased customer satisfaction, as organizations are systematically focused on meeting and exceeding customer expectations. (Babu and Thomas, 2021). In addition, it leads to improved internal efficiency through process optimization, waste reduction, lower error rates, and enhanced performance of work teams. TQM also supports a company's innovation capacity by creating an environment conducive to feedback, learning, and adaptability.

Empirical studies authors Zaidi and Ahmad (2020), Rosak-Szyrocka et al. (2022) confirm the positive impact of TQM on various dimensions of business performance, including financial indicators (e.g., return on investment, productivity, profitability), non-financial outcomes (e.g., product quality, employee satisfaction), and long-term competitiveness.

3. RESULTS AND DISCUSION

To collect data for the empirical research, a questionnaire survey was conducted, in which 3,585 companies were approached. To determine the minimum sample size, a formula for the finite population according to Yamane Taro (Lind, 2020) was applied. With a target population size of 2,504 units and the selected error $e=0.05$ was the minimum sample size derived as:

$$n = \frac{3585}{1 + 3585 \cdot 0.05^2} = 360 \quad (1)$$

The questionnaire that have been researched, we can say that a survey sample of enterprises is relevant, has sufficient denunciation, which is also verified by selected mathematical and statistical methods.

The table1. presents the percentage representation of industrial sectors in Slovakia within the research sample.

Industry sector	SK NACE 32	SK NACE 31	SK NACE 29	SK NACE 28	SK NACE 27	SK NACE 26	SK NACE 24+25	SK NACE 23
%	2,47	4,94	4,94	7,90	4,20	3,46	25,19	4,20
Industry sector	SK NACE 22	SK NACE 21	SK NACE 20	SK NACE 17	SK NACE 16	SK NACE 15	SK NACE 13	SK NACE 10,11
%	6,42	1,48	2,72	2,22	6,67	1,73	4,69	16,79

The next part of the article (Figure 1) presents the results of analyzing the performance of the wood-processing industry sector using time series modeling. The indicator used for this analysis was return on sales. The input data for this analysis were obtained from the Statistical Yearbooks of Industry of the Slovak Republic for the years 2015, 2018, 2021, and 2024.

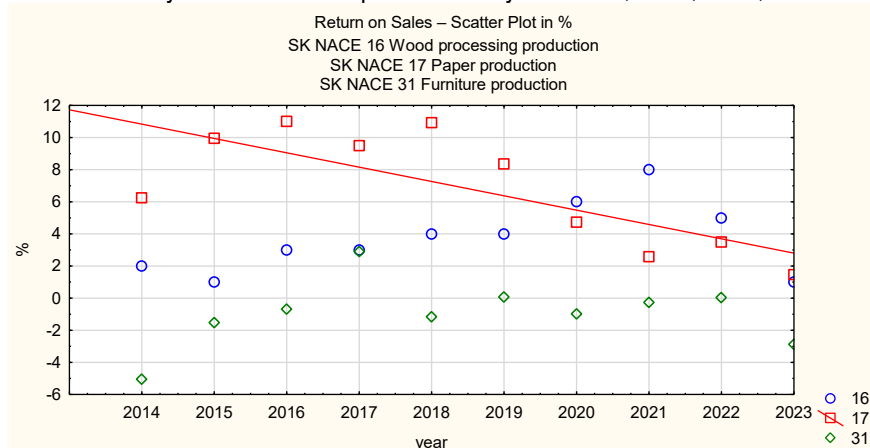


Figure 1 Linear trend model of development for SK NACE 16, 17, and 31 for the indicator "Return on Sales."

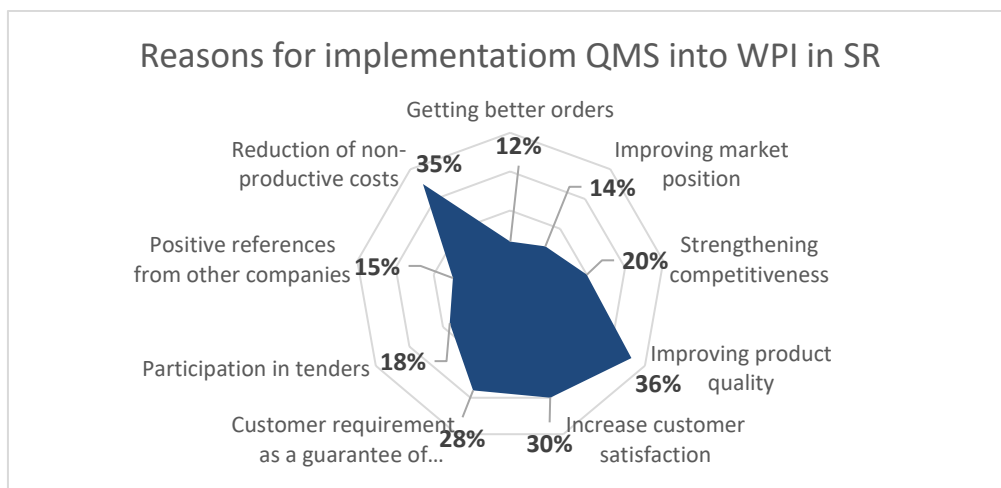


Figure 2 Reasons for implementation of quality management systems in the wood processing companies in SR

Figure 2 shows the reasons why companies in the wood processing industry have decided to implement a quality management system. The results show that among the most significant reasons for implementing quality management systems in the wood-processing industry (WPI) of the Slovak Republic are improving product quality, reducing non-productive costs, and increasing customer satisfaction.

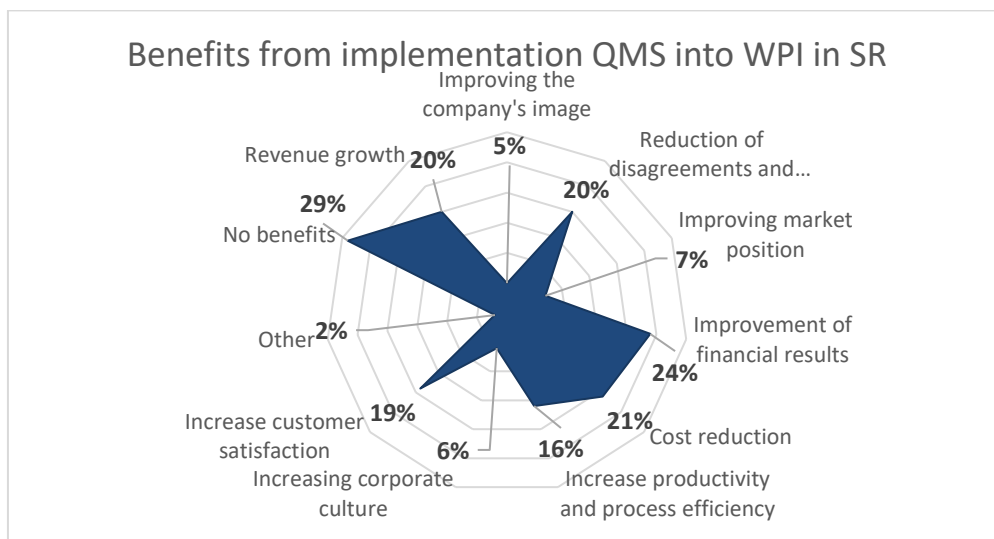


Figure 3. Benefits from implementation of quality management systems in the wood processing companies in SR

In Figure 3, we can see that nearly one-third of companies reported no benefits from the implementation of quality management systems, which contrasts with the claims made in some scientific studies (Mareček-Kolíbiský 2023, Smihunova et al. 2024). This may be due to the

formal introduction of the systems, insufficient understanding of quality principles, lack of a systematic approach, and similar factors. Other most significant benefits included the improvement of financial results, cost reduction, and revenue growth.

To illustrate the impact of the tools of the quality management system on the company's performance, we established the following hypothesis H1.

H1 Companies in the wood processing industry that use a wider range of quality management tools (QMT) also achieve a higher level of profit.

The results of the contingency analysis are shown in Table 2. The null hypothesis of independence is rejected in favor of the alternative hypothesis ($p=0.000$) – the using of QMT and achieved profit of manufacturing enterprises are significantly dependent variables. Based on the value of the contingency coefficient 0,42, the strength of dependence is evaluated as moderate.

Table 2 Results of Pearson chi-square test of contingency – the use of QMT versus achieved profit of wood - processing enterprises.

Using of QMT vs. Profit	Chi-square test	Degree of freedom	p-level	Contingency coefficient
	85,89	3	0,000	0,42

From the values of the residual frequencies in Table 3, it can be concluded that wood processing manufacturing enterprises that use a smaler scale of quality management tools achieve a loss or profit of up to 100 thousand euros. Enterprises that used wider scale of quality management also achieve a higher level of profit – more than 100 thousand euros. The findings presented in this part of the research are consistent with several international studies that confirm the positive impact of quality management systems on business performance. Gorondutse (2021), as well as Olaleye et al. (2021).

Table 3 Contingency table of residual frequencies – the use of QMT versus achieved profit of wood - processing enterprises.

Using of QMT	Profit in EUR thousands			
	< 0	0-100	100-500	> 500
wider scale	-23,87	-16,89	29,00	11,77
smaller scale	23,87	16,89	-29,00	-11,77

4. CONCLUSION

The research results confirm that quality management tools play a significant role in enhancing business performance across various economic sectors. The systematic use of these tools is particularly reflected in the optimization of internal processes, reduction of error rates, shortening of production cycles, and increased customer satisfaction. Ultimately, these benefits are also reflected in improved financial indicators such as return on sales, labor productivity, and overall cost efficiency. In companies where quality is perceived merely as a formal requirement, without being linked to business objectives, the benefits are minimal or not

observed at all. In contrast, in environments with a mature quality culture and an emphasis on data-driven decision-making, quality management tools serve as an effective means of continuous improvement and strengthening competitiveness.

Similar results were achieved in the wood-processing industry sector. Sectoral differences were also observed, where companies in the pulp and paper industry reported a higher level of use of quality management tools compared to companies in wood processing and furniture manufacturing. This is mainly due to the fact that companies in this sector are bigger, more technologically advanced and are mostly characterized by foreign capital ownership structures.

In contrast, enterprises in the remaining sectors of wood processing are mostly small or medium-sized, predominantly with domestic capital, and do not possess the necessary resources—especially financial and human—to implement quality management systems. Therefore, it must be concluded that there is a significant potential to raise awareness of quality management in these sectors, and it is essential to support the development of an organizational culture focused on continuous improvement and learning. This represents an important tool for enhancing business performance.

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MAIN INDICATORS FOR EVALUATING THE SOCIAL IMPACT OF RESEARCH PROJECTS IN THE FORESTRY-BASED SECTOR

Antoaneta Angelova-Stanimirova

Abstract: This paper outlines the main indicators for evaluating the social impact of research projects in the forestry-based sector. The literature survey from 2004 to February 2025 in the Scopus database distinguished ten pertinent sources. Analyzed and summarized the data via induction and deduction. The results gained from the paper highlight the social impact of research projects in the forestry-based sector through the lenses of economic, environmental, and social sustainability. Three separate sections from the structure of this paper. The first section provides an explanation of the research toolkit. The results are revealed in the second section. The last one includes the conclusion and discussion. Recommendations for future research refer to design more robust standards for assessing social impact and to use cost-effective impact assessment methods to ensure positive outcomes.

Keywords: social impact, forest sector, control

1. INTRODUCTION

Forests are an essential natural resource that is renewable over time, playing an essential role in our ecosystem. They are valuable for several things, including cultural and spiritual significance, biodiversity, ecological services, wood and non-timber goods, and many others (Gilani and Innes, 2020).

Taking measures to promote and safeguard forests is a crucial aspect of public governance. This raises the issue of the necessity of formulating and executing effective management strategies (Dombashov, 2024). The primary components of executing effective management strategies include monitoring and evaluation, integral parts of the control process (Nedyalkova, 2024). The examination of indicators for evaluating the social impact of research projects in the forestry-based sector is crucial for the success of these projects. The social impact of research represents an outcome of research evaluation, which numerous countries have integrated as a key aspect of science policy (Alexandrova, 2024; Lambovska, 2024).

This paper outlines the main indicators for evaluating the social impact of research projects in the forestry-based sector. To support this objective, it utilizes a comprehensive toolkit that encompasses the methods of analysis and synthesis, together with the Criteria i for executing organized literature searches.

Three separate sections form the structure of this paper. The first section provides an explanation of the research toolkit. The results are revealed in the second section. The last one includes the conclusion and discussion.

2. RESEARCH TOOLKIT

This study examines the research that has been published on the topic of "indicators for evaluating the social impact of research projects in the forestry-based sector" in the science

database that is maintained by Scopus. The search was conducted using various synonyms associated with the key phrases in the topic. The selected methodology is adopted based on Criterion i (Palinkas et al., 2015) and Lambovska and Raitskaya's (2022) approach. It entails identifying and selecting all instances that satisfy a predetermined significance criterion. The research was carried out in the subsequent phases:

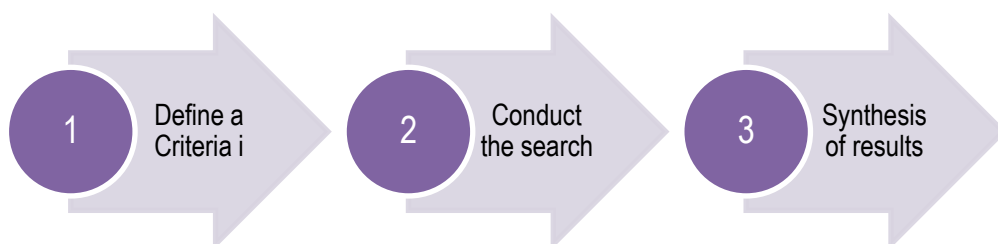


Figure 1. Research methodology

The primary elements that form Criteria i the first phase of the study are as follows. The research question for the study is: Which are the main indicators for evaluating the social impact of research projects in the forestry-based sector? To gather relevant data, the search was conducted using the Scopus database. The combination of terms ("social impact" OR "social effect") AND ("forest" OR "forestry") AND ("research" OR "study" OR "investigation") AND ("indicators" OR "criteria") AND ("evaluation" OR "assessment" OR "performance") were used as a search parameter. The basic requirement is that the documents should be related to the research topic. The search covered the years 2004 to February 2025. The search strategy specified that the search term should appear in the document's title, abstract, or keywords , and only open-access or available from the author records were included. At this phase, the author of the paper uses a structured search approach.

In the second phase, ten outcomes were identified within the required timeframe and constraints. These outcomes constitute the research sample, which will serve as the basis for further analysis.

In the third phase, the sample is analyzed, the results are summarized, and conclusions are drawn. This phase employs both analytical and synthesis approaches to ensure a thorough understanding of the social impact indicators discovered through the research.

3. RESULTS

The results of the study are systematized in Table 1. The table is arranged in alphabetical order by author's last name. The columns include document numbers from the sample, the names of the authors, the year of publication, and indicators.

Table 1. Main indicators for evaluating the social impact of research projects by authors

N	Authors	Year of publication	Indicators

1	Christensen L., Krogman N., Parlee B.	2010	Community Support Systems (CSS) (Community Support, and Social Healing)
2	Dobbs C., Escobedo F.J., Zipperer W.C.	2011	Ecosystem Services and Goods (ESG)
3	Egan A., Estrada V.	2013	Community Stability (CS); Economic Impacts (EI); Education and Outreach (EO); Job Creation (JC); Local Community Involvement (LCI); Stakeholder Involvement (SI)
4	Elizabeth Jackson J., Lee R.G., Sommers P.	2004	Longitudinal Analysis (LA)
5	García-Hernández J., Waluyo-Moreno I.J.	2022	Driver-Pressure-State-Impact-Response (DPSIR) Framework
6	Gilani H.R., Innes J.L.	2020	Biodiversity Conservation (BC); Ecosystem Services (ES); Policies and Legislation Supporting Sustainable Forest Management (PLSSFM); Protective Functions (PF); Stakeholder Involvement (SI)
7	Rana P., Miller D.C.	2021	Local Community Involvement (LCI); Local Livelihood Benefits (LLB); Predictive Proxy Indicators (PPIs)
8	Schweier J., Magagnotti N., Labelle E.R., Athanassiadis D.	2019	Economic Impacts (EI); Sustainability Impact Assessment (SIA)
9	Sherrouse B.C., Semmens D.J., Clement J.M.	2014	Social Values for Ecosystem Services (SolVES) (Aesthetic, Biodiversity, Cultural, Economic, Future, Historic, Intrinsic, Learning, Life sustaining, Recreation, Spiritual, Subsistence, and Therapeutic)
10	Thompson B.S.	2023	Impact Investments (II)

Christensen et al. (2010) define as a main indicator for evaluating the social impact of research projects in the forestry-based sector – Community Support Systems (CSS). CSS are indicators that reflect community support and social healing. Some examples of these indicators include the presence of youth centres and programmed activities.

ESG stands for ecosystem services and goods, which are indicators that have an impact on human well-being. Some examples of ESG indicators include tree cover, soil pH, and soil organic matter (Dobbs et al., 2011).

Egan and Estrada (2004) highlight six indicators: Community Stability (CS), Economic Impacts (EI), Education and Outreach (EO), Job Creation (JC), Local Community Involvement (LCI), and Stakeholder Involvement (SI). CS: Evaluating the stability and resilience of communities engaged in forestry initiatives. EI: Assessing the economic advantages and alterations resulting from management (also Schweier et al., 2019). EO: Inviting young people (those between the ages of 18 and 25) to help carry out the project's goals and outcomes, as well as to increase both the quantity and quality of trainings provided. JC: Assessing the quantity of employment opportunities provided. LCI: the degree of participation of local society

in management processes (also Rana and Miller, 2021). SI: The extent to which stakeholders participate in the design, execution, and evaluation of forest management actions. (also Gilani and Innes, 2020).

In their research, Elizabeth Jackson et al. (2004) define the approach of Longitudinal analysis (LA). LA consists of conducting surveys and studies over an extended period of time in order to gain an understanding of the long-term social effects of forest management policies.

A study by García-Hernández and Waluyo-Moreno (2022) contributed to the Driver-Pressure-State-Impact-Response (DPSIR) Framework. This framework is utilized to examine the relationships between society and the environment, encompassing economic value, land use, and ecosystem services.

According to Gilani and Innes, the main indicators for evaluating the social impact include Policies and Legislation Supporting Sustainable Forest Management (PLSSFM), Protective Functions (PF), Biodiversity Conservation (BC), Stakeholder Involvement (SI), and Ecosystem Services (ES). ES refers to forest areas specifically designated or managed for particular ecosystem services or cultural and spiritual qualities.

Local Livelihood Benefits (LCI): Indicators pertaining to property rights and local livelihood advantages, including seedling survival rates and community-driven monitoring. Together with LLB and PPIs are the indicators according to Rana and Miller (2021). PPIs, or predictive proxy indicators, are measurements that are taken during the implementation of a program in order to forecast the long-term effects on society and the environment.

The research by Schweier et al. (2019) distinguished two indicators – EI and Sustainability Impact Assessment (SIA). SIA encompasses the examination of the societal, environmental, and economic sustainability dimensions.

Social Values for Ecosystem Services (SolVES): A method for evaluating, mapping, and quantifying non-market values recognized by ecosystem stakeholders (Sherrouse, 2014).

According to Thompson (2023), Impact Investments (II) is the basic indicator for evaluating the social impact. II: Assessing financial and impact risks in initiatives designed to improve forest management and biodiversity conservation.

Table 2 presents a synthesis of these indicators by categorizing them into four groups: Approaches, Community Engagement, Socio-Economic Outcomes, and Sustainability.

Table 2. Groups of the main indicators for evaluating the social impact of research projects

Group	Indicators
<i>Approaches</i>	DPSIR framework, SolVES tool, Longitudinal analysis, Impact investments
<i>Community Engagement</i>	Community support systems, stakeholder involvement, local community involvement, education and outreach, policies and legislation supporting sustainable forest management
<i>Socio-Economic Outcomes</i>	Job creation, community stability, economic impacts, local livelihood benefits, protective functions, biodiversity conservation, ecosystem services
<i>Sustainability</i>	SIA, PPIs, ESG indicators

4. CONCLUSION AND DISCUSSION

This paper outlines the main indicators for evaluating the social impact of research projects in the forestry-based sector and includes the methods of analysis and synthesis, as well as the Criteria i for conducting structured searches of the literature, are included in the toolkit of the paper.

Based on the results of this study the main conclusions and inferences can be drawn. First, the results of the conducted study indicate that, for the period under consideration from 2004 to 2025, there is an insufficient number of publications on the research topic (Table 1). Second, the analysis allows several conclusions to be made: To begin with, the Economic Impacts is identified as the most frequently used indicator, which is also included in the approaches developed by the authors under study. Additionally, Socio-Economic Outcomes represent the largest group of indicators included in the study. Following this, the Community Engagement group ranks second, while Sustainability comes in third. The indicators included in Sustainability are complex in nature. Next, evaluating the social impact involves the use of a combination of quantitative and qualitative metrics. Lastly, this study introduces 22 indicators for evaluating the social impact of research projects in the forestry-based sector. These indicators are categorized into four groups: Approaches, Community Engagement, Socio-Economic Outcomes, and Sustainability.

Recommendations for future research refer to design more robust standards for assessing social impact and to use cost-effective impact assessment methods to ensure positive outcomes.

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ESSENTIAL COMPONENTS OF MANAGEMENT CONTROL SYSTEMS IN THE FORESTRY-BASED SECTOR

Antoaneta Angelova-Stanimirova

Abstract: This paper outlines the essential components of management control systems (MCSs) in the forestry-based sector. The data was gathered via a Design Science Research Process methodology. The literature survey found 13 relevant sources in the Scopus database. Both deduction and induction were used to examine and summarise the data. The obtained results provide valuable insights into creating and implementing an optimised management control system in forestry-based sector organisations. The structure of the paper is divided into three distinct sections. In the first one, the research toolkit is explained. The next section discloses the findings. It is followed by the last – third section, which encompasses the discussion.

Keywords: forest sector, control, management control systems

1. INTRODUCTION

Management control is considered crucial for the effective and efficient functioning of organisations (Lambovska, 2018). Management control systems (MCSs) are vital instruments used for monitoring, controlling, and improving operations and performance (Gomes et al., 2025). Partially, MCSs serve as the primary tools that provide managers with the necessary information to make strategic decisions and achieve organisational objectives (Lambovska and Angelova-Stanimirova, 2025). Reputational damage, financial hardship, bankruptcy, and organisational collapse can result from poorly functioning MCSs (Santosa et al., 2025). To ensure that organisations meet their objectives, they need to obtain a deep understanding of the MCSs and a clear awareness of their primary components.

This paper outlines the essential components of MCSs in the forestry-based sector.

The data was gathered via a Design Science Research Process methodology. Both deduction and induction were used to examine and summarise the data.

The structure of the paper is divided into three distinct sections. In the first one, the research toolkit is explained. The next section discloses the findings. It is followed by the last – third section, which encompasses the discussion.

2. TOOLKIT

This study adopts a modified version of the Design Science Research Process (DSRP) methodology, as outlined by Peffers (2007). This approach involves the execution of research activities as process-dependent stages that facilitate the completion of fundamental tasks and the production of primary work artefacts. The DSRP comprises five essential stages (see Fig. 1).

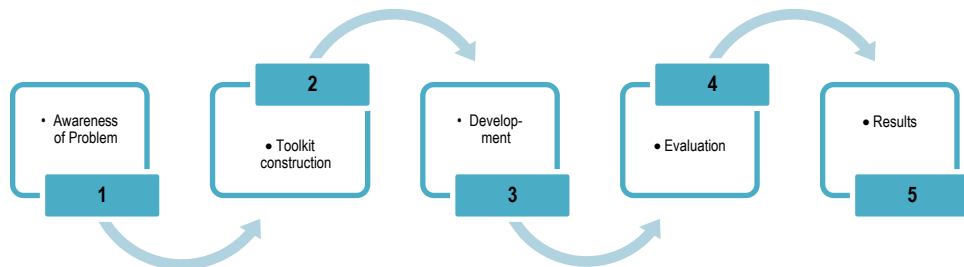


Figure 1. Research approach (adapted DSRP, Peffers (2007))

The initial stage, “Awareness of Problem”, emphasised the formulation of a preliminary proposal for a study topic – the analysis of existing accomplishments and outcomes, as well as relevant scientific fields and industry. The second stage, “Toolkit construction”, followed the initial idea and serves as a creative framework to outline the study processes. The third stage, “Development”, involved the elaboration and expansion of the initial research. The research was conducted using the scientific literature indexed by the Scopus database. The search criteria included combinations and synonyms of the phrases “components of management control systems” and “forestry”. Following the approach of Lambovska and Raitskaya (2022), the documents had to be directly related to the research topic. The fourth stage, “Evaluation”, involved assessing all documents according to the established inclusion and exclusion criteria. After the process was completed, the sample was prepared for analysis. The fifth section, “Results”, typically signifies the conclusion of a specific research cycle. The employed toolkit utilised a structured search approach during the Awareness of the Problem and Suggestion stages. The remaining stages were predicated on synthesis, analysis, induction, and deduction research methods.

3. FINDINGS

The findings of this research are highlighted in Table 1. There are four columns in the table. They are arranged in the following order: sample number, author names, year of publication, and components of MCSs in the forestry-based sector. On the basis of the surnames of each author, the table is arranged in alphabetical order.

Table 1. The sample and the components of MCSs in the forestry-based sector

N	Authors	Year of publication	Components
1	Abrams, J.	2019	Governance Structures
2	Boissière, M., Beaudoin, G., Hofstee, C., Rafanoharana, S.	2014	Sustainability Indicators
3	Dombashov, R.	2024	Sustainability Indicators
4	Gunn, E.	2005	Adaptive Management; Hierarchical Planning
5	Hickey, G.M., Innes, J.L.	2005	Governance Structures
6	Khasanov, E., Zelenkov, P., Petrosyan, M., Murygin, A., Laptenor, V.	2015	Automation and Technology

7	Mackey, B., Morgan, E., Keith, H.	2023	Sustainability Indicators
8	Mezenina, O.	2019	Information Systems
9	Packalen, T., Marques, A., Rasinmäki, J., Rosset, C., Mounir, F., Rodriguez, L., Nobre, S.	2013	Decision Support Systems (DSS)
10	Prandi, F., Magliocchetti, D., Poveda, A., De Amicis, R., Andreolli, M., Devigili, F.	2016	Automation and Technology
11	Reynolds, K.	2005	Decision Support Systems (DSS); Sustainability Indicators; Adaptive Management
12	Sannikov S.P., Pobedinskiy V.V.	2018	Information Systems; Automation and Technology
13	Trubins, R., Jonsson, R., Wallin, I., Sallnäs, O.	2019	Decision Support Systems (DSS); Behavioural Matrix

По-долу са изяснени основните компоненти на системата за управленски контрол открити в научната литература в това изследване.

Regarding *Governance Structures*, Abrams (2019) notes that effective forest management is a complex process that necessitates the establishment of robust governance institutions. It is necessary to involve a wide range of stakeholders for guaranteeing legitimacy and enhancing decision-making capabilities. Compliance with local, national, and international norms and standards is essential for upholding sustainable forestry practices (Hickey and Innes, 2005).

Dombashov (2024) emphasises the importance of establishing and overseeing *sustainability indicators* in the context of environmental regulation for developing sustainable management practices in the forestry-based sector. Machey et al. (2023) emphasise that the indicators typically encompass various dimensions, such as ecosystem integrity, efficient planning, and robust governance. A fundamental idea is that forests should be managed sustainably to fulfil the social, economic, ecological, cultural, and spiritual requirements of both current and future generations (Reynolds, 2005). Additionally, the study by Boissière et al. (2013) suggests that involving local people in monitoring and reporting can enhance the precision and cost-effectiveness of sustainability evaluations.

According to the studies by Reynolds (2005) and Gunn (2005), *adaptive management* is the ongoing development of management methodologies. To accomplish this, it is essential to evaluate results and derive insights from past experiences. Gunn (2005) characterises *hierarchical planning* as a process that involves deconstructing complex systems into manageable units. This type of planning enables facilitating enhanced control and decision-making across several organisational levels.

Regarding *Automation and Technology*, Khasanov et al. (2015) elucidate that the implementation of automatic control systems in forest farms and the timber industry can improve efficiency and precision in forest management practices. Modern technologies such as radio-frequency devices and uncrewed aerial vehicles are utilised for continuous monitoring and data collection, both of which are vital for making informed management decisions. The importance of these modern technologies is further underscored by the research of Sannikov and Pobedinskiy (2018) and Prandi et al. (2016).

Mezenina (2019) distinguishes *Information Systems* for Forest Inventory and Land Management as a key component of forestry-based sector management. This author defines efficient management as necessitating comprehensive information systems that integrate various components, such as land management, forestry cadastre, forest inventory, and land monitoring. Sannikov and Pobedinskiy (2018) add that, in the long run, these interconnected systems play a crucial role in monitoring both the qualitative and quantitative conditions of forest stands.

According to Trubins et al. (2019), DSS play a vital role in delivering model-driven assistance in the formulation, construction, and maintenance of strategies and policies within the forestry-based sector. DSS facilitate the evaluation of various management scenarios. Stakeholders can use DSS to explore the potential outcomes of different possible approaches (Reynolds, 2005). DSS analysis helps to identify the implications of each scenario, ensuring that forest management decisions are well-informed and aligned with ecological and economic objectives (Packalen et al., 2013).

Within the context of management scenario modelling in the forestry-based sector, Trubins et al. (2019) present the *Behavioural Matrix* as a fundamental component of behavioural assumptions.

Table 2 outlines the number of mentions of MCSs' components in the forestry-based sector. The table consists of three columns: one for the components, a second for the corresponding sources, and a third for the number of mentions. The sources refer to those in Table 1.

Table 2. Number of mentions of MCSs' components in the forestry-based sector

Component	Sources	Number of mentions
Adaptive and Hierarchical Planning	4, 11	2
Automation and Technology	6, 10, 12	3
Behavioural Matrix	13	1
Decision Support Systems (DSS)	9, 11, 13	3
Governance Structures	1, 5	2
Information Systems	8, 12	2
Sustainability Indicators	2, 3, 7, 11	4

4. DISCUSSION

The current investigation into the essential components of MCSs in the forestry-based sector, as captured in the scientific literature indexed in Scopus, gives grounds to make the following conclusions: First, the findings of the study indicate that there are insufficient publications on the subject of the research (Table 1). Second, the most frequently cited component of the MCSs is Sustainability Indicators, which is mentioned four times. It is followed by Automation and Technology, along with Decision Support Systems (DSS), each referenced in three of the documents that were reviewed (Table 2).

The author of the paper suggests two primary directions for further investigation into this subject:

- Expanding the scope of the study by increasing the sample through additional databases.

- Tracking the evolution of the separate components of MCSs in the forestry-based sector over time.

5. CONCLUSION

This research examines the MCSs used in the forestry-based industry, breaking them down into their fundamental components. A Design Science Research Process methodology was employed to gather data, and a literature review within the Scopus database identified thirteen relevant sources.

The research findings indicate that there are seven essential components for MCSs in the forestry-based sector, as follows: Adaptive and Hierarchical Planning, Automation and Technology, Behavioural Matrix, Decision Support Systems, Governance Structures, Information Systems, and Sustainability Indicators.

This paper provides valuable insights into creating and implementing optimised MCSs in forestry-based sector organisations. According to the author, understanding the essential components of MCSs in the forestry-based sector will contribute to addressing current issues related to environmental protection and responsible forestry utilisation.

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HUMAN RESOURCES IN CZECHIA: INTEGRATING GENDER-DIMENSION FOR THE SUSTAINABILITY OF THE FOREST-BASED SECTOR

Petra Palátová, Roman Dudík

Abstract: Contribution deals with the current situation in the forest-based sector in Czechia. Presented results are part of the ongoing international project Fem2forests (2024-2026). The main emphasis is given to the situation in forestry-related education, both from the point of view of students (perception, barriers, needs) and the viewpoint of the labour market (needs, current and future challenges). Results from a questionnaire survey (conducted among students in and outside the forestry sector) and guided interviews with females at different working positions are the core of this paper. Situation in the Czech Republic is also presented in the context of other Danube region countries, especially in areas of perceived needs and barriers that young women face when they are deciding about their careers and what they face during their educational paths. Conclusions lead to suggested future design of changes in the forestry education to make the careers in forestry more inclusive and more attractive for women.

Keywords: HR, education in the forest-based sector, labour market, Fem2forests

1. INTRODUCTION

The forest-based sector is undergoing changes that bring with them changing needs and requirements from employers and students. Attitudes towards formal and informal education are also changing. One of the requirements is to increase the inclusiveness of education, which also comprises gender issues. At the European level, gender is incorporated into the Treaty of the European Union (EU, 2025) and the Gender Equality Strategy (EU, 2020) and is monitored by, for example, the European Institute for Gender Equality (EIGE). Activities are aimed at reducing gender-based violence, securing equality in the workplace, including equal payment for women and men, enabling a return to the labour market (especially after parental leave), flexible working arrangements, the inclusion of women in STEM fields, and breaking down gender stereotypes. Gender equality is also part of the Sustainable Development Goals, with a separate goal 5 dedicated to it (UN, n.d.).

In the forest-based sector, gender issues are gradually receiving greater attention. The forest-based sector is traditionally considered a male-dominated industry (Andersson, Lidestav, 2016), and women are often a group that is disadvantaged in terms of access to resources, decision-making, and economic opportunities (FAO, 2025; Ota et al., 2024; Elias et al., 2024).

In the Czech Republic, gender in forestry and wood-processing sector is more a matter of pilot activities (at the level of individual organizations—raising employee awareness of gender topic, gender reporting, or participating in gender audits). More comprehensive activities are carried out through projects (e.g., Fem4Forest, 2020-2022; and Fem2forests, which is currently being implemented); however, gender and equality are included, for example, in the Strategy for Gender Equality for 2021-2030 (Government of the Czech Republic, 2021) and the Action Plan for Equal Pay for Women and Men in the Czech Republic 2023-2026 (Ministry of Labour and Social Affairs, 2023). Support for the inclusion of women is also necessary because studies confirm that more gender-diverse teams achieve better results (Hansen et al., 2016; Larasatie, 2018).

The article looks at women's views on gender issues in the forest-based sector in the Czech Republic and puts the results in the context of the outputs of the international Fem2forests project.

1.1. Project Fem2forests

The Fem2forests is an international Interreg Danube Region Programme project entitled *Innovative pathways for efficient involvement of girls and young women in the forestry sector* and runs from January 2024 to June 2026. It is a project co-financed by the European Union with a total budget of EUR 1.6 million, coordinated by the Slovenian Forestry Institute and involving 15 partners from 9 countries (including 2 partners from the Czechia). Its objectives are to develop innovative careers for girls and young women, integrate gender aspects into the education of forestry institutions, and create conditions for the inclusion of women in the forest-based sector (Gozdis, 2024).

2. METHODS

The paper analyses data from annual reports and websites of educational institutions in the Czech Republic that provide secondary forestry education (six schools) and two universities focused on forestry, wood-processing industry and related fields of study (Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague and Faculty of Forestry and Wood Technology, Mendel University in Brno). The article also draws on data obtained during the Fem2forests project, specifically data obtained through an online questionnaire survey (LimeSurvey platform, data collection took place in April and May 2024 in Czech language). The last part of the presented information is based on interviews conducted with women who completed forestry education and now are working at different positions. The interviews were in-person semi-structured and were conducted in January 2025; the respondents agreed to the processing of their personal data via an informed consent form.

Given the scope of the paper, information on perceptions, barriers, and challenges in the forest-based sector in the Czech Republic is presented, and the results are compared with the findings of the entire Fem2forests project consortium (9 countries – Slovenia, the Czech Republic, Croatia, Romania, Austria, Germany, Bosnia and Herzegovina, Serbia, and Ukraine).

3. RESULTS

3.1. Gender equality in Czechia

The Czech Republic has long performed poorly in the gender equality index (59.9 compared to 71), with only four countries performing as poorly (Slovakia) or worse (Greece, Hungary, Romania). On the other hand, the worst results are in power, while the best results are in knowledge, where there is a participation in formal education and vocational training throughout life and gender segregation (EIGE, 2025).

3.2. Education in the Czech Republic and gender-reporting

The labour market and education offerings are closely linked—they influence each other's demand and must respond to changes in the macro and microenvironment, as well as to trends.

Professional positions in forestry and woodworking industries usually follow studies in relevant fields (most often a high school diploma in forestry and respective fields at two universities in Prague and Brno). Secondary education in forestry in the Czech Republic is provided by a total of six secondary schools. It is not easy to determine the gender ratio among students from official data (annual reports). Gender reporting mainly concerns data on employees and rarely on pupils and students.

Table 1. Data on gender reporting at secondary forestry schools

Nr.	School name	Data source	Gender reporting (employees)	Gender reporting (pupils, students)	Data on girls/women
1	Střední lesnická škola, Hranice	Annual report 2023/2024	Yes	No	N/A ¹
2	Střední lesnická škola a Střední odborná škola, Šluknov	Annual report 2023/2024	Yes	No	N/A
3	Střední lesnická škola Žlutice	Annual report 2023/2024	Yes, direct ²	No	N/A
4	Česká lesnická akademie Trutnov střední škola a vyšší odborná škola	Annual report 2023/2024	Yes	No	N/A
5	Střední lesnická škola a Střední odborné učiliště, Křivoklát	Annual report 2021/2022	Yes	No	N/A
6	Vyšší odborná škola lesnická a Střední lesnická škola Bedřicha Schwarzenberga, Písek	Annual report 2023/2024	Yes	Yes, for registered and accepted students	58/14 Forestry 19/0 Forest Mechanization 28/10 Forestry (Higher Vocational School)

Source: LŠ v Písku, 2024; SLŠ a SOŠ Šluknov, 2023; SLŠ Žlutice, 2024; ČLA Trutnov, 2024; SLŠ Křivoklát, 2023. SLŠ Hranice, 2024.

3.2.1. Data on gender reporting at higher education institutions providing education in forestry and woodworking

The Faculty of Forestry and Wood Technology at Mendel University in Brno does not report information on the proportion of female students in its publicly available annual reports. The faculty offers education at all university levels (bachelor's, master's and doctoral) in Czech

¹ N/A = no data available

² The annual report includes dedicated table on gender reporting

and English. Current trends focus on production ecology in an ecosystem approach, landscape management as a balance between cultural landscape and the current use of resources, and the development of wood-based materials (LDF, 2025).

The number of female students at the Faculty of Forestry and Wood Sciences of the Czech University of Life Sciences Prague (FLD CZU) accounts for approximately one third (35%, or 37% for bachelor's and master's degrees) – however, there are differences between study programs. At the doctoral level, the ratios are more balanced. FLD CZU offers higher education at all levels (bachelor's, master's, and doctoral), in both Czech and English. In addition, the FLD CZU also responds to specific needs by offering lifelong learning courses (in 2025, these include face-to-face courses in Furniture Design, Modern Wooden Buildings, and combined courses in Sustainable Forestry in the Age of Climate Change). These courses are completed with a micro-certificate and allow for a targeted focus on current topics. In addition, FLD CZU also participates in an MBA course, which is organized by the Prague International Business School under the auspices of the Ministry of Agriculture (FLD, 2025).

3.2. Questionnaire survey

The questionnaire survey was conducted using the same methodological approach in all nine countries participating in the project consortium. A total of 1,170 responses were collected, with 27% of respondents from forestry faculties and 20% from high schools specializing in forestry. The paper focuses on selected areas covered by the survey, specifically perceptions of forestry, barriers for women in the forestry sector, and opinions on the perception of forestry in society.

In terms of perception, the results with more than 40% are displayed. Czech Republic do not differ significantly from the overall results (see Table 2). Paradoxically, however, in percentage terms, the results are even more pronounced.

Table 2. Biggest misconceptions/stereotypes about forestry careers among peers

	Overall results + ranking 1-5	Results from Czechia + ranking 1-5
Forestry is not for women	57% (1)	69% (1)
Limited opportunities	52% (2)	53% (3)
Hard physical work	48% (3)	51% (4-5)
All foresters are hunters	42% (4)	58% (2)
Low payment	41% (5)	
Forestry does not require higher education		51% (4-5)

Source: Fem2forests, 2024

Table 3. The most common responses – barriers for women in forestry

	Overall results among forestry students	Overall results among non- forestry students	Czechia results among forestry students	Czechia results among non- forestry students
Gender stereotypes/stigma associated with forestry professionals	61%	52%	67%	33%
Underestimation of women's abilities and contribution to forestry	57%	37%	71%	13%
Lack of visibility of successful female in forestry (role models)	50%	41%	40%	27%
Cultural and social norms discouraging women from forestry careers			46%	20%

Source: Fem2forests, 2024

The results concerning barriers for women in forestry are interesting from the perspective that the responses of female Czech students studying forestry and non-forestry subjects differ significantly. The most common response was “underestimation of women in forestry”, which was given by almost three-quarters of female respondents – however, only 13% of female respondents in non-forestry fields of study chose the same answer. The answer to the question of how forestry careers are perceived was interesting. They are perceived positively by respondents in Germany (50%), Slovenia, and Ukraine (49%), while the least positive responses were recorded in Serbia (27%). However, there were significant differences between the individual responses in each country, with the answer “I don't know” also frequently selected. In the Czech Republic, 37% of female respondents perceive a career in forestry positively, 18% negatively, 24% indifferently, and 21% did not express an opinion (Fem2forests, 2024).

3.3. Semi-structured interviews

A total of 90 respondents participated in the interviews in all countries. In the Czech Republic, 10 female respondents aged 27–64 with forestry education (at least 5 years of university education, in 3 cases also with a completed doctoral degree) in various positions across the Czech Republic (working at university, secondary school, research, in a state

enterprise, being self-employed, working in state administration, even in a private enterprise) participated.

The questions focused on experiences related to education and professional careers. One area of the interview focused on gender-specific challenges in forestry professions. In general, respondents emphasized that the role of women in society (especially in relation to family care—the role of mother or caregiver for other family members) plays a greater role than gender itself. Three respondents even mentioned positive support from colleagues (e.g., in obtaining further education or overcoming obstacles when starting a work position), and several appreciated that there are clear criteria for job positions and that gender does not play a role. Two respondents mentioned that there may be a negative pay gap between the sexes. Only one respondent specifically mentioned an experience of men being given preference in the teaching of technical subjects (at secondary school).

3. DISCUSSION

The results of the research conducted in the Czech Republic through questionnaires and structured interviews largely correspond to the overall project outputs. The questionnaire survey of female students reveals significant differences between the responses of women and girls studying forestry and other fields of study. These results confirm the need to better communicate the employment opportunities available to graduates of forestry and woodworking study programs and to show that forestry and woodworking offer many jobs that require higher qualifications (specific knowledge) and also consider new technologies and trends. It is also necessary to specifically reduce stereotypes traditionally associated with the field. These activities may attract more girls and women who do not have a clear idea of their professional prospects in the forest-based sector. The results of the interviews show that gender is a topical issue, but negative experiences in the workplace (or during studies) are often linked to personal experiences (i.e., specific teacher/supervisor/colleague). It is positive that many women have received support (e.g., in the form of support for further studies or for starting work) and that gender is not a priori an obstacle to building a career in the forest-based sector.

The challenge facing the Czech forest-based sector and its future attractiveness is to enable adequate financial remuneration and to explain to society the essential role of employees in forestry, including their specific knowledge and skills. Unfortunately, forestry is often perceived negatively, and similar responses were found out in the questionnaire. Gaining public support and understanding, which in the Czech Republic is linked to climate change and the continuing aftermath of the bark beetle calamity, is essential through a targeted communication strategy (Riedl et al., 2019). Current communication challenges in the Czech Republic are also related to the fact that forests are perceived positively, but foresters are often distrusted or unconvincing. Communication is also not sufficiently integrated into strategic management (Riedl, 2025).

Nevertheless, the model example of FLD CZU shows that there is no decline in the proportion of women/girls interested in studying (i.e., the number of applications submitted) and, at the same time, there is no decline in the number of women/girls enrolled in studies (Annual report FLD CZU, 2025). CZU supports equal opportunities (e.g., CZU and FLD CZU

report gender-disaggregated statistics, use gender-sensitive knowledge, offer training on gender issues, are actively involved in gender projects, have adopted a gender equality plan, and monitor non-discriminatory processes). However, gender-oriented activities and reporting in gender are not standard in the Czech Republic (see, for example, publicly available annual reports), despite reporting requirements, for example in ESG reporting.

3. CONCLUSION

Gender is part of European and national strategies and activities and is also being incorporated into the forest-based sector. Although the proportion of women and girls studying in the field is lower than that of men, available statistics, surveys, and interviews show that the proportion of women in the Czech Republic has not been declining in recent years. This situation can be supported by better communication and awareness-raising among the public and future female students through demonstrations of the jobs that graduates can do, thereby reducing barriers and stereotypes. In the future, the labour market and the education market will have to work closely together to create an inclusive environment that will prepare qualified graduates who will have no problem finding employment in the field.

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INNOVATION AND SUSTAINABLE DEVELOPMENT OF EUROPEAN SMALL AND MEDIUM-SIZED ENTERPRISES IN THE WOOD PROCESSING INDUSTRY

Lyubcho Varametzov, Simeonka Petrova, Lyubomira Todorova, Yavor Stanev

Abstract: Innovation-oriented small and medium-sized enterprises play an important role in the transition to sustainable development of economies, in increasing the well-being of societies and in adding value in all sectors of the European economy, including the wood-processing industry. The main objective of this study is to analyze and measure the impact of innovations introduced by European small and medium-sized wood-processing enterprises on their sustainable development in the period 2012-2022. The turnover was used as the dependent variable to assess the economically sustainable development of wood-processing enterprises, and in terms of innovation, the set of indicators includes “enterprises with new or improved business processes introduced by type of innovation” and “enterprises with new or significantly improved products introduced by type of innovation”. The methodological framework of the study includes the application of the IBM SPSS Statistics software product, the Excel program, as well as the method of linear regression and correlation. The results obtained allow the identification of similarities (differences) between small and medium-sized wood processing enterprises in individual European countries and the derivation of emerging patterns.

Keywords: innovation, sustainable development, European small and medium-sized enterprises, wood processing industry

1. INTRODUCTION

The wood-processing industry is an important part of the economies of the European Union (EU) member states. Its socio-economic significance can be expressed through the gross value added (GVA) it generates and the employment it provides. In 2022, the gross value added (GVA) in the wood-processing industry amounted to over 144 billion euros, representing more than 7.50% of the total value added generated by the industry within the European Community (Eurostat, 2023). Within wood-based industries, more than 3.10 million people were employed in the EU in 2022, accounting for over 10.50% of total manufacturing employment (Eurostat, 2023). The highest levels of employment were recorded in the manufacture of wood and wood products, as well as in furniture production.

The majority of European wood-processing enterprises are small and medium-sized enterprises (SMEs). In 2022, there were over 408 000 active SMEs in the wood-processing industry across the EU, accounting for more than 19% of all manufacturing enterprises (Eurostat, 2023). They combine supply chain activities related to timber production, encompassing significant portions of the furniture and printing industries, pulp and paper manufacturing, as well as various other processing operations.

Innovations by SMEs engaged in this manufacturing subsector are among the key instruments for their sustainable development. The implementation of innovations drives a dynamic transition towards economic business approaches that integrate social and environmental practices for the efficient and responsible use of natural resources, including the mitigation of negative environmental impacts. A significant number of European wood-processing enterprises are undergoing transformation, driven by a growing need to adopt

modern business processes, tools, and technologies aligned with the principles of sustainability (Richnak, Drabik, Hanulakova, & Rehak, 2024). Through its adopted long-term vision, the European Commission calls for investment in realistic technological solutions to achieve a prosperous, competitive, and climate-neutral economy by 2050 — a Clean Planet for All (European Commission, 2018). Among the key areas of focus are the developing industries, including the wood-processing sector.

In this regard, over the past decades, the demands placed on forest-based industries in Europe have increased. Innovations have emerged as a key driver for sustainable economic development that considers social and environmental issues, including climate change (Šebestová & Sroka, 2020). The transition to the principles of sustainable development is a priority for the wood-processing industry, as it contributes to balancing economic efficiency, social responsibility, and environmental sustainability (Tsymbaliuk & Nevar, 2023). The role and significance of innovation as a driver of efficiency, competitiveness, and sustainable growth in SMEs are extensively discussed in the academic literature (Rosenbusch, Brinckman, & Bausch, 2011; Expósito & Sanchis-Llopis, 2019; O'Regan & Ghobadian, 2005; Van Auken, Madrid-Guijarro, & Garcia-Perez-de-Lema, 2008). Researchers Klewitz and Hansen (Klewitz & Hansen, 2014) conducted a systematic review of studies addressing sustainability-oriented innovations (SOI) in SMEs and found that the research is highly dispersed across various disciplines, research communities, and journals. According to the cited authors, there is a lack of a clear understanding of SOI practices in SMEs at the product, process, and organisational levels. Moreover, individual studies tend to focus on the impact of innovations on only one of the key pillars of sustainability, rather than addressing its economic, social, and environmental dimensions simultaneously.

It should be noted that SMEs in the wood-processing industry, as an important source of innovation, employment, and economic growth, possess significant potential to achieve sustainability in their development. The enterprises studied can unlock their vast potential for progress in sustainable development by adopting environmentally friendly business practices that reduce their ecological footprint, as well as by adhering to principles of social responsibility and contributing to the well-being of local communities (Franco & Rodrigues, 2021). Their involvement in achieving sustainable development goals can take various forms – such as reducing environmental impact, preserving biodiversity, and restoring natural resources – making them a key contributor to sustainability efforts (Šebestová & Sroka, 2020).

The concepts and insights related to innovation and sustainable development, as presented, are both relevant and practically applicable to European wood-processing SMEs. Given its complexity, the process of innovative business transformation in these enterprises – viewed as an opportunity for sustainable development – shapes the focus of research interest. In this regard, the present study adopts the perspective that innovations are among the key instruments for ensuring the sustainability of business development in the enterprises defined as the subject of investigation. The primary aim of the research is to analyse and measure the impact of innovations introduced by wood-processing SMEs in the EU on their sustainable development during the period 2012–2022. Based on this analysis, the study identifies both similarities and differences among the surveyed SMEs across EU member states and highlights the most significant emerging patterns.

2. METHODOLOGY

The present study focuses on analysing significant manifestations of the relationship between the economically sustainable development of European wood-processing SMEs, expressed by the magnitude of their net turnover, and two selected variables characterising their innovation profile – namely, “enterprises with introduced new or improved business processes” and “enterprises with introduced new or significantly improved products”. In this context, SMEs from the wood processing industry operating in the 27-member states of the European Union have been studied. The methodological framework of the research includes the application of linear regression and correlation method, conducted using IBM SPSS Statistics software and Excel. The values of the assessed variables were obtained from the Eurostat database for the period 2012-2022.

3. RESULTS AND DISCUSSION

During the analysed period from 2012 to 2022, the growth rate of the net turnover of the studied enterprises was 0.2397. The measurement of the average annual growth rate indicates a favourable increase in the value of the examined indicator by a factor of 1.2396. These results reflect a positive rise in the evaluated metrics and demonstrate a favourable average rate of development over the ten-year period under analysis.

The methodological framework adopted in the study directs the research focus towards interpreting the correlation between the variation of the dependent variable – “net turnover realised by wood-processing SMEs” – and the selected independent variables – “introduced new or improved business processes” and “introduced new or significantly improved products”. Determining the direction of the relationship between these selected variables necessitates conducting a regression analysis and fulfilling the research objective, which is based on the premise that innovations are among the key instruments for the sustainable economic development of wood-processing SMEs. In the last year of the analysed period, the statistical monitoring of innovation activity among the surveyed SMEs allows for visualisation based on the introduced product and process innovations (Eurostat, 2023): see Figure 1.

As shown in Figure 1, the statistical analysis of innovation activity among European SMEs in the wood-processing industry reveals that the relative share of innovations in business processes exceeds that of new or significantly improved products by an average of 2.14 percentage points. The study of wood-processing SMEs across the 27 EU member states provides grounds to conclude that significant variations are observed in the analysed indicators. The comparative analysis shows that certain countries report higher values compared to the EU average. For instance, in countries such as Portugal, Estonia, Italy, and Belgium, the relative share of surveyed enterprises engaging in business process innovations in 2022 ranges between 73.00% and 77.00%, whereas in Ireland, Romania, Malta, and Bulgaria, this share varies between 36.00% and 43.00% (Eurostat, 2023). Consequently, the variation of the analysed indicator, reflecting differences between the compared groups of countries, reaches average values exceeding 35.00%. The assessment of the second indicator – product innovations – shows that in 2022 Cyprus, Slovenia, and Greece reported the highest relative shares (between 58.00% and 62.00%), while in others, such as Romania and Ireland, the values of this indicator were comparatively lower (between 27.00% and 31.00%).

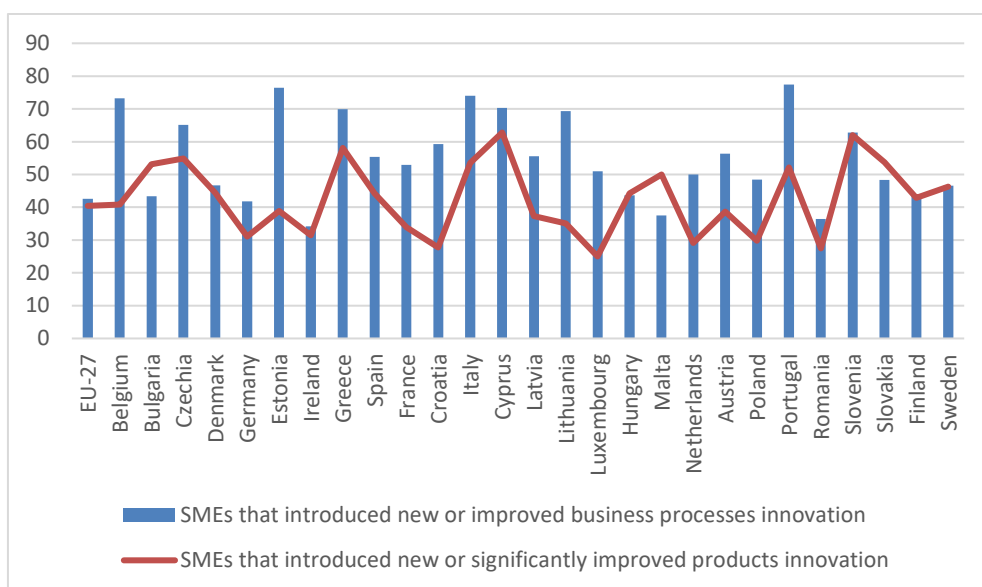


Figure 1. Relative share of SMEs in the wood-processing industry in the 27 European Union member states with introduced new or significantly improved products and business processes, 2022 (in %)

The obtained correlation matrix shows a significantly high correlation coefficient of 0.948 between the two independent variables, which is very close to one (see Table 1).

Table 1. Correlation between the independent variables

Indicators		SMEs that introduced new or significantly improved products innovations	SMEs that introduced new or improved business processes innovations
SMEs that introduced new or significantly improved products innovations	Pearson Correlation	1	0,948**
	Sig. (2-tailed)		0,000
	N	11	11
SMEs that introduced new or improved business processes innovations	Pearson Correlation	0,948**	1
	Sig. (2-tailed)	0,000	
	N	11	11

The results illustrated in Table 1 demonstrate a high degree of correlation, indicating the presence of so-called multicollinearity between the two independent variables. This means that the two variables vary almost identically, and if one is included in the regression model, adding

the other will not provide additional information. For this reason, based on the empirical results diagnosing multicollinearity, the independent variable – SMEs in the wood-processing industry with "introduced new or improved business processes" – is excluded from the multiple linear regression model as a cause of significant multicollinearity. The second analysed independent variable is selected as having a substantial influence and a consistent effect on the net turnover realised by the surveyed SMEs, serving as a measure of their sustainable economic development. The regression analysis yields the following results regarding the relationship between the reported "net turnover realised" by European wood-processing SMEs and the new or significantly improved products they have introduced: see Table 2.

Table 2. Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0,978	0,957	0,952	7621,111

As the data in the table show, the correlation coefficient (R) takes the value of 0.978. Measuring the strength of the relationship between the analysed variables indicates that when $0.7 < R < 1.0$, a strong dependence exists, i.e., a high correlation. The reported value provides grounds to define a strong dependence between the "net turnover realised" by wood-processing SMEs in the EU and the product innovations they introduce. The coefficient of determination (R^2) is 0.957, which supports the assessment that more than 95% of the differences among SMEs operating in the European wood-processing industry can be explained by the variations in the extent to which they introduce new or significantly improved products in their business activities. The data from the same table also show the values of the adjusted coefficient of determination, which takes a favourable value of 0.952, as well as the standard error.

The use of a correlogram makes it possible to visualise the relationship between the total value of the "net turnover realised" by wood-processing enterprises and the introduction of product innovations. Figure 2 illustrates both the regression line and the trend model. The regression line depicted in the figure visualises the relationship between the independent and the dependent quantitative variables.

During the period 2012–2022, an upward trend is evident in the relative share of SMEs with "introduced new or significantly improved products," ranging between 7.43% and 40.40%, with the latter value reached at the end of the analysed period (Figure 2). Variations in the innovation activity of European wood-processing enterprises regarding the introduction of new or significantly improved products account for the fluctuations in the size of the realised net turnover over the ten-year period.

The results of the conducted study indicate a high correlation and a very strong dependence between the variation in the "realised net turnover" and the influence of the quantitative variable "introduced new or significantly improved products". Due to the presence of multicollinearity, the second independent variable – "introduced new or improved business processes" – was excluded from the regression model; nevertheless, this does not negate its role as a significant and systematically influential factor. Moreover, the obtained empirical results provide a basis for interpreting the changes in the innovation profile of SMEs across the 27 European Union member states, as well as the similarities and differences observed.

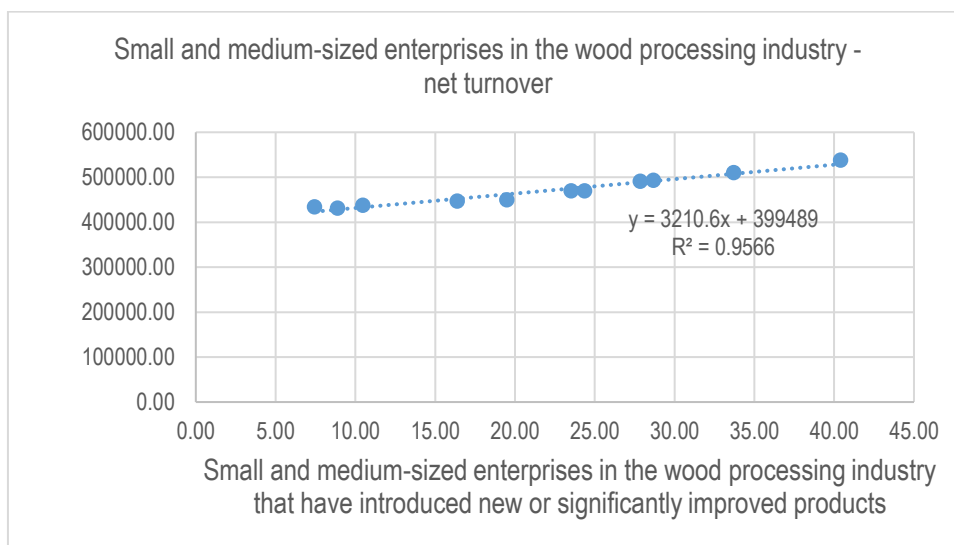


Figure 2. Dynamics during the period 2012–2022 of the relative share of SMEs in the wood-processing industry of the 27 European Union member states that have introduced new or significantly improved products, in %

Within this defined research domain, there exists an opportunity for scholarly discussion. It is relevant to compare these findings with results from other researchers at the European level. In academic works addressing the research question, determinants of economic, social, environmental, and other dimensions are evaluated, while simultaneously identifying more significant challenges to overcome (Hansen & Nybakk, 2016). Barriers emerge related both to financing and access to new international markets, the availability of research outcomes, limited opportunities to secure cheaper resources and effectively manage costs, the hiring of qualified personnel, and others (Kaputa, Paluš, & Vlosky, 2016). These identified challenges underscore the necessity for the systematic development of policies aimed at promoting the innovation potential of the European enterprises under study.

4. CONCLUSION

The analysis of the innovation activity of European SMEs in the wood-processing industry reveals a higher relative share of innovations made in business processes compared to those in new or significantly improved products. The study of enterprises across the 27 European Union member states identifies significant variations in the analysed indicators. Some countries register values exceeding the average. The majority of innovative wood-processing enterprises in Europe simultaneously develop both product and process innovations. This group of countries includes Portugal, Estonia, Italy, Slovenia, and others. The assessment of the dependence of sustainable economic development of the surveyed enterprises reveals a strong correlation with both the introduction of new or improved business processes and the introduction of new or significantly improved products. The two variables display almost

identical variation. Thus, innovations emerge as one of the key instruments for achieving sustainable development of forest-based industries in Europe.

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AGILITY PERCEPTION AND AWARENESS IN SLOVAK WOODWORKING AND FURNITURE COMPANIES

Andrea Janáková Sujová, Martin Halász

Abstract: In the 21st century, the concept of agility is a key factor of successful business, which enables companies to respond flexibly to dynamic market conditions and changing customer needs. The wood and furniture industry represents a strategically important sector of the Slovak economy, which is facing challenges related to globalization, technological change and increasing demands for sustainability and efficiency of production processes. The main objective of this paper is to analyse the level of awareness and perception of agility in Slovak wood and furniture companies. In order to obtain relevant results, a questionnaire survey was conducted with 278 respondents. The results show that Slovak woodworking and furniture enterprises understand the importance and benefits of agility as a concept, and at the same time they are taking some steps towards building it, but there are still barriers that prevent its successful implementation in practice. The conducted research is a contribution to building agility in wood and furniture enterprises in Slovakia.

Keywords: agility, perception, awareness, woodprocessing enterprises, furniture enterprises

1. INTRODUCTION

In today's rapidly changing business environment, agility has become a key factor for staying competitive and ensuring long-term success. Enterprise agility is generally understood as the ability of businesses to adapt quickly to unexpected changes, exploit new opportunities and respond effectively to external challenges (Nogalski et al., 2020). Especially in industries that are highly dependent on fluctuating market demand and resource availability, agility becomes a critical factor for resilience and operational efficiency (García-Alcaraz et al., 2019). While previous research has extensively investigated agility in the manufacturing and service sectors (Saha et al., 2020), its application and awareness in the wood processing industry remain under-researched.

The wood processing industry plays an important role in the Slovak economy, primarily involving wood processing, furniture manufacturing and the production of wood products. Enterprises in this sector face specific challenges, including resource constraints, sustainability requirements and the need for technological adaptation (Mathrani, 2021). Unlike other industries, wood-based enterprises often operate in rigid supply chains where production flexibility is limited by raw material availability and regulatory constraints. Therefore, achieving agility in this sector involves not only making quick decisions, but also ensuring operational adaptability without compromising sustainability and long-term stability (Karvonen et al., 2018).

The concept of agility in the business environment encompasses a number of dimensions, including organisational flexibility, digitalisation and the ability to respond flexibly within the supply chain (Aghina et al., 2020). According to research on business agility, firms that integrate digital technologies and data-driven decision making exhibit higher levels of adaptive capability and resilience (Nogalski et al., 2020). This is particularly important for wood processing companies, where market volatility, environmental policies, and international competition require companies to operate with a higher degree of agility (García-Alcaraz et al., 2019). Despite the growing recognition of agility as a competitive advantage, its practical implementation in the wood processing industry remains inconsistent, mainly due to a lack of strategic awareness and limited knowledge dissemination (Saha et al., 2020).

While studies on corporate agility have primarily focused on large corporations and technology-driven industries, the need for agility awareness in traditional manufacturing sectors, including the timber industry, is becoming increasingly urgent (Mathrani, 2021). Research suggests that promoting agility requires not only structural changes in organizations, but also a shift in managerial thinking and the

implementation of agile frameworks tailored to industry-specific conditions (Karvonen et al., 2018). However, there is currently limited empirical research assessing the level of awareness and perception of agility in the wood processing industry.

The aim of this paper is to analyse the level of awareness and perception of agility in Slovak woodworking and furniture companies based on a questionnaire survey. The research focuses on assessing the ability of enterprises to be agile, identifying barriers to agility and factors that influence its implementation in the wood and furniture industry. Through descriptive statistics and visualization of the results in the form of graphs, the paper provides an empirical insight into the attitudes of enterprises towards agility in this sector.

2. METHODOLOGY

The methodological procedure of the research was divided into several logically arranged parts. In the first phase, an analysis of secondary sources was carried out, which focused on the issue of business agility and its importance in the business environment. The methods of analysis, synthesis, deduction, comparison, summary and analogy were used to elaborate the theoretical background.

Primary data was collected using a questionnaire survey that was electronically distributed to enterprises operating in the woodworking and furniture industry in Slovakia between May 2024 and September 2024. In total, there are 5,374 enterprises in this industry, according to data from the Finstat portal (2024). Our sample consisted of 2,122 woodworking and furniture enterprises. The number of respondents who successfully completed the electronic questionnaire was 278. The questionnaire consisted of two parts. The first part focused on the basic identification of respondents and included questions on the size of the enterprise, main business, ownership structure and return on equity. The second part explored the agility of enterprises, with questions focusing on the ability of enterprises to respond to unexpected changes, barriers to increasing agility, benefits of an agile approach, and factors influencing enterprise agility.

Descriptive statistics were used to evaluate the data, and the data were processed and visualized using Microsoft Excel. The present evaluation was preceded by the determination of the minimum size of the research sample. The following formula was used to determine it (Labudová et al., 2021):

$$n \geq \frac{z^2 \cdot p \cdot (1-p)}{c^2} \quad (1)$$

n - research sample size

z - critical value of the normalised normal distribution for the selected confidence level

p - estimated population size

c - permissible margin of error

In the case of our research, the confidence level (z) was 90%, the margin of error (c.) was 5% and the population size was 20 000 enterprises. By calculation, we found that our minimum range of respondents to allow generalization of the results to the entire population was 267.

3. RESULTS

The return rate of our questionnaire survey was 13.1% of enterprises operating in the wood and furniture sector in Slovakia according to SK NACE (C16 and C31). The first part of the questionnaire survey focused on the basic characteristics of our research sample, which allowed a more detailed specification of the individual sectors. The results of this analysis are taken through Table 1.

Table 1. Research sample identification

Questions	Answers							
Number of employees	0 - 9		10 - 49		50 - 249		250 +	
	39.93 %		40.29 %		15.15 %		8.27%	
Company ownership	Net domestic capital		Domestic capital prevail		Net foreign capital		Foreign capital prevail	
	70.86 %		15.47 %		6.47 %		7.19 %	
Return on Equity (ROE)	< 0 %	0.1% - 1.99%	2.0% - 3.99%	4.0% - 6.99%	7.0% - 9.99%	10% >		
	6.12 %	18.71 %	26.62 %	22.30 %	8.99 %	17.27 %		

From Table 1, we observe the basic identification of our research sample. The number of employees shows us that these are mainly small and micro enterprises that have capital tied up in the home environment (70.86%). The highest return on capital achieved is at ROE between 2% and 3.99% and in 26.62% of the cases, while the next highest return on capital employed is at ROE between 4% and 6.99% and in 22.3% of the cases. This trend can thus be attributed to the cautious investment policy of enterprises in the wood and furniture industry, which is expected in terms of their size and thus represents the typical (slightly positive) profitability of this type of enterprises.

In question 1, we asked respondents how they apply the concept of agility in their enterprise. The results of this question are shown through Figure 1.

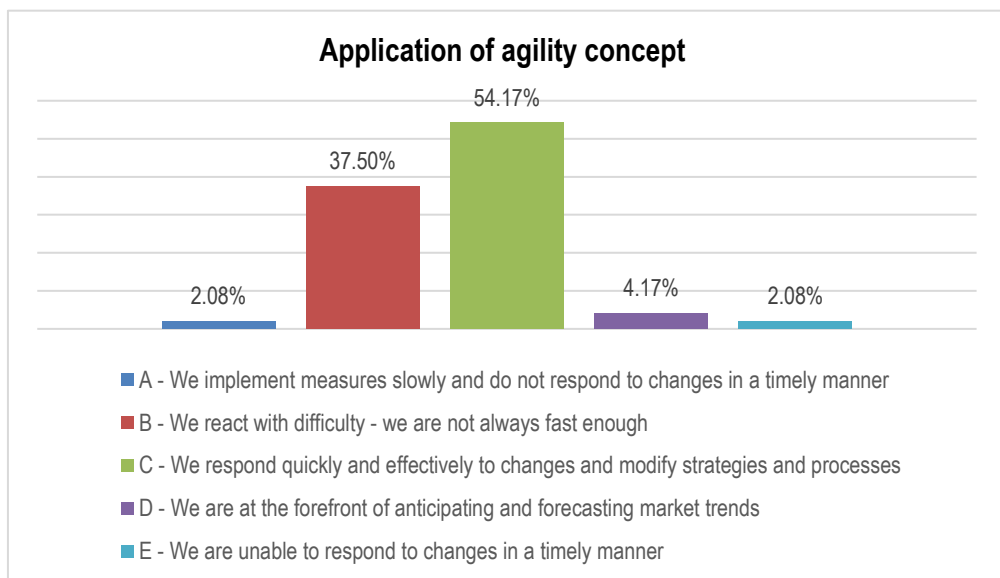


Figure 1. Application of agility concept

As we can observe from Figure 1, the majority of businesses characterize their agility capability as responding quickly and effectively to change by implementing changes in strategies and processes (150 respondents). The second largest group perceives their enterprise's agility capability as responding with difficulty, where the speed with which the enterprise responds is an important factor (104 respondents).

The next question looked at the steps respondents are taking to improve agility in their enterprise. The results are presented using Chart 2.

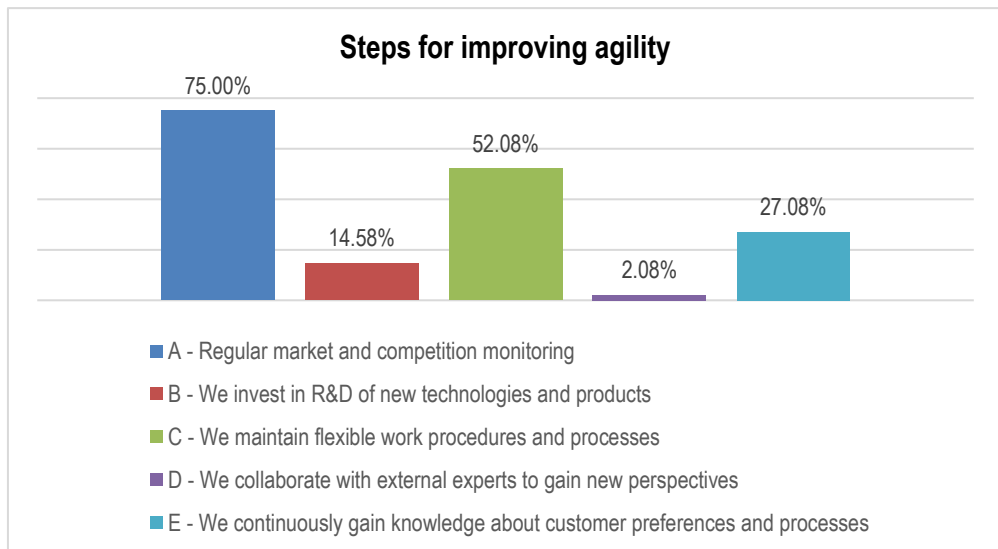


Figure 2. Implemented steps for improving agility

From Figure 2, we observe that the largest group of respondents identified Step A as the most frequently implemented step to improve agility in their enterprise (208 respondents), with Step C being the second most frequently identified step (144 respondents). In the next question, we asked respondents what barriers they perceived in their enterprise's efforts to be agile. The results of this question are presented through Figure 3.

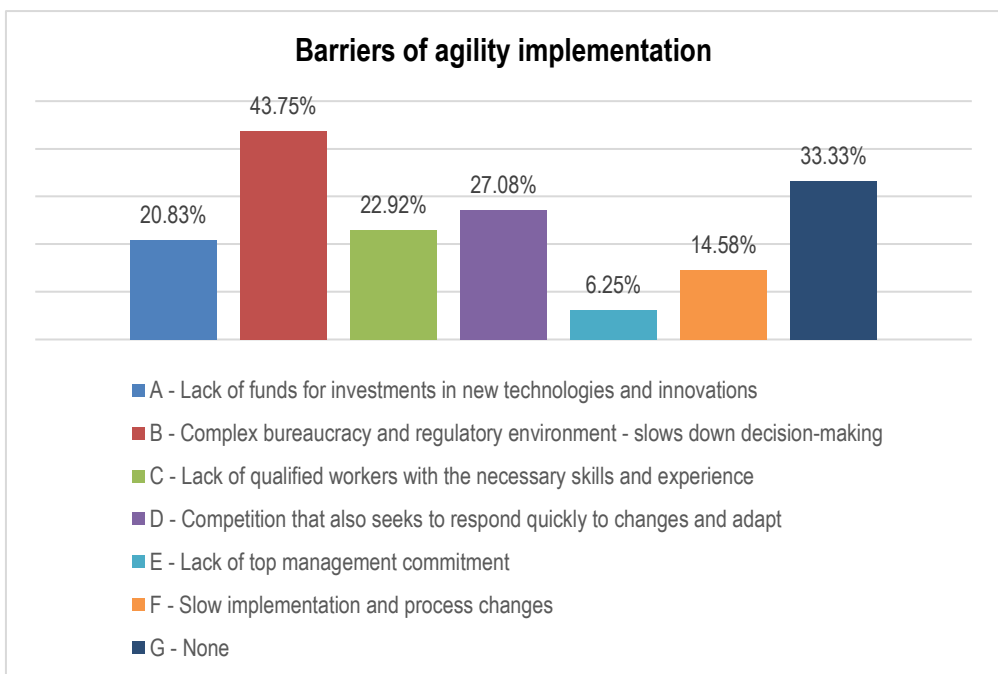


Figure 3. Barriers of agility implementation

From Figure 3, we observe that respondents identified answer B as one of the main barriers to the implementation of agility in Slovak wood and furniture enterprises (121 respondents). The second largest group was answer G, where respondents did not consider any of the above barriers as a barrier to implementing agility in their business (92 respondents).

The last question looked at the benefits that respondents see in applying the concept of agility to their business. The results of this question are presented using Figure 4.

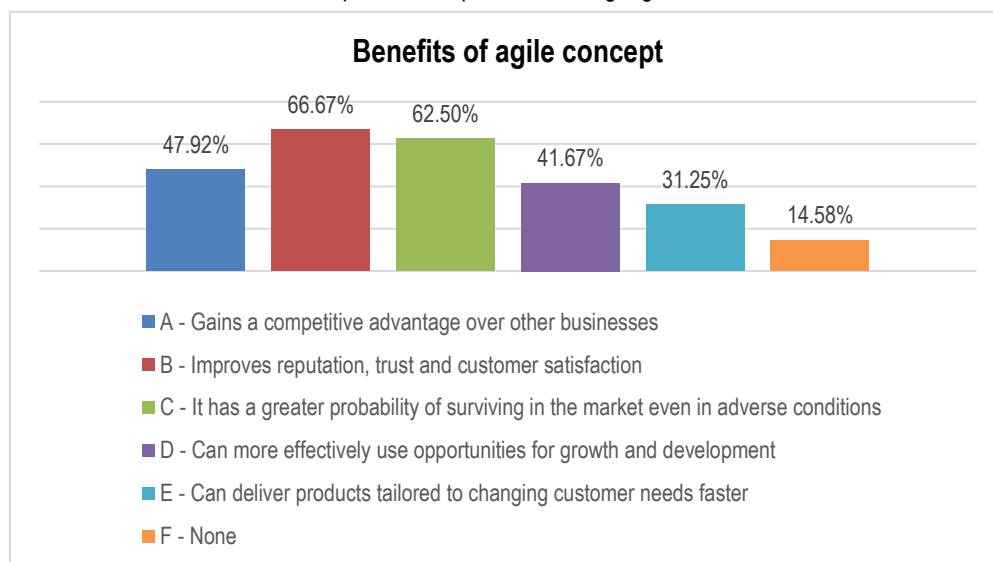


Figure 4. Benefits of agile concept

Figure 4 shows that the largest group of respondents consider answer B as the most important benefit of implementing agility in their business (185 respondents), the second largest group -173 respondents consider answer C as the most important benefit.

3. DISCUSSION

The research results show that agility as a concept is a key factor for maintaining competitiveness and ensuring the long-term success of enterprises in the woodworking and furniture industries. Despite the growing recognition of its importance, its practical implementation in this sector remains inconsistent, mainly due to limited strategic awareness and specific barriers to its development. Respondents characterise their level of agility primarily as the ability to respond quickly and effectively through changes in their strategies and processes. This statement is consistent with that of authors Agina Froide et al. (2020), who highlight that corporate agility is a combination of speed and stability, while allowing for efficient resource allocation and rapid response. From the findings, we further found that regular monitoring of the market and competition is the step most commonly taken by respondents to improve agility in their enterprise. Authors Karvonen et al. (2018) support this assertion, stating that successful agile transformation requires constant monitoring of market trends and the ability to dynamically adapt business strategies to the changing environment. Bureaucracy and the regulatory environment were identified as the most commonly perceived barrier to agile implementation, as evidenced by Saha et al. (2020), who state that high levels of regulation and bureaucracy can significantly slow down the process of adapting agile principles. The most notable benefit was the highlighting of reputation and customer satisfaction. However, the work of the authors García-Alcaraz et al. (2019) disagree with this assertion,

stating that the primary benefits of agility in enterprises are more likely to be improvements in operational efficiency and supplier flexibility.

4. CONCLUSION

Agility has now become a key factor for ensuring competitiveness and long-term success in today's dynamic business environment. The results of the research show that although the respondents in the wood and furniture industry enterprises in Slovakia are aware of the importance of agility along with its benefits and are taking some steps to improve agility barriers are still present which are a key factor preventing a seamless orientation towards agility as a concept. Thus, despite gaining the significant competitive advantage that agility brings, businesses struggle to implement it systematically.

A limitation of the research is the focus on a specific industry sector, which may limit the generalizability of the results to other industries. Another limitation is the primary focus on the questionnaire method only, whereby the subjective perception of agility by respondents may have led to some response bias. Future research should focus on identifying specific strategies to increase agility in the sector, particularly in the context of digitisation and sustainable resource management. At the same time, it would be useful to investigate the impact of agility on the long-term resilience of businesses in volatile market conditions

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PEOPLE - FOREST - WOOD: INCLUSIVE INTEGRATION MODELS. THE CASE OF THE KOBIERZYN URBAN FOREST PARK IN THE KRAKÓW METROPOLITAN AREA IN POLAND

Leszek Wanał, Jan Klimek, Władysław Kusiak, Łukasz Sarniak

Abstract: The study discusses the question of forested urban areas as spaces of education and therapy for people with various mental disorders. Based on the case of a garden-city in Krakow's Kobierzyn district, the opportunities and dangers of the practical idea of integral human development were verified. It asked how to use urban forestry resources, for the benefit of urban residents at risk of mental dysfunction. Using a case study and individual in-depth interview technique, an assessment was made of past activities in the selected metropolitan area (Kraków). A model for integrating the tools of forestry, urban management and medicine to improve the quality of life of residents of a large urban agglomeration in Poland has been proposed.

Keywords: urban forest, forest park, forest therapy, mental disorders, Kobierzyn, Kraków, Poland.

1. INTRODUCTION

Can a forest be a 'creator' of a natural refuge for city dwellers? Does it have the potential to be a friendly place to live, a so-called 'cittaslow' [1, 8]? Can a forest become a promoter of integral human development [7]? Is it possible to find a park or perhaps a forest garden in a metropolis that is a source of health? Such a place has been found on the outskirts of the urbanised area of Kraków. It is Kobierzyn [2], first a suburban village, then a district of the city. A surprised observer discovers a small but 'precious pearl' of an urban forest in Kraków.

Poland has a documented historical tradition of building symbiosis between the city, its healthy and sick inhabitants, and the forest or urban forest garden. Although in 1772, after the first partition, Poland formally lost Lviv (Lwów), it was still a truly "living" Polish city. The first state institution for the mentally ill in Galicia was the psychiatric ward of the regional hospital in Lviv, established in 1790. It was still a real "living" Polish city. The first state institution for the mentally ill in Galicia was the psychiatric ward of the regional hospital in Lviv on Piary Street (now Nekrasov Street), established in 1790. The hospital quickly became overcrowded. Lviv decided to build a new, larger facility on the city outskirts. In 1862, land was purchased with proceeds from the State Lottery, one third of the estate in the village of Kulparków. The new building was opened in 1875. It even had its own railway station, as a branch of the Czerwonice main line. Patients came from all over Galicia. Between 1904 and 1906, six new pavilions were built, and the modern hospital, equipped with water supply, central heating and its own sewage system, could accommodate about 1,800 patients [6]. However, this was not enough. As early as 1903, plans were made to build a new, second national hospital for the mentally ill in the western part of Galicia. The location of Kulparków on damp clay was problematic, so a new site was sought. Initially, the plan was to build on land in Lusina, south of Kraków. The design was developed in 1907 by architect Adolf Kamienobrodzki. However, because the Lusina site had problems with water access, a new location was found in Kobierzyn. Professor Władysław Klimczak from the Lviv Polytechnic, author of the general plan for the hospital, was appointed

construction manager. Dr Jan Mazurkiewicz was appointed director of the new institution. In 1908, he went on a study trip, visiting 33 psychiatric hospitals in Switzerland, Germany and the Netherlands [2]. Today's Kobierzyn was created based on these experiences.

2. MATERIAL AND METHODOLOGICAL BACKGROUND OF THE STUDY

Identifying the therapeutic conditions of the urban forest garden in Kobierzyn required studying the natural environment in the area under investigation. Despite changes, certain common features have been preserved. This was first recorded on an archival plan (Figure 1) and then on a diagram of the natural development of the hospital grounds (Figure 2).



Figure 1. Archival visualisation of the 'Project for a park and orchard at the national institution for the mentally and nervously ill in Kobierzyn' from 1909, developed by W. Żochowski.
Source: archives of the Dr J. Babiński Specialist Hospital in Kraków. [6].

The hospital complex's green areas consist of avenues, groups of trees and forests. The avenues are mainly planted with *Aesculus hippocastanum*, *Acer pseudoplatanus* and specimens of *Crataegus* and *Betula pendula*. Shorter sections are planted with small-leaved lime trees (*Tilia cordata*), common beeches (*Carpinus betulus*) and common rowans (*Sorbus*

aucuparia). Other groups of trees, such as poplars (*Populus*), European beeches (*Fagus sylvatica*), larches (*Larix*), spruces (*Picea*) and pines (*Pinus*), appear between the avenues and inside the pavilion gardens. On the north-western side of the rond-point, between the avenue leading to the farm and the northern section of the internal ring road, there is a pine forest. Trees are planted along almost the entire length of the hospital grounds. Among them are several long-lived English oaks (*Quercus robur*). Two flower beds have been preserved. The first, circular flower bed fills the rond-point in front of the administration building [6]. It features perennial plantings. The second flower bed is quadrangular in shape and divided by a cross-shaped avenue, with a small lawn in the centre and impressive western red cedars (*Thuja occidentalis*). In the northern part of the hospital there are fields and remains of a farm. On the southern slope of the "thyme hill" there are old farmlands and a solar farm. An orchard is being restored at the south-eastern end. Some of the small inner gardens are partially cultivated. But the most important people are the patients, medical and support staff, as well as visitors [4, 9].

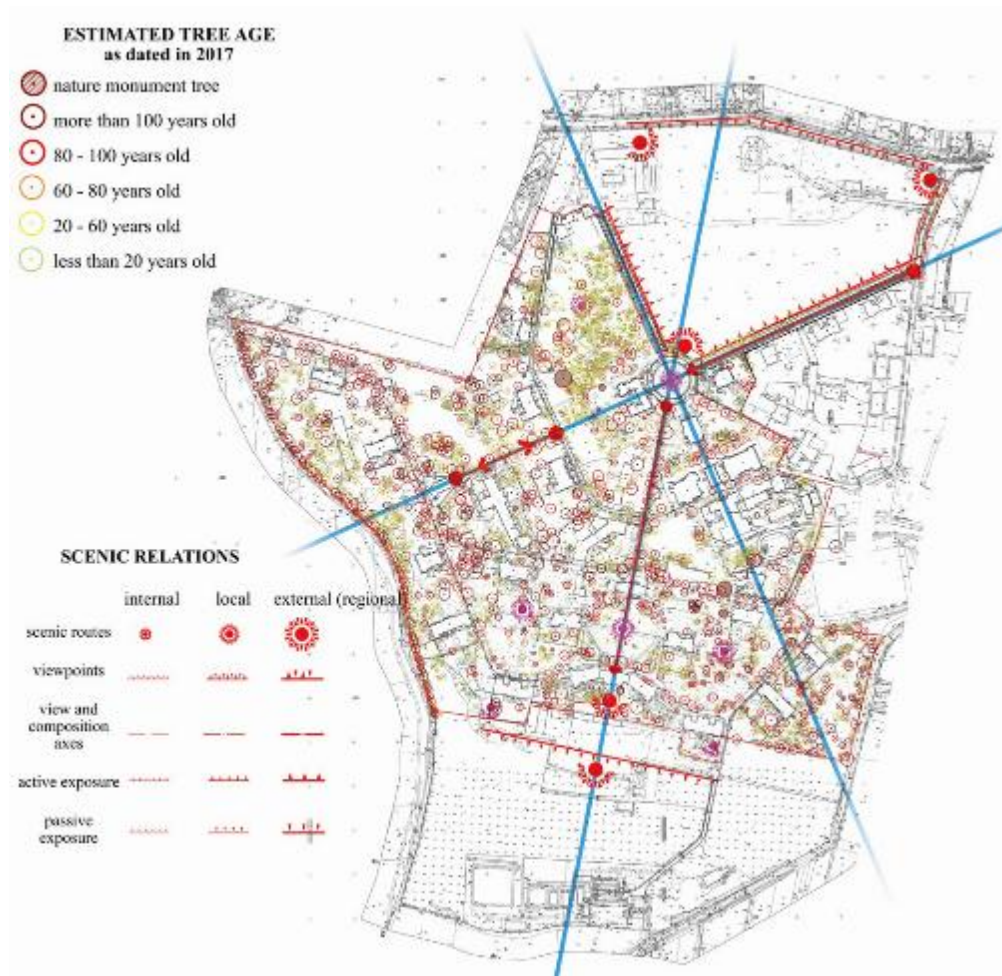


Figure 2. Schematic diagram of tree inventory with estimated age distribution and main compositional elements against the background of a sketch map of the hospital in Kobierzyn.
 Source: based on K. Koprynia's study, 2017 [6].

The starting point for a possible evaluation of urban forest parks and their importance, was a retrospective analysis. It was based on historical, but also current data sources. The experience of forest complex users in Krakow-Kobierzyn, where the Dr. Józef Babiński Clinical Hospital operates, was verified. The site was designed as a garden-city. The case study for this place made it possible to assess the current situation and development dilemmas.

A diagnostic survey completed the analysis. Opportunities and threats to the activities of the unique forest complex were studied. Ten specialists were invited to the expert survey. Individual in-depth interviews were conducted. They were supplemented by the authors' participatory observation during a visit to a forest-park in Kobierzyn. The results of the pilot study were aggregated as anonymous. Finally, key relationships were identified: people – forest – wood, against the background of the most significant dysfunctions and needs of patients.

3. SELECTED RESULTS

The first, though no longer the most recent, result is the design of a therapeutic garden on the hospital campus. This idea is evolving and still requires further development (Figure 3). The forest park renovation project (Koprynia 2017) is based on the original layout of the park and garden from 1909 (the map was drawn up on a scale of 1:500). A therapeutic garden model was prepared for the psychiatric ward. Historical plans and photographs were used. The tree stand is to be supplemented with new trees (*Aesculus × carnea*, *Pinus*), shrubs (*Ligustrum*, *S. vulgaris*), ground cover plants and herbs (*Vinca minor*, *Rosa*, *Lavandula*, *Thymus vulgaris*), as well as vegetables [6].



Figure 3. Therapeutic garden design at the court ward in the revitalised hospital park.
Source: Based on K. Koprynia's study, 2017 [6].

Small park architecture (chess tables, benches, outdoor gym) will be available for patients and visitors. You'll be encouraged to try horticultural therapy, forest therapy, but most of all, to rebuild relationships that have been damaged by feelings of exclusion [3, 10]. The therapeutic factors identified in the expert IDI, subsequently verified during walks in the Kobierzyn forest, conversations, but above all by listening to people, are summarised in Table 1. Some of them are marked with a coloured background (the most frequently recurring opinions). A value chain emerged: people – forest – wood, along with the idea of an inclusive integration model.

Table 1. Criteria determining the Inclusive Integration Model – on the case of Kobierzyn.

CITY FOREST-BASED PARK INCLUSIVE INTEGRATION MODEL			
Dysfunction / Need	PEOPLE's activity	FOREST urban garden	WOOD working therapy
loneliness	mutual listening, interpersonal relationships	walking together, garden work	working together to find wood materials, as well as the purpose and recipients of the made items
mental depression	medical therapy, pastoral care, building relationships and responsibility	cooperation in finding forest-sourced stuff for therapy workshops	making small wooden toys for hospitalised children
alcoholism	Alcoholics Anonymous AA-group, support from others, pastoral care	cleaning park and forest areas, shaping responsibility	simple woodworking crafts - as gifts for those in need
neuroses	pharmacological treatment, personalised medical assistance	joint identification of tree and plant species during a forest walk	simple craftwork in wood
mental disorders	pharmacological treatment, personalised medical assistance	identifying forest aromas, listening to birdsong, contemplating silence	simple woodworking crafts - as gifts for those in need
lack of work- life balance	verification of life priorities, building relationships and responsibility	planning walking in the forest with loved ones, friends, other patients	making small wooden Christmas and Easter decorations and religious souvenirs
nature deficit disorder	regular urban- forest-garden walks	collection of wood- based waste for small-scale arts and crafts	making little wood- based things as part of small-scale handicrafts
physical inactivity	simple walking programme, appropriate forms of activity, jogging	walking and sports activities on forest trails	physical work in "home" carpentry

Source: own elaboration based on the results of individual in-depth interviews [8]

4. CONCLUSIONS

The most important conclusions from the case study analysis in the Kobierzyn forest garden are as follows: (1) people need a hospital forest garden that is renovated and functional; (2) active therapy is needed not only for current patients, but also for potential ones. If human loneliness tops the list of dysfunctions in the digital age, then it is essential to listen to the voice of nature and other people, preferably by going to the forest [5].

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CRISIS AS THE CHALLENGE THROUGH AGILE APPROACH IN SLOVAK WOODPROCESSING COMPANIES

Andrea Janáková Sujová, Ľubica Simanová

Abstract: The current business environment characterized by instability and unexpected changes requires constant adaptation of companies and their transition to agile management models. The aim of the paper is to analyze whether the enterprises of the DSP SR were able to use the unpredictable changes of the environment in the crisis pandemic period to their advantage thanks to proactive agility. By conducting primary research in the form of guided interviews and creating case studies, the best practices of representative DSP enterprises were identified in relation to changes in financial performance. The main contribution of the study is new empirical insights into the agility capability of DSP enterprises as a pathway to sustained competitiveness.

Keywords: proactive agility, coronacrisis, best practices, case studies, Slovak woodprocessing companies

1. INTRODUCTION

Agility has gained considerable attention in today's turbulent times, and this is mainly due to the impact of the causes of the global pandemic COVID - 19, which has precipitated changes in consumer behavior, new communication platforms, as well as in the concepts of strategic agility used in various industries (Shaikh, 2021). Dealing with crisis situations and unexpected events require an agile approach, which is essential for fast, continuous and regular delivery of products and services, for meeting frequent changes in client requirements, as well as for increasing the level of transparency of project status and engagement of development teams with a focus on the quality and functionality of the delivered result. Tallon and Pinsonneault (2011), Sherehiv and Karwowski (2014) and Appelbaum (2017) agree on the definition of agility as the ability of an enterprise to react and adapt quickly in response to continuous and unpredictable changes in the internal and external business environment and to respond proactively to change. In his research, Joiner (2019) suggests that organizations with higher levels of organizational agility cope more effectively with rapid change and create value for stakeholders more quickly. Kurniawan et al. (2021) consider the ability to respond quickly to change, high levels of flexibility and the ability to control uncertainty as key factors to ensure the survival and growth of an organisation. Companies need to be able to deal with change, proactively creating and changing strategies and tactics related to business agility (Qosasi et al., 2019; Barlette & Bailleite, 2020;) in order to use them to cope with fluctuating internal and external changes. In addition to organisational agility, the social responsibility of modern organisations, according to Xia et al. (2018), lies in the efforts of individual stakeholders and the business to achieve a balance in terms of economic, social and environmental aspects. Torugsa et al. (2018) consider the economic dimension of proactive corporate social responsibility as a way in which firms seek to prevent problems that may arise in their interactions with customers, suppliers and market participants. The way a firm operates in the marketplace is an indicator of the incorporation of economic responsibility into its core business and decision-making, creating value by encouraging the production of new and diversified products demanded by consumers, reducing input costs, and improving production efficiency.

2. METHODOLOGY

The intention of the research, the results of which are presented in this paper, was to find out whether DSP SR companies were able to use the unpredictable environmental changes in the pandemic crisis period to their advantage through proactive agility. By conducting primary research in the form of guided interviews linked to changes in financial performance, best practices of representative DSP enterprises were identified through case studies. To this end, we designed a structure of guided interviews with owners and managers of manufacturing firms from selected industries and conducted a total of 36 interviews, of which 12 were from the wood processing industry. The interview content was constructed based on the findings from the literature reviewed on business agility as well as the impacts of the pandemic on business operations. Businesses were selected as representative by length of time in the market, size, ownership and by the level of financial performance relative to the industry as a whole. We selected semi-structured interviews to allow for open-ended and follow-up questions on the topic. The interviews were conducted in person, in 2024, when the effects of the pandemic had already died down. The guided interviews included questions from during and after the coronacrisis crisis, covering barriers and challenges, the most affected areas, the infusion of opportunities and innovation, financial and non-financial measures for business continuity, the impact of implemented measures on outcomes, successes and misjudgements about implemented measures.

The second part of the research was the analysis of changes in the development of financial indicators of sales and profit of the analysed firms during the pandemic, i.e. in the years 2019-2022. The source of data was the database of financial statements finstat.sk, which compulsorily by law publishes all financial information of active firms in the Slovak Republic. To increase validity, secondary data from the financial database was consulted along with primary data as a means of refining the findings (Gerbl et al., 2015; Yin, 2018). Sources of secondary data included firms' financial statements, annual reports, and data archived on the websites of the surveyed firms. We triangulated all data from primary and secondary sources using the procedure outlined by Tellis (1997). The results of the interviews and secondary data analysis were compiled into a case study. In the last stage, we identified enterprises with significant improvements in business performance during the pandemic as best practice cases.

3. RESULTS

Businesses that have been agile and implemented change during the pandemic have been able to improve their financial performance in terms of sales and profits in a period of restrictions and constraints. These enterprises have used the pandemic as a business opportunity to their advantage and are best practice cases. Of the enterprises surveyed, 4 such enterprises have been classified as best practice cases under the DSP, 3 of which are timber enterprises (C16) and 1 furniture enterprise (C31). These are micro, small and medium enterprises, and the measures they have implemented have had the most significant positive impact on sales and profits.

3.1 Results of the analysis of sales and profit through change indices

The analysis of revenue and profit has been carried out using year-on-year change indices for the years 2020 to 2022. The best performers were the 4 companies as shown in Table 1.

Table 1. Sales and profit - index of change in %

Enterprise no.	Revenues - indices of change				Profit - indices of change			
	20/19	21/20	22/21	average	20/19	21/20	22/21	average
1	9.05	34.01	17.26	20.11	4.83	186.84	35.55	75.74
8	-3.84	88.41	159.62	70.06	39.17	387.14	46.63	157.65
9	-9.30	82.91	16.82	30.14	9.58	218.40	11.25	75.58
11	-5.16	32.65	3.54	9.83	-8.47	805.88	6.49	241.30

Source: compiled from Finstat data

As can be seen in Table 1, the indices of changes in sales show negative values only in 2020, when the whole economy of the Slovak Republic experienced a decline in demand and thus a decline in sales in 3 enterprises ranging from 3.84% to 9.3%. However, in the following years, after the measures were taken, sales increased significantly, most notably in enterprise 8 by 160%, and there is a further increase in sales in the following year. A more significant improvement is seen in profits, except for enterprise 11 in the first year of the pandemic, enterprises increased their profits and in the second year of the pandemic up to triple digit percentage increases. Further profit increases were also achieved in the following year 2022.

3.2 Results of the content analysis of the structured interviews

During the pandemic, all DSP enterprises in Slovakia had to overcome the following obstacles: increased security and hygiene measures, the transition to online communication, staff shortages due to sick leave and mandatory quarantine, supply shortages of input materials, and most importantly, the increase in the price of input materials and energy. Most enterprises reported that a positive change they could respond to was the increase in demand for products such as household furniture instead of e.g. office furniture. This trend was also conditioned by the transformation of work from the corporate to the home office environment and the shift to e-shop sales.

In the companies included among the best practice examples, the speed of change implementation and low cost was a key criterion in the decision to take action, which is the essence of the agile approach. The specific challenges faced by these enterprises, the measures implemented and the non-financial results achieved are presented in the following section.

Enterprise No 1: a medium-sized furniture enterprise with 68 employees, home ownership and 13 years on the market:

- Challenges and constraints: the company dealt with low liquidity, significant cost increases and the problem of sustaining production, increased demand for products
- Measures implemented during the coronacrisis: use of bridging loans, financial reserves and state aid, investments in new technologies and digitalization, innovations in the product range
 - addition of new production of home office furniture, conclusion of long-term contracts for energy supplies, input materials and product sales
- Achieved results: increased flexibility in production and delivery, increased digitalisation and efficiency of processes, more efficient use of material inventories, entry into new markets, acquisition of new customers
- Changes in the company during and after the pandemic: increase in stock of materials, introduction of online communication and sales, reorganisation of processes

Enterprise No 8: a timber enterprise focused on the production of sawn timber and prisms, a small enterprise with 44 employees, home-owned and 29 years on the market:

- Challenges and constraints: the business dealt with a decline in demand and performance as well as financial losses in the first year of the pandemic.
- Measures implemented during the coronacrisis crisis: use of several forms of state aid, optimisation of process costs, customisation of product offerings.
- Non-financial results achieved: adaptability to customer demands, retention of key employees, cost reduction, improved management and employee attitudes towards waste

Enterprise No 9: a timber enterprise focused on the production of wooden pallets and sawn timber, a micro-enterprise with 8 employees, domestically owned and 34 years on the market:

- Challenges and constraints: the company was dealing with a shortage of input materials and supply disruptions
- Measures implemented during the coronacrisis crisis: adapting marketing and online activities to the online environment, increasing digitalisation, seeking cooperation in other markets, optimising processes
- Achieved results: digitalization of processes, increased skills with online technologies, acquisition of new market segments in the online space.
- Changes in the business that occurred during and after the pandemic: the introduction of both online communication and sales.

Enterprise No 11: a woodworking enterprise focused on the production of building and joinery products, a small enterprise with 22 employees, home ownership and a market life of 27 years:

- Challenges and obstacles: closure of showrooms, disruption of supply chains, lack of staff and replacement, postponement of planned investments
- Measures implemented during the coronacrisis crisis: flexible responses to supply and logistics challenges,
- Budget, cost and liquidity reviews, introduction of flexible working models, adaptation of marketing and sales strategies to the online environment
- Results achieved: improved flexibility and adaptability, strengthened teamwork, development of digital infrastructure, increased process efficiency
- Changes in the company during and after the pandemic: introduction of online communication and sales, changes in supplier relationships and supplier selection, reorganisation of processes and workflows

The best practices of wood and furniture manufacturing companies in the Slovak Republic in the context of dealing with the corona crisis can be summarized as follows:

- **Innovations in the product range** made it possible to take advantage of the increased demand for certain types of wood and furniture products. For example: the transition to the production of office furniture for households, products of atypical dimensions according to customer requirements.
- **Discovering new markets.** Companies that have innovated their product portfolio, analysed and assessed their market potential, understood the changed needs and demands of customers and current market trends. At the same time, they had to consider the right allocation of resources to ensure the success of projects through to the launch of products to the end consumer.
- **Flexibility in terms and conditions and customer orientation.** Flexible firms have been able to react quickly to market changes. Maintaining prices at a level acceptable to both the customer and the producer - firm representatives stated that they tried to maintain fixed prices for energy and input materials by contracting them out. Important factors for customer retention were stable relationships with suppliers and customers, long-term contracts, strengthened communication including online communication and the provision of truthful and transparent information on contractual obligations.
- **Digital transformation and automation,** executives said in interviews, has been accelerated by the coronacrisis. Companies had to quickly implement new technologies and digitise processes to continue doing business and communicating with customers, boosting online communication significantly. For example, manufacturing companies have had to move towards the use of computer technology not only owned by the company but also by their employees.

- **Employment:** companies quickly took measures to protect the health of their employees, provided protective masks, shields, temperature gauges, disinfectants in a timely manner and in sufficient quantities, ensured that their workers were tested, adopted a work-from-home policy, provided employees with various benefits (providing protective equipment and disinfectants for employees and their families, ensuring that employees are tested and vaccinated, increasing financial benefits, providing vitamin packs), retained key employees, increased social responsibility and had enough active employees.
- **Quick reactions to changes and unplanned processes.** Business representatives commented that the success of the measures taken depended to a large extent on their correctness and timeliness. They also pointed to the fact that the acquisition of new distribution channels, whether face-to-face or online, had an impact on employee performance, process optimization, management and employee attitudes towards waste, the reorganization of work processes and procedures, as well as the strengthening of teamwork.
- **Investments** were directed to the purchase of machinery and nological equipment during the change of technology (in the furniture company), to the digitalization, automation and robotization of processes, as well as to the purchase of IT technologies, which allowed to speed up and streamline processes, the respondents said.

3. CONCLUSION

The pandemic period brought unforeseen changes to the way businesses operate. The pandemic situation changed from one day to the next, greatly influencing how businesses reacted to the new conditions. Some enterprises were able to react flexibly to the new situation and use the crisis to their advantage, while others struggled to recover from the effects of the pandemic or even ceased their production and economic activities. This paper has mainly highlighted good practice cases of Slovak wood and furniture enterprises. Although the profit results presented through the change indices for 2020-2022 were turbulent at the beginning and during the coronacrisis, on the other hand, the revenue results stabilised in the years mentioned and the enterprises continue to operate. These results, in the context of the implementation of the identified good practice cases in Slovak wood and furniture enterprises, showed that when enterprises responded flexibly to changed market conditions, focused on innovation of the product range and development of new products, developed activities to discover new markets and position innovative and new products on the market, they were flexible in changing business conditions and were customer-oriented, implemented digital transformation and automation, strengthened online communication significantly, secured increased demand for innovative and new products that resulted in increased orders and sales. Respondents reported that the closure of retail outlets and a strong focus on online trading, thereby increasing cash turnover and securing liquidity, contributed to stabilising and in some cases increasing sales. Companies that took early measures to protect the health of their employees, kept employees regularly informed about the situation in their companies and did not have to reduce staff or replace them with less qualified employees had minimal impacts on sales and profits.

The main contribution of the article is the identification of manufacturing companies in the wood and furniture industry in Slovakia that have been able to use the crisis as an opportunity for business through the application of agile approach. The coronacrisis tested the level of flexibility and the ability to apply agile principles also in manufacturing enterprises in the woodworking industry and bring new empirical insights into the agility capability of DSP enterprises as a path to sustainable competitiveness.

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FURNITURE-AS-A-SERVICE: BENEFITS AND BARRIERS ON THE PATHWAY TO SUSTAINABILITY

Baltova, Stela

Abstract: The EU furniture industry is very innovative in terms of products and processes with a strong vision to be green and sustainable in all aspects of modern policies. Scientific achievements in the field of the reasonable implementation of new technologies in production processes along the path of the green transition and a definite shift from linear to circular models of production and management result in new requirements for manufacturers, as well as for customers of furniture. Companies are starting to see value in furniture subscription services. Consumers are becoming increasingly conscious and sustainability-conscious having their contribution to circular consumption. Renting or leasing furniture is an option for doing this instead of buying it, which can save money and help reduce costs and waste less resources. The article highlights the barriers, benefits and challenges to the furniture-as-a-service model to achieve sustainability.

Keywords: furniture, servitization, circular economy, circular consumption

1. INTRODUCTION

Furniture is an integral part of the feeling of functionality, regardless of its purpose. The megatrends shaping the world furniture sectors are the resource capacity, climate change, digital natives, ageing society, connectivity, digitalization urbanization, globalization, affluent consumer growth. The European furniture market is a significant sector, with ready-assemble (RTA) furniture valued at 15.5 billion or 20% of the total market. Furniture consumption in the EU is estimated at 10.5 million tons per year (World Furniture Online). Home furniture accounts for 82% of furniture consumption, the remaining 18% is related to business-to-business (B2B) consumption. Furniture waste in the EU accounts for more than 4% of the total municipal solid waste stream and amounts to 10.78 million tonnes. Waste originating from commercial sources is estimated to contribute to 18% of the waste generated across the sector. (Wulf et al., 2024). According to statistics from the European Federation of Furniture Manufacturers, 80% to 90% of furniture waste in the EU in municipal solid waste is incinerated or sent to landfills, and only approximately 10% is recycled. The research of Besh (2005) states that the greatest environmental impacts of office furniture are related to the production of raw materials and the disposal of old furniture. Otherwise furniture sector is very inovative, but some innovations have led, like fast food and fast fashion, to the production of so-called Fast furniture, which is usually made from cheaper materials at a lower cost and is designed so that it does not last long (Furmston & Braithwaite, 2025; Maier, 2021). Consumers can then afford to change their furniture more often, depending on fashion trends. Quick furniture that is mass-produced and relatively cheap is easy to obtain and then easily abandoned. It is believed that the main cause of furniture waste is due to fast consumption and disposal, which stem from changes in consumer behavior and preferences.

In the last 10-15 years of this century, many proposals such as "The Model of the Future? Renting furniture instead of buying" are found both for home and office furniture, for restaurants, hotels, etc. There is extensive research in the literature on the Product-as-a-Service model and subscription services as a manifestation of the business model in various areas for a wide range of products, including the subscription form, but on "furniture as a service" are very limited.

Over the past few years, environmental policies and in the context of the circular economy have aroused the interest of many bloggers in this model for furniture and are found in the electronic space of their views and comments, which are actually the predominant, even almost all published sources of information are expert opinions on specialized sites, blogs.

The aim of this article is to conceptually deduce, based on the academic literature and on expert opinions, the main benefits and barriers to achieving sustainability through the application of the Furniture as a Service model and to provide views for future research. The study is limited to B2B consumers, in particular experts and managers in the industry - designer and owners of hotels and restaurants and managers of coworking spaces in Bulgaria. The choice of this target group stems from two main considerations. First, the small hotels and restaurants, specifically operating only during the summer or winter season not claiming to have their own brand, prefer not to invest in machinery, equipment and furniture, but to rent. The second one is related to the trend to develop fashionable and high level functionable coworking spaces in Bulgaria. After the decline in their activity during Covid-19, it is on the rise again, new, some extremely modern and with their own signature shared office spaces are being opened. They are hired by companies, by entrepreneurs at the beginning of their activity, by temporary residents in a given destination, by self-employed persons and especially by foreigners.

2. PRODUCT-AS-A-SERVICE – A BUSINESS MODEL FOR SUSTAINABILITY

There is a lot of evidence in the scientific literature that among the business models that create strategic business growth and have the potential to minimize the negative environmental impact of both production and consumption is the Product Service Systems model (PSS) (Mont, 2002). PSS is formed when a manufacturing company takes action to serve itself and begins to implement a business model based on services that, together with the product, are able to satisfy the specific needs of the customer, creating value, often focusing on sustainability and resource efficiency (Batlles-de la Fuente, 2021). This process shapes the PSS model as an integrated combination of products and services, and innovative growth of the manufacturing company is achieved (Kim et al., 2015). At its core, it is a model of moving from product-centric to a user-centric and lifecycle-oriented approach to business.

The Product-as-a-Service business model has acquired connotations in the context of the Product Service Systems (PSS) model, being its specific manifestation, distinguished by providing access to a specific product or group of products. In the PaaS model, ownership of the product is not transferred from the manufacturer or suppliers to the end user, but they control the product during all stages of its use by the customer. The service is paid by the client.

Then, the main advantage of the PaaS business model is that the value embedded in the products is used for more than one lifecycle (Golinska-Dawson et al., 2024). The development of the PaaS model has been supported by the rapid development of digital innovations, which have led to the rapid development and use of infrastructure for sharing assets, created conditions for new business models such as those in the sharing economy and subscription economy, the "pay-as-you-go" model has been simplified (Keller et al., 2010).

According to the 17 UN Sustainable Development Goals the UN Sustainable Development Goals (SDGs), the furniture industry violates several of the goals, and the circular economy is considered a significant driver for the sustainable development of the sector to achieve a reduction in resource consumption, repair and recycling of materials and products to

reduce waste (Liu et al., 2023). In this important period for the furniture industry, it is of primary importance to study the possibilities of sustainable business models and approaches that have already yielded a positive result in reducing the negative impact on the environment and achieving the social impact of corporate production in other products and services in the sectors of the economy, offering conceptual visions and promoting business, as well as users to apply them.

In April 2025, the European Commission adopted the 2025-2030 working plan for the Ecodesign for Sustainable Products Regulation (ESPR) and Energy Labelling Regulation. Furniture, together with textiles and steel are the products that should be prioritized to introduce ecodesign requirements and energy labelling over the next five years. The philosophy and the ambition of the plan is to foster sustainable, repairable, circular and energy efficient products across Europe in line with other related policies and regulations. The circular economy model is an economic system that includes 3Rs (reuse, remanufacturing or recycling of materials) in all stages of production, distribution and consumption (EllenMac Arthur Foundation, 2013). Being a restorative or regenerative industrial system, the circular economy replaces the concept of "end of life" with restoration, reuse, elimination of waste through appropriate design of materials, products, systems and business models.

Many business models of the circular economy are already known, some of a conceptual nature only (Wulf et al., 2024), among which is the PaaS model, for which there are still not enough applied practices for a large part of the products, including the furniture sector, which is among the priorities of the EC to achieve sustainability. Product-as-a-Service is a business model focused on the customer rather than the product. (Hidalgo-Crespo et al., 2024, Golinska-Dawson, 2024). By expanding services and innovation, by controlling during the entire product life cycle from design to consumption, by reducing the environmental impact, an increase in value is achieved through various processes for the product, the customer and for the business. Golinska-Dawson et al. (2024) in their research on the electrical and electronic equipment sector conclude that in the PaaS model, the principles of circularity must be simultaneously incorporated into the design of the product and the design of the service provided in order to create a more sustainable product-service system. Services, depending on the product and its purpose, can be related to repair work, recycling, processing to a new raw material or a new product.

The PaaS model is known and researched in SMES, as well in large corporations, but still not enough for many sectors as to reveal to manufacturers the benefits, barriers, challenges for developing and implementing such service-oriented business models. It is even considered that the PaaS model is more successful compared to other servitization approaches (Hedvall et al., 2025). Moreover, there remains a shortage of research on companies that are still in the process of developing, implementing and scaling their PaaS business models, and there is almost no research on the furniture sector.

3. FURNITURE-AS-A-SERVICE AND WHY SUBSCRIPTION FOR SUSTAINABILITY

Furniture sectors apply a plenty of circular practices (Cooper, T. et al., 2021; Kulakovskaya et al., 2024; Pinho et al., 2025). There are very few examples of FaaS, rather there are almost none described in the scientific literature, they are found in blogs, in the website of companies declaring to operate as FaaS. In the European Union's sustainable

development policies, as well as in each Member State, the understanding is given that consumers can reduce furniture waste by implementing sustainable practices such as second-hand purchases, repair and maintenance of products, choosing furniture made from sustainable materials. The Nordic model of the so-called Løppemarket in Denmark is a good example of widespread sustainable practice.

Renting furniture is a preferred option for individuals renting a home, for workers who reside temporarily for work for a longer period of time, students, as well as real estate agencies. The dynamic development of the event industry has also led to the expansion of companies that offer furniture for organizing events of various nature. The sharing economy has also given scope for the emergence of separate spaces, in which the individual approach to each office tenant has formed a trend for personification in furnishing.

F-as-a-service is an example of the circular economy practices in furniture industry. A new way of thinking about furniture as a service. It is defined as an innovative business model that offers temporary access to furniture through subscription or leasing instead of purchase. Thus, as already clarified, the principles of the circular economy for sustainable consumption and extending the life cycle of the product through reuse, repair and recycle are applied.

Co-working spaces have a dynamic nature of work, they are hired for relatively shorter periods of work, for example, by entrepreneurs, even digital nomads, by companies that are temporarily on the market and support the principles of reducing the negative footprint on the environment. Customers get up-to-date design, low start-up costs, support, if they choose a subscription model, they feel flexible and without long-term commitments. Like other sectors, manufacturers or traders continue to own the product, control its entire life cycle and undertake various options for its processing, repair, recycling, generating revenue and achieving sustainable growth at all stages.

In search of motivating factors for the transformation of the furniture industry according to the principles of the circular economy and how to most smoothly change their model from linear to circular, some studies conclude that furniture manufacturers are ready to acquire knowledge about the digitalization of production and all processes along the entire product value chain, including gaining knowledge including from platform as a service itself (Georgieva et al., 2023; Wulf et al., 2024). The interviewed experts confirm the willingness of restaurant managers and small, mostly seasonally operating hotels to grasp the opportunities soaring from the FaaS model and are open to have knowledge and shared practices on.

PaaS offerings are gaining attention in the new literature on subscription services, being cited as an extension of the traditional concept of subscriptions (i.e., market-based offerings where customers are provided with access to a service for a recurring fee) from the software, information technology, and digital media sectors (Kowalkowski & Ulaga, 2024).

The subscription service model is finding more and more interest among researchers and businesses as a modification to market offerings mainly for support, where customers are provided with access to the service for a recurring fee and borrowed from the software, information technology and digital media sectors (Kowalkowski et.al, 2024). The focus is on highly professional satisfaction of the needs of the business user and even subscription services are evolving in the field of innovation in business models (Kowalkowski & Ulaga, 2024). Research and study of practices are needed to deliver in depth knowledge on the FaaS model to achieve sustainability.

4. CONCLUSION AND FURTHER RESEARCH

In this paper two main research questions were addressed: whether the widespread Product-as-a-Service business model is applicable in the furniture sector and whether environmental sustainability can be achieved in line with the current policies in the European Union to apply circular economy principles in the sector. The study showed, firstly, that there is very little even lack of research on FaaS model practices in the furniture sector, but experts believe the businesses in some niches of the the hospitality, restaurant and coworking spaces are interested in gaining knowledge about the model and its possibilities to incorporate the principles of the circular economy in order to achieve a reduction in the negative environmental impact of their activities, achieving business growth and building productive business partnerships.

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INTEGRATED DEVELOPMENT OF FOREST AND WOOD-BASED SCIENCES ON THE BACKGROUND OF THE UNIVERSITY IDEA

Leszek Wanat

Abstract: The study discusses the problem of the forest sciences' status in the modern research, development and education model. The background of comparative and descriptive analysis became the idea of the university, the first European traces of which can be found not only in Bologna or Paris, but also in Ohrid. Against the background of various concepts of the modern university, a model for the development of applied, wood-based sciences was sought, referring to the sources of the philosophy of science, market theory, as well as the experience of the digital age. Finally, the most important directions of forest sciences development in the view of integration challenges in science were identified: economic, practical - transformed into so-called applied sciences.

Keywords: forestry, wood technology, *sylvicultura oeconomica*, university idea, integral economics.

1. INTRODUCTION

When Hans Carl von Carlovitz proclaimed '*Sylvicultura oeconomica*' in 1716 [2], he probably did not expect that the idea of "sustainability" would become an economic dilemma in the future [3]. It is not at all obvious that this "sustainability" means the same thing as the circular economy, or especially the integral economy [13, 18], which recognises care and even responsibility for every inhabitant of the earth – our "common home" – as the basis for development [1, 11].

How did von Carlovitz understand this? He sought to explain natural, economic and social phenomena in forestry by engaging in a discussion with classical economics [12, 21]. Indeed, von Carlovitz's model promotes sustainable forest management [3, 4]. In practice, this means harvesting and processing only the amount of wood that can be restored (potential capacity) through forest regeneration (effective capacity) [14]. Therefore, one of the pillars of forest regeneration is its natural regeneration [15]. But is 'sustainability' alone enough? Is such a model acceptable? At the dawn of a new digital age, which some call techno-feudalism [6, 17], it has been understood that a revision of previous economic theories is necessary.

Forestry science also finds itself in a new situation. Questions are being asked about the tasks for both the new generation of universities and the new generation of businesses [10]. What is expected today from the actors shaping the wood market: universities, institutions, businesses and individuals? What does humanity expect from nature, from the forest, and what, in turn, does the forest have the "right" to expect from humans [7, 8]?

Is it possible to 'frame' these questions within the critical perspective of the contemporary debate on the university of the future?

METHODOLOGICAL BACKGROUND

When discussing the status of forestry sciences in the contemporary model of research, development and education, reference was made to the spirit of the scientific conference venue. The idea of the university, whose first traces in Europe can be found not only in Bologna

and Paris, but also in Ohrid, became the backdrop for comparative and descriptive analysis. In the context of various concepts of the university, a model for the development of forestry-based sciences was sought, drawing on the sources of the philosophy of science, market theory and the experiences of the digital age. Ultimately, a goal was identified – in the context of integration challenges in science: natural, economic, practical – transformed into the so-called idea of an entrepreneurial university. Selected state-of-the-art items (secondary data) ultimately provided information for descriptive analysis [9].

3. GENIUS LOCI - THE FIRST SLAVIC UNIVERSITY

Since we have been invited to discuss the development of natural, agricultural and forestry sciences in Macedonian, ancient Ohrid, it would be a huge mistake to reject the spirit of the place (genius loci), which retrospectively helps to reveal the most important tasks of science today, when we call our era modern, digital, technological, based on artificial intelligence, and forward-looking. What was science like before? Where did it originate? Was it present in the Macedonian forests?

A community of people looking in the same way, united into a single 'whole', striving to build universality in diversity, refers to the Latin 'universitas'. However, there is no evidence that the first educational institution in the world was created exclusively by Latin civilisation. After all, education has been around since ancient times. We do not know all cases of such activity: for example, in China, Egypt, India, the Mayan civilisation, or finally in Europe. Indeed, their popularity was determined by the power of social media, and thus the eternal power of communication: information and advertising. The most famous ancient Greek academy seems to have been the Muzeion in Egypt's Alexandria. And the academic disciplines? The most important subject turned out to be... theology. It was first taught in home schools, then in public schools. It is widely believed that the oldest institution of this type, based on science, was the school in Bologna, Italy, founded in 1088 [10].

Let us refresh the question: what exactly is Europe, who created it and who is creating it today? A geographical view of the continental map of the new era (the one that took shape after Christ) through the prism of history points to the south as the leading point. It was in the south that the religious, scientific, economic and cultural centre, known today as Europe, took shape. The west and north were peripheral areas. The Church was the sole promoter of education. It should be noted that relatively little is known about the educational potential of so-called Eastern Europe, especially in terms of teaching and learning. This was an area dominated by the Eastern Church and Oriental thought, and later by the Orthodox Church. It is known that in 313, Emperor Constantine the Great established Christianity as the 'dominant religion', which became the basis for the organisation of the Church in the Roman Empire, in close symbiosis with the state. What did this mean for Ohrid, where the conference debate is taking place? After 395, when the Roman Empire split into two parts, Macedonia became part of the Eastern Empire. Later, depending on the balance of military power, Macedonia changed its protectors many times [5]. These included Byzantium, the Kingdom of Bulgaria, and Serbia. Only the Eastern Church ensured relative stability for the community of residents.

It was a time when Cyril (Constantine) and Methodius, the great apostles of the Slavs, travelled to Moravia. They worked on the Glagolitic alphabet and began translating the Bible into the Slavic language. The brothers were accompanied by Clement and Naum. After Cyril's death, they returned to Macedonia as teachers of theology. However, their efforts to establish

the liturgy of the Roman Church ultimately failed. In Bulgaria, Tsar Boris (852–889) instructed them to educate the Bulgarian ecclesiastical hierarchy to celebrate the liturgy in the Slavic language. Naum remained in the centre, organising the so-called Literary School in Pliska. Clement, meanwhile, went to Ohrid with the same task, namely to organise a second school. Borys established both schools almost simultaneously (in 885 or 886). In Pliska, clergymen were engaged in translation. They developed the Cyrillic alphabet, which was derived from the Greek uncial script, supplemented with ligatures and consonants from the Glagolitic and Old Church Slavonic alphabets for sounds not found in Greek. It was also a centre of poetry, painters and artistic ceramics. In 893, after a brief period of paganism, Boris convened a council in Preslav. The state significance of Christianity was restored. The capital, as well as the school, was moved from pagan Pliska to Christian Preslav [5].

Clement spent seven years in Kutnitsa (886–893). Naum then joined Clement, and together they organised a church school in Ohrid. It was an institution called the Literary School. After the Council of Preslav, it became a kind of central institution, educating new generations of clergy in Ohrid. They were the scholars of their time. They commonly used both Cyrillic and Glagolitic scripts. Approximately 3,000–3,500 students were educated there. Thus, first Clement and Naum, and then their well-educated successors, clergymen and teachers, translated biblical texts, hymns, psalms and sermons into Old Church Slavonic [5].

In 893, Tsar Simeon (893–927) invited Clement back to Preslav. He was to become Archbishop of Ohrid. However, Clement did not support the widespread use of Cyrillic, which he considered to be a Hellenised version of the alphabet (domination of Byzantium). Tsar Simeon, on the other hand, sought to balance relations between Rome and Byzantium. The ruler recognised Slavic as the official language of Macedonia. It is interesting that Rome also recognised Slavic as a liturgical language, alongside Hebrew, Latin and Greek. The significance of Cyrillic was to alleviate distrust towards Byzantium. Ultimately, Clement was appointed bishop of Drebica (on the periphery of the state) by Simeon. A Greek clergyman, Gavril, was appointed archbishop of Ohrid. Thus, the tsar's political opponent was 'exiled'.

It should be noted that it was in Ohrid that Clement founded a monastery in honour of Saint Panteleimon the Healer. It was also there that the Ohrid apostle was buried in 916. Naum built a church on the banks of the Crni Drim stream in honour of the archangels Gabriel and Michael, and was buried there in 910. Although the Bulgarian Church was formally subordinate to the Patriarch of Constantinople, thanks to the work of Clement and Naum, it became independent in practice. It received its own archdiocese. Schools in Ohrid and Preslav contributed to the replacement of Greek with Slavic [5]. Old Church Slavonic was recognised as the fourth official language of the Christian Church. So, can we say that it was in Ohrid that the first Slavic university was established, which operated until 1767? There could certainly be a dispute between Ohrid and Preslav, and perhaps other centres, because everyone wants to be first. However, nothing can take away from Clement and Ohrid the title of the Slavic capital of science, from which we too can draw inspiration today.

4. SELECTED RESULTS OF THE STATE-OF-THE-ART REVIEW AND DISCUSSION

Is the idea of a university solely attributable to Latin schools? What does it matter that the commonly used term *universitas* (literally: whole) comes from Latin? Like *corpus*, *consorcium*, *communio* and *collegium*, it means a union, corporation or association, but always emphasises the communal nature of the university structure. Currently, following the Latin model of

communio, the term academic community (academic society) is used in relation to universities. It consists of academic teachers (active and retired), administrative staff, students (including doctoral students) and, finally, graduates [10]. However, it cannot be denied that contemporary scholars, clergy of the Eastern Church, and fathers of Eastern spirituality had their own unique understanding of the community of disciples (derived from Jesus' teachings in the New Testament) [7].

Perhaps we need to recognise the historical coexistence of two ideas of the university. Some will call them 'old' and "new". Others may see them as the two 'lungs' of a university Europe that has been shaped over centuries, eastern and western. Most often, however, these two paths are seen in the context of historical succession.

The first of these ('old') refers to Plato's Academy. It points to the fundamental principle of the university's activity, which is the search for truth, establishing knowledge as the supreme good. In modern times, Humboldt's liberal university referred to this concept. The German model emphasises freedom and independence in research and teaching. At the same time, it adopts the principle of combining research and teaching functions, where the primary purpose of the university is scientific research, which is the source of new ideas [13, 14].

The second concept (which can be called the 'new' idea) emphasises the primary role of education. Knowledge becomes a tool for education in three areas: vocational (the aim is to prepare for a profession), cultural (the acquisition of general, theoretical knowledge) and methodological (mastering research methods and intellectual work). Today, this idea is reflected in the functional model, also known as the French model. The guiding principle of education in this model is pragmatism, and the goal is to educate civil servants or teachers in state universities [19].

Against this background, an important concept, which can be called indirect, is presented by the British (Newman) model. It favours personality development and intellectual education, with an emphasis on educating the intellectual elite. The British model excludes combining teaching and research, arguing that abilities in both areas rarely go hand in hand. Another modern idea can be pointed out – that of the American university. Such a university is a place where theory is transformed into a tool for civilisational development [18].

This concept assumes a close link between scientific research and education. It expresses the belief that only those academic teachers who conduct scientific research are sufficiently creative [22]. Only they can therefore ensure the proper intellectual development of young people, whom the American model expects to be leaders of progress.

4. CONCLUSIONS

What ultimately becomes the real challenge? Is it the integration of natural and forest sciences with applied sciences and technological reflection? Or perhaps we need to see it differently? And if the real challenge for the new generation of universities, including those calling themselves entrepreneurial universities, is to shape a new kind of person, that is, a mature individual ready to build the society of the future, a community of meaning? Of course, we do not know the future. Hence the enormous importance of entrepreneurship – this method of looking at tomorrow, at the future, as a vision of what is to come. And if we compare this view with J. Schumpeter's concept of entrepreneurship, known as 'creative destruction' (schöpferische Zerstörung) [10]. It seems that only university activity that challenges the order

and state of affairs (of the state, religion, economy, freedom, citizenship, law) is the activity most conducive to this probabilistic entrepreneurship. Or perhaps only such a 'philosophical' university, one that asks questions, is in fact entrepreneurial [19]. Entrepreneurship stems, in a sense, from dissatisfaction, from the courage to say 'no', from disagreement with the status quo. Is it not true that a university that implements even a thousand valuable projects but does not negate anything cannot be a good breeding ground for innovation?

In the digital age, the economy intuitively turns to universities for negation, for the creative power of destruction (of the old!), because without overcoming the old and moving on to the new, there can be no talk of development. The idea of entrepreneurship, and with it the idea of 'sustainability', attempts to bring together two cultures that are currently competing with each other: the humanities and the culture based on science and technology [20]. But is trying to negate everything and start from scratch the best way to overcome this kind of civilisational impasse? Finally, it seems that there is no need to create new concepts: a university is entrepreneurial by its very nature [10]. Perhaps this 'second entrepreneurship', widely promoted as an epoch-making discovery and a necessity, is artificial and, at best, a therapeutic substitute.

So what should we choose? It is worth taking a chance, choosing an encounter with the forest [16], with creativity based on forestry and wood, allowing you to observe, listen, think and discover meaning more, rather than trying to be creative 'on demand'? Perhaps this dream of finding the truth will become an experience of encounter, in which the truth finds me?

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ARTIFICIAL INTELIGENCE AND DIGITAL INNOVATION

CHALLENGES AND OPPORTUNITIES IN MANAGING FORESTRY INDUSTRY ENTERPRISES WITH ARTIFICIAL INTELLIGENCE

Rumen Dombashov

Abstract: With the continued depletion of natural resources due to climate change, new challenges are being created for the management of forestry industry enterprises. A modern toolkit for analyzing climate change and modeling ecosystems is artificial intelligence, which provides an opportunity for sustainable management of natural resources. This report provides a systematic review of the scientific literature on the use of artificial intelligence in the management of forests and forestry industry enterprises. The review was conducted in the indexed scientific databases Web of Science and Scopus for the period until the end of 2024. The report consists of three parts. The first part forms the research framework on which the review was conducted. The second part summarizes the results of this study. The third part contains a brief discussion of the challenges facing forestry industry enterprises. The review shows that the use of artificial intelligence can be used to assess logging, identify threats to biodiversity and fire risk, and detect areas of deforestation and illegal logging.

Keywords: artificial intelligence, management, forestry industry

1. INTRODUCTION

In the context of digital transformation and increasing environmental demands, forestry industry enterprises are facing the need to change their traditional management models. In the last decade, artificial intelligence (AI) has established itself as a key tool in all business and non-business sectors (Velez, Sivakumar, & Zlateva, 2025; Raitskaya & Lambovska, 2024), which offers new opportunities for optimization, sustainability and competitiveness. The integration of artificial intelligence supports decision-making, resource management and business adaptability to market and climate change.

The purpose of this report is to provide a systematic review of the scientific literature on the application of artificial intelligence in forest management and forestry industry enterprises.

The review was conducted in the indexed scientific databases Web of Science and Scopus over the period from 2020 to the end of January 2025. Methodologically, the search protocol is based on elements for a systematic review of the scientific literature recommended by Moher et al. (2009).

The report consists of three parts. In the first one, the research framework within which the review was carried out is formed. The second part summarizes the results of this research. The third part contains a brief discussion on the opportunities and challenges faced by forestry industry enterprises.

2. METHODOLOGY

The systematic review in this report is based on the recommendations of Moher et al. (2009) and the methodology of Angelova-Stanimirova & Lambovska (2024) in the scientific

databases Web of Science and Scopus, over the period from 2020 to the end of January 2025. Based on the capabilities provided to these bases, the following search strategies were set: WoS: (artificial NEAR/0 intelligence) AND (management) AND (forest* AND industry) Scopus: (artificial PRE/0 intelligence) AND (forest AND management)

As a result of these search restrictions, 38 scientific publications on the Web of Science and 144 entries on Scopus were found. After reviewing the summaries and content, records that are unrelated to the topic of this review are beyond its purpose and have no open access were eliminated. The number of sources used was reduced to 13.

3. RESULTS

The results of the review of the scientific literature on the topic studied are presented in Table 1.

Table 1. Application of Artificial Intelligence in Forestry Industry Enterprises

Efficient use and sustainable management of natural resources	Efficient allocation of natural resources Forest mapping and monitoring Identifying risks Water management	(Badem et al., 2024), (Pedro et al., 2024), (Mehri & Alesheikh, 2022), (Charlton et al., 2023), (Velasquez-Camacho et al., 2023) (Mitra et al., 2025), (Choi et al., 2024), (Ramadan et al., 2024)
Forecasting market trends	Assessment of forest areas	(Jafary et al., 2023) (Koster, R., & Fuchs, 2022)
Making timely management decisions	Efficiently Plan Yields Optimizes logistics Monitors enforcement and compliance with international regulations	(Filho et al., 2024) (Gbadegesin, 2023) (Ewertovski et al., 2024)

4. DISCUSSION

The management of forestry industry enterprises encompasses not only a biological understanding of forest, but also the application of economic principles that optimise the use of limited natural resources.

3.1. Capabilities in the management of forestry industry enterprises with artificial intelligence

Artificial intelligence offers new opportunities for sustainable and effective management of forest ecosystems by monitoring biodiversity with drones, predicting forest fires and optimising logging processes. AI can assess the resilience of forest structures to climatic, economic or social shocks (Ewertovski et al., 2024). Modern models are also used to predict

economic outcomes based on different forest scenarios, combining data from climate, market, logistics and resources.

3.1.1. Efficient use and sustainable management of natural resources

With the integration of artificial intelligence, large volumes of data can be analyzed and effective strategies for use of natural resources can be proposed, resulting in better yield planning and less losses. Using AI, data from climate change monitoring are analyzed, creating the basis for smart forest management (Ramadan et al., 2024).

Modern models for assessing the potential of forests for yield and sustainable management often use factor analysis based on six main components: height, slope, exposure, temperature, precipitation and soil type, explaining more than 90% of the variation in environmental data. These factors serve as input variables for artificial intelligence algorithms that support risk zone classification and management decision-making (Mehri & Alesheikh, 2022). AI makes it possible to predict climate factors that are necessary to preserve the ecological integrity of forest systems and efficiently allocate water resources (Badem et al., 2024). Artificial intelligence algorithms processing large databases are also applied to predict air pollution (Choi et al., 2024).

On the other hand, AI can monitor forests in real time, identifying the risks of fires, diseases and illegal logging, and provide recommendations for the sustainable management and protection of these resources. The proposed systems use a network of sensors located in forest areas to collect real-time data on the main indicators of climate change. Such smart systems can be integrated into forestry industry enterprises to control pest populations that threaten biodiversity or economic resources (e.g. wood) (Charlton et al., 2023).

The AI application can geoposition forest stands through high-precision satellite imagery and deep learning and computer vision models. Based on the information received, trees for the needs of forestry industry enterprises are classified (Velasquez-Camacho et al., 2023). Automated classification extracts the most essential details from the images, allowing a more accurate and rapid mapping of areas (Mitra et al., 2025). The up-to-date information provided on tree species distribution allows precise planning, monitoring and control of resources (Pedro et al., 2024).

3.1.2. Forecasting market trends

The application of AI can predict market trends, allowing enterprises to adapt their strategies and better manage their assets. The large volume of market data and the impact of heterogeneous factors on the price of forest stands make it necessary to automate the assessment of the value of forest areas subsequently subject to yield, afforestation or investment (Jafary et al., 2023).

Artificial intelligence is also applicable in enterprises that manage forests of different ages and types. Its integration makes it possible to assess the economic value of each tree, which will make it possible to make felling decisions and thus maximise the long-term value of the plantings (Koster & Fuchs, 2022).

3.1.3. Supports management decision-making

Artificial intelligence provides timely and accurate data on the real state of forest resources, allowing the enterprise to plan yields efficiently and optimize logistics. Automated road detection and optimisation of storage areas reduce operating costs (Filho et al., 2024). The application of AI in these two aspects is particularly important for enterprises that manage large and hard-to-reach territories.

On the other hand, monitoring data can be used as evidence of sustainable forest management needed to obtain international certificates. Smart algorithms can also be integrated into systems related to compliance with environmental and forest regulations, automatically detecting deviations from the norm and alerting the relevant institutions. This increases the effectiveness of law enforcement and paves the way for a more transparent, timely and objective response from public authorities (Gbadegesin, 2023). On the one hand, it improves the image and is pivotal to the long-term sustainability and reputation of forestry industry enterprises.

3.2. Challenges in the integration of artificial intelligence in forestry industry enterprises.

Difficulties in deploying an AI-enabled system can be divided into several areas, depending on how they relate to the development of these systems.

The most significant difficulties are:

- Highly qualified professionals are required to develop and maintain software related to forest management;
- Problems arise related to the collection of data from various sources, such as sensors, satellite images and drones;
- Significant financial resources are required for the deployment of new technologies and staff training;
- It takes a considerable amount of time to integrate into traditional enterprise processes;
- The deployment of AI must comply with ethical standards and environmental regulations;
- It is necessary to overcome the psychological attitude of experts and consumers.

5. CONCLUSION

This report presents a systematic review of the scientific literature on the application of artificial intelligence in forest management and forestry industry enterprises. The review covers publications indexed in scientific databases Web of Science and Scopus over the period from 2020 to the end of January 2025. Methodologically, the search protocol is based on elements for a systematic review of the scientific literature recommended by Moher et al. (2009).

The results of the review show that forestry industry enterprises use artificial intelligence to effectively manage natural resources, sustainably manage forests, predict market trends and support timely management decisions.

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AI-DRIVEN QUALITY MANAGEMENT IN THE WOOD INDUSTRY: ENHANCING STANDARDS THROUGH AUTOMATION AND DATA-DRIVEN INSIGHTS

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Abstract: The wood industry is undergoing a significant transformation driven by evolving consumer expectations, stringent regulatory requirements, and increasingly complex production processes. This paper explores the role of Artificial Intelligence (AI) in quality management across the entire lifecycle of wood products, from raw material assessment to final product validation. By harnessing machine learning, predictive analytics, and real-time data processing, AI-powered systems can detect defects with greater accuracy, streamline inspection procedures, and facilitate data-driven decision-making. These advancements not only reduce production costs but also enhance regulatory compliance and improve product reliability, ensuring a competitive advantage for industry stakeholders. The findings highlight how AI-driven approaches contribute to higher efficiency and consistency in quality control, offering valuable insights for manufacturers, researchers, and policymakers in the wood sector.

Keywords: AI, wood industry, predictive analytics, machine learning

1. INTRODUCTION

In traditional wood-based panel production, quality assurance is reactive, and sample based. For example, in panel production, operators commonly rely on sampling and destructive testing: once per shift a board is sawn from the line and tested for properties such as internal bond strength, bending strength, density and formaldehyde content in a lab, with results available much later (Jan Bär et al., 2022). Routine surface grading of lumber and wood-based panels in traditional quality control (QC) is commonly done by humans. Visual inspection is still performed largely by eye: production-line operators first scan boards under lighting and then carry out detailed, manual defect grading at dedicated stations (Haifei Xia et al., 2025). Visual controls are slow and labour intensive, and their accuracy depends on the individual worker. In practice this leads to inconsistent decisions, a tendency to miss small or complex flaws, and rising error rates as inspectors tire (Yizhe Li et al., 2024). Traditional approach often results in quality deviations being caught too late, leading to scrap or rework, and it places high pressure on plant operators (Jan Bär et al., 2022; Amir-M. Naddaf-Sh et al., 2025). Furthermore, traditional systems often lack comprehensive data management, defect occurrences might not be systematically registered, and much tacit knowledge remained with individual workers rather than in accessible databases (Hanseok Ma et al., 2022). As a result, nowadays traditional quality control can be slow, inconsistent, and incapable of providing continuous feedback, which hinders continuous improvement in the production process. While skilled workers and periodic tests have upheld basic quality standards, the limits of human-centric inspection are increasingly evident given modern production speeds and complexity.

AI-driven quality management systems, particularly those using computer vision and machine learning, offer the potential to overcome the limitations of traditional methods by

providing real-time, automated inspection and predictive analytics. Early implementations within various industries have shown improvements. In particleboard production, the reinforcement-learning detector PPOBoardNet have achieved defect detection accuracy 79.0% (mean average precision), and processing in ≈ 36 ms per image (Haifei Xia et al., 2025). Example from different sector, but applicable as well as within wood industry, an AI vision system on a shipyard painting line cut coating-quality incidents from about 3 % to below 1 % per quarter (Ma & Lee, 2022). Advances of AI implementation suggest also benefits for wood products quality assurance, from catching defects earlier to optimizing resource use. However, introducing AI into wood industry workflows also raises new challenges, such as integrating with existing system and ensuring that AI outcomes are transparent and trusted by workers (Carlos Agostinho et al., 2023; Mohammad Nagahisarchoghaei et al., 2023).

2. MODERN INDUSTRIAL SOFTWARE SOLUTIONS AND VISION-AI ADVANCEMENTS

To illustrate the advantages of modern industrial software solutions, we reviewed several Technology and industry solutions. For example, EVORIS software overcomes the delay caused by traditional visual inspection approaches. Continuously aligning high-resolution video streams with thousands of PLC and auxiliary sensor signals collected from every stage of the line (from chipping through finishing) in a single time-synchronised database. Machine learning models fed by this dataset can estimate key board properties (internal bond strength, density profile, or formaldehyde emissions) in near real time, well before the panel leaves the continuous press. Because these predictions are displayed to operators during the same production run, they can fine-tune variables such as glue dosage or press temperature immediately, reducing dependence on downstream lab feedback and increasing first-pass yield (Bär et al., 2022). Similarly, by deploying twin area cameras and a detector based on YOLOv3 -, Ma et al. (2022) achieved 90.4 % accuracy (about eight percentage points higher than an SSD baseline) and the automated alarms and PLC interface shortened line downtime by roughly two hours per shift (≈ 11 %). Careful camera positioning and lighting adjustment, rather than specialised HDR hardware, allowed the vision-AI system to operate reliably in the brightly lit, cluttered shipyard environment. In a related area of image processing Hwang & Sugiyama (2021) highlight homomorphic filtering as a proven way to correct uneven illumination and sharpen contrast in wood-identification images, and separately note that CNN models have been ported to smartphone platforms such as MyWood-ID and XyloPhone, enabling field - based species recognition without laboratory equipment. Building upon these advancements, Ivanova (2024) observes that vision - based AI systems can classify tree species during harvesting operations, allowing crews to sort spruce, fir, beech and others more efficiently before they enter the supply chain. By improving identification and coordination on - site, these tools support harvesters in selecting appropriate bucking and forwarding plans, helping prevent unsuitable material from reaching storage yards. Additionally, integrating with the XMANAI platform links each hybrid AI model to post-hoc SHAP value plots and saliency-style heat-maps, recorded together with fine - grain provenance metadata. This lets operators inspect the exact surface region that triggered an alarm while preserving a full audit trail of data, models, and explanation artefacts within the platform's provenance registry supported by MLflow (Agostinho et al., 2023). Complementary XAI surveys recommend overlay heat-maps and concise natural-language justifications to help managers validate automated grades in industrial settings (Ahmed et al., 2022; Nagahisarchoghaei et al., 2023). In conjunction with

advanced AI analysis, Vision sensors and collaborative robots collect data locally and exploit edge-/fog-computing gateways for preliminary AI processing. The consolidated information is then forwarded to the cloud or enterprise layers for real-time monitoring and other manufacturing functions (Andronie et al., 2022).

2.1. AI-driven Advancements in Defect Detection and Quality Management

A compelling exploration of recent advancements in artificial intelligence reveals transformative methodologies for defect detection and quality management in industrial applications. Ting Li et al. (2024) note that generative-adversarial networks can isolate real defect patches and blend them into defects-free images. At the same time, greatly enlarging scarce training sets for industrial visual inspection. Additional studies, such as the one by Jain et al. (2022), have shown that incorporating GAN-synthesized anomalies increases detection sensitivity by approximately 5% when compared to traditional augmentation techniques. Moreover, blending other transformation methods such as Mosaic and MixUp has proven to enhance the accuracy of YOLOv5, a popular object detection model, in identifying small and difficult-to-spot flaws on printed circuit boards (PCBs). However, the authors caution that while GANs can introduce greater diversity to training datasets, they need to be trained carefully to prevent degradation of quality when genuine defect samples are scarce. Furthermore, the Data-Analytics Environment (DAE) offers a low-code Machine Learning Operations (MLOps) workspace where factory workers assemble data pipelines by dragging and dropping operator blocks for ingestion, regression training through LightGBM, and model serving through MLflow. The Apache Airflow flow management platform schedules and executes each workflow, while an intermediary MongoDB store captures the input and output of every step to maintain a complete audit trail for quality management purposes (Grilo et al., 2024). Building on these advancements Oborski et al. (2022) present an AI-driven visual-quality control unit designed for a holonic shop-floor control system. The inspection results are transmitted in real time to the existing machine-monitoring and shop-floor IT layers, so that the production parameters can be adjusted online - and the accumulated quality data can later support the optimization of long processes.

2.2. Innovations in Defect Detection using Advanced CNN Architectures

The lightweight aluminium surface defect detector levitated by Li et al. (2024) embed Ghost blocks, an optimised CBAM attention module, and a feature pyramid network into Faster RCNN (ResNet50 backbone). Trained on a 3200-image dataset covering nine aluminium defect classes, the network attains 94.25 % mAP and demonstrates robust detection of both large and subtle flaws in high-resolution images, with modest model size and inference speed suitable for industrial quality control. Similarly, Liu et al. (2024) further contribute to the field by improving YOLOv8 with a deformable-convolution backbone module, a shallow-layer lowsemantic featurefusion module that embeds bilevel routing attention (BRA) and MPDIoU regression loss. The resulting YOLOv8_DSM achieves 63.4 % mAP(0.5 : 0.9) while maintaining 144 FPS on an RTX 4090-based PC inspection system, meeting real-time requirements for detecting diverse, small PCB surface defects.

3. AUTHORS APPROACH TO THE AI-DRIVEN QUALITY MANAGEMENT

In cooperation with the Slovak Association for Quality (SAFQ, 2025) and industry partner Smartvision, the Institute of Industrial Engineering and Management is pilot testing the cooperation of a collaborative robot and AI image processing within quality management. The setup contains a standard computing workstation running ADMIN 4.0 software, integrated with an industrial vision camera, shown on figure 1. This configuration supports an extensive portfolio of inspection functions (Smartvision, 2025):

- Shape analysis - Inspection of objects using shape analysis, comparison with a reference, and determination of deviations.
- Quality inspection - Recognizes accuracy, position, shape, and orientation, as well as signs of correctness.
- Quality control - Recognizes the presence of correct and incorrect elements on the inspected object.
- Anomaly and defect detection: Sees surface damage and manufacturing inaccuracies such as scratches, excess and missing material, and cracks.
- Object position detection and counting - Allows you to recognize objects in space and their number when checking the packaging of materials. Recognition of the exact position of objects allows dynamic quality inspection in the workspace.
- Packaging inspection - Recognizes the completeness of the package by counting the presence of products, checking their correctness, and recognizing packaging materials.
- Workplace Monitoring - Anticipating workplace situations and controlling material handling by scene recognition.



Figure 1. Computing workstation with vision camera in usage

The acquisition of the equipment was made possible through grant funding from the Tatra Banka Foundation (Nadácia Tatra banky, 2025). The preliminary trials are focused on the integration of real-time defect-detection capabilities into the existing quality-assurance workflow.

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THE ROLE OF VIRTUAL AND AUGMENTED REALITY IN COMMUNICATION AND RETAIL TRADE SERVICE OF FURNITURE

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Abstract: Annually, approximately 254, 062 tons of new pieces of furniture are sold in the Slovak Republic, which represents 46.7 kg of furniture per person. Despite of and maybe because furnishings and some categories of household accessories are ranked to the products of occasional demand, it may take for consumers several weeks to make the choice. They do webrooming, read reviews, search for inspirations, go in-person shopping, and consider the products in a physical shop before purchase. Throughout this process, modern technology plays an important role, creating dynamic communication or allowing for digital-based visualization of the retailer's furniture and accessories into the planned space. The aim of the scientific literature review is to summarize the theoretical background on the issue of the implementation of state-of-the-art technologies (e.g., virtual reality, augmented reality, interactive elements) by buyers in the process of communicating and selling. The purpose of the empirical part of the paper is to identify examples of good practice in the usage of technology in communication and purchase of furniture on the Slovak market.

Keywords: sales, furniture, virtual reality, augmented reality

1. SCIENTIFIC LITERATURE REVIEW

Technological innovations, including the fast adoption of smartphones by consumers and the recent wave of digital transformation, have accelerated the emergence of virtual reality (hereafter also referred to as VR) and augmented reality (AR) in several industries and made them easily available to nearly anyone. For example, in healthcare, combining different types of technologies and realities allow for less invasive interventions and improved patient comfort during procedures (Mishra, 2022). In culture, VR and AR are vital in making cultural heritage accessible to larger audiences, especially when physical entry to artifacts is limited (Bekele, 2018). In a similar context, the potential usage of AR and VR is being explored for tourist destinations and sites that have succumbed to over tourism, resulting in deterioration or even destruction (Bec et al., 2021). The use of VR and AR has also been investigated in landscape architecture and environmental designing (Portman et al., 2015), in architecture, engineering and construction sectors (Delgado, 2020) or various fields as training tools (Kaplan, 2021).

Technologies of VR and AR have been increasingly attracting the attention of marketing researchers. For instance, the benefits of AR compared to web-based product presentations (Kowalczyk et al., 2021), customer experiences with VR and AR (Wedel et al., 2020), the impact and implications of these technologies on each stage (before, during and after purchase) of the customer journey (Hoyer et al., 2020), and the use of VR, AR, and AI (artificial intelligence) to create personalised brand experiences have all become objects of investigation. Rauschnabel et al. (2022) even discuss AR marketing as a new subdiscipline of marketing, and related to it, the need for a differentiated customer route model for AR marketing strategy. Virtual reality can be characterized as a computer-generated simulation of a situation that involves the user perceiving it through one or more of the senses (sight, hearing, and touch) and interacting with it in a way that appears real (Wedel et al., 2020). VR experiences can be achieved through a variety of hardware, such as head-mounted displays, large screens, mobile devices (smartphones) or desktop computers and laptops supplemented by other devices for simulation

or viewing. Augmented reality is a separate type of VR, in which digital devices are implemented to overlay additional sensory information (e.g., sounds, objects, avatars, graphics, labels) in the real world. This provides contextual information that improves appearance, usability and delivers an enhanced interactive experience. The difference between VR and AR lies in the fact that while VR creates a perception of reality based entirely on virtual information, AR enhances the awareness of the real world with additional computer-generated information (Carmigniani et al., 2011).

2. METHODOLOGY

The investigated objects according to SK NACE involve seven furniture retailers in specialised shops and one furniture manufacturer (Decodom) operating retail outlets and an e-shop on the Slovak market. In terms of revenues in 2024, the top furniture retailers in Slovakia include Ikea Bratislava, XLSK Furniture (revenues of Möbelix and XXX Lutz combined), Jysk, Sconto Furniture, Kondela, Decodom, and Asko Furniture. Each of the explored firms offers the sale of furniture, lightings, and other households' goods through physical shops and an e-shop. In addition, the market leader, Ikea Bratislava, sells furniture via a mobile application. Our research is focused on online and digital planning tools based on the implementation of interactive elements of virtual or augmented reality in furniture trade, and the need to communicate their existence and user-friendliness. A planner is usually an easy to use online or digital tool that guides the customer through the process of selecting, projecting, and placing of furniture items according to actual room dimensions. Thus, the buyers themselves design the modular furniture or interior furnishings. Some planners also offer a printable 3D visualisation. The scientific literature review is compiled from available scholarly and professional sources focusing on the issues of technological innovation, marketing communication, virtual, and augmented reality. The results are composed from available websites, social networks, and mobile applications associated with the objects of exploration. A combination of several scientific methods was applied when amassing the study. As for scientific authorities, we investigated Highly Cited Papers in WoS, without time limit, with the keywords virtual and augmented reality. To be able to determine the state of the art in the Results subsection, we analysed websites and mobile applications. The studied criterion is the existence and availability of planning tools. We analysed the obtained information to identify key findings and recurring phenomena. Based on the results of the analysis, we drew conclusions for further research from the above practice examples.

3. RESULTS

Decodom offers customers a 3D online planner for modular kitchens and living rooms of the HOME and SMILE program on its microsite. For the customised program (FAMILY), it is required to make an appointment in person or online. (Vyberte si kuchyňu, ktorá vám ideálne sadne, n.d.). However, in the catalogue of furniture and interior accessories of the online planner, not all products that Decodom displays in its outlets or sells via the e-shop are available to the customers.

The market leader, **Ikea Bratislava**, allows buyers to use 3D online planning tools by rooms (e.g., kitchens, living rooms) and by programs (e.g., storage spaces, sofas). In 2024 Ikea made available to customers its next-generation 3D online and digital planner IKEA

Kreativ. It enables to use interactive templates or scan own room. Interactive models are blank templates or existing room designs that customers can customise to suit their needs. They offer customers the possibility to try out furnishings and accessories in realistic room layouts. Furniture and accessories can be easily added, swapped, removed, and moved, downloaded as ideas, shared with friends and family, or ordered online. Scanning and designing one's own room via the function of augmented reality provides customers with the space for capturing a wide-screen image of a room in their household, into which they can add 3D pieces of furniture and accessories from the IKEA catalogue or, conversely, remove existing scanned furniture. All they need to do is create a series of photographs of the room, which are then automatically assembled into a widescreen interactive replica of the space with accurate dimensions and perspective. The furniture and accessories are displayed at a scale that realistically matches the photographed space and interacts with the other furnishings in the room. (Ako funguje ikea kreativ?- Ikea slovenská republika, n.d.). To recognize scanned spaces, Ikea Kreativ uses artificial intelligence and computer vision technologies, like those used in autonomous vehicles. These include AI neural networks that have been specifically developed to identify objects and the geometry of indoor spaces, stereo vision algorithms for 3D vision, computer photography algorithms to capture wide-angle photos, and 3D mixed reality graphics to achieve realism. Algorithms of AI environment of Ikea Kreativ also allow furniture, or part of it, to be deleted from the captured space so that customers can edit their own spaces even if completely empty (Ikea Kreativ prichádza na Slovensko, n.d.) To scan the space that the customer wants to design or modify, a mobile phone and the Ikea app are required.

Möbelix has an online 3D planner for kitchen units. The buyer can choose between a blank room template and models with proposed designs. It also offers an online and digital 3D configurator for cabinets and wardrobes. Like kitchen arranging, when designing storage rooms, the customer can choose between a blank template of a cabinet or wardrobe or a model with proposed designs. Since the companies **XXX Lutz** and **Möbelix** have a common owner in Slovakia (XLSK Furniture), it does not come as a surprise that they use the same online 3D planner for kitchen units, closets, and wardrobes. The only difference lies in the colour of the planner heading and the user commands. While XXX Lutz's brand identity is dominated by red colour, Möbelix's brand identity is governed by blue. Similarly, as with Möbelix, customers can apply the configurator for closets and wardrobes on the XXX Lutz websites or on their smartphones. The resulting set-up can be downloaded in a pdf document, including a price estimate.

Other retailers (Jysk, Sconto, Kondela, Asko) substitute the absence of 3D online and digital planners with inspirational photographic templates in different styles posted on their websites or social networks Pinterest and Instagram. The social networks are based on publishing and sharing visual content, with Pinterest defining itself as a visual idea search engine (Help. Pinterest, n.d.). All the investigated planning tools, whether 2D (e.g., Decodom), 3D or in augmented reality (Ikea Kreativ), have been so far free for a wide range of users, apart from the need to register and provide an email address when downloading the mobile app or the list of planned products. The planners appear to be user friendly, however, a prerequisite for their application is the sufficient digital and computer literacy of the users. They are available on the landing websites or in the mobile app. Ikea supports their importance and active use by buyers via placing a link in the heading of the website between the main categories and Möbelix in the body of the landing page. In comparison to them, on the websites of Decodom and XXX

Lutz the customer has to use the search engine of the respective site and enter the keyword planning or configurator to access the planning tools.

For the market leader, Ikea Bratislava, planning tools are one of the topics suitable for communication with the public. For instance, in 2024, when Ikea Kreativ was launched on the Slovak market, the Ikea press centre published several press releases about this new tool as part of its Public Relations. These press releases are still available today among other press releases, as well as in various trade and lifestyle periodicals. In case of the other investigated companies, the planning tools (their existence, free availability, or user-friendliness) are not a relevant issue for marketing communication.

4. DISCUSSION AND CONCLUSIONS

It could seem that 3D online and digital planners available for free to any customer are mandatory tools when trading furniture, and incorporating virtual or augmented reality is their natural perfection. However, there are several facts to consider, as follows:

- Not all the companies, dispose of the necessary financial, technical, technological, or personnel resources, or the use of planning software is not a part of their business philosophy or plan. However, for the brand Ikea, we can state there is consistency between the mission “solutions for all those with big dreams, but little money” and its values “Ikea is not like other companies and does not want to be either” (Vízia, hodnoty a obchodná myšlienka Ikea, n.d.);
- The planning software needs to be bought or even tailor-made to suit the specific retailer or manufacturer. We found out that the brands Möbelix and XXX Lutz use the same designing software for the same kind of assortment (kitchen units, wardrobes), differing only in the manifestations of corporate identity. The decision to utilize the same planners might be based not only on the fact that they have a common owner and an identical product range. Using the same projecting software thus reduces the owner’s development and licencing costs and ensures the same standard of service for customers;
- Planning tools must be filled with data. Each piece of furniture and accessory in the product catalogue need to have an accurate 2D or 3D model, based on the dimensions of the product, its weight, used materials, colours, or safety. The retailer must have a database of products in the digital form;
- Planners are particularly useful when selling modular or configurable furniture, which is why Möbelix, XXX Lutz, Decodom, and Ikea, whose product ranges include such pieces of furniture, offer some form of designing tools. Ikea Kreativ goes beyond this by allowing the projecting of an entire room, including solitary furniture items and accessories;
 - Another reason why furniture sales may or may not be linked to planning tools is the target group and their digital skills. Not all the customers are equally ready to start using online and digital projecting tools.

We believe that planning tools should be seen as an opportunity to achieve both economic and communication goals. In case the drafting software has applicable the complete assortment of the retailer, it can inform the customer (advertising objective) about the different categories of furniture items or accessories when browsing the room furniture offer. By locating the furniture pieces in a blank room template or in an own scanned space, the planner can lead the customer to try them out (sales promotion objective). Satisfied users of planners can spread awareness (Public Relations objective) of the brand and arranging tools in their communities, bringing other customers to apply them, which will be reflected, for instance, in higher web

traffic, more downloads of the mobile app, new registrations for the loyalty program, or usage of additional services. Projecting customers may not require the same level of assistance from in-shop staff as non-arranging buyers.

It could appear that online and digital planners available free to any customer are a mandatory tool in furniture sales and incorporating virtual or augmented reality is their natural advancement. However, our research has shown that not all the objects of investigation have the necessary resources available, or the use of designing tools has not been a part of their business philosophy or business plan. Retailers Jysk, Sconto, Kondela, and Asko substitute the absence of online and digital planners with inspirational photographic templates in a variety of styles posted on their websites or on the social networks Pinterest and Instagram. The clear market leader is Ikea Bratislava, for which augmented reality planning tools are not only a part of customer service, but also one of the issues suitable for Public Relations communication. Considering the explored market (Slovak), it is necessary to point out the resulting limitations of our findings. Generalisation to for example the European market would require a comparison of our results with the approach of retailers on foreign markets. The object of follow-up investigation may be, apart from regional differences, also the readiness of consumers to use planners or the potential of setting the topic of arranging tools in marketing communication.

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FEASIBILITY OF APPLYING ARTIFICIAL INTELLIGENCE IN THE DESIGN AND RENEWAL OF FOREST BUFFER ZONES IN BULGARIA

Gergana Slavova

Abstract: One of the major global issues today is global climate change and the higher temperatures being experienced around the world. People have long known that trees in particular and forests in general are the right solution to conserve soil moisture, improve soil erosion and reduce wind erosion. Afforestation is therefore one of the best solutions for adapting to climate change. Therefore, in the fight against soil degradation and the desertification of specific areas and their conversion into deserts, the best means is afforestation and the creation of artificial ponds. In our country, an extremely good solution to combat global warming and stop soil erosion, as well as reduce wind erosion and conserve soil moisture, is the construction and maintenance of protective forest belts. It is an interesting fact that in the sixties-seventies of the last century in Bulgaria extremely well structured forest belts were created in the region of Dobrudja, but with the passage of time and under the influence of unlawful human activities, such as illegal logging, most of them are not in a form that allows their full functioning. The aim of this paper is to propose the use of new information technologies and large databases on which the use of artificial intelligence is based, as a real opportunity to design and renew where necessary forest field protection belts in Bulgaria. The methods of extrapolation, deduction, induction, comparative analysis method, Ishikawa method and artificial intelligence method were used to achieve the set objective. The proposals and conclusions made on the basis of this study can be successfully used by all national and regional institutions working in the field of forestry.

Key words: artificial intelligence, forest sector, field protection, forest belts

1. Main purpose, economic and natural-biological characteristics of natural protective forest belts in North-Eastern Bulgaria

Forest belts have an extremely good influence on maintaining a favourable micro-climate in an area. In turn, the microclimate is the characteristic climate of an area and it plays a key role in the development of the agricultural sector. It has a direct impact on the development and growth of crops, as well as on the livestock reared in an area and the agricultural produce they produce. In reality, forest belts are involved in shaping the microclimate created by the forest vegetation and create the possibility of adaptation of different plant species and varieties in the fields between the belts, while at the same time creating extremely favourable conditions for the adaptation of plants and animals in the forest belt itself to the field conditions. In the north-eastern planning area, i.e. in the whole of southern Dobrudja, one of the best solutions for preserving a balanced microclimate and preventing the area from becoming a desert is the construction of forest field protection belts. They were created in the last century by humans in order to have a strong impact on wind and soil erosion. They were created on the basis of artificially planted forest species, both trees and shrubs in order to ensure the preservation and good biodiversity in the area. The field forest belts in Southern Dobrudzha form a network of 400 to 1000 acres, and the total length of the belts is 5000 km, covering an area of 78 thousand acres. The current average height of the belts in Bulgaria is about 18 - 20 m. In Bulgaria, fields are currently considered to be well protected from wind erosion and contribute greatly to biodiversity conservation in the area. It is important to note that at the beginning of this year (2024) the afforestation of 300 ha of new field protection belts in Dobrudja started. They are being created on the territory of three farms in Dobrich region - Forestry State Forestry Balchik,

Forestry State Forestry General Toshevo and Forestry State Forestry Dobrich, and it is claimed that about 10 to 15% increase in yields on fields on which field protection belts are built, compared to those on which they are missing. Trees in them began to be planted en masse in the 1950s and 1960s.

Historically, research into the benefits of building field shelter belts began earlier in the 19th century around the world. Here we can point to two main schools, the Western and the Eastern School in the person of K. Г. Bates, the main researcher of the protective properties of trees for soil and for wind erosion in the USA as early as 1911 and of the Russian scientist Dokuchaev, who made a scientific study of the prevention of the use of trees in the Russian steppes with his special expedition in the period 1892-1894. Research papers by both scientists have studied the impact of forest belts on the microclimate of fields as a protective measure to produce better yields due to conserved soil moisture levels, reduced wind and soil erosion (Bennett and all, 2015, Bonan, 2008, Klein and all, 2007, Liu and all, 2014, Liand and all, 2019). Real forest belts in the world have been created to combat wind and water erosion, and in our country also due to the drought and dry weather experienced in our homeland, as well as strong winds and specifically in the Dobrudja region in northeastern Bulgaria ('Encyclopedia 'Bulgaria', Volume 5). The forest belts in Bulgaria serve mainly to protect against wind erosion caused by dry hot northeast winds that cause soil drying in our country, but also to preserve soil moisture as much as possible in modern global warming. The composition of the forest belts is of tree species which are the dominant ones and which can be seen in Figure 1, but in addition there are many shrub species. There are also belts that have no single tree species in their composition. These consist of the shoot or seed origin of trees in the forest belts of Bulgaria.

For example, in the north-eastern region of Bulgaria, the cerra is the main tree species used in the creation of forest belts. It has a seed origin of 98%, gledicea 72%, acacia 10% seed origin and 90% shoot origin. (Dodev and all, 2023) Many of the belts in southern Dobrudja are dominated by acacia and smell magnificent during flowering. This tree is also honey-bearing, besides it is self-sown, but this is not the case with mountain ash where 85% is seed origin and 15% is shoot origin. In walnut we have 100% seed origin and in red oak also 100% seed origin, in summer oak it is 98% seed origin and only two percent shoot origin, while in field elm 20% seed origin and 80% shoot origin. The ratio in field ash is 87% seed origin and 13% shoot origin, and in Blagovets 100% seed origin (Dodev and all, 2023). The current average height of the belts in Bulgaria is about 18 - 20 m. In Bulgaria, fields are currently considered to be well protected from wind erosion and contribute greatly to biodiversity conservation in the area. It is important to note that at the beginning of this year (2024) the afforestation of 300 ha of new field protection belts in Dobrudja started. They are being created on the territory of three farms in Dobrich region - Forestry State Forestry Balchik, Forestry State Forestry General Toshevo and Forestry State Forestry Dobrich, and it is claimed that about 10 to 15% increase in yields on fields on which field protection belts are built, compared to those on which they are missing, and other eastern claims that this percentage is even higher, namely 15-30% (Radev, 2024) The protection of the field protection belts in recent years has been a paramount task for the experts of the forest holdings in Dobrudzha, especially after the drying and pest attacks and destroyed parts by unscrupulous poachers identified by the scientists. Fig. 1 shows Mainly

cultivated tree species in % of forested area of forest belts with specific tree species in the North-East region of Bulgaria.

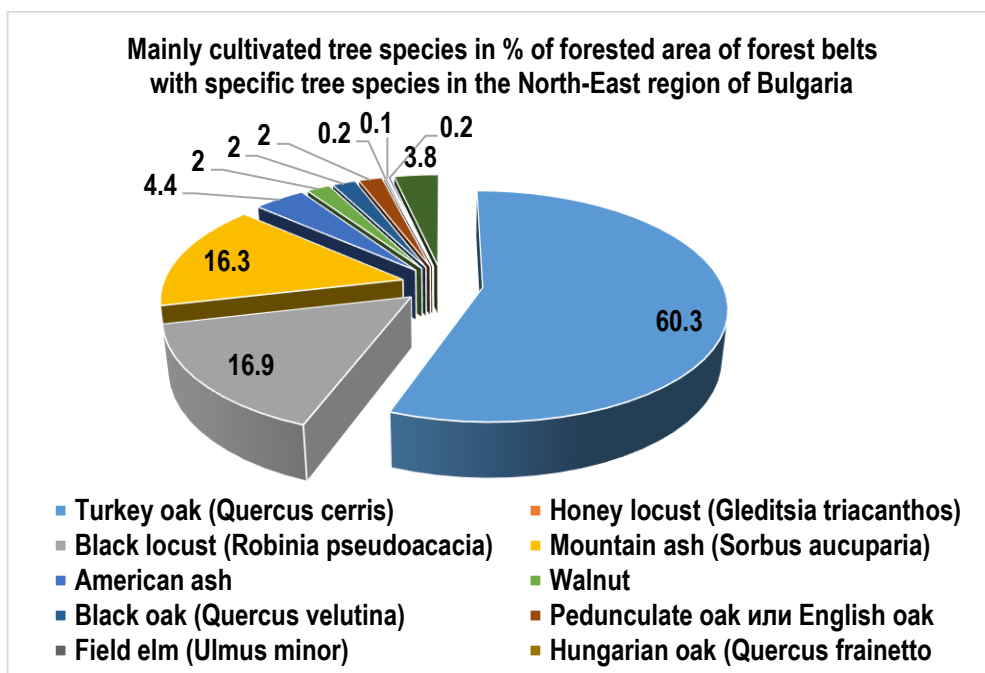


Fig.1 Mainly cultivated tree species in % of forested area of forest belts with specific tree species in the North-East region of Bulgaria

Source: figure adapted from Dodev and all, 2023

1.1. Conservation Measures and Afforestation of Forest Belts

To our great regret, in recent years, our country has witnessed a very unfavourable trend of depreciation and illegal clearing of forest belts in the north-eastern region of the country. Therefore, there are two active projects in the North-Eastern Bulgaria, thanks to which some of the forest belts in the region are being restored. One such project is "Forests of the North-East", which is restoring 2,000 hectares of field protection forest belts on the territory of Dobrich, Balchik and Genarel Toshevo. The project covers a 4-year period. It has so far removed old Acacia trees in the forest belts of 100 acres and planted new ones, as Acacia requires 15 to 20 years maximum to reach full development and then needs to be replanted. The "Forests of the North-East" project has a cost of EUR 1 386 763, and these funds have been entirely devoted to the restoration of the grassland belts in the analysis area.

2. APPLICATION OF ARTIFICIAL INTELLIGENCE IN THE CONSTRUCTION OF FIELD PROTECTION BELTS IN BULGARIA

Artificial Intelligence (AI) can significantly support the improvement of forest belts in Bulgaria through the use of advanced monitoring, analysis and management technologies in

this area. Monitoring and analysis of the status of forest belts in Bulgaria, including real-time detection of potential threats. This can be done through certain Satellite links and drone images analysed using AI. For example, deforestation and illegal logging can be detected, as well as different types of diseases on trees and forest vegetation, as well as pest infestations in forest stands. Economic monitoring and analysis can be used to predict and account for drought, hail and other climatic anomalies in the country's forest belts. Another extremely important aspect is the identification of forest tree species and their classification by species, age and degree of cover, as well as their distribution and the identification of other different shrub and herbaceous plant species included in the composition of forest belts in the northeastern region of Bulgaria. The application of artificial intelligence in the design and renovation of forest buffer zones in Bulgaria can optimize the afforestation and regeneration of forest vegetation species, especially in areas where there are illegal logging or drought-killed trees and shrubs. Artificial intelligence can analyse: soil data, climatic conditions, altitude, species composition and tree species resistance. It can make correct predictions and analysis of the risks of planting new trees and preserving them. This leads to better planning and planting of appropriate tree species for specific areas and sustainable growth of forest belts in the North East planning area. Machine learning can be used to model: the development of the woodland belt over time, and to predict the effects of different management strategies on the woodland belts themselves (e.g. thinning, creation of fire buffers, correct selection of good adjacency and allelopathy between growing species). In addition to all this, artificial intelligence can help to assess the risk of fires and of expected climate change, expected droughts and high humidity. It can be used to build a system to alert citizens and notify them of expected adverse effects. Artificial intelligence can also help greatly in the afforestation process itself, by suggesting where and with what species to afforest in the forest belts themselves. All of this helps managers in the Northeast region to plan at an administrative level, as well as forest workers to make more correct and scientifically sound decisions. It can also be used to design a system for tracking the growth of plant species using data practically taken directly from the specific terrain via satellite images and photographs. Artificial intelligence also helps a great deal in the proper management of biodiversity, including the detection of invasive species - unwanted plant or animal species in the composition of forest vegetation. Through its use, complete monitoring and control is easily achieved by automatically counting different vegetation types using cameras, sensors and control sensors. Through artificial intelligence, specific smart applications can easily be created for the forest service as well as for various naturalists and citizens. Mobile apps with AI can identify different types of trees, as well as pests on them and diseases by photo, and also send alerts when problems are detected in a given area, such as poaching for example. This makes inspections and reporting by forest officials much easier. Forest belts often border agricultural land. Artificial intelligence can help a lot to optimise the protective functions of forests against soil and wind erosion. For example, Copernicus (EU) - uses artificial intelligence to analyse satellite data for landscape monitoring and this can be applied with great success to forest belts in the north-eastern region of Bulgaria, and Google Earth Engine is a platform using artificial intelligence that is based on specific ecological analyses, as well as National Forestry Services in Scandinavian countries use artificial intelligence to predict timber yield and disease attack on forest species.

By applying artificial intelligence to the monitoring, management and control of forest belts in North-Eastern Bulgaria, the condition and resilience of forest belts can be improved through specific advanced technologies. An intelligent monitoring and early warning system for disease,

logging, fire and other threats can be successfully built. Artificial intelligence-based algorithms can be used to optimise afforestation, select specific tree species and manage forest belts and forests over the long term. Currently in Dobrudzha in the forest belts there is a mass death of red oak and acacia, also the cerra and the summer oak are threatened by large damage (Executive Forest Agency). The State Forestry Enterprise-Balchik has a nursery where young saplings for the forest belts of Dobrudzha are grown. Specialists carry out surveys of forest and field territories, as well as the territories of forest belts for the presence of diseases, pests and mass insect infestations. Forest belts are an agrotechnical facility to protect fields from wind and soil erosion. They are much more than a small wooded area. The fertility of the SFRS and of the 'Golden Dobrudzha' depends to a large extent on the protective forest belts. Their purpose is to stop the troublesome drywood, which carries away the topsoil and with it disturbs the humic horizon and soil fertility in the area. Scientific studies have found that when forest belts are present, yields in the area are 20 to 30% higher.

Bulgaria has very good lowland conditions in the North-Eastern planning area, which coincides with much of Southern Dobrudja, this is an excellent prerequisite for the establishment of extensive forest belts, but as we have seen from the analysis, many of them are highly vulnerable to poaching, climate change, plant diseases, pests and all kinds of pests. Currently, the lack of digital monitoring makes it difficult to detect problems in a timely manner. Therefore, in our opinion, artificial intelligence can offer many new opportunities for precise and sustainable management of forest ecosystems. First of all, it can collect and analyze data through satellite and drone images of target areas (Danube Plain, Dobrudzha). It can collect data on different forest species, soil conditions, climate and stressors. Also with its help a large database of GIS information data can be built, it can help enormously in the field of disease detection, fires and illegal logging, it can be involved in the planning of afforestation and reforestation in the forest belts, and it can also assist in the overall monitoring of the effect of the new tree and shrub species planted, by periodically monitoring the results of the newly formed new stands in the forest belts of the Northeast region. It can be used to create a mobile app for forestry officials and citizens that, by photographing and reporting specific problems, can identify specific types of diseases and pests on trees through camera tracking and filming, as well as through the application of sensors. Based on this, training modules for volunteers could be developed, including training and participation of local communities, as well as specialized forestry workshops for foresters, farmers and NGOs and environmental organizations. For all this to be successful, however, there is a need to train young people and interested individuals and groups to work with the new technologies. A strong partnership and support could be provided by the National Forest Agency / Executive Forest Agency and specific Bulgarian universities, such as Forestry University-Sofia, University of Economics-Varna, Department of Agricultural Economics, Sofia University-Sofia with specialized fields in biology and chemistry, Agricultural University-Plovdiv with specialties such as plant protection, UASG-Sofia with ecology and GIS. Specific software companies working with specialised software and artificial intelligence, such as Scalefocus, Ontotext or other international software partners, would be very helpful. To illustrate the whole partnership process, we will use Fig. 2. To renew the forest belts in Dobrudja, the following processes need to be implemented: A comprehensive analysis of the forest belts in North-Eastern Bulgaria. Identification of illegal logging, diseases, pests, and other phosomagic circumstances that have significantly altered the structure of forest belts in the SIRP. Then designing and modelling, based on artificial intelligence, how to renew and construct the new or at least renewed forest belts; Planning and

implementing the supply of saplings and shrubs suitable for reforestation, such as acacia, blackthorn, mountain ash, walnut, red oak, summer oak, field elm, field ash. Planting and seeding of the intended forest and shrub species. In order to best plan the renewal of forest belts in the north-eastern region, the precise allocation of water and fertiliser required for afforestation should also be carried out. Specialised planning software and artificial intelligence can be successfully applied in the framework of this whole process. For example LandPKS or a dedicated AI dashboard based on them can visualise everything in real time. The next very important step is monitoring and follow-up. After planting the selected tree species, the AI can: Monitor the growth of the new saplings with drones or artificial vision cameras. Thanks to it, diseases and pests on the plants can be detected much earlier. In addition, AI can monitor the need for replanting or maintenance. With the help of AI and forestry specialists from BAS and the Executive Forest Agency, Institute of Forestry - Sofia, Forest Protection Station - Varna, as well as Forestry University - Sofia, the entire process of forest belt renewal in the North-Eastern Planning Region of Bulgaria can be designed, implemented, monitored, managed, organised and controlled. In order to implement the overall process of forest belt renewal in the SIRP, it is necessary to procure forest tree and shrub species, manpower, specialized equipment, application of modern technologies, use of artificial intelligence, and satellite image data, from drones, precision sensors for monitoring and observation, laboratory, soil and meteorological data from BAS, the Institute of Forestry, the Executive Forest Agency, the Regional Forest Directorate, and all state forestry enterprises in the north-eastern region of Bulgaria.

3. REAL RENEWAL OF FOREST BELTS IN THE NORTH-EASTERN REGION OF BULGARIA

On the territory of the Northeastern region, the Northeastern State Enterprise was established, which processes the forests in the Varna, Dobrich, Shumen and Targovishta districts, on this territory there are a total of 9 forest nurseries, two of them of national importance, and the number of saplings produced is 2.5 million. According to Eng. Radev, the total amount for the creation of one acre of a new field protection belt amounts to BGN 4116, and it includes: shredding of the residues from the belt logging, milling with a shredder, soil preparation, purchase and planting of forest saplings, complete reforestation and cultivation. (Radev, 2024). In the past year, 88 acres of new field protection belts have been created in the General Toshevo State Forest Enterprise under the project 'The lands and forests of the eagle' Combining the current projects, the competence of scientists from the Bulgarian Academy of Sciences, the Executive Forest Agency, as well as local forestry farms and of course artificial intelligence in its ability to analyze, predict, monitor, reflect, communicate, we can achieve a much better future for the forest field protection belts in Northeast Bulgaria.

2.1. Building an intelligent management and monitoring system for forest belts in the North-East region of Bulgaria using artificial intelligence and by leveraging European and national funding programmes

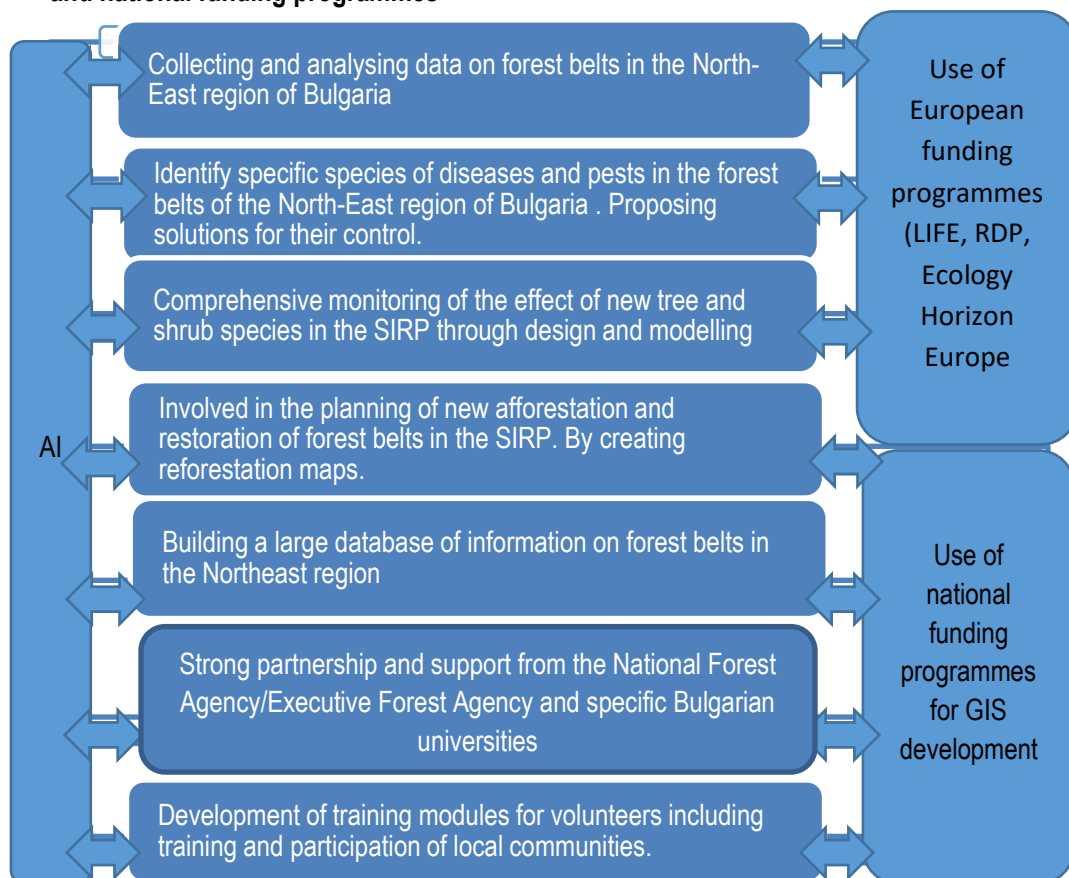


Fig.2 Building an intelligent management and monitoring system for forest belts in the SIRP using artificial intelligence and leveraging European and national funding programmes

CONCLUSION

Realistically, AI cannot replace the work of forestry scientists, nor the specific work of foresters, but it does augment with precision the specific workflows of forest belt restoration in the Northeast Planning Region. Based on it, all work processes and their details are carried out much more efficiently. It contributes enormously to the sustainability of restoration actions. For the northeastern region of Bulgaria, where the climate is changing markedly and droughts are frequent, such an approach would allow for the sustainable restoration of protective forest belts

- to better combat erosion, both soil and wind, as well as to retain soil moisture and create a better microenvironment for all field organisms.

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DIGITAL TRANSFORMATION OF THE FORESTRY SECTOR IN THE CONTEXT OF INDUSTRY 5.0

Katya Antonova

Abstract: Digital transformation in the context of Industry 5.0 is a topical aspect in the development of the forestry sector. The implementation of new technologies such as artificial intelligence, Internet of Things, satellite surveillance, blockchain technologies, geographic information systems, drones, etc. enable sustainable management of forest ecosystems.

Collaboration between smart forest management technologies and humans support decision-making, provide transparency and traceability, and machine learning and predictive analytics improve forest resource management. This study analyzes the innovative approaches to digitalization of the forest sector in Bulgaria, examining both the advantages and the challenges to their implementation. The successful integration of digital technologies in forestry in the context of Industry 5.0 requires a balance between automation and expert management, as well as effective regulatory policies and cooperation between the public and private sectors.

Keywords: Industry 5.0, Forestry, Digital Transformation, Smart Technologies

1. INTRODUCTION

Sustainable management of natural resources and adaptation to climate change are among the key priorities in global development policies. The main goal declared in the European Green Deal is to make Europe a climate-neutral continent. In this sense, the topic of digital transformation is extremely relevant and significant and is becoming a major factor for the development of industries worldwide and in particular for the Bulgarian economy. Digital transformation is also imperative for the forestry sector, as it is a strategic element of the bioeconomy and plays an essential role in protecting ecosystem services, regulating the climate and providing resources for many industries. In this context, digital transformation is establishing itself as a critical tool for increasing efficiency, transparency, forecasting and sustainability in forest resource management.

The object of research in this article is the forestry sector in Bulgaria, and the subject is the processes of application of digital technologies in the sector.

The author's goal is to analyze both the main advantages that digitalization brings to the forestry sector and some challenges, including the limited digital competence of those employed in the sector, the lack of standards, the need for a regulatory framework and the low level of investment in new innovative technologies. Increasing efficiency and reducing costs, as well as awareness of the impact of effective forest resource management on climate change, are essential for the sector.

Rapid technological changes are preparing the forestry sector to integrate digital tools for resource management. The specificity of Industry 5.0 is that it builds on the concept of Industry 4.0 by emphasizing the role of people in their interaction with innovative technological solutions. This new framework puts an emphasis on sustainable development, social responsibility and

human-machine cooperation. Within this transformation, digital technologies such as artificial intelligence (AI), Internet of Things (IoT), satellite surveillance, drones, blockchain and geographic information systems (GIS), etc. become indispensable tools for the modernization and management of the forest sector.

This article explores the possibilities for applying smart technologies in the forestry sector in Bulgaria, looking at specific benefits, challenges and prospects for their application in the context of Industry 5.0.

2. APPLICATION OF TECHNOLOGICAL INNOVATIONS IN THE FORESTRY SECTOR

The main features of the Fourth Industrial Revolution include digitalization, automation, efficient production, and interconnection between machines through the Internet of Things (IoT), **cyber-physical systems**, **cloud solutions**, and **Big Data analytics**. The concept of Industry 5.0 builds on the previous one, putting environmental protection, social responsibility, sustainability and people at the center of production and organizational models. The main goal is not only automated, fast and cheaper production, but also finding solutions for intelligent and sustainable management. Industry 5.0 aims to put human well-being at the center of the production process and drive innovation through human-machine collaboration. The idea of the new concept is to foster the transition from technological innovation to value-based innovation, focusing on achieving sustainability, social responsibility and worker empowerment (EU, 2021).

Industry 4.0 technologies continue to play a key role, but the new concept puts an emphasis on combining human creativity with the precision of artificial intelligence and robotics, the Internet of Things, blockchain technologies, digital twins, and more. At the heart of the new technological revolution (5.0) is the priority of sustainability, the well-being of employed and personalized consumer experiences, as well as environmental impact, ethical transformation, sustainable decision-making, and social value creation (Leng, J. et al., 2022).

In this context, **the forestry sector** is a suitable example for the implementation of the principles of Industry 5.0, as it combines the need for technological progress with the requirement for sustainable and environmentally friendly resource management. Technological innovations such as mobile connectivity, cloud technologies, artificial intelligence, Internet of Things, satellite monitoring, blockchain technologies, geographic information systems, digital twins, etc. can be essential for sustainable development of the forest sector (Kleinschmit et al., 2017; Nunes et al., 2020; Kumar, 2022).

Mobile connectivity and the capabilities of 5G technologies allow remote control of processes through the use of algorithms, artificial intelligence, etc., which allows the fastest and most complex execution of tasks, and the speed of data exchange saves time and resources. Mobile connectivity allows many industries to implement a mixed mode of operation without being limited by space and time.

Through the use of cloud technologies, users can store, access and use various resources through the Internet, offering flexibility, efficiency and opportunities for innovation. Cloud technologies are a convenient way to process and store information remotely, which allows for the sharing of projects and optimization of processes related to the purchase of powerful servers, software licenses and other resources. They play an increasingly important role in forest resource management, as they offer scalability, accessibility, and capabilities for integrated processing and analysis of large databases, as well as real-time access and monitoring. Cloud technologies allow centralized access to management systems, including

geographic information systems, forest inventory systems, harvest tracking systems, etc. Cloud technologies enable the use of automated alarm systems that provide information about forest fires, illegal logging, pest infestations, etc. Types of vegetation, the presence of a risk of fires, etc. can be recognized. Artificial intelligence is defined as "a system that can reason and learn to mimic human intelligence, especially in repetitive, rule-based tasks, with greater precision, speed, and cost savings" (Kondapaka et al., 2023).

The Internet of Things is a system of billions of Internet-based interconnected devices. The essence of connectivity and the use of the generated data is expressed in increasing productivity, reducing costs and improving user experience. The management of forest resources is made possible through the use of intelligent systems, including the construction of "smart forests", in which the state of forest resources can be monitored through mobile applications through visualization of real-time data. **By automating processes using scanners, drones and cameras, forests can be monitored and** a database can be created for future maintenance.

There are also some challenges, security, privacy and traceability of data require special attention. Insufficient internet connectivity in remote areas, the high upfront costs of building IoT infrastructure, and the need for trained personnel can also be a problem when using it for forest management.

In recent years, the integration of blockchain technologies has gained popularity in connection with the use of blockchain to protect mobile devices and improve data security. Through this technology, it becomes possible to trace forest resources from harvesting to the end user, using traceability systems, for verifying legally acquired wood, as well as platforms for monitoring and verifying afforestation processes.

One of the new technological solutions for collecting information is through the use of satellite observation (remote sensing), which is carried out through sensors mounted on board artificial satellites that orbit the Earth and collect information about its surface through various types of electromagnetic radiation. Satellite observation is carried out through the use of geostationary or polar satellites, as well as active, passive or thermal sensors.

Data collected by drones are valuable in terms of providing accurate analysis of the state of forests (Iglhaut et al., 2019; Mulverhill et al., 2020), including for tree species, because of their density and height (Imangholiloo et al., 2019, Castilla et al., 2020). According to Puliti et al. (2019), the use of drones to study the state of forests maintains high levels of accuracy and can significantly reduce costs compared to the necessary costs in field surveys.

The use of geographic information systems (GIS) is a technological solution that is extremely necessary for implementation in the forestry sector. GIS is a computer system for collecting, storing, analyzing and visualizing geospatial data. The system can be applied for mapping of forest areas and inventory of tree vegetation, monitoring of changes in the forest fund (felling, afforestation, diseases), analysis of soil, climatic and relief characteristics affecting tree growth, planning and optimization of deforestation, risk assessment of fires and other natural disasters. Many studies highlight the effectiveness of using GIS, including: (1) combining satellite observations for dynamic forest monitoring (Gitas et al., 2020); (2) modelling forest growth and productivity by creating models that simulate the growth of forest plantations under different climate scenarios (Pretzsch et al., 2017); (3) GIS can map and assess ecosystem services such as carbon sequestration, biodiversity and erosion protection (Seidl et al., 2019); (4) GIS allows optimizing fire prevention strategies by identifying risk areas and planning fire evacuation routes (Chuvieco et al., 2018), etc.

3. DIGITAL TRANSFORMATION OF THE FOREST SECTOR IN BULGARIA

In the context of accelerated climate change, biodiversity loss and socio-economic imbalances, the forest sector is becoming increasingly strategic for Bulgaria's sustainable development. The European Union has set in its policy through **the European Green Deal** the ambition to make Europe the first climate-neutral continent by 2050 (European Commission, 2019). **carbon sequestration, restoration of biodiversity and ensuring the green transition.**

According to data from the National Statistical Institute (NSI) and the Executive Forestry Agency (EFA), as of 2023, forest resources are as follows (see Table 1).

Table 1. Forest resources in Bulgaria (2023)

Source	Indicator	Value (hectare)	Share of the territory of Bulgaria (%)
National Statistical Institute (NSI)	Forest area (by land use)	3 692 000	33,3 %
Executive Forestry Agency (EFA)	Forests and forest areas (according to the forest management map)	4 270 269	38,5 %

There is some difference between the values indicated by the different sources in the table, which can be explained by different methodologies, but both values are correct within their definitions and scope. The NSI uses a definition based on functional land use, with only areas with permanently forested terrain classified as "forest territory", while the EFA takes into account all forest areas. including unforested forest areas, forest nurseries, fire clearances and service infrastructure and areas under afforestation.

They are valuable ecosystems that provide resources for the economy, have an impact on clean air and are also used as recreation areas. The sustainable management and use of forests is related to the maintenance of their biodiversity, productivity, vitality, capacity for renewal and restoration, as well as their potential to perform relevant environmental, economic and social functions in their relationship with other ecosystems. Forests in Bulgaria have provided and provide jobs for people in rural areas. According to NSI data, 8.7% are considered natural forests, a significant part of them are semi-natural – 74.4%, and about 74.7% of the forests in the country have special and protective functions. Over the past few decades, the amount of wood in Bulgarian forests has been greater than the amount of harvested wood, which implies sustainable use and management. The challenges related to the effects of climate change, nature protection and the environment are interdependent with the efficient use of forest resources and the maintenance of the added value potential for industries that use wood as a raw material.

One of the big problems that we can take into account, due to the onset of climate change, especially during the summer months, is the frequency and scale of forest fires. According to the statistics of the EFA for the period 2010-2024. in Bulgaria, more than 7000 forest fires have been registered, which cover 1.1 million hectares. In 2024, they are about 256, in which 45,435 hectares have burned. About 29,976 ha are part of protected areas (Natura 2000), which is 0.53% of the total area of forest areas in Bulgaria.

Approximately 40-50% of Bulgarian forests are categorized as forests with a high risk of fires. For 2024, Bulgaria ranks second in Europe in terms of the number of fires (after Cyprus), with 90% of fires caused by human activity. About 80% of fires start outside forests (agricultural areas or pastures) and are transferred to forests.

4. SOME STRATEGIC MEASURES FOR SUSTAINABLE DEVELOPMENT OF THE FOREST SECTOR IN BULGARIA

The National Recovery and Resilience Plan of Bulgaria, developed on the basis of the Recovery and Resilience Facility of the European Union, adopted by Decision No. 203 of the Council of Ministers of 07.04.2022, outlines key objectives related to green and digital transformation. The strategic objectives set for the forestry sector are: (1) improving the knowledge base to enhance adaptation to climate change, including capacity building for research, education and dissemination of results; (2) improvement and protection of forest resources, including sustainable management of processes related to forest renewal and increase of area and wood stock in forest areas, maintenance of biodiversity; (3) improving the potential for sustainable use and management of forest resources, including improving the potential for the durable use of higher-value wood products and a greener use of woody biomass in energy production.

Under the priority "Biodiversity" to the "Green Bulgaria" pillar, a budget of over 70 million BGN is provided. In particular, the measures are related to the transformation of coniferous into deciduous crops, the restoration of local species, protective forest belts and valuable habitats. Another important measure envisaged in the Plan is related to the conservation and management of genetic material of climate-adapted forest species, protection and restoration of natural, including forest habitats.

In our view, some more specific strategic measures in the context of the three main objectives identified for the forestry sector could be:

(1) Improving the knowledge base on climate change adaptation:

- building a digital platform in which, through the use of technologies such as satellites, drones, field stations, etc. to integrate databases to support research and practical work on the management and adaptation of the sector in order to tackle climate change;

- establishment of centers in partnership with scientific organizations for the implementation of innovations for sustainable management of forest resources, including opportunities for financing applied research related to the adaptation of forests to climate change;

- conducting trainings for specialists in the field of digitalization of the forest sector, including skills in working with geographic information systems and the use of artificial intelligence, as well as developing predictive models using artificial intelligence for analyzing the risk of climate change and forest fires.

(2) Improvement and protection of forest resources:

- creation of a national system for monitoring the state of forests in real time for early detection of fires, diseases, illegal logging, etc.;

- introduction of smart systems that use spatial analysis and digital mapping of forest resources;

(3) improving the potential for sustainable use and management of forest resources:

- Fostering innovation in the production of innovative wood products;

- introduction of low-carbon and resource-efficient technologies in enterprises in the woodworking sector, as well as woody biomass processing facilities for the production of clean energy;

- stimulating the possibilities for reuse and recycling of forestry by-products.

The proposed measures are based on the implementation of innovative approaches and research in order to accelerate the green and digital transition in the sector. They have the potential to support the overall transformation of the forestry sector in Bulgaria by combining the digital transformation of the sector with the sustainable management of natural resources.

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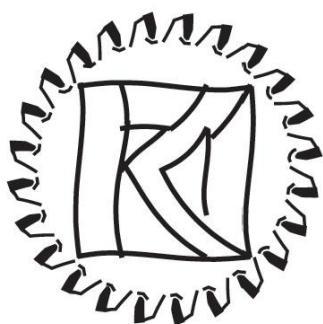
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PRECISION FARMING TECHNOLOGIES AS A FACTOR FOR ADDRESSING THE SCARCITY OF AGRONOMY EXPERTISE IN TREE PLANTING: A REVIEW

Svetla Markova

Abstract: The adverse effects of climate change and deforestation already present significant challenges worldwide, driving major efforts towards the restoration of the ecosystem via sped-up reforestation. Numerous corporate and government-supported initiatives are allocating significant funding to tree restoration projects. The large-scale success of reforestation projects requires land dedicated to growing trees, but also agronomic expertise to increase the success rate of planted tree seedlings. Considering the scarcity of expert agricultural labour and the declining attractiveness of the agricultural sector to experts, however, it is the digital technologies in farming that can play a major role in bridging the knowledge gap and lowering the expertise barrier to numerous farmers willing to get involved in tree plantation projects. This review will examine the tree plantation initiatives in Bulgaria and the Republic of South Africa and will compare the agronomy expertise challenges in the agricultural sector of the two countries. By assessing the role of precision farming technologies in supporting tree-planting activities, this research will evaluate the potential of digitalization in farming to boost the success rate of reforestation and afforestation projects. The findings will contribute to understanding how technological advancements in farming can facilitate larger-scale tree restoration efforts in regions with low availability of agricultural expertise.

Keywords: precision farming, tree planting, Bulgaria, South Africa

1. INTRODUCTION

In 2023, the atmospheric concentration of the 3 main greenhouse gases reached the highest levels in the last 800,000 years (World Meteorological Organization, 2025). Deforestation is one of the factors linked to the increase in global greenhouse gas emissions, and it is the second biggest contributor to greenhouse gas emissions after fossil fuel burning (Werf et al., 2009). Offsetting the effects of climate change includes worldwide efforts towards increasing the extent of forests.

Drawing down CO₂ by planting trees is a simple climate-change response strategy that can attract public support and hence is frequently advocated by governmental and non-profit organizations. The success of reforestation and afforestation campaigns, however, is commonly measured in terms of trees planted, with little to no information disclosed on the tree survival rates. At the same time, high death tolls of the new trees are not uncommon: in Turkey, 90% of 1 million trees planted as part of a campaign died because of insufficient water and inappropriate planting time (Deutsche Welle, 2024).

Now that the deforested land has lost its fertility due to floods and droughts, the survival of newly planted trees becomes a challenge. Trees nowadays require an adapted irrigation regime, as well as nutrition, per the changing climate and soil conditions. Increasing the span of forests is no longer limited to the act of planting trees, but becomes tied with years of follow-up effort to ensure the young tree's survival. The use of remotely-controlled precision farming technology adapted for forest planting could highly support this effort, thanks to ensuring the

precise meeting of the needs of the plants on one end, and making up for the lack of agricultural specialists controlling, monitoring, and nurturing the plants.

This review aims to compare popular reforestation and afforestation initiatives in Bulgaria and South Africa and outline the approaches that influence the success of such campaigns. This review is also looking at evaluating the ability of precision farming technologies to cater for factors increasing the success of tree planting campaigns.

2. METHODS

The methods used in this paper include literature review, analysis of statistical data from national statistics portals, analysis of published website data on tree planting campaigns, review of scientific studies, and non-structured interviews with experts from suppliers of precision farming solutions.

3. DISCUSSION AND RESULTS

Global reforestation initiatives aimed at sequestering carbon emissions via large-scale efforts to plant millions and billions of trees became more intense starting in the early 2000s, due to a rising awareness of climate change, land degradation, and biodiversity loss. Bulgaria and South Africa make no exception, with global and national tree planting initiatives taking place, each with a different target audience and public involvement. Some of the most popular campaigns that continue as of July 2025 are presented in Tables 1 and 2 below.

Table 1: Major tree planting campaigns in Bulgaria, active as of July 2025

Campaign	Territory/period	Current results	Survival follow-up
Gorata.bg (NPO)	National/2013-current	5M+ trees planted	No
EU 3 billion trees by 2030 (regional)	EU/2021-2030	EU 32M trees Bulgaria 350	No
WWF Bulgaria (NPO)	National/Ongoing	2M+ trees planted	No

Some of the major reforestation and afforestation initiatives in Bulgaria are launched as part of regional policies and campaigns. Bulgaria's Strategic Plan for Development of Agriculture and Rural Areas includes afforestation and reforestation actions, in line with EU CAP objectives. The country has also joined the EU's 3 billion trees campaign. Most popular with the public is the tree-planting initiative of NPO Gorata.bg. None of the major campaigns, however, reports follow-up on the tree health or survival rates.

In South Africa, the major campaigns are also governmental or NPO-led. All of them, however, show an effort to provide check-ups and monitoring on the trees planted. The ambitious 10 million trees campaign initially focused on numbers, but later issued a 2025 sub-campaign where care for the planted trees was included (South African Government, 2025). The campaigns in South Africa, where monitoring is claimed to be done, report significantly fewer trees planted compared to major campaigns in Bulgaria. Quality monitoring of the trees

requires agronomic expertise, travel, and time spent. It is thus dependent on the availability of expert personnel and is thus a major factor behind the lower numbers reported.

Table 2: Major tree planting campaigns in South Africa, active as of July 2025

Campaign	Territory/period	Current results	Survival follow-up
10M trees. 1M trees in 2025 (government)	National/2021-2026.	3 trees	No. 2025 campaign in select sites + care
Food and Trees for Africa (NPO)	National/1990- now	5M trees planted	3 check-ups on each tree
SA Reforestation Trust (NPO)	National/2015-now	31,000+ trees planted.	Trees are cared for by professionals

Follow-up monitoring on saplings planted is, however, of major importance: regardless of the sapling quality at planting, once it is moved to a new environment, its survival is questionable. Critical determinants of sapling survival include their vigour and condition at the time of planting, the wetness of the soil into which saplings are planted, the trauma of transplant shock from nursery to field soils, and the care taken during planting (Preece et al., 2023). Experiments show that an adequate supply of water is essential to plant growth, and the size of individuals of a given species can vary several-fold in response to variation in moisture level (Es'haghi & Mousavi, 2015). The first 12 to 36 months after planting are critical for young trees as they adapt to new site conditions, develop their roots, and get established (Forestry Commission, 2025). Tree planting is recommended to be done during periods that support root development while minimizing physiological stress. Regional factors such as soil type, rainfall patterns, and species specifics must be considered. Campaign reports, however, over-emphasise on number of trees planted as a metric for forest restoration success, rather than managing and monitoring the planted trees over longer timescales.

Considering the climate changes and soaring temperatures, with 2024 being the warmest since global records began in 1850, rainfall patterns can no longer be considered consistent, and severe drought is expected in many areas. In Africa, the droughts are predicted to last 6, 8, and 13 months, significantly longer than the usual 4-month period (Yahaya et al., 2024). In Bulgaria, projected increases in temperatures are likely to sharpen the existing risks of temperature-related hazards such as droughts. The adverse weather implies a need for a human-controlled growing environment for the young trees until they are able to withstand the potentially harsh growing conditions and adapt. This means adequate irrigation that meets the needs of the plants but is considerate of the water scarcity. Proper nutrient supply, regular monitoring and required maintenance are needed within the first years of growing the trees. Agricultural and forestry expertise should be involved in this process, per the specifics of the plants, the soil, weather, nutrients, and other conditions. But, with tree planting campaigns that span huge territories and involve individuals, the agronomy expertise needed is difficult to supply. In both Bulgaria and South Africa, there is a trend of diminishing skilled labour force in the sector 'Agriculture, forestry and fishing'. In Bulgaria years 2019-2023 show a 12% decrease in experts in the field, from 18,4 to 16,2 thousand (NSI, 2025). In South Africa, the sector faces

a shortage of skilled workers, which presents challenges to productivity and innovation (Agricultural Business Chamber, 2024).

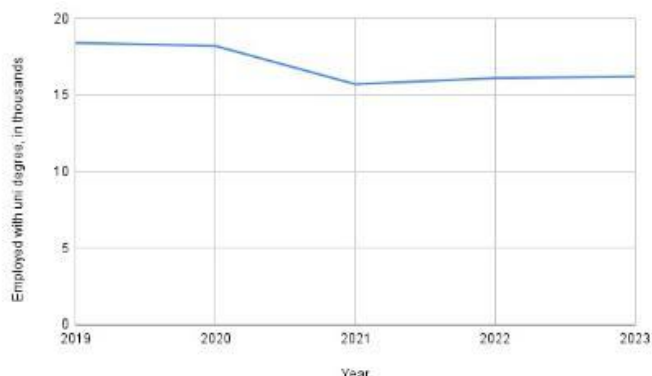


Figure 1: University degree employees, sector 'Agriculture, forestry and fishing', Bulgaria (2019-2023) (NSI, 2025)

Precise irrigation and fertigation systems can offer a viable solution that minimizes manual work, improving plant health and resource efficiency. These systems integrate sensors, controller hardware, and software to deliver precise amounts of water and nutrients based on real-time environmental and crop-specific data, thus reducing reliance on human judgment and labour-intensive operations. Automated sensor-based fertigation can reduce input costs and improve yield consistency, particularly in remote or under-resourced regions where access to trained personnel is limited (Blanco et al., 2020). Such solutions would also address the increasing scarcity of skilled labour in forestry and agriculture, particularly considering that regions with planted trees may be scattered, with huge time required for transit. Thus, precision farming systems can provide a sustainable pathway for maintaining high levels of performance with regard to tree planting and monitoring.

Recent studies confirm the importance of precision farming solutions. Peng & Xie (2025) emphasize that data-driven systems enable real-time irrigation scheduling, increasing the efficiency of water usage as well as the ecosystem resilience. Reviews of IoT-enhanced irrigation show that soil moisture sensors significantly improve the application of water, ensuring sustainable water management and healthier plant growth (Ivanova, 2025). In forest nurseries and reforestation sites, this translates into care that aligns with specific soil conditions and changing weather, ensuring young trees receive just what they need - boosting survival, lowering costs, and preserving precious resources.

Precision farming solutions that use advanced technologies such as remote sensing and AI-driven decision support tools can replace agronomic expertise to a great extent, establishing decision-making processes via data-driven approaches. Automated systems collect rich historical data on soil conditions, crop health, weather patterns, nutrient levels, and more, enabling follow-up analysis and optimisations on the automated decisions taken by the systems. Studies such as those by Bongiovanni & Lowenberg-DeBoer (2004) show that precision agriculture solutions can increase the efficiency of the used input as well as improve the plant growing processes. Recent advancements in AI allow precision systems to adapt and learn from data over time. This increases the performance of the solutions and mitigates the growing shortage of skilled agronomists, particularly in labour-constrained regions (Wolfert et

al., 2017). The availability of such solutions does not exclude the know-how of an agronomist but rather complements and enhances it, allowing an agronomist to remotely monitor and adjust the decision-making process in terms of irrigation or nutrients applied based on the incoming sensor data. The resulting know-how can then be replicated for planting conditions featuring similar characteristics. A single agronomist can also work with multiple precision farming solutions, monitoring and optimising on an ongoing basis.

Farmers in Bulgaria and South Africa are already using precision farming solutions for growing tree saplings and young trees (ONDO, 2025). Deploying precision farming solutions in forests, however, would require restrictions on the tree planting campaigns. The reforested sites must meet criteria like mobile coverage, water sources, and equipment deployment zones. In addition, precision farming solutions for irrigation and fertigation typically work with drip irrigation, which would require subsurface installation in an animal-welcoming environment.

A challenge for the application of precision tools and models in the forest environment is that they are developed for agricultural systems and may lack the adaptability needed for diverse forest species and ecological dynamics. The high initial investment for sensors, drones, and automation systems could be a barrier, especially in low-budget restoration projects in Bulgaria that are mostly donation-funded. Even with budgets available per different regional or international funded programs, tree planting should happen on predefined reforestation/afforestation sites of a reasonable size rather than individual, scattered trees in private properties to ensure cost efficiency. The steep, rocky, or heavily vegetated areas with difficult access may create challenges for maintaining the ground-based machinery.

There is a need for tailored approaches and further research on adapting precision farming technologies to meet the specific demands of afforestation, reforestation, and sustainable forest management. Such efforts, however, can pay out in thriving and rewarding tree-planting campaigns, in healthy forests, optimized resource usage and increased involvement of individuals, private and public organizations, and the government.

4. CONCLUSIONS

Based on the review and analysis done in this paper, conclusions can be made as follows:

- Tree planting initiatives that cater for the needs of the plants in their first years result in a lower number of trees planted, but potentially better long-term results.
- The use of precision farming technologies can scale up the effort in increasing the world's forests, even in the situation of scarcity of agronomy experts.
- Precision farming solutions can ensure the irrigation and nutrient needs of the young trees are met while ensuring sustainable water and nutrient management.
- Automated precise farming solutions for forest management require an initial investment, but could be feasible for tree planting campaigns concentrated in larger areas that have the needed prerequisites.

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MARKET TRENDS, MARKETING, AND CUSTOMER ENGAGEMENT

GAMIFIED MARKETING IN E-COMMERCE FOR FURNITURE RETAIL IN BULGARIA

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Abstract: This paper explores the impact of integrating gamified elements in e-commerce for furniture retail in Bulgaria, examining how such strategies can not only capture consumer attention but also enhance sales performance. By analyzing leading Bulgarian online furniture stores, the study seeks to identify best practices and areas for improvement to increase customer engagement and optimize marketing strategies in the digital furniture retail sector.

The research aims to evaluate the effectiveness of gamification in enhancing user experience and engagement by systematically assessing key gamification elements in selected e-commerce platforms. The study employs a structured checklist to analyze the presence and effectiveness of interactive features, personalization, loyalty programs, and the implementation of emerging technologies such as AR and VR. The selection of e-commerce platforms - JYSK, Yavor, Mebeli Videnov, IKEA, Mebeli Como, etc. - is based on their popularity among consumers and active digital presence.

A control group of students evaluates each criterion on a five-point scale to determine the degree of implementation of gamified strategies. The collected data are then analyzed and compared to identify the strengths and weaknesses of gamification approaches across the selected online stores. The findings serve as a foundation for developing targeted recommendations aimed at improving engagement and the overall effectiveness of digital marketing practices in the Bulgarian furniture retail.

Keywords: e-commerce, furniture retail, gamification, digital marketing.

1. INTRODUCTION

The global furniture e-commerce market is experiencing notable growth. According to Cognitive Market Research (2025), it reached \$28.2 billion in 2024 and is projected to grow at a 5% CAGR through 2031. Europe holds over 30% of the market, driven by digital technologies and shifting consumer preferences toward online shopping.

The furniture market is largely influenced by overall consumer spending, which in turn is shaped by factors such as per-capita income, household debt, and consumer sentiment. The landscape of leading key players in the furniture market is being reshaped by the rise of e-commerce, with emerging companies like Wayfair, Amazon, Made.com, Home24, Overstock.com and others rapidly gaining ground and challenging traditional industry leaders.

According to the *Furniture: Market data & analysis* (2024) in Bulgaria, the furniture market is projected to reach a revenue of US\$790.17 million in 2025, with an expected annual growth rate (CAGR) of 1.84% between 2025 and 2029. The Bedroom Furniture segment leads the market, accounting for a projected volume of US\$205 million. On a per capita basis, revenue is estimated at around US\$120.36 in 2025. The furniture market in Bulgaria is growing steadily, driven by rising demand for stylish, high-quality, and eco-friendly furniture. Key trends include the growth of online shopping and increasing interest in customizable pieces.

The Merkle Loyalty Barometer Report (2024) indicates that consumer loyalty program enrollment is increasing. While traditional rewards like discounts and free products remain important, the report explores the impact of gamification and various marketing tools on loyalty

programs. Gamified program features, such as challenges, badges, and leaderboards, have seen relatively consistent appeal and retail loyalty programs. However, fewer than half of consumers actively seek these features in core loyalty programs, suggesting that brands should use them strategically, possibly in promotional campaigns for testing and learning.

Key trends influencing the market today include the integration of AR for virtual product visualization, the use of AI in generative design, a shift toward sustainable and eco-friendly materials, and the incorporation of smart technologies into furniture products. Innovations such as 3D printing and smart lighting systems are redefining the way furniture is designed, manufactured, and experienced, signaling a future where functionality, sustainability, and digital interactivity are core to consumer expectations (Furniture: Market data & analysis, 2024).

2. LITERATURE REVIEW

The e-commerce furniture industry has rapidly transformed how consumers shop for home furnishings. Once primarily reliant on brick-and-mortar stores due to the high cost and tactile nature of furniture (touch and feel), the sector has experienced significant online growth. Innovations like augmented reality (AR), personalization engines, and faster logistics are further accelerating market expansion. Within retail furniture sector, despite challenges such as the inability to physically test products, companies are improving user trust through detailed product information, return policies, and immersive technologies. Previous studies have proven that e-commerce logistics are set to become real-time and intelligent in the coming decade, driven by the adoption of IoT, Big Data Analytics, and Cloud Computing across system, operational, and decision-making levels (Li, Y. et al., 2020). Successful furniture e-commerce hinges on providing an information-rich, service-oriented, emotionally resonant, and technologically advanced online experience that minimizes perceived risks and maximizes consumer confidence and satisfaction (Zhang, S. et al, 2022).

The industry is increasingly leveraging Artificial Intelligence (AI) and Extended Reality (XR), specifically Augmented Reality (AR) and Virtual Reality (VR), to overcome the inherent challenges of online furniture sales (Billewar, S. et al., 2022). AI is transforming customer service through intelligent chatbots, optimizing inventory management by predicting demand, and personalizing product recommendations by analyzing user behavior. This allows for tailored marketing campaigns and a more intuitive "browse" experience. AR and VR are proving particularly impactful, enabling consumers to visualize furniture in their own homes in real-time, effectively "trying before buying" and reducing uncertainty about fit and aesthetics. This capability not only boosts conversion rates but also minimizes returns, a significant cost factor for bulky items. The 3D product configurators that allow for real-time customization and visualization of furniture pieces, addressing the desire for personalized designs and providing a comprehensive view beyond static 2D images (Lihra, T. et al, 2012). There's also a growing emphasis on omnichannel retailing, seamlessly integrating online and offline experiences, and a continued rise of Direct-to-Consumer (DTC) brands that offer a more personal connection with customers and often prioritize sustainability. The consumer preferences are transferred to the furniture industry considering the changing anthropometric parameters in the market when designing new products and preparing marketing strategies (Hitka, M. et al., 2024).

As consumers increasingly view furniture as a reflection of their social status and lifestyle, seeking spiritual over purely material satisfaction, the online furniture industry is responding

with sophisticated digital tools and business models that cater to these evolving demands, promising a more immersive, intelligent, and tailored shopping journey. Among the major segment trends stands emphasis on user-friendly online platforms and competitive pricing strategies.

Gamification has become a key trend in digital marketing, especially within the fast-evolving e-commerce sector. In the competitive furniture retail industry, gamified strategies help brands create engaging user experiences and build customer loyalty (Furniture E-Commerce Market Report, 2025).

3. METHODOLOGY

The furniture market was analyzed by conducting a desk-based empirical research approach, focusing on the analysis of 10 websites of online furniture retailers operating in Bulgaria (see Table 1).

Table 1. Key Performance Indicators of Top Furniture Retailers in Bulgaria (2021–2023)

№	Company Name	Revenue (BGN '000)	Revenue Growth (%)	Net Profit (BGN '000)	Profit Growth (%)	Number of Employees	Employee Growth (%)
		2021	2022	2023	23/22	2021	2022
1	JYSK Bulgaria	436,283	561,397	612,448	9.09	5,890	17,508
2	Veleya Global	183,989	229,808	245,339	6.76	6,533	1,462
3	IKEA - House Market Bulgaria	133,152	151,332	163,583	8.10	16,760	17,333
4	AIKO Multi Concept	101,879	128,186	135,392	5.62	13,231	18,687
5	Mömax Bulgaria	29,541	40,171	43,805	9.05	1,262	2,891
6	Prima Group 2004	42,913	43,546	42,725	-1.89	818	340
7	Interior-I	31,804	37,816	36,133	-4.45	4,159	7,030
8	MebelMag	14,640	19,948	22,831	14.45	529	1,397
9	Ralitsa Furniture Houses	11,494	14,351	15,091	5.16	351	177
10	Zona Dom	13,835	19,391	14,475	-25.35	315	579
	Average for Top 10	99,953	124,595	133,182	6.89	4,985	6,740

Source: Capital, 17.02.2025 Available at
https://www.capital.bg/biznes/stoki_i_prodajbi/2025/02/17/4731079_top_10_na_verigite_za_o_bzavejdane_koleblivi_prodajbi/

Apart from the official data and major players, 26 master degree students of Digital Marketing course at Faculty of Economics and Business Administration were asked to identify by voting the major furniture retailers. The students were permitted to select more than one website. This multi-selection approach allowed students to evaluate multiple retailers, reflecting a broader analysis and richer data set, but also resulting in a higher total vote count than the number of unique voters. The results are presented in Table 2 and one company – Yavor is not among the top 10 key players. One possible reason is the tradition and long story of the company, even not being among the top leading retailers.

Table 2. Top 5 Furniture Retailers (as per vote)

Rank	Retailer Name	Customer Rating (out of 10)	Number of Votes
1	IKEA – House Market Bulgaria	8.9	85
2	JYSK Bulgaria	8.7	41
3	Aiko Multi Concept	8.5	46
4	Yavor	8.4	22
5	Mömax Bulgaria	8.3	19

The websites included in the study were selected based on their popularity and their active presence in the digital space. This ensured that the analysis covered relevant and representative online platforms. The primary aim of the study was to identify and assess the use of gamification elements on these websites and evaluate their impact on improving the user experience. The collected data was used to derive insights into how Bulgarian furniture retailers use gamification to improve marketing strategies, strengthen user retention, and attract new customers.

The study is guided by the following hypotheses:

H1: Gamification is not widely or effectively used in Bulgarian online furniture stores.

H2: Online furniture retailers that use gamification tend to achieve better customer engagement and business results.

We acknowledge the limitation of the approach and further research with a broader participant base is recommended to validate findings. First, the evaluation relies on subjective assessments by a relatively small and homogeneous group—26 master's students in digital marketing—which may not fully represent the diversity of typical customers. Second, the analysis focuses only on selected popular retailers, which may not capture the full spectrum of gamification strategies used across the Bulgarian furniture market. Additionally, the study evaluates visible gamified elements on websites but does not account for backend data or internal performance metrics that could provide deeper insight into customer engagement and conversion rates. Finally, the dynamic nature of e-commerce platforms means features can change frequently, and the findings may not reflect long-term strategies.

3. RESULTS

A comparative review of the identified five leading Bulgarian furniture retailers' websites reveals significant differences in the use of gamification elements, customer engagement tools, and overall digital experience aimed at boosting sales and loyalty.

IKEA.bg stands out with a well-rounded gamification approach, scoring the highest overall rating. Their strategy includes interactive games like the "Guardians of the Magic Forest" contest, which encourages online voting and rewards participants with personalized prizes. IKEA's loyalty program, "IKEA Family," allows customers to earn points and receive bonuses, contributing to a reported 6% increase in total sales and a 14% growth in online turnover in 2024. They also offer a furniture configurator that supports real-time customization, enhancing user experience though lacking advanced AR/VR or social interaction features. The site integrates social sharing options effectively, maintaining a strong social media presence with millions of followers. Mobile accessibility and relevant, attractive rewards further reinforce customer engagement.

In contrast, JYSK.bg exhibits a much weaker gamification presence. While the site features easy navigation and personalized product recommendations, it lacks a dedicated loyalty program and only includes minimal interactive elements such as challenges or "wheel of fortune" games. The absence of inspiring content and limited social sharing incentives results in lower user engagement. Although some data collection mechanisms are in place, the overall experience is less engaging compared to competitors.

Aiko-bg.com demonstrates a moderate to strong gamification strategy by combining a loyalty club with engaging interactive elements like sweepstakes and giveaways. Their website offers intuitive navigation and personalized product suggestions, supported by additional inspirational content that extends user time on site. The integration of social media campaigns, especially on Instagram, encourages active sharing and interaction. However, emotional connection through storytelling is somewhat underdeveloped, leaving room for deeper customer engagement.

Videnov.bg excels in integrating gamified experiences within their platform, notably through the "Virtual Room" feature that allows users to customize interiors interactively. The company's loyalty card offers immediate discounts, a competitive advantage over deferred rewards programs elsewhere. Regular campaigns using games and giveaways further enhance engagement. The site boasts the best navigation and personalization tools among the evaluated companies and effectively uses social media influencers to amplify reach. While it lacks some visual incentives for email subscriptions, its rich content and well-structured blog contribute to longer visitor retention.

On the other end, Yavor.bg has the least developed gamification and loyalty infrastructure. Although the site is easy to navigate and offers useful filtering options, it lacks interactive games, loyalty programs, and social sharing incentives. Promotional banners help to some extent but do not significantly increase visitor engagement or emotional connection with the brand. To improve, Yavor should consider introducing room configurators, AR/VR features, and more active social media campaigns to build customer loyalty.

This analysis illustrates that successful gamification strategies require a balanced mix of interactive games, loyalty rewards, personalized experiences, and social media integration. IKEA and Videnov lead in this regard, while others have clear opportunities to innovate and enhance their customer engagement through digital gamification.

4. CONCLUSION

The study confirms that gamification is an increasingly relevant and underutilized strategy in the Bulgarian e-commerce furniture sector. While the global trend emphasizes interactive, personalized, and immersive experiences as key drivers of customer engagement and loyalty, the local market presents a mixed picture. Among the retailers examined, IKEA.bg and Videnov.bg stand out for their strategic and consistent integration of gamified elements such as loyalty programs, online contests, product configurators, and social media campaigns. These companies not only lead in customer engagement but also demonstrate higher digital performance and sales growth, supporting the hypothesis that gamification correlates with improved business outcomes.

Conversely, several retailers—including JYSK.bg and Yavor.bg—display limited or inconsistent use of gamified features. These brands focus primarily on transactional efficiency rather than experiential engagement, missing opportunities to build emotional connections, increase customer retention, and differentiate themselves in a competitive marketplace. The lack of dynamic features such as voting, ranking, storytelling, and AR/VR integration suggests a gap between consumer expectations and the digital strategies employed by these companies.

The student voting exercise reinforced consumer perceptions of leading digital experiences and provided additional qualitative validation of the website assessments. Notably, the inclusion of Yavor, a traditional brand not among the top economic performers, highlights the enduring value of brand heritage but also underscores the need for modernization and digital innovation to remain competitive.

Both hypotheses are confirmed. In summary, while gamified marketing remains in its early stages across much of the Bulgarian furniture e-commerce landscape, its potential is clearly evident. Retailers who embrace gamification as part of a broader digital transformation strategy—focusing on interactivity, personalization, and emotional engagement—are better positioned to attract and retain customers in an increasingly competitive and digitally driven market. Future research could extend this analysis with a larger and more diverse participant base and further explore the direct impact of specific gamified features on user behavior and conversion rates.

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GAMIFICATION OF TRADITIONAL BULGARIAN WOODCARVING AS A CULTURAL HERITAGE TOURISM PRODUCT

Sonia Mileva, Neviana Krasteva, Desislava Alexova

Abstract: Traditional Bulgarian woodcarving is a vital component of the country's cultural heritage, yet it faces challenges in preservation and engagement due to modernization and declining artisan participation. As cultural tourism increasingly shifts toward interactive and experience-based models, gamification presents an innovative solution for revitalizing traditional crafts. This study explores the potential of gamifying woodcarving tourism to enhance visitor engagement, preserve artisanal knowledge, and create sustainable economic opportunities for craftsmen. Using a mixed-method approach, including field observations, interviews with artisans, and analysis of gamification strategies in heritage tourism, this research identifies key gamification techniques such as augmented reality (AR) craft guides, interactive storytelling, skill-based challenges, and virtual apprenticeships. Findings suggest that integrating these elements into cultural tourism can attract younger audiences, improve tourist experiences, and support craft education. Furthermore, the study highlights challenges such as artisans' resistance to digital tools and the need for sustainable implementation strategies. By leveraging gamification to transform woodcarving into an interactive cultural experience, Bulgaria can enhance its heritage tourism sector while safeguarding traditional craftsmanship. This research contributes to the discourse on cultural sustainability, proposing a model where technology and tradition coexist to ensure the longevity of intangible cultural heritage.

Keywords: Gamification, cultural heritage, woodcarving, tourism, Bulgaria, traditional crafts.

1. INTRODUCTION

Traditional Bulgarian woodcarving is a significant element of the country's cultural heritage, deeply embedded in its architecture and artistic identity. Woodcarving has long been a key feature in structures such as churches, monasteries, homes, and public buildings, adding both aesthetic and symbolic value. The craftsmanship as intangible heritage reflects distinct artistic ideals, often inspired by nature, incorporating floral motifs, vines, and leaves into elaborate wooden designs (Namicev, P.; Namiceva, E., 2018).

However, despite its cultural significance, Bulgarian woodcarving faces challenges in preservation due to modernization, declining artisan participation, and a lack of integration into contemporary cultural and creative tourism. Many traditional craftsmen struggle to attract new generations to the trade, and limited initiatives exist to promote woodcarving as an interactive experience for visitors (Mileva, S. Gesheva, A., 2025)

Cultural heritage tourism has grown globally, with increasing demand for immersive and experience-based attractions (Qiu, Q. et al. 2022). Tourists today seek more than passive observation; they want to engage, participate, and connect with local traditions. While tangible heritage—such as historical monuments—has received significant attention in the tourism industry, intangible cultural elements like craftsmanship, storytelling, and artisanal skills remain underutilized as tourist experiences.

One emerging approach to revitalizing cultural tourism is gamification—the application of game-like elements to engage people, encourage participation, and enhance learning experiences (Mileva et. al, 2021).

This study aims to explore the potential of gamifying Bulgarian woodcarving tourism as a means to: enhance visitor engagement and learning experiences; preserve and promote traditional woodcarving skills; support artisans by creating sustainable economic opportunities and to identify key challenges and solutions in implementing gamification in cultural tourism.

By addressing both the artistic and economic aspects of Bulgarian woodcarving, this research highlights its potential as a valuable cultural tourism product that could benefit both the heritage sector and the wider tourism industry.

2. LITERATURE REVIEW

Traditional craftsmanship is a vital form of intangible heritage, with safeguarding efforts focusing on preserving artisans' skills and knowledge rather than just craft objects. Globalization, mass production, and shifting social conditions threaten traditional crafts, making them less attractive to younger generations. To sustain these practices, innovative methods like gamified learning, financial incentives, market development for authentic handmade products, and legal protections are essential (UNESCO). Research suggests that integrating traditional crafts into tourism through interactive demonstrations, workshops, and direct engagement with artisans can enhance visitor experiences and contribute to heritage preservation (Thurley, S. et al., 2015; Horjan, G., 2011).

Previous studies have mainly explored the architectural role of woodcarving but have overlooked its potential as a cultural tourism product (Liang, Y., & Qi, Z., 2021; Wasela, K. 2023). UNESCO significantly contributes to the recognition and protection of traditional crafts and cultural practices through its 2003 Convention for the Safeguarding of Intangible Cultural Heritage (ICH).

In the context of heritage gamification, research highlights a strong emphasis on historical, architectural, and archaeological heritage, with gamification primarily applied to boost visitor engagement, foster motivation, and stimulate creativity. In terms of technologies, Mobile Applications, Augmented Reality (AR), and Virtual Reality (VR) dominate current gamified heritage initiatives and promotion of traditional crafts (Marques, C. et al., 2023; Partarakis, N. et al. 2025). Studies also show a trend toward employing novel gamification approaches specifically for promoting cultural heritage, aiming to make heritage experiences more interactive and appealing to modern audiences (Khan, I. et al. 2020).

By applying gamification to heritage tourism related to woodcarving interactive storytelling, skill-based challenges, augmented reality (AR) craft guides, and virtual apprenticeships could provide new ways for tourists to experience the craft (Zabulis, X. et al., 2020). This approach could attract younger audiences, stimulate interest in traditional skills, and create new economic opportunities for artisans. Gamification, by preserving intricate craft processes and increasing global visibility, creates new opportunities for sustainable engagement and tourism development (Xu, F. et al., 2017).

3. METHODODOLGY

To achieve these objectives, the research employs a mixed-method approach, including interviews with artisans, field observations, and analysis of gamification strategies in cultural tourism. Data was collected through a combination of desk research, field observations, and

semi-structured interviews with traditional artisans and representatives from regional craft chambers across Bulgaria.

Following a literature review on cultural heritage tourism in Bulgaria, field observations were conducted. Four regions were selected — Gabrovo, Veliko Tarnovo, Montana, and Sofia Province — based on their strong historical significance, the presence of recognized master craftsmen, and the existence of specialized attractions related to traditional woodcarving.

Subsequently, data collection was carried out through interviews with selected seven respondents (R1 – R7) from these areas, including experienced woodcarvers and craft organization representatives. Participants were chosen based on their active involvement in traditional woodcarving and their potential interaction with cultural tourism initiatives. The questions for semi-structured interview are presented in Table 1.

Table 1. Questions for semi-structured interview

No	Questions
Q1	How do you view the importance of your craft for cultural tourism, and in what ways do you engage tourists — whether through demonstrations, participatory experiences, or integrating new approaches like gamification?
Q2	Can you describe how you present your woodcarving products to tourists, what challenges you face in adapting your craft for tourism (such as product size, marketing, and workshop organization), and how you see the future of traditional woodcarving?
Q3	How do you incorporate interactive or gamified elements into your workshops or participation in cultural events, and what challenges do you face

The interviews were conducted between February and April 2025, with some of the workshops visited in person. Respondents were selected based on recommendations from the Bulgarian Chamber of Crafts, as well as randomly among those willing to participate. Each interview lasted approximately 30 minutes; in some cases, a follow-up conversation was necessary to clarify specific details. Visits to the workshops were planned considering the geographical location and the distance of each site from the capital city.

The study is guided by the following hypotheses:

- (1) Traditional craftsmanship in Bulgaria is not widely recognized or developed as a tourism product through innovative methods such as gamification and virtual apprenticeship models.
- (2) Woodcarvers' craftsman predominantly focuses on the sale of their products and show limited engagement in creating interactive and experiential tourism activities, including gamified heritage experiences.

The study is limited by the small sample size and regional focus, which may not capture the full diversity of woodcarving traditions across Bulgaria. Further research with a broader participant base is recommended to validate findings.

4. RESULTS

All respondents (N=7) highly valued the importance of their craft (woodcarving) for cultural tourism. However, none demonstrated exceptional artisanal abilities that incorporated gamified experiences. The closest approximation to gamification observed was the organization of

artisan workshops, participation of tourist exhibition and craft markets where visitors could participate in basic craft activities. Gamification in its narrower, more structured sense—using game-like elements to enhance engagement—was largely unknown to the artisans and not recognized as a deliberate tool for attracting or involving tourists.

Two respondents (R3 and R5) learned their craft from their parents, focusing more on the aesthetic value of the objects rather than on providing tourist experiences. Woodcarvers located and operating in tourist locations such as the Etar Open-Air Ethnographic Museum and the Oreshak National Exhibition Center (Gabrovo Province) offered opportunities for tourists to observe, learn, and participate in the woodcarving process.

Regarding the Craft Product (woodcarving) and Experience the interviews revealed key insights into the nature of the woodcarving craft and the types of experiences offered to tourists. Product size was found to significantly influence visitor interaction, with smaller items being more practical as souvenirs. However, not all products were considered suitable for this purpose. While authenticity remained highly valued by both artisans and visitors, the growing influence of mass tourism highlighted a rising preference for attractive, affordable items, including 3D-printed replicas. All respondents expressed concern over the declining popularity of traditional woodcarving, often attributing it to the limited state subsidies, and the weakening of guild structures as National or Regional Craft Chambers. Many artisans reported the need to seek alternative income sources. Digital marketing emerged as a critical factor in artisans' ability to reach broader audiences. Only one respondent (R2) successfully leveraged online marketing tools to promote and sell their products, while the majority struggled with limited digital skills and resources. All seven artisans indicated that they were capable of demonstrating their craft and involving tourists in participatory experiences, responding to a growing demand for hands-on activities. However, the sustainable organization of workshops and the integration of gamified activities remained a significant challenge, largely due to the absence of consistent institutional support and funding.

The organization of craft open-air workshops and participation in cultural events from municipal calendars provided important opportunities for interacting with tourists through demonstrations and training sessions incorporating playful elements. However, such initiatives were rarely sustainable over time, often due to a lack of understanding and insufficient institutional support from local authorities.

The artisan workshops as major interactive engagement with tourists are run in small spaces with limited room for visitors, typically working alone or with one to two assistants. Few artisans (R4 and R6) combined workshops with exhibition spaces. One notable exception is R4 from Sofia region, which reported to offer various gamified activities, though woodcarving was only a supplementary focus.

5. CONCLUSION

The findings of this study underscore the significant value that artisans place on traditional Bulgarian woodcarving within the context of cultural tourism. However, the research reveals a notable absence of gamified approaches in their current practices, with the closest approximation being basic craft workshops, tourist exhibitions and craft markets. The study partially confirmed the research hypotheses. While woodcarving holds strong cultural significance and offers potential for enriching tourist experiences through gamification, structural challenges—such as limited workshop capacity, lack of digital marketing skills, low

institutional support, and decreasing popularity of the craft—hinder its full development as a sustainable tourism product.

Furthermore, a lack of collaboration between artisans and tourism service providers, coupled with inconsistent service quality at tourist information centers and the absence of unified tourist portals, presents a substantial impediment to creating a cohesive and accessible tourism experience. These factors collectively limit the potential to fully integrate and promote woodcarving as a compelling element of cultural tourism.

Addressing these challenges is crucial for the sustainable development of woodcarving tourism. It is recommended that stakeholders prioritize fostering collaboration between artisans and tourism stakeholders, provide training and resources to enhance artisans' digital marketing skills, and establish robust institutional support mechanisms. Moreover, exploring funding opportunities and initiatives that support the creation and implementation of gamified experiences can further revitalize this traditional craft.

Future research should focus on developing and testing specific gamification models tailored to Bulgarian woodcarving, assessing their long-term impact on artisan livelihoods and tourism revenue, and investigating strategies to effectively scale up successful initiatives. A broader study encompassing a larger sample size and wider geographical representation would also provide a more comprehensive understanding of the challenges and opportunities across the entire country. Nevertheless, the integration of gamified activities in events, workshops, and heritage trails demonstrates that innovative approaches can enhance the attractiveness of woodcarving and heritage crafts for modern audiences.

In conclusion, while traditional Bulgarian woodcarving holds immense potential as a cultural tourism product, overcoming the identified structural and collaborative barriers is paramount. By strategically integrating gamification and addressing the systemic challenges, it is possible to safeguard this invaluable cultural heritage and ensure its sustainable transmission to future generations.

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SUSTAINABILITY PREFERENCES OF CUSTOMERS AND THEIR IMPACT ON PURCHASING FURNITURE

Gloria Ilieva

Abstract: Sustainability has become an increasingly influential factor in consumer decision-making, particularly in industries with significant environmental impact, such as furniture production. This study explores the sustainability preferences of Bulgarian consumers and their effect on purchasing behaviour within the furniture sector. Through a survey-based approach, the research examines key factors such as environmental awareness, material preferences, willingness to pay for sustainable options, and the perceived importance of eco-certifications. The findings provide insights into consumer attitudes toward sustainable furniture, highlighting trends and potential implications for manufacturers and retailers. The results aim to contribute to a deeper understanding of sustainable consumption patterns in Bulgaria and offer strategic recommendations for businesses seeking to align with evolving consumer expectations.

Keywords: sustainability, consumer, furniture

1. SUSTAINABILITY IN THE FURNITURE SECTOR

In recent years, the concept of sustainability has become a central concern in both academic discourse and business practice, particularly in industries with significant environmental and social impacts such as furniture manufacturing. Driven by increasing awareness of climate change, resource depletion, and ethical consumption, customers are progressively incorporating sustainability criteria into their purchase decisions (Vermeir & Verbeke, 2006; White et al., 2019). The furniture industry, similarly to others, is pressured to continue innovating and developing to answer the shift in consumer's demand. (Dimitrova, 2022). This shift presents both opportunities and challenges for the furniture industry, which is traditionally associated with intensive use of natural resources, especially wood and other forest products.

Sustainability in furniture can manifest through various dimensions - use of certified or recycled materials, durability and longevity of products, eco-friendly production processes, and even social responsibility within supply chains (Niinimäki, 2017). As consumers become more informed and environmentally conscious, they develop distinct sustainability preferences that influence not only what products they choose but also how much they are willing to pay and which brands they trust. Understanding these preferences is critical for furniture manufacturers and retailers who seek to align their offerings with market demands while advancing their sustainability agendas.

Although there is growing evidence of consumer interest in sustainable products in general (Peattie & Belz, 2010), the specific ways in which sustainability preferences shape purchasing behaviour in the furniture sector remain underexplored. Existing studies have often focused on either general attitude toward green products or narrow aspects such as willingness to pay for certified wood, leaving a gap in understanding the broader interplay between sustainability preferences and consumer decisions in this industry.

This paper aims to address this gap by investigating the sustainability preferences of furniture customers and examining how these preferences impact their purchasing behaviour. By identifying key sustainability attributes valued by consumers and analysing their influence

on purchase choices, this study contributes to both academic knowledge and practical guidance for companies striving to meet the evolving expectations of their customers.

1.1. Survey on consumer sustainability preferences regarding furniture

The author surveyed 173 respondents through posting on various social media groups related to furniture, home furnishings, and sustainable products in Bulgarian language. The questions they were asked are focused on environmental awareness, material preferences, willingness to pay for sustainable options, as well as the perceived importance of eco-certifications.

Table 1. Survey questions and percentage of responses

1. How would you rate your level of awareness about environmental issues (e.g. climate change, deforestation, waste)?	
Very low	8.09%
Low	15.61%
Moderate	52.60%
High	20.81%
Very high	2.89%
2. How often do you consider the environmental impact of products you buy?	
Never	6.36%
Rarely	18.50%
Sometimes	60.11%
Often	15.03%
Always	0.00%
3. In your opinion, how much does the furniture industry contribute to environmental problems?	
Not at all	1.73%
A little	10.40%
Moderately	61.86%
A lot	21.39%
I don't know	4.62%
Section 2: Material Preferences	
4. When buying furniture, how important is the choice of material to you?	
Not important	4.05%
Slightly important	19.65%
Neutral	21.39%
Important	48.55%
Very important	6.36%

5. Which materials do you prefer when purchasing furniture? (Select all that apply)	
Solid wood	8.67%
Engineered wood (e.g., MDF, particle board)	73.99%
Recycled or reclaimed materials	10.40%
Metal	6.94%
6. How likely are you to choose furniture made from recycled or reclaimed materials?	
Very unlikely	13.87%
Unlikely	21.39%
Neutral	25.44%
Likely	28.32%
Very Likely	10.98%
7. Would you be willing to pay more for furniture that is environmentally friendly?	
No	73.41%
Yes, up to 5%	15.03%
Yes, up to 10% more	9.83%
Yes, more than 10%	1.73%
9. How familiar are you with eco-certifications for furniture (e.g., FSC, PEFC, Cradle to Cradle)?	
Not familiar	85.55%
Slightly familiar	12.72%
Moderately familiar	1.73%
Very familiar	0.00%
10. How important is it for you that furniture carries an eco-certification label?	
Not important	12.72%
Slightly important	32.94%
Neutral	39.31%
Important	15.03%
Very important	0.00%

More than 70% of the respondents have indicated that they have moderate to very high level of awareness of environmental issues. However, only 15% claim to often consider the environmental impact of their purchases, and none said always; most (60.1%) think about it sometimes. When asked about the role of the furniture industry in environmental problems, a majority (61.9%) see it as contributing moderately, and 21.4% believe it contributes a lot. The data demonstrates that customers recognize the environmental consequences of their actions

and acknowledge the furniture industry's impact, but this awareness does not consistently translate into habitual, environmentally conscious purchasing behaviour.

Within the material preferences questions section, 54.9% of respondents rate the importance of material as important or very important. Interestingly, a strong majority (74%) prefer engineered wood, while only small shares prefer solid wood (8.7%) or recycled/reclaimed materials (10.4%). Attitudes toward recycled materials are mixed: about 39.3% are likely or very likely to choose them, but 35.3% are unlikely or very unlikely, and a quarter are neutral. While material choice matters to customers, preferences skew heavily toward engineered wood - likely reflecting affordability and availability (especially for a country like Bulgaria, where the minimum and average salaries remain lower compared to other EU countries) - and only a minority actively prefer environmentally friendly materials.

The willingness of the respondents to pay a premium for sustainable furniture is very low. Nearly three-quarters (73.4%) of the respondents are unwilling to pay more. Only 15% would pay up to 5% extra, and very few (11.6%) would go beyond that. For most customers, sustainability is not compelling enough to justify a price premium, with economic and functional attributes like price and quality taking precedence.

There is a low level of familiarity and importance attached to eco-certifications. The perceived importance of eco-certifications is still modest: only 15% consider them important and none rated them as very important. Lack of awareness suggest that such labels currently have limited influence on customer choices in this sample. Although customers are largely unfamiliar with specific certification schemes, many exhibit a relatively high level of trust in them once they are aware. This suggests potential for growth if awareness and education efforts increase.

2. STRATEGIC RECOMMENDATIONS FOR THE FURNITURE INDUSTRY REGARDING SUSTAINABLE FURNITURE MANUFACTURING

The findings of this study yield several important recommendations for furniture businesses seeking to align their offerings with the sustainability preferences of customers while addressing the barriers to sustainable purchasing behaviour identified in the survey. These recommendations are grounded in the empirical data and supported by relevant literature.

Price sensitivity emerged as a significant barrier to the adoption of sustainable furniture, with the majority of respondents unwilling to pay a premium for environmentally friendly products. This result aligns with previous research demonstrating the dominance of price and quality considerations over environmental concerns in consumer decision-making (e.g., Young et al., 2010). Therefore, it is imperative that businesses strive to minimize the cost differential between sustainable and conventional furniture. Strategies such as optimizing production processes, improving supply chain efficiencies, and leveraging economies of scale can help achieve this objective. Furthermore, businesses should communicate the long-term value proposition of sustainable furniture - including durability and potential savings over time - to justify any price premium that remains.

While respondents exhibited moderate general environmental awareness, familiarity with eco-certifications was remarkably low, despite the relatively high level of trust expressed toward these labels when recognized. This suggests an opportunity to educate consumers about the significance of sustainability in the furniture industry and the role of certifications as credible

signals of environmental responsibility (Dangelico & Vocalelli, 2017). Businesses are encouraged to develop educational initiatives through point-of-sale materials, online platforms, and marketing campaigns to elucidate the meaning and benefits of eco-certifications. Transparent communication and storytelling about the company's sustainability practices can further strengthen consumer engagement and trust (Peattie & Crane, 2005).

The data indicates that, although most consumers are unaware of specific certification schemes, a substantial proportion trust these labels as indicators of sustainability. This latent trust represents a valuable asset for companies to leverage. Firms should prioritize obtaining credible certifications (e.g., FSC, PEFC) for their products and prominently display these certifications in marketing and on product labels. Providing concise explanations of the criteria and rigor underlying these certifications may further enhance their perceived importance and influence on purchasing decisions (Testa et al., 2015).

Respondents' material preferences indicate a clear inclination toward engineered wood, with limited interest in solid wood or recycled materials. It is important to note that this could be due to price sensitivity and popularity of use of these materials, as well as their functions. Businesses should consider exploring more sustainable alternatives where possible.

The findings also reveal an intention-behaviour gap: many consumers express concern about environmental issues yet report only occasional consideration of environmental impacts when purchasing furniture. To bridge this gap, businesses can employ behavioural interventions or "nudges" (Thaler & Sunstein, 2008), such as making sustainable options more visible, framing them as default choices, and highlighting their popularity or social desirability. Such strategies have been shown to increase the uptake of sustainable products without requiring significant changes in consumer preferences or willingness to pay.

Interestingly, although most respondents are unfamiliar with eco-certifications such as FSC or PEFC, those who are aware of them exhibit a relatively high level of trust in these labels. This suggests that better communication and education about eco-certifications could enhance their influence on customer choices and bridge the gap between environmental awareness and actual purchasing behaviour. Brands could implement messaging focusing on these topics within their social media strategy to influence the public opinion (Iliev, 2025).

The results underscore the need for the furniture industry to make sustainable options more accessible, competitive, and clearly communicated to consumers. Furniture businesses can benefit from an openness to change and adaptness to the changing environment (Iliev, I., 2024). Companies can benefit from leveraging the existing trust in certifications while addressing barriers such as price sensitivity and lack of information. Furniture businesses can contribute to advancing sustainability in the industry by adopting a multifaceted strategy that integrates competitive pricing, education, certification, product innovation, behavioural interventions, and market segmentation. By addressing both cognitive and practical barriers identified in this study, firms can enhance the alignment between consumer values and purchasing behaviour, thereby achieving both environmental and economic objectives.

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COMMUNICATION BETWEEN SALESPERSONS AND CUSTOMERS IN THE FURNITURE MARKET: DOES GAMIFICATION IMPROVE INTERACTION OUTCOMES?

Tsvetan Davidkov, Neviana Krasteva, Aleksey Potebnya

Abstract: This article presents the findings of a study conducted among customers in physical furniture stores in Bulgaria. The research tests the hypothesis that communication outcomes between salespersons and customers improve when gamified elements are integrated into the preliminary research phase. Key indicators – such as customer engagement, brand affinity, and trust – were evaluated based on participation in gamified activities. The study also investigates whether such gamification influences the motives behind visiting a physical store. Data were collected through a structured survey administered to 107 respondents across three retail chains (IKEA, Aiko, Yavor). The findings indicate a moderate positive association between participation in gamified activities and enhanced emotional and attitudinal outcomes, though no consistent link was observed between gamification and customers' reasons for visiting stores. The results highlight the potential of gamification to strengthen pre-purchase customer experience but also suggest that practical, tactile, and informational motives continue to drive in-store visits.

Keywords: gamification, customer experience, retail communication, furniture market, buyer behavior

1. INTRODUCTION

This article presents the results of a study conducted among customers in physical furniture stores in Bulgaria. In most cases, customers conduct a preliminary research to better understand the available options and clarify key questions before visiting the store. As part of this process, some customers engage in communication that includes gamified elements, while others do not – either because such an option is not available or because they choose not to participate.

The study tests the following hypothesis (H1): when customers engage with gamified elements during the preliminary research phase, the outcomes of communication between salespersons and customers improve – such as increased engagement, higher conversion rates, enhanced customer satisfaction, and stronger brand perception. This hypothesis is verified through interviews conducted at the point of sale.

Additionally, the study explores an important supplementary question (Q1): what are the primary motives for visiting a physical furniture store, depending on whether customers engaged with gamified elements during their initial research?

2. LITERATURE REVIEW

The rapid development of digital technologies has brought to the forefront the issue of integrating online and offline brand communication efforts, especially in sensitive areas where the tactile sensations of consumers are of critical importance – as is the case in retail furniture

sales. Increasingly, questions are raised about how the evolving nature of buyer–seller relationships should be reflected in communication strategies and in achieving a balance between physical and digital presence.

There is growing importance placed on involving consumers in the sales funnel through mechanisms such as loyalty programs and gamification.

Former research demonstrates that combining traditional sales methods with direct engagement through gamified elements and loyalty incentives can enhance the visitor experience and contribute to increased sales volumes (Krasteva, 2024; Ilieva, 2024).

In the context of gamification in retail, studies emphasize increased visitor engagement, motivation, and purchase stimulation. Technologically, mobile applications, augmented reality (AR), and virtual reality (VR) are the dominant tools used by major retail chains (Ventsislavova Georgieva & Popova-Terziyska, 2023; Olšiaková et al., 2022; Krasteva, 2024). Several studies also highlight emerging communication approaches specifically developed for promoting home furniture, aiming to make the in-store experience more interactive and appealing to modern consumers (Gao & Wu, 2025; Meena, 2024).

Shulan Yu, Hongli Zhang, and Qun Zheng (2024) examine how short video advertisements affect consumers' intentions to purchase furniture. In Central and Eastern Europe, Zinchenko and Chindyaev (2025) investigate approaches to fostering consumer loyalty in the furniture market, including through gamification. Another study – “The Influence of E-commerce on the Furniture Market in Poland: Analysis of Sales Changes and Consumer Preferences” – further demonstrates the timeliness of this topic (Białachowska & Niedbala, 2023).

The reviewed literature suggests that the role of gamification remains underexplored, particularly in the Eastern European socio-cultural context. At the same time, available studies support the assumption that in-store consumer behavior is an extension of the experience shaped during the preliminary online research phase. The closest study to our research is that of Krasteva (2024), which explores how gamified activities affect both communication outcomes and customer motives when visiting physical furniture stores.

3. DESCRIPTION OF THE STUDY

To test the proposed hypothesis (H1) and to answer the research question (Q1), the study applied three groups of indicators¹:

A) Indicators for specific outcomes of communication between salespersons and customers during the preliminary research.

After the preliminary research, to what extent do you agree with the following statements:

¹ The questionnaire also includes other indicators related to the outcomes of the preliminary research. A selection of these indicators is presented here.

V1: I have already decided what I want to buy (46)²;

V2: The research was interesting and fun (38);

V3: This research gave me pleasure (38);

V4: After the research, I became a bigger fan of these furniture products (26);

V5: As a result of the research, my trust in the manufacturer (brand) increased (19).

The response scale used: 5 – completely true; 4 – rather true; 3 – equally true and untrue; 2 – rather untrue; 1 – completely untrue.

(The percentage shown in parentheses reflects the share of respondents who identified with the statement, i.e. the sum of the responses “completely true” and “rather true” among those who answered.)

B) Indicators for the presence or absence of gamified elements during the preliminary research.

Sometimes furniture sellers invite potential customers to take part in various activities (online or offline). During the preliminary research, did you participate in any of the following?

V6: Participation in a loyalty program (36)³;

V7: Activities to learn more about products, prices, purchasing terms (23);

V8: Work in virtual interior design rooms (24);

V9: Events organized by sellers (e.g., holidays, themed events) (17);

V10: Games and competitions involving points or rewards (29);

V11: Downloading and using a mobile application (32);

V12: Communication with sellers or other customers via platforms, email, chat, etc. (33);

V13: Supporting public causes (e.g., sustainability, social projects) (19);

V14: Sharing personal ideas and feedback upon request (24);

V15: Performing specific roles (e.g., assembling a product yourself) (11).

(The percentages in parentheses indicate the share of respondents who participated in each activity, as a percentage of all surveyed.)

The hypothesis H1 is tested through these two groups of indicators. It is considered confirmed if results measured by indicators V1–V5 are higher among those who participated in the gamified activities listed in V6–V15. Verification is based on bivariate cross-tabulation analysis.

C) Indicators for customer motives to visit physical furniture stores.

How important is it for you, during your visit to the store, to clarify the following:

V16: To see how the furniture actually looks (84)⁴;

V17: To check the quality of the furniture in person (“A sight to behold and a touch to feel.”) (94);

V18: To assess the furniture’s comfort (92);

V19: To be sure the furniture is aesthetically pleasing (78);

V20: To take measurements and confirm it fits your space (82);

V21: To verify how easy it is to assemble (61);

² In parentheses after each indicator, the relative share of respondents who identify with the statement is indicated (percentage of those who responded – combining the answers “yes” and “rather yes”)

³ The percentage shown in parentheses after each indicator reflects the share of respondents who participated in this type of activity (as a percentage of all respondents).

⁴ The percentage shown in parentheses after each indicator reflects the share of respondents who identified with the statement (percentage of those who responded – combining the answers “very important” and “rather important”).

V22: To check for promotions or discounts (55).

Scale: 5 – very important; 4 – rather important; 3 – equally important and unimportant; 2 – rather unimportant; 1 – not important at all.

(Percentages reflect the sum of responses “very important” and “rather important.”)

Q1 is analyzed based on cross-distributions between indicators V6–V15 and V16–V22. We are interested in the presence and strength of statistically significant associations.

Data collection.

The fieldwork was conducted from April 10 to April 17, 2025, by student interviewers from the Faculty of Economics and Business Administration at Sofia University, under the supervision of Dr. A. Potebnya. A total of 107 respondents were surveyed in physical furniture stores: IKEA (73), Aiko (18), Yavor (16). The survey method was direct, anonymous, and paper-based. After logical and quality control, all questionnaires were included in the analysis.

The gender distribution was 47% female and 53% male. Age distribution was as follows: 24% up to 30 years old; 34% between 31 and 40; 32% between 41 and 50; and 10% over 50. These proportions provide a relatively balanced representation of key customer segments.

4. RESULTS AND DISCUSSION

Since purchasing furniture in physical stores typically involves preliminary research, it is important to note that most respondents conduct it by browsing online and on the web (59% of those surveyed); 38% obtain information from family and friends. During the preliminary research phase, 29% visit physical furniture stores. About 1/5 of respondents (21–22%) use one or more of the following sources: social media, customer reviews, consultations with experts. Approximately 6% of respondents also rely on specialized brochures, catalogs, or magazines. This distribution accurately reflects customer behavior in the course of preliminary research.

An important indicator for understanding customers' thinking and behavior is the culture of furniture shopping. A characteristic feature of this culture is the belief that buying furniture is an investment. The arguments are:

a) 3 out of 5 respondents believe that furniture is purchased rarely and that the purchase should therefore be carefully considered (only 18% agree with the statement that furniture is a “consumable” – something for short-term use);

b) nearly 3 out of 5 respondents are convinced that when buying furniture, one should purchase the best they can afford;

c) 65% of respondents agree with the statement that “good furniture is expensive – it is a long-term investment.”

As expected, most customers in these stores lean toward mass-produced furniture (only 3 out of every 10 respondents consider it truly important to own unique pieces – “items you won’t see in every home”). Nearly 3 out of 5 respondents prefer to purchase furniture from physical stores (as opposed to online shopping).

Verification of H1.

The bivariate distributions between indicators 1–5 and indicators 6–15 (a total of 50 cross-tabulations) provide grounds to conclude that the communication outcomes during the

preliminary research phase are better when games are used than when they are not. In 24 out of the 50 examined crosstabs, such a dependency is present. H1 is rather confirmed⁵.

There is evidence that participation in gamified activities enhances the positive experiences during the preliminary research (e.g., interesting and fun – v2). This participation also increases the sense of enjoyment (v3); it enhances brand liking (v4); and leads to greater trust in the brand (v5). At the same time, it is clear that these tendencies do not result in higher purchasing readiness (i.e., already formed purchase decision).

The studied characteristics of the consumer experience are influenced in different ways by gamified activities. The feeling that something interesting and fun is happening (v2) correlates with eight of the gamified activities. The enjoyment effect (v3) depends on five different activities. Brand liking (v4) – also on five activities. Increased trust (v5) – on five activities as well. The observed dependencies provide guidance for the potential of the studied gamified activities to influence key characteristics of the consumer experience. These configurations depend both on the actual nature of the gamified activities and their interpretation by customers, as well as on the individual characteristics of the customers and their shopping culture.

Answer to Q1.

Based on an analysis of the cross-tabulations between indicators 6–15 and indicators 16–22 (a total of 70 cross-tabulations), it was found that in only 6 cases (8–9%) a dependency is present. Overall, there is no evidence of a consistent dependency between participation in gamified activities and the motives of customers for visiting physical furniture stores (Q1).

The initial assumption in formulating this question was based on the idea that participation in gamified activities during the preliminary research would form a consumer experience (including new knowledge – emotions – attitudes – beliefs – expectations, etc.) that would influence the motives (reasons) for visiting physical stores. Such a link exists only in individual, isolated cases. It should be assumed (and tested) that customers' motives for visiting physical furniture stores may be better explained by other outcomes of the preliminary research – for example, to what extent it provided sufficient information about the desired products; the prices (including promotions and discounts); conditions for delivery, installation, and warranty services; reviews by other users.

5. CONCLUSION

The conducted study provides new insights into the role of gamification in shaping customer experience in the furniture retail sector. The results demonstrate that participation in gamified activities during the preliminary research phase positively correlates with emotional and attitudinal outcomes – such as enjoyment, trust, and brand affinity. However, this engagement does not directly lead to a stronger intention to purchase.

⁵ The strength of the associations (measured using Cramér's V) falls within the range [.252 ÷ .604]; in most cases, the values of Cramér's V are within the range [.252 ÷ .400]. Associations with values of Cramér's V between [.200 ÷ .400] are classified as moderate (Moderate association) – see Rea & Parker (2012).

Furthermore, gamified elements do not significantly influence customers' primary motives for visiting physical stores, which remain rooted in practical needs: visual inspection, tactile verification, measurements, and price evaluation.

These findings suggest that while gamification can enrich the pre-purchase experience and support brand positioning, it should complement – not replace – the functional value expected by furniture consumers. Future research could explore how hybrid strategies integrating gamification with value-driven product communication may enhance both digital and in-store interactions.

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FOREST-BASED BUSINESS MODELS IN CULTURAL AND CREATIVE TOURISM IN RURAL AND REMOTE AREAS: A SUSTAINABLE BUSINESS MODEL CANVAS APPROACH

Maya Ivanova, PhD

Abstract: This paper explores how forest-based cultural and creative tourism (CCT) can serve as a driver of sustainable development in rural and remote areas. By combining natural landscapes with cultural practices and creative industries, such business models offer opportunities for economic diversification, cultural preservation, and environmental stewardship. Using the Sustainable Business Model Canvas (SBMC) as a conceptual framework, the study analyses five types of forest-based business models, including eco-lodges, creative residencies, storytelling tourism, forest gastronomy, and adventure and experiential learning. Each model is examined in terms of its value proposition, key stakeholders, revenue streams, eco-social impacts, and operational challenges.

Findings highlight the essential role of local communities and their leaders in ensuring successful implementation, as well as the need for cross-sector cooperation and supportive policies from public authorities. While forest settings offer unique experiential and multisensory value, tensions between tourism development and conservation must be carefully managed. The paper concludes that forest-based CCT models can enhance socio-economic resilience and environmental awareness when grounded in participatory governance and place-based innovation. Recommendations are made for policy interventions, capacity building, and future research on long-term sustainability and transferability across different forest regions.

Keywords: Forest-based business models, Sustainable Business Model Canvas, Cultural tourism, Creative tourism, rural and remote areas, forests

1. INTRODUCTION

Cultural heritage is a key source of local identity and pride, offering significant potential to promote indigenous culture and attract both domestic and international tourists. In rural and remote areas—often situated in peripheral regions far from major roads and supply chains—industrial development is usually not feasible due to the high investment costs and long-term returns required. Instead, the development of local cultural attractions and tourism is often seen as a more accessible and sustainable path for regional revitalisation. Forests frequently form part of these areas due to their natural characteristics and geographic isolation. They are widely perceived as spaces for rest and recreation, making them attractive destinations for tourists (Joshi *et al.*, 2019). When combined with cultural resources, forest landscapes can provide enriched tourism experiences and new opportunities for economic development. However, to harness this potential effectively, forests require appropriate models of economic governance that balance natural and cultural preservation with economic and social benefits for local communities (Sgroi, 2020). This creates a strong rationale for exploring the integration of cultural and creative tourism within forested environments.

The aim of the paper is to conceptualize forest-based business models in cultural and creative tourism by revealing the key drivers and challenges, main participants and regulatory constraints, all of them presented and evaluated within the framework of Sustainable Business Model Canvas.

To do this the paper will first provide the foundation of cultural and creative tourism (CCT), its application in forest landscapes and the key components of the used analytical tool – Sustainable Business Model Canvas (SBMC). Then several forest-based SBMC will be explored, analysing main participants, drivers, challenges and barriers. The final sections will discuss important aspects and implications about the forest-based SBM.

2. LITERATURE REVIEW

Tourism is widely recognised as a means to improve local living standards and address challenges such as depopulation, migration, and infrastructure deficits in rural areas (Falak *et al.*, 2016). In the post-COVID-19 context, many people have increasingly sought peaceful, nature-based experiences and digital detoxification, reinforcing the appeal of rural tourism as an alternative to urban and mass tourism (Liu *et al.*, 2023). When local communities are actively involved, tourism becomes not only an economic activity but also a way to preserve and promote cultural heritage (Castanho *et al.*, 2023). Furthermore, responsible rural tourism raises environmental awareness and encourages sustainable use of local resources (Liu *et al.*, 2023).

Forests, often located in remote rural areas, offer strong potential for development as cultural and creative tourism destinations. Traditional forest landscapes enriched with cultural elements have been shown to resonate well with visitors (Chen *et al.*, 2017), providing both therapeutic and recreational benefits (Zhong *et al.*, 2024). Combining natural forest environments with local cultural traditions can create rich, immersive experiences. However, research indicates that local residents often value forests more for timber and economic use than for tourism or recreation (Frick *et al.*, 2018; Chen *et al.*, 2017). This highlights the need to introduce viable models that demonstrate how cultural and natural resources can be monetised sustainably, ensuring long-term socio-economic benefits for local communities.

In this context, business modelling becomes essential. A business model is defined as “a coherent set of activities that creates value for customers and defines mechanisms for the business to profitably sustain itself” (Reinhold *et al.*, 2019, p. 1120). For forest-based cultural and creative tourism, the Sustainable Business Model Canvas (SBMC) offers a suitable framework. Building on the classical Business Model Canvas (Osterwalder & Pigneur, 2010), the SBMC illustrates how key organisational functions connect with supply chains and stakeholder networks to generate and distribute value (Joyce & Paquin, 2016). Importantly, it also integrates eco-social costs and benefits (James *et al.*, 2025), emphasising long-term value creation not only for the business itself but also for the wider community and environment.

3. FOREST-BASED BUSINESS MODELS IN CULTURAL AND CREATIVE TOURISM

Table 1 presents a range of forest-based business models, evaluated using the Sustainable Business Model Canvas (SBMC) framework, which explicitly includes eco-social costs and benefits, thus providing an excellent fit for analysis of their diverse nature. A common feature across all models is their forest setting, with ecological aspects almost always

integrated alongside cultural and creative activities or resources. Each column of the table corresponds to a specific SBMC component.

Table 1. Forest-based sustainable business models

SBMC	Brief Description (Activities and resources)	Value proposition	Revenue streams	Target customer segments	Key partners/ Stakeholders Participants	Eco-social costs and benefits	Challenges
1. Eco-lodges and cultural retreats	Nature-based accommodations offering artistic, wellness, and cultural experiences. Integration with local crafts, storytelling, and traditional knowledge	Authentic, immersive, and eco-conscious tourism experiences	Accommodation, guided experiences, creative workshops	Pupils, Health and Eco-conscious tourists; specialized clubs	Local historians, museums, forestry departments	Costs: maintenance, lodging; Benefits: awareness, local jobs	Remote access, visibility, environmental protection
2. Creative Residencies and Artisan Workshops	Hosting artists, musicians, and craftspeople in forest environments. Traditional crafts and digital innovation as cultural heritage preservation	Artistic inspiration in nature, skill-sharing, and local craftsmanship	Residency fees, workshop participation, sales of creative works	Artists, students, cultural tourists	Municipalities, art schools, craftsmen, local artisans	Costs: infrastructure, staffing; special equipment. Benefits: jobs, education, crafts revival	Development costs, institutional support, visitor impact
3. Cultural Heritage and Storytelling Tourism	Reviving myths, legends, and indigenous traditions in forest settings. Interactive experiences: folklore trails, theatrical performances, and digital storytelling	Authentic cultural storytelling, historical education. Oral history documentation, immersive experiences, tourism events	Live performances, podcasts, AR-enhanced experiences	Families, cultural tourists, schools, domestic travellers, educational tours, themed souvenirs	Storytellers, anthropologists, schools, theatres, historians, museums	Costs: staff, seasonality; Benefits: heritage preservation, youth engagement	Authenticity risks, weather dependency, content development
4. Gastronomy and Forest-to-Table Experience	Culinary experiences based on forest ingredients (wild food, mushrooms, herbs). Sustainable farm-to-table dining and foraging tourism	Unique food experiences rooted in local biodiversity and promoting traditional forest foodways	Dining services, food tours, product sales, workshops	Culinary tourists, foodies, amateur chefs	Local farms, forest food producers, culinary and botanical experts	Costs: venues maintenance; safety, training; Benefits: biodiversity, local food promotion	Seasonal limits, legal compliance, overharvesting risk
5. Adventure and Experiential Learning Tourism	Adventure-based tourism blended with cultural education. Activities like forest survival training, wildlife tracking, and eco-volunteering	Sustainable adventure with cultural and ecological learning	Tour fees, training programs, conservation donations	Adventure tourists, families with kids, hikers; pupils, specialized clubs	Conservation groups, outdoor education providers, survival experts	Costs: training, equipment Benefits: education, low-impact tourism	Seasonality, service quality

The forest-based business models are built around various activities that incorporate cultural elements within forest environments. These models also consider visitor flows, which necessitate appropriate tourist infrastructure. This unique blend of culture, tourism, and forest landscapes supports both business feasibility and sustainable development, reinforced by local entrepreneurship and community engagement.

For instance, SBM 3 (Cultural Heritage and Storytelling) requires careful preparation of content and coordination between indigenous guides and external cultural experts. Similarly, SBM 4 (Gastronomy and Forest-to-Table Experience) relies on well-trained personnel knowledgeable in mushroom picking and related practices (i.e. mycotourism, see Joshi *et al.*, 2024), as well as experts in gastronomy and socio-cultural traditions to ensure synergy across all activities. These collaborative efforts encourage stronger cooperation among local stakeholders and external partners, leading to enhanced eco-social benefits (Joshi *et al.*, 2024).

A particularly engaging model is SBM 2 (Creative Residencies and Artisan Workshops), which combines contemporary arts with traditional crafts while offering educational experiences to visitors—a powerful means of promoting and transferring knowledge across generations and cultures.

4. DISCUSSION

Forest-based business models cannot be implemented without the active involvement of local communities. These models go beyond business operations and serve broader goals such as community building and place-making, thereby generating additional social value and benefits (Joshi *et al.*, 2016).

A typical feature of such models is their location—forests are often situated in rural and remote areas, which are less industrialised and distant from urban centres. In these settings, the launch of new business initiatives often encourages collaboration rather than competition (Falak *et al.*, 2016). This is especially true among older residents, who tend to have a stronger sense of sharing and mutual support. However, this may create challenges in practice, as younger people—who are generally more entrepreneurial and willing to take risks—are often less engaged or absent due to urban migration.

Forests are most commonly associated with their ecological functions (Frick *et al.*, 2018), which can limit the integration of cultural and creative elements into tourism offerings. At the same time, this perspective supports environmental responsibility in the implementation of forest-based business models.

A key tension remains in how forests are used for tourism and business. Many tourists expect basic infrastructure such as parking areas, picnic spots, and fire sites, yet they also express concern for nature conservation and minimal disruption to natural settings (Frick *et al.*, 2018). This dilemma is mirrored among local stakeholders (e.g. businessmen and residents), where the former require infrastructure to support business development while the latter insist on preserving the natural environment.

Forests also provide rich multisensory experiences (Frick *et al.*, 2018). Visitors associate forests with distinct smells (e.g. herbs, wood), sounds (e.g. birdsong, rustling leaves), and visuals (e.g. shaded meadows, dense trees), as well as specific temperature or humidity (Zhong *et al.*, 2024). These features can enhance the visitor experience and can be linked to traditional practices such as herb or mushroom foraging, food or cosmetic preparation, or artistic activities like painting or craft-making using local materials.

Finally, forest biodiversity—its flora and fauna—can be incorporated into tourism products through local stories, legends, and cultural symbols, further enriching the authenticity and appeal of forest-based business models.

5. CONCLUSION

Forest-based cultural and creative tourism offers a valuable opportunity for sustainable development in rural and remote areas. By combining natural landscapes with local traditions, crafts, and storytelling, these models create distinctive visitor experiences while supporting local economies and cultural preservation. The Sustainable Business Model Canvas (SBMC) effectively captures their value, structure, and eco-social impact.

To succeed, these business models require cooperation among stakeholders, tailored training programmes, and sensitivity to the ecological limitations of forest areas (Melnykovich *et al* 2018). Promoting cultural narratives and multisensory experiences can further enhance tourism appeal (Zhong *et al*, 2024; Liu *et al*, 2023).

Active engagement of local communities and their leaders is essential (Joshi *et al*, 2024). Their preferences, capacities, and concerns must be considered to ensure inclusive and meaningful participation. Also, government and local authorities play a crucial role in providing the necessary infrastructure, policy support, and long-term vision for sustainable tourism development (Gang, 2011).

Future research should focus on evaluating the long-term sustainability of such models, including their environmental, social, and economic outcomes. Comparative studies across different forest regions would help identify effective practices and adaptable approaches.

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CULTURAL HERITAGE OF ISTRIA AS INSPIRATION FOR FURNITURE DESIGN IN TOURIST ACCOMMODATION

Danijela Domljan, Boris Iliev, Nikola Lukež, Zoran Vlaović

Abstract: Today's problem with furnishing the interior of modern tourist accommodation is often the lack of indigenous expression originating from the local environment. The aim of the paper is to present the process of designing a functional collection of contemporary furniture inspired by indigenous elements of the cultural heritage of Croatian region of Istria for furnishing rural tourist accommodation facilities. The paper explores traditional Istrian heritage, including tradition, motifs, symbols, ornaments and similar artifacts, and analyzes the contemporary needs of users/tourists in order to create design guidelines and define requirements. The process of creating conceptual solutions for a desk, as part of a furniture assortment, using ornaments of Istrian heritage and respecting the given requirements is presented.

Keywords: furniture design, cultural heritage, rural tourism, accommodation interiors, design methods

1. INTRODUCTION

Cultural and rural heritage are increasingly linked to tourism, thanks to ecological and sustainable guidelines of global development. As contemporary tourism trends shift from mass tourism to individualized and authentic local experiences, tourism has often been used as an economic justification for preserving cultural heritage and historical artifacts (Timothy, 1997). It is evident that globalization negatively impacts local cultural and rural heritage, compromising their integrity and authenticity (Stelios and Melisidou, 2010; Demonja and Baćac, 2012), which has also spurred the development of rural eco-tourism.

Today's sustainable and ecological modern tourism, focused on rural development and supported by cultural and creative industries in rural areas, contributes to the preservation of rich cultural-historical heritage as well as environmental advancement (Cerquetti, 2022; Jelinčić, 2024). Trends in conscious sustainable tourism are increasingly oriented toward intangible dimensions of tourist demand: experience and immersion (Craneiro et al, 2015). This includes discovering natural local beauty, traditional food and drink, handmade souvenirs, local customs, and even the interior design of accommodations where tourists stay.

However, despite the emphasis on "sustainability" in rural tourism facilities and hotel accommodations, the interiors and furnishings in such establishments often lack authenticity in reflecting the local landscape or exaggerate regional design elements, thereby compromising aesthetic integrity. Apartment owners, frequently in a rush to operationalize their properties, resort to inexpensive furniture from nearby retail stores (Obranković, 2022), while global hotel chains impose their own standardized interior styles. This approach leads to a loss of authenticity, uniqueness, and diversity in traditional cultural heritage across rural locations, depriving guests of a fully immersive experience. It has been observed that a key issue in modern tourist accommodations today is the absence of an authentic design language rooted in the local environment.

This paper presents an approach to the design process of creating conceptual solutions by utilizing heritage ornaments while adhering to specified requirements, with the ultimate goal of developing a functional collection of contemporary furniture inspired by indigenous elements of cultural heritage. As part of the author's broader research (Domljan et al., 2025), the study illustrates the development of a desk — a component of a furniture assortment that also includes a side table and a dresser — designed for the living room furnishings of a sustainable rural heritage-inspired tourist apartment in Croatia's Istria region, drawing on its local tradition and cultural legacy.

2. MATERIALS AND METHODS

The study analyzed artifacts discovered at historical sites and museums in Istria. The Croatian part of the Istrian peninsula is located in the western region of the Republic of Croatia and is renowned for its tourism, gastronomy, and processing industry (Prodan, 2023).

The research examined ethnographic heritage objects from Istria, which served as inspiration sources for designing new interior products. The review included collections of furniture, traditional objects, folk costumes, tools, jewelry, and other equipment used in historical rural interiors, as well as the cultural heritage of park monuments at analyzed outdoor sites. For the purposes of this study, visits were conducted to museums and ethnographic collections across Istria: (1) The Glagolitic Alley in Roč and Hum; (2) the Buje Ethnographic Museum; (3) the Ethnographic Museum of Istria in Pazin; (4) the Pazin City Museum in Pazin; and (5) the Kažun Park in Vodnjan. Field research was carried out, involving observation and photography. In terms of design methodology, the Cyclical Method of the Creative Process (Domljan and Janković, 2022) was applied. This method begins with defining the problem and user needs, establishing requirements, conceptualizing design solutions, and proposing guidelines for the final product solution.

3. RESULTS

The field research enabled the collection of information that forms a comprehensive mosaic of findings, as presented in Table 1.

Table 1. The artifacts identified during field investigations served as design inspirations

Location	Photographs
(1) The Glagolitic Alley	
(2) The Buje Ethnographic Museum	

(3) Ethnographic Museum of Istria and (4) Pazin City Museum		
(5) The Kažun Park		

3.1. Concept development

To formulate a conceptual solution in the first phase of the creative process, an analysis of furniture placement needs within the interior was required. The 5W analysis (Who, What, When, Where, Why) defined the following parameters:

- **WHO** / uses the furniture: Individuals, couples, families with children, various age groups (young, elderly), domestic/foreign tourists
- **WHAT** / function of the furniture: relaxation, leisure, work (laptop use), socializing, food and beverage consumption, storage
- **WHERE** / furniture placement: vacation homes, apartments, tourist rental rooms, living room including workspace
- **WHEN** / usage timeframe: annual vacations, free time, business trips
- **WHY** / need for such furniture: to provide an authentic interior experience reflective of the chosen tourist destination

Defining requirements is the most critical phase in concept creation, as collectively, they establish the primary guidelines for developing product design solutions. The requirements for the new desk concept, as the part of a larger furniture collection, are interdisciplinary and are presented in Table 2.

Table 2. Key design requirements for the desk concept development

Requirements	Description
Functional performance	• Develop a multifunctional product capable of serving various purposes (work, reading, dining) while maintaining space efficiency • Ensure compatibility with other elements of the furniture collections for cohesive integration (coffee table, chest of drawers/commode)
Ergonomics considerations	• Apply standard anthropometric measurements for adults • Based on average adult height of 174.3 cm (Panero and Zelnik, 1990)
Aesthetic appearance	• Primary materials: Oak-veneered laminated board (traditional Istrian woodcraft); Medium-density fiberboard (MDF); Steel • Surface Treatments: Plant-based clear oil finish for oak components; Polyurethane lacquer for MDF; matte lacquer finish option

	• Color Palette: Muted green accents; natural wood grain, tone and luster preservation • Ornamentation: Incorporates motifs from Istrian ethnographic artifacts; simplified geometric patterns and designs
Psychosocial	• Create a pleasant and relaxing atmosphere through thoughtful selection of materials, colors, and forms • Utilize "warm" materials (oak) and tones with aesthetic characteristics – positive impact on human health and wellbeing (Mamić and Domljan, 2024)
Health & hygiene	• Ensure easy hygiene maintenance to accommodate frequent user turnover • Use ecologically safe and health-friendly surface treatment materials
Ecological sustainability	• Employ rational utilization of biodegradable and/or recyclable materials • Source FSC and PEFC certified solid wood for all wooden components
Structural integrity	• Guarantee stability, strength and durability against various loads (leaning, etc.) while ensuring user safety
Technical & technological feasibility	• Easy repairability with replaceable components • Develop technical solutions according to manufacturer's capabilities and equipment availability
Economic viability	• Position in a higher price segment for both the desk and all collection

The ideation process begins with inspiration and progresses through sequential development phases (Figure 1): Phase I - Initial concept based on inspirational elements; Phase II - Creative exploration with added complexity; Phase III - Functional analysis and evaluation; Phase IV - Optimization and refinement. This structured approach culminates in the final design solution (Figure 2).



Figure 1. Development phases of the desk conceptual design



Figure 2. Final desk solution with ornamental detailing



Figure 3. Furniture collection in interior context

4. DISCUSSION AND CONCLUSION

The study demonstrates how even a small geographic region like Istria successfully preserves and transmits its modest yet valuable cultural and rural heritage. This heritage serves as inspiration for contemporary sustainable furniture design in tourist accommodations within observed rural areas. The research highlights the following conclusions, acquired values, and future challenges:

- The research presents a sustainable furniture design concept through a desk prototype that adapts Istria's rural heritage elements for tourist accommodations, demonstrating scalable application potential to other tourism regions.
- A primary design challenge lies in balancing aesthetics, conceptual expression, semantics, and cultural heritage reinterpretation. The solution must simultaneously meet functional requirements and evoke the distinctive experience of the local geographic region.
- The proposed heritage value analysis model and its implementation in conceptual solutions offers potential for tourism promotion and regional rural identity branding initiatives.

Further investigations should be directed toward: (a) confirming the developed concept's practical applicability and user suitability, (b) evaluating compliance with all specified requirements, and (c) testing implementation in authentic tourist accommodation environments.

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BEYOND FUNCTIONALITY: WOODEN INTERIOR ELEMENTS AS CARRIERS OF CULTURAL IDENTITY AND SUSTAINABILITY IN THE EDUCATIONAL ENVIRONMENT

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Abstract: This study analyzes the role of wooden interior elements in Sofia University "St. Kliment Ohridski" as artifacts integrating sustainable development and the preservation of cultural heritage. Through a focus on authentic furniture, paneling, and architectural details, the work examines the mechanisms through which their preservation contributes to maintaining the "*genius loci*", cultural memory, and institutional identity. Emphasis is placed on the University's Aula as a historically significant space, testifying to key events in national history and, simultaneously, as an object of architectural and artistic value. The analysis considers the university's interior as an emblematic example of the development of furniture production in the early 20th century, marked by the introduction of electrification and new production technologies that led to the emergence of factory-made furniture. By applying a comparative analysis with other European universities, the study demonstrates the potential of wood in interior design as a means of connecting historical heritage with contemporary sustainability requirements. The article focuses on the role of wooden elements as carriers of historical narratives and cultural traditions, which shape the specific atmosphere of the educational environment and contribute to the formation of the identity of generations of students. Additionally, the connection between the authentic interior and the principles of sustainability is examined, emphasizing the preservation of cultural heritage.

Keywords: wooden elements, cultural identity, sustainability, educational environment, Sofia University, *genius loci*

1. INTRODUCTION

In line with current global efforts towards sustainability and cultural heritage preservation, the importance of both tangible and intangible remnants has become increasingly apparent. Universities, being enduring testaments to history and culture, encapsulate the essence of the periods during which they were established. They commemorate the legacy of previous generations while simultaneously embodying a distinctive amalgamation of history and contemporary existence. The university building and its internal areas and design are often viewed mainly for their functionality, however they encompass much more. In our research, we employ the Sofia University "St. Kliment Ohridski" as a case study to examine its interior spaces, particularly the Aula and its wooden components, as essential embodiments of cultural identity and as tools promoting sustainability. The analysis is further broadened through a comparative examination of other Southeastern European universities from the late 19th century, specifically the University of Zagreb (Croatia) and the University of Iași (Romania), chosen for their temporal relevance and importance within their respective communities and urban development.

The primary assertion is that the interior of Sofia University, through its emblematic design, well-chosen materials, and skilled craftsmanship, functions not merely as an academic setting but also as a custodian of national cultural identity and heritage. This study conducts a comparative analysis with other Southeastern European institutions from the same period to investigate how university architecture serves as a medium for conveying socio-cultural values, institutional authority, and long-term sustainability.

2. LITERATURE REVIEW

Comprehending the essence of a place, requires an examination of its physical attributes and spirit of place (*genius loci*), alongside human endeavours, intentions, and shifting values that influence the perception of its authenticity and relevance across time (Jive'n, G. & Larkham, P., 2003). To assess it, we focus the analysis on the Sofia University Aula, a place of significant architectural and artistic merit and a witness to pivotal events in Bulgarian national history (Arnaudov, 1939). The wooden interior elements and design of the University are regarded not simply as architectural aspects, but as essential components of its *genius loci*. These characteristics embody the cultural memory, aesthetic values, and social identity of the academic community and the concept of the University (universum). Their stewardship promotes sustainability via conservation and reuse, while also fostering cultural resilience and ensuring continuity for future generations of students. The wooden interiors are dynamic elements that contribute to the development of community, creativity, and belonging – values crucial for a resilient and sustainable academic environment (Vecco M., 2020; Skounti, A., 2008; Lokas, I. et al., 2023). The University exemplifies the intersection of historical preservation, sustainability, and education, illustrating that tangible structures can cultivate intangible values that, in turn, uphold institutional and cultural identity across time (Whitton, P., 2018).

3. METHODOLOGY

A comparative study was used to show the unique features and changing trends in academic interior design, architectural solutions, and the use of wood at Sofia University "St. Kliment Ohridski" as well as in selected other Southeastern European universities as examples. The study uses a lot of historical data, such as government documents, construction records, archival photos, specialised bulletins, and the official archives of Sofia University. Additionally, are incorporated contemporary observations, backed up by recent photos of the interior areas.

The analytical framework brings together a number of important theoretical ideas, with a focus on the idea of *genius loci*, or "spirit of place." This includes both the tangible and intangible aspects that make the University special. The study also explores the relationship between cultural memory and institutional identity, approaching the interior not merely as a functional space but as a chronicle of historical narratives and cultural practices. The topics of continuity and sustainability are given special consideration, examining how the preservation of the authentic interior aligns with broader principles of cultural heritage protection and sustainable development.

4. HISTORICAL AND ARCHITECTURAL BACKGROUND OF SOFIA UNIVERSITY

Founded in 1888, Sofia University "St. Kliment Ohridski" is the oldest higher education institution in Bulgaria, conceived as a key pillar in the formation of a modern educational system in the newly liberated Bulgarian state (3.03.1878). Emerging ahead of most universities in the Balkans – except those in Athens (1837), Iași (1860), Bucharest (1864), and Zagreb (1874) – the University embodied both national ambition and European educational ideals (Arnaudov, 1939).

Initially housed in temporary locations, operated out of nine different both state-owned and rented properties before the construction of the University's own dedicated building in 1934 (Kolev, V. et. al., 2018). The building of the Rectorate was made possible by the philanthropic

donation of the Georgiev brothers, Evlogi and Hristo, prominent merchants and patriots (The Will of Evlogi Georgiev and the Sofia University (1914). Their endowment, exceeding 13 million gold leva, laid the financial and institutional foundation for the University and its physical foundation.

The architectural development of the Rectorate reflects the long and complex historical process that shaped the University's identity. A competition in 1906 awarded the project to the French architect Henri Bréasson, but his design was never realized. After World War I, the Bulgarian architect Yordan Milanov (graduated in Vienna) reworked and expanded the project. His vision added monumental features such as a central dome and Baroque-inspired façades. In 1924, the first stone was laid. Different architects worked on the building in stages, notably Lyuben Konstantinov (Konstantinov, 1993), who made the design more classicist. The construction took 60 years and ended in 1985 when the northern wing was finally expanded.

The University's Rectorate building and its interiors, especially the Aula, were not only emblems of institutional grandeur, but also tangible representations of national memory, cultural yearning, and changing architectural practice. The many ways they have grown – thanks to historical events, industrial modernisation, and artistic vision – make a great case for looking into how physical space shows intangible traits, which adds to the University's *genius loci*.

5. THE INTERIOR OF THE SOFIA'S UNIVERSITY RECTORATE: CULTURAL MEMORY AND SYMBOLIC NARRATIVES

A visual language of institutional dignity and national identity is created by fusing Renaissance, Baroque, and Classical styles in the interior of Sofia University's Rectorate. Important architectural features such as the central marble staircase, the floors made of Czechoslovak terracotta mosaic, the Italian marble wall cladding, and the vibrant stained glass windows made by well-known Bulgarian artists serve both decorative and profoundly symbolic purposes. Presenting key figures from Bulgarian cultural history, such as Saints Cyril and Methodius, Kniaz Boris I, Tsar Simeon, St. Kliment of Ohrid, and John the Exarch, these components tell a story of a historical and cultural continuum. The stained-glass windows were damaged during the 1943–1944 bombings, but restored by Prof. Dechko Uzunov (1983), demonstrating a sustained dedication to heritage preservation (Todorova, T., & Zidarova, L., 2003).



Figure 1a: Aula, 1934 r.

Source: https://www.uni-sofia.bg/index.php/bul/universitet_t/istoriya/simvoli_na_universiteta/aula



Figure 1b: Aula, 2025

Source: Own author's archive (Ani Istatkova)

The symbolism embedded in the architecture positions the University as a “temple of knowledge”, where elements such as the triumphal arch, life-tree columns, and the ascending stairway toward the Aula signify a spiritual and intellectual journey. The spherical ceiling of the Aula, richly ornamented, represents the cosmic egg, a metaphor for universal wholeness and intellectual completeness. (See Figure 1a and 1b) Beyond its physical features, the interior expresses the University's role as a guardian of national memory and a shaper of public values and civic identity.

6. THE ROLE OF WOODEN INTERIOR ELEMENTS IN EXPRESSING CULTURAL IDENTITY AND SUSTAINABILITY

Within the broader architectural and symbolic framework of Sofia University “St. Kliment Ohridski,” the wooden interior elements – particularly in the Aula and representative halls – play a significant role in articulating cultural memory, institutional identity, and sustainability. Far from being merely decorative or conservative, the use of solid oak and walnut was a deliberate choice aligned with prestigious European academic architecture of the early 19th century, aiming to convey permanence, dignity, and national aspiration.

The wooden parts of the interior, especially in the Aula and representative halls, are very important for expressing cultural memory, institutional identity, and sustainability within the larger architectural and symbolic framework of Sofia University “St. Kliment Ohridski.” The choice of solid wood and walnut was not just for being “retro” or “conservative”; it was a conscious choice that fit with the prominent European academic architecture of the early 19th century. The goal was to represent permanence, dignity, and national aspiration.

The woodwork in the building presents the stability and cultural continuity of the early Bulgarian state through its academic architecture. The Bulgarian craftsmen and workshops who contributed to the timber interiors are still kept. Alexander Nikolov and Bogdan Drandev made the wall paneling, balustrades, and benches in the Rectorate. Dobri St. Zagralov made the floorboards, parquet flooring, and wooden stairs in the Aula Magna (See Figure 2a and 2b). The main material was solid oak wood from the state-owned forestry company “Ticha”. It was chosen for its strength, beautiful appearance, and symbolic value in high-end institutional settings. Marko Kitanov and Milan Nikolov were in charge of the oak joinery. The construction protocols from the early 1930s (e.g., protocols №113/6.11.1930; №120/25.11.1930; №134/23.12.1930; №163/22.02.1931; №31/28.05.1931) show how carefully the interior work was planned and documented.



Figure 2a: A moment from the construction of the Rectorate of Sofia University - craftsmen laying the parquet floor in the Aula, early 1930s. Archive photos. Old Sofia (www.stara-sofia.bg)



Figure 2b: Aula, 2025
<https://impressio.dir.bg/gallery/kontsert-s-kauza-e-v-podkrepa-na-tvorts-i-sas-zritelni-uvrezhdaniya?i=1>

During this period, there was a noticeable trend in Sofia toward using solid oak furniture for dining rooms and offices – furnishings that were heavy, stately, and intentionally representative (Parvanov, 2008, p. 66). Although comprehensive archival information about the furniture makers for all spaces in the Rectorate is scarce, surviving authentic pieces – such as the chairs in ceremonial halls 1 and 2 and the Rector's office – are stylistically consistent with the work of Dimitar Tsolov. These items bear a striking resemblance to the furnishings in the Bulgarian National Bank building, designed and furnished during the same era, for which records confirm Tsolov as the producer (Parvanov, 2008, p. 236). Furthermore, some darker-stained wooden furniture within the university recalls the stylistic features of the furniture produced by the firm Nemechek. These pieces are characterised by slightly curved contours and stylistic influences from Germanic Mediaeval design and the Viennese Renaissance, reflecting an orientation toward early forms of serial production and a synthesis of traditional craftsmanship with modern utility (Parvanov, 2008, p. 77). The interior of Sofia University's Rectorate from the 1930s reflects the characteristic trends of the period, including richly decorated wooden doors, panelling, parquet flooring, and libraries. However, general furnishings, such as benches in auditoriums and office furniture, were mass-produced and lacked specific design. This shift was a result of post-war national catastrophes, limited financial resources, the onset of industrialisation and modernism, and the influence of the Art Deco style. This trend became particularly pronounced after 1945 and nationalisation. This layered approach to interior wood design – encompassing functionality, durability, and visual grandeur – demonstrates how material choices serve as enduring custodians of cultural identity, reflecting both national aspirations and international stylistic currents. The wooden interiors of Sofia University are thus not merely elements of architectural ornamentation but integral to the institution's spatial narrative and academic symbolism.

7. COMPARATIVE ARCHITECTURAL APPROACHES IN SOUTHEAST EUROPEAN UNIVERSITIES

Beginning in 1898, the planning for Sofia University examined the practices of other institutions, such as those in Zagreb, Iași, Athens, and Bucharest. Important decisions regarding the necessary functions and the layout of the space were aided by these comparisons (Arnaudov, 1939). The goal of each of these colleges was to create massive, impressive structures that would serve as both educational institutions and national symbols of cultural identity. Some of the earliest official university buildings were in Sofia, Zagreb, and Iași. They played a significant role in forming the community and exemplifying the values of community, education, and prestige. Studies on the construction, renovation, and expansion of these buildings reveal that this was a laborious process that lasted for decades or even centuries and involved many different procedures. Whether the buildings were designed for university use (as at Sofia University) or were repurposed for academic purposes (as at Iași and Zagreb universities), it is clear that a deliberate effort was made to transform them into national symbols of culture and education. Each institution made an effort to be more academically honest and representative, but they each did so differently depending on the circumstances of their respective nations and the advancements in technology. For example, the oldest university in Romania, the University of Iași, was established in 1860. The institution's strength and cultural sophistication are displayed in its opulent oak interiors. In contrast, steel structures were used in the early stages of the University of Zagreb's construction. This was a

progressive method that blended new technical solutions with conventional materials like wood (Sgrada sveuchilista u Zagrebu, 1999; Križić Roban et al., 2022, 83, 84, 89). These differences show that each nation has a unique modernisation and identity-building approach. In Southeast Europe, university buildings served as more than just workplaces. They also turned into "guardians of memory," compiling tales of culture and history.

8. CONCLUSION

The case of Sofia University "St. Kliment Ohridski" reveals how material preferences – particularly wooden interior elements – serve not only as architectural features; they serve as enduring custodians of cultural identity, institutional memory, and sustainable development. The Aula is the university's heart in both a literal and figurative sense. It's a place where the country's history, its creative vision, and its dreams for education can all meet. Crafted with precision, purpose, and deep symbolic resonance, the wooden furnishings and paneling in this space embody the values of permanence, dignity, and civic responsibility that were central to the vision of the early Bulgarian state. By tracing the provenance, craftsmanship, and stylistic language of these elements, the study demonstrates how wood—as a traditional yet adaptable material—bridges historical heritage and modern sustainability principles. The emphasis on local resources, artisanal labor, and the reuse and conservation of authentic interiors positions the University as a model for integrating environmental and cultural sustainability in institutional design.

The comparative analysis with other Southeast European universities further underscores that while material, stylistic, and technological approaches varied, a shared aspiration to monumentalize education and embed it within the national cultural landscape persisted across the region. Despite different paths to modernization, these institutions collectively highlight the power of architecture—and wooden interiors in particular—as media through which societies express continuity, belonging, and evolving identity. In this light, the authentic wooden interiors of Sofia University are not static remnants of the past, but active contributors to the genius loci of the institution. Their continued preservation is not only a matter of heritage conservation but a vital strategy for fostering a sustainable, inclusive, and identity-rich educational environment for future generations.

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CORK FLOORING MARKET IN SELECTED SEE NON-EU COUNTRIES: OPPORTUNITIES AND BARRIERS TO DEVELOPMENT

Slavica Petrović, Dragan Borota

Abstract: The article analyzes the types of cork flooring and their presence in the markets of selected SEE non-EU countries. In this sense, an analysis of the main characteristics of cork tiles and cork panels as the main types of cork floor coverings has been carried out. In order to identify the main trade flows of these products, the European countries that are the largest suppliers of selected SEE non-EU countries were analyzed. To compare the market supply, selected markets of SEE non-EU countries were analyzed. In particular, the barriers assumed to have an impact on market development in selected SEE non-EU countries were analyzed.

Keywords: cork, flooring, cork tiles, cork panels, supply.

1. INTRODUCTION

Cork is the "protective layer of bark which, periodically, can be harvested from the trunk and branches of the cork oak (*Quercus suber* L.) constituting the raw material for cork products" (ISO 633:2019). Cork is initially taken from a 15 to 20 year old trees and the process is repeated every 8 to 10 years without damaging the tree (source: <https://www.mantoncork.com/history-of-cork/>). Annual height increment varies, but is estimated at around 60 to 90 cm per year in the early stages of growth (Gil L., et al., 2008). The average productivity of cork oak forests is around 150 kg of cork per hectare over a ten-year utilization interval, while in forests with large trees it can be between 2000 and 5000 kg/ha (Ciesla MW, 2002). A single tree can produce between 100 and 200 kg of cork during its lifetime (Ciesla MW, 2002). Cork oaks can live between 200 and 250 years (Gil L., et al., 2008).

In Europe, cork is mainly produced in Portugal, Spain, Italy and France. These countries account for 65% of global cork production, while the remaining 35% is produced in North Africa (source: <https://www.mantoncork.com/history-of-cork/>). The total area of cork oak forests worldwide is 2.2 million hectares, of which 54% is in Spain and Portugal (source: <https://www.mantoncork.com/history-of-cork/>).

This natural, renewable resource has been used since ancient times, as evidenced by numerous finds (sources: <https://corkforest.org/history-of-cork/>; <https://www.mantoncork.com/history-of-cork/>). Remains of cork barrels, women's shoes and roofing material dating back to the 4th century BC have been found in Italy, and wine amphora stoppers dating back to the BC period have also been found in ancient Egyptian tombs (sources: <https://corkforest.org/history-of-cork/>; <https://www.mantoncork.com/history-of-cork/>). Today, the range of products made from cork is very broad and extends from various homeware to women's accessories, floor and wall coverings, furniture and car seats (sources: <https://corkforest.org/history-of-cork/>; <https://www.mantoncork.com/history-of-cork/>). Cork as a material stands out for its acoustic and insulating properties.

2. METHODOLOGY

The research is conducted using the chosen methodology, which consists of general scientific methods, namely the content analysis method, induction, deduction and synthesis. The content analysis method was used to study the matter that is the subject of European standards which define the characteristics of cork flooring, as well as the promotional material of various European and world associations promoting cork and cork products. Other methods were used to draw conclusions based on the research conducted.

Data from the Eurostat database were used to analyze the supply of cork flooring to the EU market (<https://ec.europa.eu/eurostat/comext/newxtweb/setupdimselection.do#>). The data for trade in cork and cork products in the above database can be found in Chapter 45 - "Cork and cork products", subchapter: 4504 - "Agglomerated cork, with or without a binding substance, and articles of agglomerated cork". The analysis of supply on the EU and non-EU markets, the results of which are presented in this article, was carried out for products with customs tariff SH: 45041091 - "tiles of any shape, blocks, plates, sheets and strip, solid cylinders, incl. discs of agglomerated cork, with a binding substance (excl. corks and stoppers)" (Eurostat, 2025). The market research in Serbia revealed that the same customs tariff is used for cork supplied to the market in rolls. Accordingly, it is not possible to analyze import values by individual categories of cork flooring. For this reason, summary data for the import values of cork floor coverings are presented in the part of the paper analyzing the supply on the EU market. Customs tariff SH: 45041091 was introduced in 1994 and has not been modified since. Cork flooring combined with vinyl or other materials was not included in the analysis.

The term "total import value" is used to indicate the aggregate value of the EU imports (between member states) and imports from non-EU markets.

3. TYPES AND PROPERTIES OF CORK FLOORING

Cork flooring is defined as "floor covering the main component of which is agglomerated compositon cork, intended to be used with a finish" (EN 12466:1998). Composite agglomerated cork is a „product obtained by agglutination of cork fragments with a binder not derived from cork cells" (ISO 633:2019). Cork fragments are sorted by size for uniformity, mixed with a binder and compressed under heat and pressure to form boards that are later cut to specific dimensions (National Floor Association of Canada). Since cork is a natural material, products from different batches may differ in color and gloss (Danish industry). Depending on the size of the cork fragments used in the production of the flooring, the wearing layer of the flooring may look as shown in Figure 1.

Because they are made from the bark of the cork oak, it is common for the unversed in the market to think that cork flooring is a type of wood flooring. However, according to the official classification, cork flooring belongs to the group of elastic flooring and not to wood flooring (European Resilient Flooring Manufacturers' Institute). During use, cork flooring should not be exposed to direct sunlight, as this will cause the cork to fade (Danish industry). To avoid damage and scratches on the flooring during use, users are advised to protect certain parts of the furniture that come into direct contact with the flooring (Danish industry).



Figure 1. The appearance of the wearing layer in cork floorings⁶

3.1. Types of cork flooring

Cork flooring is produced in two forms, as cork floor tiles and cork floor panels (Figure 2). A cork tile is a “flat, thin slab, square or rectangular, resulting either from cutting blocks or from continuous production” (ISO 633:2019). A cork panel consists of a certain number of layers, because of which this type of flooring is also called engineered floor covering. In terms of structure, cork floor panels are similar to laminate floors.

A special category of cork products is cork supplied to the market in rolls. This type of product is used as an underlay when installing floors made of different materials, including cork floors. The cork underlay has the function of a sound insulator, is not waterproof, and is required to have a specific density of 190-210 kg/m³ (National Floor Covering Association of Canada). However, some European retailers present cork in rolls as part of the floor covering range, recommending it for installation in commercial premises.⁷



Figure 2. a) Cork tiles



b) Cork floor panels



c) cork in roll⁸

3.1.1. Properties of cork tiles

Cork tiles are produced in square and rectangular shapes. The most common side dimensions of square tiles are 150 mm, 200 mm, 300 mm and 600 mm, while rectangular tiles are usually produced in lengths of 230 mm, 300 mm, 460 mm and 600 mm and widths of 150 mm, 230 mm, 300 mm and 460 mm (National Floor Covering Association of Canada; Danish industry). The thickness of the cork tile can be between 3 mm and 10 mm (National Floor Covering Association of Canada; Danish industry). Cork tiles can be produced as self-adhesive, making them very easy to install. If they are not self-adhesive, care should be taken when

⁶ (Source: <https://www.bricoflor.co.uk/cortex-corknatura-uv-pro-bj03022-sprint-varnished-click-cork.html>, <https://www.bricoflor.co.uk/cortex-corknatura-uv-pro-bjd3003-spurt-nature-click-cork.html>; <https://www.bricoflor.co.uk/cortex-corknatura-uv-pro-bj21072-shipdeck-click-cork.html>;)

⁷ https://www.flooringstores.com/a/blog/best-cork-flooring?srsltid=AfmBOorwlgV9FUB_xGS-JuVPs3G7y0PmX1mUU_kpPPt-BI3vMBsFFIF

⁸ Source: figure 1: <https://www.musicar.rs/pluta/pluta-ploce/>; figure 2: <https://www.bricoflor.co.uk/cortex-corknatura-uv-pro-blv0010-spurt-gravel-click-cork.html>; figure 3: <https://uradi-sam.rs/unutrasnja-oblaganja/pluta-u-rolni-25m2-5mx05mx4mm.html>

choosing the adhesive with which they are laid. Cork tiles are installed by gluing them to a dry, clean and flat surface and can also be installed on a cork underlay in rolls (National Floor Covering Association of Canada). Cork tiles can be produced with or without surface treatment. The surface treatment increases the durability and resistance of the cork floor. If the tiles are produced without surface protection, this can be applied after the tiles have been laid and installed in the room where the floor is to be used. Cork tiles are sold in packages and their number in a package depends on the manufacturer. Cork tiles can be used in rooms with underfloor heating. The most important standard defining the properties of cork tiles is EN 12104: 2023: "Resilient floor coverings – Cork floor coverings – Specification".

3.1.2 Properties of cork panels

Cork floor panels are usually manufactured in the following nominal dimensions (National Floor Covering Association of Canada – NFCA):

- width: 190 mm and 300 mm;
- length: 900 mm;
- thickness: 11 mm and 13 mm.

A five-layer cork floor panel consists of: a surface protection layer (1), a cork veneer (2), a compressed cork layer (3), an HDF panel with fasteners on four sides (4) and a compressed cork underlay (5). The fifth cork layer has antibacterial properties and provides sound and heat insulation.



Figure 2. Cork floor panel structure ⁹

Cork floor panels are laid using a click system, without adhesives and fixing to the subfloor, which is why this method is also known as floating installation (source: <https://www.corkflooringsupply.com/cork-flooring-buying-guide>). As they are produced as a surface-treated product, the floor can be used immediately after installation. Floor panels can also be laid on top of an existing floor covering. Since the panels are surface-treated, the furniture cannot leave marks on the floor. However, it is recommended that the furniture parts are fitted with protective felt pads so that the floor is not damaged when the furniture is moved. Cork floor panels can be used in households for bedrooms, living rooms, children's rooms, kitchens, staircases, hallways and pantries, as well as in commercial facilities. For 5-layer panels, manufacturers provide a 10-year guarantee for household flooring and for 6-layer flooring a 15-year guarantee for domestic use and a 5-year guarantee for commercial flooring¹⁰.

⁹ Source: <https://www.corkflooringsupply.com/cork-flooring-buying-guide>

¹⁰ Source: <https://www.bricoflor.co.uk/cortex-corknatura-uv-pro-bj03022-sprint-varnished-click-cork.html>

The number of panels in the package depends on the manufacturer. The basic properties of a cork floor panel are defined in standard EN ISO 20326:2018: "Resilient floor coverings – Specification for floor panels/assembly for loose laying".

3.3. Supply of cork flooring to the EU market

EU countries are the most important for the supply of cork flooring to their own market (Figure 1) (Eurostat, 2025). In the period 2010-2022, the value of EU imports at Member State level ranged from € 65.1 million (2012) to € 87.3 million (2019) (Eurostat, 2025). In the period 2023-2024, it initially fell to € 66.1 million in 2023 and then to € 52.2 million in 2024 (Eurostat, 2025). During the period under review, there was a significant decline in EU imports of cork flooring from non-EU countries (Figure 1). Since 2010, when the value of EU imports from these countries amounted to € 19.3 million, it fell to € 1.7 million by 2018 and then reached € 3.0 million in 2024 due to continuous growth (Eurostat, 2025). The graph also contains linear trend equations for EU import values at Member State level and from non-EU countries.

Taken together, the highest value of total EU imports (EU intra-imports + EU extra-imports) of cork flooring of € 96.5 million was recorded in 2010, while in the period 2011-2022 it ranged between € 74.2 million (2014) and € 91.1 million (2016) (Graph 1) (Eurostat 2025). In 2023, the value of total imports fell to € 66.1 million and in 2024 to € 55.2 million, which was the lowest value in the period 2010-2024 (Eurostat, 2025).

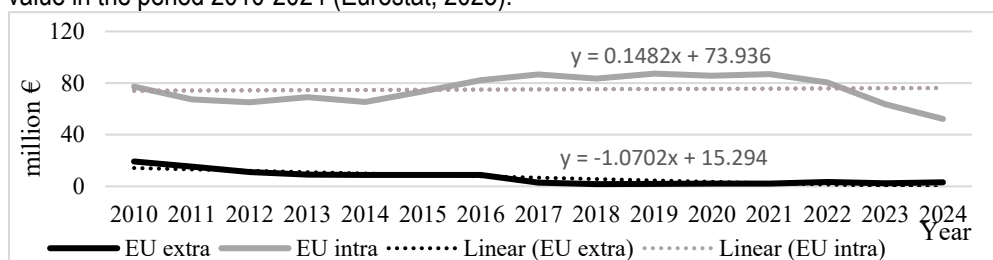


Figure 1. Value of total EU imports of cork flooring in the period 2010-2024
 (source: Eurostat, June 2025)

Portugal is the most important EU country for the supply of cork flooring to the EU markets, while Spain, Italy and France are less important. During the period under review, EU imports from Portugal were very unstable, with alternating periods of growth and decline. The highest value of EU imports of € 75.3 million was recorded in 2017, and by 2024 the value had fallen to € 42.5 million (Eurostat, 2025). The record value of EU imports of cork flooring from Spain was recorded in 2011 at € 5.5 million, from Italy in 2012 at € 3.7 million and from France in 2010 at € 2.3 million (Eurostat, 2025). By 2024, EU imports from Spain had fallen to € 0.5 million, from Italy to € 0.2 million, and from France to € 0.4 million (Eurostat, 2025). Since 2011, the value of EU imports from France has not exceeded EUR 1.0 million, and since 2015 the value of EU imports from Italy has not exceeded € 1.0 million (Eurostat, 2025) (Figure 2).

Germany imported cork flooring from Portugal the most in all years of the period analyzed, followed by Poland, Denmark and France (Eurostat, 2025). The highest value of imports from Portugal was reached by Germany with € 46.1 million in 2020, Poland with € 8.1 million in 2019, Denmark with € 6.6 million in 2017 and France with € 5.0 million in 2022 (Eurostat, 2025).

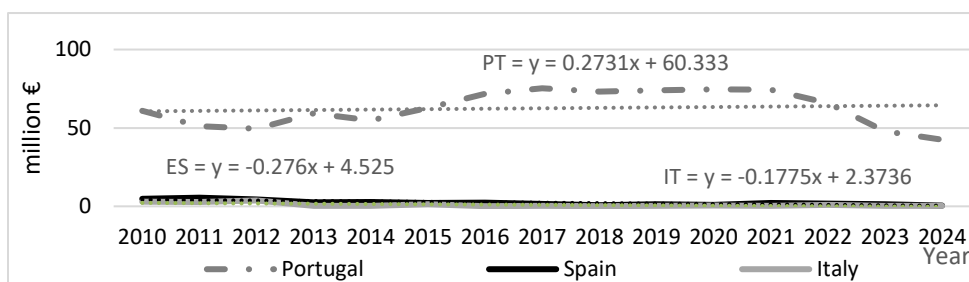


Figure 2. Value of EU imports of cork flooring from Portugal, Spain and Italy in the period 2010-2024 (source: Eurostat, June 2025)

3.4. Portugal's role in supplying the cork flooring market in SEE non-EU countries

The United States and Russia are Portugal's largest foreign trade partners. The highest value of Portuguese exports to the USA was recorded in 2013, amounting to €33.5 million, and to Russia €26.5 million in 2012 (Eurostat, 2025). Portugal exported to the USA and Russia together from 52.2% (2010) to 65.6% (2013) of the value of exports to non-EU countries (Eurostat, 2025). Exports to Russia were reduced in 2022 and completely suspended in 2023.

In addition to the USA and Russia, selected non-EU countries in south-eastern Europe were also included in the analysis, including Serbia, Albania, Bosnia and Herzegovina, Montenegro and North Macedonia. In the group of countries mentioned above, only Serbia can be said to have had and developed a market for cork flooring during the analyzed period. Portugal and Spain were the main supplier countries for Serbia, while Italy only recorded exports in 2016 (€ 4768) and 2024 (€ 1275) (Fig. 3) (Eurostat, 2025). During the analyzed period, Portugal continuously exported cork flooring to Serbia. The highest value of this export of €356 thousand was recorded in 2014 and the lowest of less than €6000 in 2023 (Eurostat, 2025). Since 2020, Serbia has become a new export market for Spain, which achieved record exports of €152 thousand in 2022 (Eurostat, 2025). However, the value of Portugal, Spain and Italy's total exports to Serbia, as well as their individual exports, clearly show that the cork flooring market is developing at a moderate pace. The largest share of export values is accounted for by cork which comes onto the market in rolls and is used as an underlay for laying various floor coverings. However, cork tiles and cork floor panels are not generally accepted floor coverings and are not known to users in Serbia. In recent years, cork flooring has been advertised in various thematic magazines for wood products and floor coverings on the Serbian market. However, these were sporadic texts that rather promoted cork as a material and emphasized its properties as a natural and renewable material. The texts contained neither technical data for cork flooring nor comparisons of its properties with other floor coverings. Considering the fact that the flooring market in Serbia is a typical market for solid parquet, it is difficult for any new product to position itself on the market if it is not properly introduced to the market. In this particular case, this would mean clearly emphasizing the technical properties of cork flooring, determining its price competitiveness compared to other floor coverings and, above all, keeping salespeople in showrooms well informed and trained. If they do not have sufficient technical information and cannot explain to the customer why they should choose cork flooring and not another floor covering, it will be difficult for them to choose this product. The information that cork is a natural and renewable material that does not cause allergies and similar arguments are not enough for the buyer to choose this type of flooring. Also, the

importance and significance of ecolabels has not yet been recognized on the Serbian market. In this sense, even if the cork flooring has one of the ecolabels used in Europe, it will not affect consumers in Serbia.

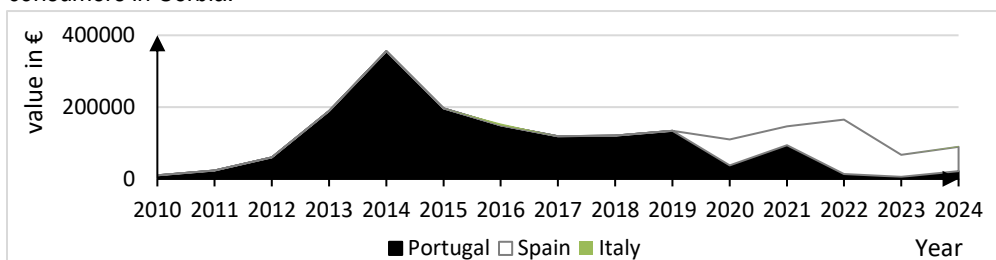


Figure 3. Supply of cork flooring from Portugal, Spain and Italy to the Serbian market in the period 2010-2024 (source: Eurostat, June 2025)

Of the other non-EU countries analyzed, only Montenegro can be singled out. Portugal and Spain were also the most important supplier countries for this market, although with significantly lower exports than to Serbia. Portugal supplied sporadic exports to Montenegro, which usually took place two years in a row, followed by several years without cooperation. The highest export value to Montenegro was achieved by Portugal in 2024 with € 6325 (Eurostat, 2025). Spain exported to Montenegro in the period 2017-2021 only, with the highest export value of € 23330 in 2017 (Eurostat, 2025). France exported cork flooring to Montenegro in 2019 only. Export of cork flooring to the BiH market was registered in 2020 only, and from Portugal (Eurostat, 2025). Italy exported symbolic quantities of cork flooring to Albania in 2012, 2014 and 2021, and Portugal only in 2021 (Eurostat, 2025). During the analyzed period, Portugal exported sporadically to North Macedonia, with the highest export value of €6495 recorded in 2014 (Eurostat, 2025).

From all this, it is clear that there is little demand for cork flooring in the markets of selected non-EU countries. The only exception is Serbia, where cork in rolls is the most commonly used underlay for laying various floor coverings. The development of supply in the markets of the other non-EU countries analyzed clearly shows that the markets did not show great interest in the new product because the demand did not increase. In most cases, the market was supplied with certain quantities that were perhaps intended for a specific facility, after which the supply was suspended.

4. CONCLUSION

Cork flooring is produced in two different forms, as cork tiles and cork floor panels. EU countries, especially Portugal, are the main suppliers of cork flooring to their own market. In the group of SEE non-EU countries, the Republic of Serbia is the largest importer of cork flooring. Portugal is the most important supplier for the market of the Republic of Serbia. In recent years, Spain has become the main supplier to the Serbia market. During the analysed period, the amount of cork flooring was symbolic for the supply of the market in other SEE non-EU countries. In order to increase the consumption of cork flooring on the market in the Republic of Serbia, it is necessary to implement a better promotional campaign based on the technical properties of cork flooring, price competitiveness compared to other floor coverings and, above all, good information and training of sales staff in showrooms. All relevant European

standards for cork flooring are adopted by the National Standardization Agency of the Republic of Serbia.

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POLICY, LEGAL FRAMEWORK, AND ESG REPORTING

INTELLECTUAL PROPERTY AND "GREEN" ACCOUNTING - LEVERS FOR SUSTAINABLE DEVELOPMENT OF THE FORESTRY SECTOR AND ITS DERIVATIVE INDUSTRIES

Roumiana Pozharevska Snejana Bacheva

Abstract: The report's goal is to highlight prospects for optimizing the actions and accountability of firms in the Republic of Bulgaria's forestry and derivative industries, so assuring their long-term sustainable development. The subject is considered from two perspectives. The first perspective involves identifying the objects and analyzing the models for managing intellectual property rights (IPR). Unfortunately, the research of practice in the Republic of Bulgaria exposes two negative trends: a lack of awareness of IPR among the sector's reporting units, and as a result, a failure to employ such resources in their activities. The lone exception is industrial design for the furniture business, which has 44 registered patents, only six of which are now active. The second aspect is to determine the role and importance of "green" accounting in ensuring sustainability in the forestry sector (forest management and silvicultural projects, for example) and its derivative industries (processing, furniture, organic wood and paper products, for example), using the conceptual framework of Regulation (EU) 2020/852, Directive (EU) 2022/2464, and the European Sustainability Reporting Standards (ESRS). The study focuses on innovations, which can lead to new chances for competitiveness and solutions to stop environmental degradation and encourage more sustainable development (Brundtland, 1987). An attempt was made to provide reliable accounting presentation and modeling.

Keywords: green accounting, forest sector, forest industry, intellectual property, intangible assets, IFRS, IFRS S1, IFRS S2, ESRS

1. INTRODUCTION

The multifunctional and sustainable development of the forestry sector and related industries should be based on approaches that do not jeopardize future product yields or future benefits from ecological services. Back in 1997, Bachmann offered criteria for determining sustainability in forest management in its catalog, on the basis of which our national specialists conduct analyses and scientific studies on the applicability and adaptability of over twenty criteria (Stiptsov, V., Mikov, M., 2017; Stiptsov, V., Paparkova, Tsv., 2017). A number of scientific forums have been dedicated to this aspect of the issue, with some of the publications addressing the topics of innovation and competitiveness of forestry industry enterprises in the context of their sustainability (e.g. Kichukova, M., Spirov, I., 2016). The topic of innovation is treated quite fundamentally, and not as a process of generating intellectual property and the importance of this intangible property for economically sustainable growth of the forestry sector and its derivative industries. The authors' study on the place and role of intellectual property rights (IPR) in managing the sustainable development of the forestry sector and its derivative industries unfortunately exposed a very low level of awareness and use. The only exception is the industrial design for the furniture industry, with 44 registered with the Patent Office, of which only six are effective to date. The IPR deficit combined with the entry of internationally established brands (e.g. from the furniture industry) into the Bulgarian market leads to a decrease in competitiveness and job losses. According to data from the industry chamber of woodworking and furniture enterprises, which provide livelihood for over 48,000 people in this country and generate over 3 billion leva in gross domestic product, in 2022 there will be a reduction in personnel by about 20 percent (Expert.bg). No less worrying is the picture in the

National Map of Intellectual Property of the Republic of Bulgaria, developed by the Department and Institute of Intellectual Property and Technology Transfer at UNWE, presented for the first time on 30 April 2025 (www.ippt-unwe.bg). Twenty-three indicators were examined, with the main goal of the National Map being to serve as a management tool in determining strategic priorities and allocating resources when developing policies in the field of innovation, economic growth and promoting regional competitiveness. Within the studied 2020-2024 period, the applications submitted in the country for inventions are 552, for utility models - 1424, for trademarks - 18,409, and for industrial designs - 500. Unfortunately, in the rankings for none of these IPR objects do legal entities from the forestry sector and its derivative industries appear among the top 10. What is more, the research team established as a negative trend that the mining industry is characterized by low innovative activity. Not without significance is the fact that the team found that in the Republic of Bulgaria the intensity of research and development, measured as a percentage of expenditure on gross domestic product, was 0.79% in 2023, while the average for the EU was 2.22%. Generally in the analyzed field, the authors believe that the practice in the Republic of Bulgaria unfortunately exposes two negative trends: the lack of knowledge of IPR by the reporting units in the sector and, as a result, the failure to use such resources in their operations.

The second aspect of the research conducted by the authors is an attempt to determine the role and importance of "green" accounting for ensuring sustainability in the forestry sector (forest management and silvicultural projects, etc.) and its derivative industries (processing, furniture, organic wood and paper products, etc.), using the conceptual framework of Regulation (EU) 2020/852, Directive (EU) 2022/2464 and European Sustainability Reporting Standards (ESRS). Special attention is paid in the conducted study to innovations, as a result of which new opportunities for competitiveness can be generated, solutions can be found to stop environmental degradation and promote more sustainable development. An attempt has been made for their reliable accounting presentation and modeling.

Research Methods. The methods used in this report are of general significance and traditionally applicable, which are: historical and logical method, comparative method, method of observation and monitoring, and regulatory approach.

Research assumption. The authors' assumption is that good knowledge of IPR objects and their effective management should presumably increase the competitiveness and sustainability in the development of reporting units from the forestry sector and its derivative industries, while also providing an opportunity to implement the circular economy model in the three main areas: less raw materials, less waste and fewer emissions. Successful process modeling and management can be achieved through the symbiotic application of creative approaches to "green accounting" and integrated reporting.

2. LITERATURE REVIEW

In the course of the conducted research and the development of an accounting model for the management and presentation of intellectual property in enterprises from the forestry sector and its derivative industries, the authors had to study sources from various aspects of economics, accounting and their regulations, in the context of achieving sustainability. Specialized literature on the specific issue under investigation was not identified at the national level. The authors determined various aspects and conducted research along the following dimensions:

- ✓ intellectual property – characteristics, types and regulations at national and international level (Borisov, B., 2009; Borisov, B., Markova, M., 2002; Borisova, V., 2009; Markova, M., 2010);
- ✓ economic dimensions and models of intellectual property management (Markova, M., 2024; Kamburova, L. 2020); digitalization and intellectual property (www.wipo.in; www.inpi.fr); national map of intellectual property (www.ipitt-unwe.bg);
- ✓ identification and management of innovation processes (Ventsislavova Georgieva, D., 2019, 2021); including forest plantations (Collet C. et al., 2020);
- ✓ management of intangible assets in commercial enterprises (Nikolova, I., 2011, 2024);
- ✓ competitiveness, control of sustainability and management of forest areas (Kichukova, M.; Spirov, I., 2016; Stiptsov, V., Mikov, M., 2017; Stiptsov, V., Paparkova, Tsv., 2017; Le monde du bois, 2023; www.wipo.in);
- ✓ conceptual foundations of accounting theory (Basheva, Sn., 2020), integrated reporting, "green accounting", accounting aspects of sustainability (Basheva, S., Pozharevska, R., 2024; Cited in Pozharevska, R., 2017 - Dinev, M., 2015, Yonkova, B., 2007, 2010, 2012); accounting framework of public-private partnership (Markova, M. Sl., 2019).
- ✓ creative accounting and possible financial fraud in financial statements and declarations (Bachev, I. 2019, 2021)
- ✓ EU Directives and Regulations, National Accounting Law, National and International Accounting Standards, IFRS, S1, IFRS S2, ESRS.
- ✓

3. INTELLECTUAL PROPERTY RIGHTS AND OPPORTUNITIES FOR ECONOMIC GROWTH AND SUSTAINABLE DEVELOPMENT IN THE SECTOR

Reporting units in the forestry sector and its derivative industries are public (state-owned or municipal), private or public-private. They are predominantly medium-sized, small or micro enterprises. Their activities can be developed in the forestry sector (forest management and silvicultural projects, biodiversity projects, etc.) and derivative industries (processing, furniture, organic wood and paper products, trade in wood and paper products, etc.). Each of the above areas of activity needs specific IPRs that are specific and applicable to it. But the most important thing is that these IPRs are known by users so that they can be used effectively and of course be adequately displayed in the annual financial statements so that they can be managed to ensure sustainability. At this stage, these requirements have not been met. As a rule, IPR, with the exception of some licensed software products, are not observed in the financial statements of reporting entities.

The wood processing industry, according to the conclusions in the National Intellectual Property Map, has low innovation activity due to the specifics of its operations. Yet one could consider treating these in the context of protecting geographical indications, traditional knowledge and skills - IPRs, which are usually associated with the intangible heritage of a country. In this area, the application of "green" service franchising can also be sought. Such an approach can ensure the rational and efficient use of wood and non-wood resources and the maximum utilization of the economic, ecological and social functions of forests.

The authors believe that it is important to consider one significant aspect regarding the forestry sector, which is related, in addition to IPR, to another group of intangible assets, "limited property rights". These rights arise from special provisions in various national regulations

(Forest Law, Water Law, Cultural Heritage Law, Protected Areas Law) and should be visibly presented in financial statements in order to more effectively manage the environmental and social aspects of sustainability. Forest areas in the country are distributed in a ratio of 72.58% state and 24.67% non-state (municipal, legal and natural person) ownership. State and municipal property, in texts specifically determined in the regulatory acts, can be granted either against payment or free of charge in the form of rights of use, easement rights and construction rights. A part of the reporting units to which these rights are granted carry out specific activities such as seed production gardens, branch collections, geographical cultures and arboretums, forest nurseries of national importance, natural areas, protected areas, sites of national cultural heritage. In relation to this group of reporting units, in addition to limited property rights, IPRs such as copyrights on new varieties and biodiversity, geographical indications, traditional knowledge and skills, products of research and development, among other, arise.

For enterprises in the manufacturing and trade sectors directly related to the forest sector, there is scope for the emergence and management of a richer range of IPRs. In the authors' opinion, these reporting units should generate and seek protection opportunities for more specific traditional national products, so as to improve competitiveness with internationally recognized and well established companies. In addition to the well-known and underutilized industrial design, efforts should be directed at art design, new technologies, utility models, trade and company brands, protected rights to online stores and domains, protected technologies for bio products related to STEAM education, etc. As a result, sustainable economic growth trends and the preservation and increase of jobs can be achieved over time.

For the sector and its derivative industries, there are also many options for innovation activity, which is currently fairly underdeveloped. The following can be main areas for innovation: raw material base; woodworking machinery and equipment; technologies in logging, woodworking and the furniture industry; interior and furniture design; materials and structures in furniture; bioeconomy, organization and management; natural sciences in support of the forestry industry and engineering design; in the educational process. In order for innovation activity to be successful and ensure sustainability, it is recommended that it be directly linked to a circular economy strategy in the sector, which unfortunately has not been developed to date.

When analyzing the utilization of IPR, the authors also take into account the fact that some micro family businesses, mainly carrying out activities related to traditional crafts, possess know-how that is passed down from generation to generation (e.g., production of wooden musical instruments) and which they prefer not to protect as IPR. The reason for this practice is the legislation in the field of IPR, which obliges patent holders to publicly disclose their knowledge and skills after 10-15 years. Hence their competitiveness in the relevant traditional production niche decreases.

If an analogy is made with the results of the activities of reporting units from other sectors that own IPR, the main conclusion is that regardless of the type of IPR that enterprises from the forestry sector and its derivative industries will use, its knowledge and use in business as a complex economic and legal phenomenon will lead to positive, lasting economic results and increased competitiveness. The following tools can be used to determine the economic significance of the use of IPR: cost-benefit method; technology/product life cycle method; impact on production, financial and human capital; basic and additional utility for the consumer; distribution in the complex economic system (Markova, M., 2024).

Last but not least, the role and importance of artificial intelligence (AI) should be noted, which has the potential to improve sustainable forest management by improving forest health monitoring, predicting and mitigating threats, optimizing logging practices, protecting biodiversity, and supporting strategic decision making. These applications can contribute to the responsible management of forest resources and the protection of vital ecosystems. Given that the world faces the challenges of climate change, it is clear that AI has a key role to play in the path to sustainability, and its use in forest management illustrates how innovative technologies can redefine entire industries. By harnessing its potential, reporting entities can not only secure a sustainable future for themselves, but also set a strong example for the entire sector.

4. GREEN ACCOUNTING AND INTEGRATED REPORTING IN THE CONTEXT OF SUSTAINABLE MANAGEMENT OF THE FORESTRY SECTOR AND ITS DERIVATIVE INDUSTRIES

In the authors' opinion, the model for financial and non-financial presentation of IPR in the forest sector and its derivative industries, in order to ensure sustainable management, should encompass several stages. First, identification and recognition of the intangible resource. Secondly, its legal protection as IPR and its accounting presentation as an intangible asset. Third, developing mechanisms for its effective use. Fourth, choosing an appropriate management model. To this end, the advantages offered by the symbiosis between creative green accounting and integrated reporting should be used. The majority of reporting entities, pursuant to the Accounting Act, apply the National Accounting Standards (NAS).

With regard to green accounting, it usually implies expanding the scope of accounting objects, as well as the creative development of methodologies for their accounting, in order to more fully present the activities of reporting units, including information on issues related to ecology and human capital. The authors want to emphasize that creativity of accounting presentation in annual financial statements means the development of models that comply with established accounting rules and regulations and are distinguished from the understanding of "creative accounting-financial fraud" (Bachev, I. 2019, 2021). IPRs are an attractive object for creative accounting due to the insufficiently clarified conceptual framework for their unambiguous recognition internationally and especially nationally as balance sheet assets, the formation of their reliable valuation and the options for reflecting their realization and recognizing revenue from it. Many of the techniques related to intangible resources, such as securitization, licensing, and leasing, can be used by reporting entities in both directions. One direction is that creative accounting should be applied as a tool for improving accounts and financial creativity, and the other – as a tool for fraud and presenting false information. Creative accounting generally means presenting a good picture of the financial position of the reporting entity through the use of legal means. To improve this presentation, creative accountants use various techniques such as depreciation, provisions, etc. The scope for creativity on the national level is expanded by the NSS 38 *Intangible Assets*, which has not been updated since 2008. It preserves the "tradition" of presenting intangible assets, in which intellectual property objects are not distinguishable and comparable, on the one hand, and there is a mixing of intangible assets of different nature into one classification group. Furthermore, according to NAS 38, all intangible assets are mandatorily depreciated, valued at historical cost and their carrying amount cannot be updated at a fair market valuation. In terms of innovative domestically created products, the situation is no better. All costs at the research stage (often

significant in size) are reported as a current expenditure, violating the principle of comparability of income and expenses. The valuation of the internally generated intangible product starts taking shape only at a proven stage of the development activity. As a result, this valuation is at times very low. Adding to this the fact that the valuation of IPR is subject to mandatory amortization, situations quite often arise in which the innovative product cannot be presented in the financial statement. To avoid such situations, integrated reporting options can be used. In practice, it is the end product of a complex integration process between the different parts of the reporting unit, on the one hand, and the customers and the environment, on the other. It is based on pillars mainly of an intangible nature such as: the reporting entity's business model; customer relationships; the reporting entity's brand and reputation; and the reporting entity's impact on and relationships with the environment. The main parameters of the non-financial statement are presented in the currently effective Accounting Law in chapter seven Annual Activity Report, Section III, Art. 48 and Art. 49. The sustainability report and disclosures should be prepared in accordance with the requirements of Regulation (EU) 2023/2772 and the European Sustainability Reporting Standards (ESRS), with a focus on the sector: ESRS 2 General Disclosures; ESRS E1 Climate Change; ESRS E2 Pollution; ESRS E4 Biodiversity and Ecosystems; ESRS E5 Resource use and circular economy. Integrated reporting is the conceptual framework that may at some point achieve future coverage of all components of the capital (tangible, financial and intangible) of enterprises. It should be noted that the topic of integrated reporting is not new in the country. Leading researchers in accounting theory such as Dinev, M. (2015) and Yonkova, B. (2007, 2010, 2012) examined the problems and benefits more than ten years ago, and laid the foundations of integrated reporting in the country. As an EU member state, the Republic of Bulgaria has transposed into its national legislation the requirements of Directive (EU) 2022/2464, which creates conditions for enterprises to disclose reliable and relevant information that will allow users of financial statements to better understand the risks and opportunities that sustainability issues raise. The requirement is introduced for large, medium-sized and small enterprises that are of public interest to include in their activity report a separate section with information related to sustainability issues. Specifically, this information includes: a description of the business model and strategy of the enterprise; the goals set and a description of the progress achieved by the enterprise; a description of the role of the governing bodies; a description of the policies adopted in relation to sustainability; a description of the main risks of the enterprise related to sustainability issues; indicators relevant to disclosure. Disclosure of sustainability issues is based on a concept of proportionality, which requires reporting to take into account the scale of operations and the main characteristics of these enterprises and the concept of "double materiality". Materiality is key in disclosure, with companies having to assess on their own what information is material and ensure that the necessary information is disclosed. Given that there are currently no accounting standards for sustainable development, companies can use the capabilities of the European Sustainability Reporting Standards (ESRS) to reveal the relationship between sustainability and the results of their operations.

5. CONCLUSION

In this paper, the authors presented the results of their research regarding the applicability of intellectual property in reporting units from the forestry sector and its derivative industries and its role as a lever for achieving sustainable development. For its effective management, it

is necessary that the potential of creative green accounting and integrated reporting should be utilized. In this regard, problem areas were identified and an attempt was made to propose a model for financial and non-financial presentation.

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INVENTORY OF WOOD ENERGY CONSUMPTION AND GHG EMISSIONS FROM WOOD FUEL COMBUSTION: A CASE STUDY OF CENTRAL SERBIA

Branko Glavonjić, Aleksandra Lazarević, Miljan Kalem

Abstract: The region of Central Serbia is one of the most forested regions in Serbia, with an average forest cover of 41%. The total forested area amounts to 589 thousand hectares, which represents 22% of the total forested area in the Republic of Serbia. The abundance of forests has also influenced a high percentage of households using wood fuels for heating purposes. Out of a total of 400.5 thousand households, 269.8 thousand, or 67%, use wood fuels. This high prevalence of households relying on wood fuels was one of the reasons for conducting research on the total consumption of wood energy and its associated GHG emissions.

The study included the most significant consumer categories: households, public buildings, commercial buildings, and district heating systems.

The results of the conducted research showed that the total firewood consumption in households during the 2022/2023 heating season amounted to 1.38 million m³, wood pellet consumption was 64 thousand tonnes, and wood briquette consumption was 117 tonnes. The average firewood consumption per square meter of heated area in households in urban areas was 0.092 cubic meters, while in rural areas, it was 0.104 cubic meters.

Converted into energy efficiency parameters, wood energy consumption amounted to 248.1 kWh/m² of heated area in urban households and 280.3 kWh/m² in rural households. These values exceed the limit of the lowest energy class in the energy passport for residential buildings [G class > 188 kWh/m² (a)].

Key words: energy, firewood, pellets, consumption, emissions.

1. INTRODUCTION

This paper continues a series of studies on wood-fuel consumption in specific regions and the associated GHG emissions during their combustion. The results presented here cover the region of Central Serbia (colloquially known as Šumadija), which comprises five counties: Šumadija County, Raška County, Rasina County, Podunavski County, and Pomoravski County. The consumption study was conducted under the Second National Forest Inventory project, supported by the Food and Agriculture Organization (FAO).

The data from this project, carried out in 2022, were used for the development of the Integrated National Energy and Climate Plan of the Republic of Serbia until 2030 with a vision for 2050 [1] and [2]. Under this Plan, Serbia has committed to achieving a 41% share of energy from renewable sources in its total gross final energy consumption by 2030. Wood energy will play a key role in meeting this target, as it currently accounts for the largest share of consumption among all renewable sources. Therefore, the results presented in this paper are of particular relevance to energy policy makers when designing measures to encourage

households, the most important category of energy consumers, to shift from fossil fuels to renewable fuels. The structure of this paper is identical to that of previously published papers on this topic, ensuring they remain mutually comparable, which is of great importance to readers.

2. MATERIALS AND METHODS

The aim of the research in this paper was to assess wood-fuel consumption across all the major consumer categories and, in that context, to calculate the GHG emissions arising from their combustion. Although wood fuels are classified as CO₂ neutral, there are still opportunities to reduce these emissions if the wood is used properly. One of the most significant factors influencing GHG emissions is the moisture content of the wood. In addition to moisture, another key determinant of emission levels is the type of combustion device used.

These and other characteristics were the focus of the investigation for this study. The research was conducted using the WISDOM methodology for the following consumer categories in the selected region: (i) *households (urban and other)*, (ii) *public buildings (schools, health-care centres, ambulances, kindergartens, local government facilities, etc.)*, (iii) *commercial buildings (restaurants, meat roasters, bakeries, car repair services, shops, business facilities, etc.)*, and (iv) *wood fuels producers (producers of pellets, briquettes, wood chips)*.

Based on the results the corresponding balance of GHG emissions was developed. The inventory included a calculation of the emissions of carbon dioxide and nitrogen oxides. In the case of households, the survey sample comprised 1,001 households, of which 534 were urban and 467 were rural. Households in the sample were selected based on the principle of random sampling from the appropriate database using relevant statistical tools. A survey on wood and wood fuel consumption in public and commercial buildings had the intention to ensure proper geographical distribution in the entire selected region. In addition to fuel consumption, the survey included questions to collect data on household characteristics, the size of the dwellings, the area to be heated, the presence of thermal insulation in the buildings, the timing and methods of wood-fuel procurement and storage, as well as other related questions.

The calculation of the GHG emissions from the wood fuels combustion process in the chosen region was based on the IPCC 2006 methodology and additions from the corresponding European standards, relevant scientific papers and publications measurements from practice.

3. RESEARCH RESULTS AND DISCUSSION

The results of the conducted research showed that the total firewood consumption in households during the 2022/2023 heating season amounted to 1.38 million m³, wood pellets consumption was 64 thousand tonnes, and wood briquettes consumption was 117 tonnes. In public and commercial facilities, 17,711 m³ of firewood and 6,653 tonnes of wood pellets were consumed. In district heating systems, 7,752 tonnes of wood chips were used.

Based on these data, it is clear that households are the most significant consumer category in this region. Therefore, the key characteristics of wood-fuel consumption in households are presented below.

As can be seen in Fig. 1., in all selected counties firewood is a dominant fuel consumed by households for heating. Its share is in the range from 72.5% in Podunavski county to 89% in Pomoravski county. In Šumadija county, the households combine wood and coal (4.3%) and

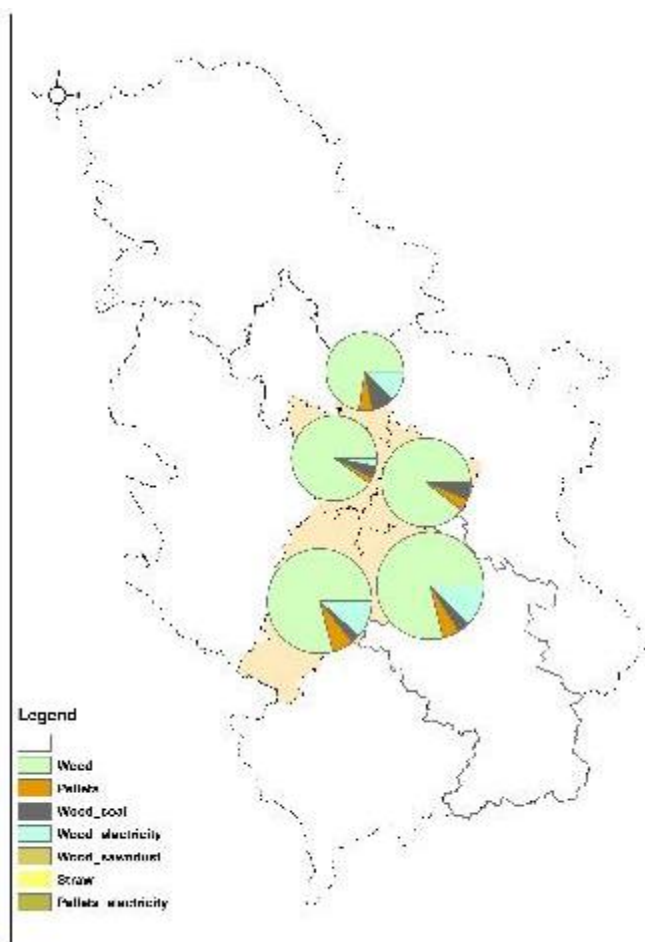


Figure 1. Overview of certain fuel types consumed for heating households in Central Serbia (Glavonjić, 2025)

wood and electricity (3%) for heating. The share of households that consume only wood pellets is in the range from 2.3% in Šumadija county to 6.6% in Raška county. Among other fuel combinations for household heating, households also used the combinations of wood-electricity, wood-sawdust, and wood-pellets. The share of such households in the total number of households using wood fuels is significantly lower compared to those using wood, pellets, and the wood-coal combination. In Šumadija county, 0.7% of the total number of households used straw for heating. This is expected, given that it is a county with a developed agricultural sector.

When it comes to the efficiency of the wood fuels consumption, it is assessed by the consumption indicators measured per household or per 1m² of the heated area. The average firewood consumption per square meter of heated area in households in urban areas was 0.092 cubic meters, while in rural areas, it was 0.104 cubic meters. These data represent the average at the level of the Central Serbia region.

Converted into energy efficiency parameters, wood energy consumption amounted to 248.1 kWh/m² of heated area in urban households and 280.3 kWh/m² in rural households. These values exceed the limit of the lowest energy class in the energy passport for residential buildings [G class > 188 kWh/m² (a)].

Such a high consumption of firewood per household is the result of the large number of rooms and the heating area during the heating season.

According to the results of a conducted survey in households, the average number of rooms in residential facilities (including kitchen, corridor, and WC/toilet) being heated in urban settlements in Central Serbia is 6.2, while in other settlements, it is 6.1. The average area of residential facilities in urban settlements in Central Serbia is 97.4 m², and in other settlements, it is 95.3 m². The average area being heated in residential facilities during the heating season at the level of Central Serbia is 64.1 m² in urban and 60.4 m² in other households.

Timing of firewood purchase relative to the beginning of the heating season is an important factor in firewood consumption because wood contains different quantities of water and that depends on the time between the moment of felling and the moment of consumption. For wood pellets and briquettes that is not the case, because their moisture is fixed in the technological process of production and amounts to approximately 8%. Reviews of households according to the timing of the purchase of firewood relative to the beginning of the heating season at the level of Central Serbia is given in fig. 2.

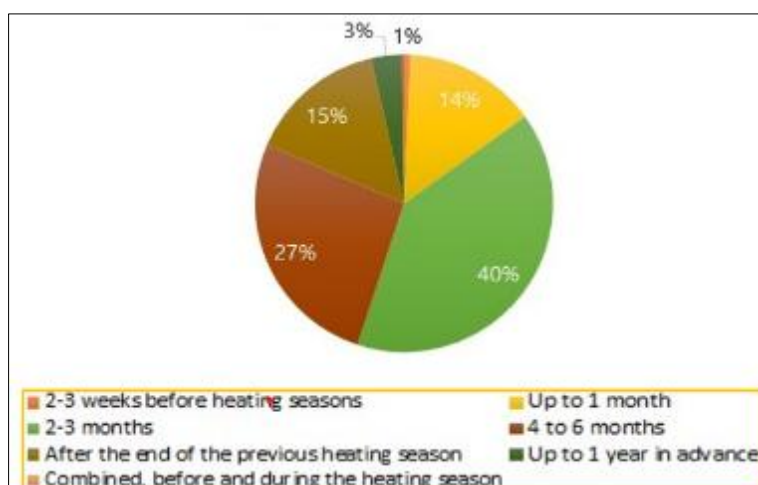


Figure 2. Timing of purchase of firewood by households relative to the beginning of the heating season at the level of Central Serbia region

The situation regarding the timing of firewood procurement in this region can be considered satisfactory, as only 15% of households purchase firewood one month before the beginning of the heating season. Two-thirds of households procure firewood between 2 and 6 months before the heating season begins, which allows sufficient time for it to dry and reach a satisfactory moisture level. The share of households that purchase firewood after the end of the previous heating season and up to one year in advance is 18%.

The heating systems are one of the most important elements on which the efficiency of consumption, as well as the consumption of wood fuels itself, depend in every household. The results of the conducted survey show that the majority of households in the selected region use individual heating appliances. The share of households that use individual heating appliances in Central Serbia is 70% while the share of households with their own central heating system is 27%. The remaining 3% of households use a combination of individual heating appliances and central heating systems.

Besides the heating system, the important firewood consumption and efficiency factor is the age of a heating appliance. According to the survey, 46% of households from Central Serbia possess heating appliances over 10 years old. (fig. 3). The share of households with up to 5 years old heating appliances amounts to 11%. By this parameter, this region is the second-best region in Serbia.

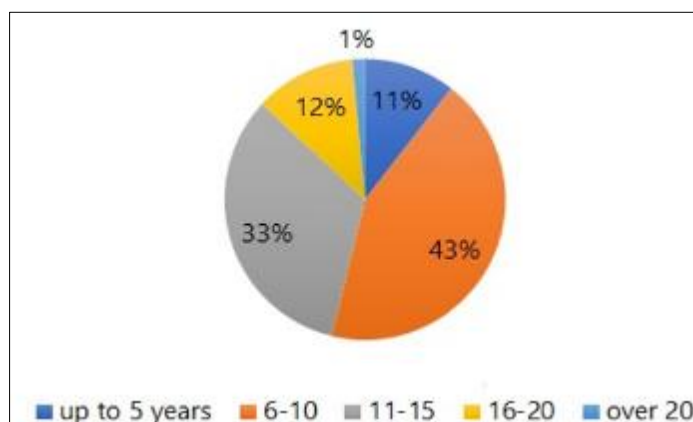


Figure 3. Frequency of certain age ranges of heating appliances in surveyed households in Central Serbia

When it comes to GHG emissions that arise from burning wood fuels, the results of conducted research have shown the following:

- Total CO₂ emissions stemming from the wood fuels combustion in Central Serbia during the heating season 2022/2023 are estimated to 1.89 million tonnes. Some 89% of these emissions stemmed from households (1.68 million tonnes of CO₂), whereas the remaining 11% stemmed from all other consumers categories;
- The emissions of nitrous oxide (N₂O) were not that high: 64.4 tonnes;
- The emission of sulfur oxides is symbolically low from wood fuels.

4. CONCLUSION

The most important conclusions related to wood fuels consumption in Central Serbia are that firewood is the dominant fuel used for household heating and that the efficiency of its use is unsatisfactory. The high consumption of wood energy, expressed through the indicator kWh/m² of heated area, is the result of the high share of heating appliances older than 10 years, which are present in 46% of households, as well as the use of individual heating devices, which are present in 70% of households. Although 85% of households procure firewood on time, in relation to the start of the heating season, the use of dried wood could not contribute to achieving satisfactory efficiency in wood energy consumption, given the unfavorable situation with the age and types of heating devices.

For this reason, the recommendation for policymakers in the field of energy efficiency is to increase funds for subsidies to households for replacing old heating devices with new, efficient ones. Although subsidies exist, they are used by a small number of households on an annual basis. With the current pace of device replacements, it would take more than 20 years to reach a satisfactory share of efficient heating devices in households in this and other regions of Serbia.

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TRANSPARENCY IN ACCOUNTING AND AUDITING OF UKRAINIAN TIMBER: EITI REPORTING AS A FACTOR OF SUSTAINABLE DEVELOPMENT

Anna Kostyakova

Abstract: The woodworking industry continues to remain the most important segment of the Ukrainian economy, and Ukraine is the largest exporter of timber to the European Union, despite the serious challenges of war. The study is dedicated to transparent accounting and auditing of Ukrainian timber through the formation of reports according to EITI standards, which is an important factor for building trust with international partners and integrating into European environmental norms. Transparency in the forestry sector has a decisive impact on sustainable development, environmental responsibility, and the economic security of the country.

Keywords: transparency, audit, timber, EITI, sustainable development, accounting, Ukraine.

1. INTRODUCTION

In the post-war period, Ukraine faces numerous challenges in the field of natural resource management, particularly in forest governance. Despite the war, Ukraine remains one of the leading exporters of unprocessed timber to EU countries. However, this dynamic underscores the need for guarantees regarding the transparency of origin, accounting, and legality of timber.

Under these circumstances, the implementation of international transparency standards, particularly the Extractive Industries Transparency Initiative (EITI), which includes the forest sector, is highly relevant. Open accounting, independent audit, and compliance with non-financial reporting standards form the basis for sustainable development and trust from international investors, donors, and consumers.

2. KEY PROBLEMS OF TIMBER ACCOUNTING AND AUDIT TRANSPARENCY

Annually, Ukraine's forests grow by an average of 35 million m³ of timber. The increasing stock indicates significant economic and environmental potential. Excessive or illegal logging leads to environmental problems, including climate change, soil degradation, and biodiversity loss. Proper control over logging volumes enables more efficient forest resource planning and reduces negative environmental impact.

Scientific and practical discourse on timber accounting transparency is focused on several critical problems reflected in SWOT weaknesses and threats:

- The absence of a unified digital timber registry and weak synchronization of systems. According to Kukhta (2022) and Bedenyuk (2023), timber data are dispersed across various institutions, complicating audit, undermining traceability, and creating corruption risks.
- Marginalization of the forestry sector in EITI reporting. Unlike the oil and gas sectors, forestry data are either irregularly published or missing, limiting public control and international verification (EITI International Secretariat, 2023).
- Underestimation of non-financial reporting. Kuzmenko (2023) stresses the low relevance of environmental and social reporting in the forestry sector, which contradicts EU approaches to sustainable development. The CSRD Directive (European Commission, 2022) and EU Forest Strategy (European Union, 2021) set standards for transparent

environmental, social, and governance (ESG) disclosure.

- Lack of independent audit. Lytvyn and Kucharets (2021) and Transparency International Ukraine (2021) highlight high corruption risks, undermining ecological safety and financial stability.
- Weak interagency cooperation. Timber accounting is not synchronized with customs declarations or integrated into public monitoring tools (FAO, 2022).
- Transparency as an investment precondition. According to Novakova, Plaksiuk, & Habinakova (2024), transparent accounting and audit create the trust needed for sustainable investment in Ukraine's forest sector.

3. RESULTS AND DISCUSSION: SOLUTIONS TO IMPROVE TIMBER ACCOUNTING TRANSPARENCY

Ensuring transparency in the forest sector is a prerequisite for sustainable development, as timber is a strategic resource in Ukraine's economy. Since 2012, the State Forest Resources Agency has implemented the Electronic Timber Accounting System (ETAS), governed by Order No. 202 and Cabinet Resolution No. 761 (Cabinet of Ministers of Ukraine, 2007). This system includes barcoded tagging and electronic data entry, enabling integration into accounting systems (State Agency of Forest Resources of Ukraine, 2022). The main goal of the EOD is to establish complete online control over the movement of timber from logging to sale, in order to prevent shadow circulation and illegal harvesting.

ETAS functionality includes:

- Mobile accounting using barcode tags, handheld devices, and portable printers (Dovhyi, 2023);
 - Centralized software WinforstPro and mobile module WinforstPro Mobile (Galuzevska, 2022);
 - Online logging map via «Forest in a Smartphone» project covering 10+ regions (Ministry of Digital Transformation of Ukraine, 2023);
 - Full traceability with geolocation, photos, crew, and transport data (Bedenyuk, 2023);
 - Mapping and GPS/photo monitoring of timber movement (Kalyniuk, 2024);
- Digital reporting and analytics, with 99% of state timber enterprises covered (UEE, 2023).

The functionality of this system:

- Tagging and mobile accounting: the use of special tags, PDAs, and mobile printers allows for data entry directly in the forest (Kaleniuk, D., 2024).
- Centralized software: WinforstPro ("Industry ITS") and the mobile module WinforstPro Mobile provide accounting and storage of data in real time (Galuzevska, O., 2022).
- Online cutting map ("Forest in a smartphone"): a project available at lkukrforest.com, covering more than 10 regions, providing access to approximately 30,000 permits online (FAO, 2022).
- Traceability: The movement of each log is recorded - time, location, crew, photo, transportation (Transparency International Ukraine, 2021).
- Cartographic representation: Users can verify the legality of logging based on geolocation in real-time, and the portal automatically determines the presence of a permit.
- Photo and GPS control: photos of logs and trackers on trucks allow monitoring of quality and route, promptly responding to deviations (Transparency International Ukraine, 2021).
- Reporting and management: the system generates electronic shipping documents (TTN), analytical reports, and provides access to various levels of users (State Forest Agency, 2022).

Currently, the EOD system covers enterprises that account for 99% of procurement in the public sector. This has led to improved accounting quality, reduced paperwork, and increased transparency (Kalenjuk, D, 2024). For example, Zhytomyr region has implemented full digitization using LIDAR and volume modeling, confirming the principle: «a digital forest has no place for illegal timber» (Ministry of Environmental Protection and Natural Resources of Ukraine, 2024).

EOD provides the foundation for transparent accounting reporting, which is essential for the integration of forestry into the EITI reporting mechanism (Extractive Industries Transparency Initiative, 2024). Digital control supports ecological balance and contributes to the fulfillment of ESG (Environmental, Social, and Governance) and CSRD requirements (European Commission, 2021). Transparent accounting stimulates institutional modernization in the State Enterprise “Forests of Ukraine”, the formation of key performance indicators (KPI), and open personnel selection (Forest Initiatives and Society, 2025).

However, there are also application problems: there are cases where the reliability of the tags does not guarantee legality – “non-representative” cuts conducted with documentation. The coverage of the system is also incomplete, and not all forest users are connected, as there are still “white spots” in the system, particularly in some regions and communal forestry enterprises (European Commission, 2022); the current system, developed back in the 2010s, is technologically outdated and unable to fully cover all potential abuses, as well as to meet modern international requirements, including the EUDR (EU Regulation on Timber) (Transparency International Ukraine, 2021).

To address these systemic issues, a direct comparison of specific electronic wood accounting systems in EU countries is proposed, where this process is also complex due to the variety of approaches (Table 1); however, common principles and elements characteristic of developed EU countries (notably Germany, Finland, and the Czech Republic) can be identified and implemented in Ukraine (European Forest Institute, 2021). These principles reflect the demands for transparency, efficiency, and compliance with international standards.

Table 1. Comparative table of electronic accounting and auditing systems for wood in EU countries (conceptual approach)

Component	General features of the systems of EU	Electronic accounting of wood in Ukraine	Directions for improvement (EITI approach)
Normative-legal framework	Consistent, in accordance with international standards (EUDR, EUTR, IAS/IFRS)	Available, but requires coordination and compliance EUDR	Unification of legislation, alignment with international standards (EITI, EU Timber Regulation). Adoption of the national 'Law on the Origin of Timber' (analogue Lacey Act / EUTR)
Electronic accounting of wood (EAW)	Comprehensive digital systems with integration at all stages of the supply chain (from procurement to sales)	Implemented (Forest EIS), but technologically outdated, there are parallel databases	Integration into a unified national system (EAW 2.0) using blockchain technologies for data immutability. Open API for public oversight

Component	General features of the systems of EU	Electronic accounting of wood in Ukraine	Directions for improvement (EITI approach)
Traceability	Comprehensive traceability using GPS, RFID tags, and online monitoring of timber movement in real-time	Marking by exchanges, there is GPS control, but there are risks of manipulation	Full integration with GPS systems for online monitoring of timber movement in real time. Extension of EOD data: GPS coordinates of logging, photo/video documentation, information about transport/driver, integration with buyer registers
Market transparency	Mostly 100% electronic trading, public access to data on prices, volumes, and beneficiaries	Auctions through Prozorro. Sales, e-auctions, but part of the forest is sold outside the exchange	100% mandatory electronic trading for all wood. Transparency of all conditions and results of sales, including prices and volumes
Access to data	Wide access through open data platforms, integration with EITI reporting, open APIs	Partial access, limited for the media and the public, incompleteness of data	Open data platform (open forest data), integration with EITI reporting standards. Ensuring full transparency and easy access to the registers of ultimate beneficial owners of companies
Control and Audit	Regular, independent external audit (financial, environmental, ESG); certifications (FSC, PEFC)	Internal audit by state structures, lack of independent external audit, corruption risks	Involvement of public institutions, anti-corruption organizations, independent audit firms. Introduction of professional certification for auditors of sustainable forest management (ESG, EITI, FSC, PEFC). Adapting EITI principles to the forestry sector
Interagency interaction	High level of integration between forestry, customs, tax authorities, and law enforcement structures	Low level of synchronization with customs declarations, tax service	High level of integration between forestry, customs, tax authorities, and law enforcement structures
Non-financial reporting	Mandatory non-financial (ESG) reporting according to the CSRD Directive, reporting on environmental impact and governance	Low significance of non-financial reporting	Open reporting for EITI: revenues, payments, taxes, logging volumes, publication of financial reports. Integration of non-financial (ESG) reporting elements in accordance with the CSRD Directive

To further enhance the transparency and efficiency of Ukraine's forestry sector, based on comparisons with the successful practices of EU countries and the potential of EITI, the following steps are necessary:

1. Transparent timber market: all timber volume must be sold through electronic exchanges

with full transparency—public and journalists should have access to all data regarding buyers, prices, and conditions.

2. Complete electronic tracking (traceability): creating a unified digital registry from logging to processing, using GPS and blockchain technologies. Integration with "Forest in a Smartphone" and customs is necessary—similar to successful pilots in the EU.

3. Expansion of EITI reporting: include the forestry sector in EITI, and mandate accounting, environmental, and social reporting. Examples from Liberia and the Philippines confirm the benefits of alignment with EITI, demonstrating the successful application of EITI principles in the forestry sector.

4. Certification of ESG auditors: develop training programs for auditors on ESG, EITI, CSRD, FSC, and PEFC - this will ensure quality control and reporting.

5. Interagency data platform: an integrated exchange system between the State Forest Agency, customs, the tax service, the public, and international auditors that will reduce corruption risks and provide operational monitoring.

6. Draconian fines and confiscation: significant increases in fines for illegal logging, as well as mandatory confiscation of tools used for illegal procurement (chainsaws, tractors, trucks).

7. Education and public engagement: launching extensive educational and informational campaigns for the public, entrepreneurs, and local communities regarding forest use rules, EOD principles, opportunities for public monitoring, and complaint mechanisms.

An important step towards reform is the registration in the Verkhovna Rada of Ukraine of a new draft law on the timber market (Verkhovna Rada of Ukraine, 2025). This draft law will serve as a foundation for the transformation of the forestry sector, focusing on:- A transparent timber market: all timber will only be traded through electronic exchange auctions, ensuring openness, competition, and equal conditions.- Full electronic accounting: total control from logging to processing and sale through a single traceability system.- The development of wood processing and manufacturing: incentives for producing finished products in Ukraine instead of exporting raw materials.- The protection of forests as an ecological resource: a balance between harvesting and restoration, a digitized and open forest cadastre, regular audits.- Institutional modernization: the establishment of an independent supervisory body, State Enterprise "FORESTS OF UKRAINE", a transparent selection of leadership, clear KPIs, public reporting.

4. CONCLUSION

The conducted analysis clearly demonstrates that the industry is at an important stage of transformation, possessing significant strengths and opportunities for development, but also facing substantial challenges and threats. The implementation of a wood electronic accounting system is undoubtedly a step towards transparency and effective management of forest resources. However, without proper control, public data access, integration with ecological tools, and full implementation of EITI standards and other international practices, this system risks remaining declarative. The forest is a strategic asset for Ukraine. If a system is built around transparency, efficiency, and deep processing, the forestry sector can become one of the pillars of the new Ukrainian economy. Thus, the implementation of the proposed systemic solutions will create a transparent, accountable, and sustainable model for managing Ukraine's forest resources, promote international integration, and enhance the competitiveness of Ukrainian timber in the EU market. This is critically important for ensuring the sustainable development of the country and strengthening trust from international partners and investors.

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FROM POLICY TO PRACTICE: CIRCULAR ECONOMY TRANSITIONS IN THE EU AND THEIR IMPACT ON THE FOREST-BASED INDUSTRY

Virginia Zhelyazkova

Abstract: Since 2015, transitioning to a circular economy has been a strategic priority for the European Union, with major legislative initiatives designed to decouple economic growth from resource use. Among the key sectors poised to both influence and be impacted by this transition is the forest-based industry — a sector uniquely positioned at the intersection of renewable resource supply, sustainable manufacturing, and bio-based innovation.

This research conducts a statistical analysis of selected environmental indicators from Eurostat as well as statistics related to the forest-based industry to assess the trajectory of circular economy implementation across the EU and its Member States. By identifying patterns of divergence and convergence in national performance, the study reveals critical insights into how uneven progress may shape opportunities and challenges for the forest-based sector.

Particular attention is paid to the Balkan EU Member States, where circular economy integration remains in early stages but where forest resources represent significant strategic potential. The findings inform a broader discussion on how forest-based industries can contribute to — and benefit from — circular economy alignment, and what policy or investment gaps remain for enabling systemic, cross-sector sustainability.

Key words: circular economy, forest-based industry, forest resources, circular materials use rate, resource abundance–efficiency paradox

1. INTRODUCTION

The shift to a circular economy (CE) represents a paradigm change in how the European Union conceptualizes economic development, decoupling it from linear consumption models and finite resource dependency. Since the adoption of the first Circular Economy Action Plan in 2015, followed by its 2020 successor as part of the European Green Deal, the EU has sought to redesign industrial production and consumption systems around principles of resource efficiency, waste reduction, and product lifecycle extension. Among the sectors deeply embedded in this transition is the forest-based industry (FBI), which lies at the confluence of renewable resource provision, sustainable material substitution, and bio-based innovation.

Forest-based industries are particularly relevant in this transition due to their ability to support circular material flows, provide alternatives to fossil-based inputs, and act as carbon sinks through sustainable forest management and long-lived wood products. However, despite strategic alignment at the EU level, actual implementation across Member States varies considerably, affecting the pace and quality of CE integration in different industrial sectors. This paper investigates this uneven landscape through the lens of CE indicator analysis and explores its specific implications for the forest-based industry, with a regional focus on the Balkan EU countries.

2. LITERATURE REVIEW

The academic literature on the circular economy has grown significantly over the last decade, reflecting increasing interest in operationalizing sustainability transitions across industrial systems. Early conceptualizations of the CE — such as those by Murray, Skene, and Haynes (2017), Geissdoerfer et

al. (2017), and Kirchherr, Reike, and Hekkert (2017) — emphasized the CE as a regenerative system aimed at minimizing resource input and waste through reuse, recycling, and redesign. These studies highlighted the CE's potential to redefine economic value creation by aligning ecological and economic objectives.

However, a key strand of the literature emphasizes the systemic challenges of implementing CE principles, particularly in resource-intensive industries. Reike, Vermeulen, and Witjes (2018) argue that CE remains normatively and operationally fragmented, with significant variation in how countries and sectors interpret and apply its core principles. Bocken, de Pauw, Bakker, and van der Grinten (2016) further emphasize the need for business model innovation to truly embed CE practices, suggesting that circular strategies often remain peripheral in traditional industrial ecosystems. Other studies have examined regional disparities in CE implementation. De Jesus and Mendonça (2018) analyze CE policy diffusion across the EU and point to institutional, economic, and cultural barriers as key drivers of divergence. Ghisellini, Cialani, and Ulgiati (2016) present a comparative review of CE practices across global regions, suggesting that top-down policy frameworks, while necessary, must be matched with bottom-up engagement and sector-specific adaptation.

Within the EU context, the Eurostat Circular Economy Monitoring Framework (Eurostat, 2023) has become a key reference for assessing national progress, yet few studies integrate this data with sectoral analyses. Lehner, Mont, and Heiskanen (2021) observe that while CE policies emphasize the use of indicators, the integration of those metrics into specific industrial strategies remains insufficiently developed. Furthermore, Korhonen, Honkasalo, and Seppälä (2018) note that the CE often faces epistemological inconsistencies, leading to unclear implementation paths and evaluation metrics.

The forest-based industry has received focused attention in the context of the bioeconomy, particularly in Nordic and Central European contexts. Hetemäki et al. (2017) discuss the synergies and trade-offs between circular and bioeconomy strategies in the forest sector, noting that cascading use of wood and substitution of fossil-based products with timber-based alternatives represent key areas of circular innovation. Similarly, Stegmann, Londo, and Junginger (2020) stress the importance of cross-sectoral integration and policy coherence for maximizing the circular value of forest biomass.

Forest-rich but economically less advanced EU regions, such as the Balkans, remain underrepresented in the literature. Some national studies (e.g., Lazarević & Valve, 2017 for Croatia; Iliev, 2020 for Bulgaria) suggest that while forest resources are abundant, institutional capacity and innovation infrastructure remain weak, hindering CE integration in forest-based sectors. However, there is a lack of comparative or quantitative studies that systematically analyze the link between CE indicator performance and forest industry development in the Balkans within the EU-wide CE context.

The present paper seeks to fill this gap by offering a novel empirical approach that triangulates selected relevant Eurostat indicators with forest-based industry statistics, paying particular attention to Balkan Member States. This contribution is twofold. First, it advances the literature by statistically linking general CE performance with sectoral readiness and structural constraints in the forest-based economy — a nexus often overlooked in current scholarship. Second, it provides regional insights into how national divergences in CE implementation shape strategic opportunities for the forest-based sector, particularly in under-analyzed Member States where forest endowments are high, but policy and investment frameworks remain weak.

3. METHODOLOGY AND DATA SOURCES

To test the relationship between forest abundance and circular economy outcomes in the Balkans, we constructed a cross-sectional econometric model based on national-level data from eight countries for the most recent period (2020–2023). The dependent variable — resource productivity (EUR of GDP per kg of domestic material consumption) — was selected as a core indicator of material efficiency and CE performance. The key explanatory variable was forest cover (% of national territory), while control variables included GDP per capita, urbanization rate, the industrial share of GDP, environmental protection expenditure (as % of GDP), and the education index as a proxy for innovation capacity. The

analysis employed an ordinary least squares (OLS) regression with robust standard errors to account for heteroskedasticity. All data were obtained from publicly accessible international databases: Eurostat (2023) for resource productivity and economic indicators, FAO (2020) for forest cover, the World Bank (2023) for urbanization and industrial structure, OECD (2022) for environmental expenditure, and UNDP (2022) for the education index. The model offers an exploratory empirical test of the "abundance–efficiency" paradox within the circular economy framework, focusing on renewable biomass in forest-rich economies with divergent CE trajectories.

4. ECONOMETRIC ANALYSIS OF FOREST RESOURCES AND CIRCULAR ECONOMY PERFORMANCE IN THE BALKANS

A well-documented phenomenon in environmental economics is the so-called resource abundance–efficiency paradox. According to this paradox, countries endowed with abundant natural resources, such as forests, may exhibit lower levels of resource productivity and circular material use — not due to scarcity, but precisely because of resource plenitude. The underlying logic is that when access to primary materials is easy and cheap, there is less economic pressure to develop efficient, circular, or innovative practices to retain value within the system. This insight echoes the broader literature on the resource curse, which demonstrates that abundance can lead to underinvestment in productivity-enhancing technologies and long-term resilience (Korhonen et al., 2018; Deutz et al., 2020).

In the case of forests, the paradox may manifest differently compared to fossil resources, given their renewable nature. Nonetheless, if forest biomass is predominantly used for low-value applications (e.g., fuelwood), and if reuse or cascading innovation is weak, resource abundance may still obscure underlying inefficiencies in circular performance. Therefore, unless compensated by strong governance, innovation policy, or market incentives, high forest endowment does not automatically result in high resource productivity.

To empirically investigate this relationship, we conducted a cross-sectional econometric analysis using data from eight Balkan countries: Bulgaria, Romania, Slovenia, Croatia, Greece, Serbia, Albania, and North Macedonia. The dependent variable is resource productivity (EUR of GDP per kg of domestic material consumption), which serves as a proxy for efficient material use. The core explanatory variable is forest cover (% of national territory), complemented by structural and socioeconomic control variables: GDP per capita, urbanization rate, share of industry in GDP, environmental expenditure (% of GDP), and the education index (used as a proxy for innovation capacity and awareness).

The data were drawn from Eurostat (2023), FAO (2020), World Bank (2023), OECD (2022), and UNDP (2022), covering the most recent period between 2020 and 2023. The model was estimated using method of ordinary least squares (OLS) with robust standard errors, accounting for potential heteroskedasticity. The regression specification is as follows:

$$\text{Resource Productivity}_i = \beta_0 + \beta_1 \text{ForestCover}_i + \beta_2 \text{GDPpc}_i + \beta_3 \text{Urban}_i + \beta_4 \text{Industry}_i + \beta_5 \text{EnvExp}_i + \beta_6 \text{Education}_i + \varepsilon_i$$

The results (see Table X) indicate a positive but statistically insignificant coefficient for forest cover ($\beta = 0.025$, $p = 0.225$). While this may superficially suggest that greater forest area correlates with higher resource productivity, the result lacks statistical strength and must be interpreted cautiously. The modest coefficient and lack of significance are more consistent with the theoretical paradox: that forest abundance alone does not generate circular benefits unless mediated by supportive institutional and policy contexts.

Notably, both GDP per capita and the education index are positively associated with resource productivity. These findings reinforce the importance of socioeconomic development and knowledge systems as enablers of circularity. In forest-rich but low-performing CE countries like Romania or Bulgaria, forest biomass continues to be used for subsistence or low-value functions, with limited

innovation, recycling, or industrial symbiosis. This results in lower overall productivity despite large natural endowments.

Given the small number of years for which it has been made, the analysis remains exploratory. Nonetheless, it supports the paper's central argument: that resource abundance, when not matched by institutional quality, innovation frameworks, and investment capacity, may mask inefficiencies in circular economy performance.

Future improvements could include:

- Testing interaction terms (e.g., ForestCover × Education or ForestCover × Governance Quality)
- Incorporating quadratic terms to assess non-linear effects
- Applying panel data methods to assess within-country variation over time
- Exploring clustering effects between EU and non-EU countries

This initial model serves as a conceptual proof of the abundance–efficiency paradox in the context of renewable biomass and CE implementation in the Balkans.

Table 1. OLS Regression Results – Determinants of Resource Productivity (Balkan Countries, N = 8)

Variable	Coefficient	Std. Error	t-Statistic	p-Value
Intercept	−0.681	1.156	−0.59	0.586
Forest Cover (%)	0.025	0.016	1.52	0.225
GDP per Capita (EUR)	0.00009	0.00008	1.09	0.34
Urbanization Rate (%)	0.01	0.018	0.57	0.597
Industry Share of GDP (%)	0.002	0.025	0.08	0.938
Environmental Exp. (% of GDP)	0.783	1.194	0.66	0.542
Education Index	1.422	1.87	0.76	0.49

Model Summary: R-squared = 0.765 | N = 8 | Estimation method: OLS with robust standard errors

Variable Descriptions and Sources:

- Forest Cover: FAO (2020). *Global Forest Resources Assessment*. <http://www.fao.org/forest-resources-assessment/en/>
- Resource Productivity: Eurostat (2023). *Resource productivity*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Resource_productivity
- GDP per Capita: Eurostat (2023). *GDP per capita (EUR)*. <https://ec.europa.eu/eurostat/databrowser/view/tec00115/default/table?lang=en>
- Urbanization Rate: World Bank (2023). *Urban population (% of total)*. <https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS>
- Industry Share of GDP: World Bank (2023). *Industry (including construction), value added (% of GDP)*. <https://data.worldbank.org/indicator/NV.IND.TOTL.ZS>
- Environmental Expenditure: OECD (2022). *Environmental protection expenditure (% of GDP)*. <https://data.oecd.org/leo/environmental-protection-expenditure.htm>

- Education Index: UNDP (2022). *Human Development Reports: Education Index*.
<http://hdr.undp.org/en/content/education-index>

5. DISCUSSION AND CONCLUSION: FROM POTENTIAL TO PRACTICE

The findings suggest that while forest resources in the Balkans offer considerable potential for circularity, this potential remains largely untapped due to structural, institutional, and financial constraints. The lack of integrated CE strategies, low rates of public investment in innovation, and weak linkages between policy and industry are key factors limiting CE transition in the forest-based sector. Our analysis underscores that CE progress is not solely a function of resource availability but also of governance capacity and strategic alignment.

This calls for a multi-pronged policy approach: strengthening CE-related governance in forest strategies; expanding EU funding absorption through targeted technical assistance; incentivizing innovation in value-added wood products; and fostering regional knowledge-sharing platforms. By addressing these structural gaps, the forest-based sector in the Balkans could move from resource extraction to circular value creation, contributing more meaningfully to both national economies and EU sustainability objectives.

Author's Note:

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GREEN TAXES AS A TOOL FOR SUSTAINABLE DEVELOPMENT IN THE FOREST INDUSTRY: APPROACHES AND IMPACTS

Zhelyo Zhelev

Abstract: The forest industry is important for sustainable economic development in Europe, but faces challenges related to resource efficiency and climate change objectives. Green taxes are being implemented in many EU countries as a tool to reduce the environmental footprint of industrial activities, including the extraction, processing and transport of wood. The paper examines the role of these fiscal mechanisms in the context of sustainable forest resource management and effective fiscal control. A comparative approach is used to analyse European Commission policies and reports, as well as examples from countries with active environmental fiscal reform. Impacts on corporate behaviour, sector transparency and investment in green technologies are assessed. The results show that although green taxes are not always directly targeted at the forest sector, they have an indirect impact on the sector by promoting energy efficiency and responsible management. It is concluded that the integration of fiscal instruments with sustainability policies offers real potential for improving the EU forest sector.

Keywords: green taxation, forestry sector, sustainable development, fiscal policy

1. INTRODUCTION

In the context of accelerated climate change and the growing need for sustainable management of natural resources, the forestry industry occupies an important place in the policies of the European Union (EU). Fiscal policy instruments, particularly green taxation, are regarded as a means of accounting for environmental externalities and encouraging sustainable practices in sectors with a significant environmental impact, such as the extraction, processing and transportation of wood (Phoomsavarth, 2023).

According to Ahmad et al., green taxes regulate pollution and stimulate structural changes in industries by providing economic incentives that encourage businesses to adopt more efficient, environmentally friendly practices (2024). The Green Deal and the Fit for 55 mechanisms, for instance, propose reforming tax systems with respect to carbon emissions taxation (Zolkover, Lagovska, Valihura, Zhelef, & Shynkar, 2024). The application of green taxes in the forestry industry varies between EU member states. Scandinavian countries, for instance, have a strong link between fiscal incentives and sustainable forest management policies. (Sharif, et al., 2023). However, data also suggest that introducing green taxes can have a dual effect: encouraging innovation while limiting development capacity in the absence of appropriate financial support (Yang, Zheng, & Wu, 2024).

2. A REVIEW OF FISCAL POLICIES IN THE EU WITH A FOCUS ON THE FORESTRY SECTOR

Green taxation is a modern fiscal policy tool that transforms the negative environmental effects of companies' economic activities (Gazanfarli & Zhelev, 2025). Its main function is to address market imperfections caused by environmental damage by implementing the 'polluter

pays' principle (Eroğlu, 2019). Within the EU, environmental taxation forms an integral part of the Green Deal and the goal of achieving carbon neutrality by 2050. Although EU legislation does not impose uniform rates, it introduces framework directives that Member States must follow. The main types of green tax include those on energy products, CO₂ emissions, and the use of natural resources, and these taxes are applied to industries that depend on forest resources. (Louca, 2007).

An analysis of the implementation of green taxation across the EU reveals differences. Sweden introduced a carbon tax in 1991, which led to significant reductions in emissions and a transformation in industrial structures (Andersson, 2019). Meanwhile, Hungary is aligning with EU environmental policy by introducing carbon taxes and sustainable transport initiatives (Muth, Weiner, & Lakócai, 2024). Greece uses green taxes to stimulate economic growth and generate revenue for public environmental programs, thereby emphasizing the importance of enforcing environmental legislation (Thanasas, Slimistinou, Kontogeorga, & Lampropoulos, 2023). Studies show that implementing green fiscal policies modernizes industries and increases investment in carbon capture and storage technologies (Jolovski, 2024).

The financial impact of green taxes has been the subject of considerable analysis. A study by Tsiantikoudis et al. shows that the funds collected are often reinvested in projects to restore damaged forests and educate local communities about the environment (2022). Similar practices can be observed in Central and Eastern European countries, where environmental taxation is used to encourage responsible resource management. However, according to Barna and Mura, green taxes in the EU are only as effective as the consistency between national tax systems and the Union's common regulatory framework, which is still not fully harmonized (2011).

Based on reviewed fiscal policies, green taxation in the EU is found to have significant potential to impact the forestry industry by putting fiscal pressure on harmful practices and encouraging sustainable investment. However, their effectiveness ultimately hinges on political will, institutional capacity and the level of private sector engagement. To achieve sustainable results, green taxes must be integrated into long-term strategies combining financial mechanisms with regulatory standards, carbon footprint monitoring, and business participation in forest industry management.

3. ANALYSIS OF THE EFFECT OF GREEN TAXES ON THE FORESTRY INDUSTRY IN THE EU

Green taxation is one of the main tools of modern fiscal policy for achieving sustainable development (Obranković, et al., 2024). In the context of the forestry industry, green taxes can serve a dual function. On the one hand, they can discourage environmentally harmful practices by placing a tax burden on them. On the other hand, they can stimulate environmental innovation and sustainable forest management by encouraging green investments.

To assess the impact of green taxation on the forestry industry in the EU, the article compares seven Member States: Sweden, Finland, Germany, France, Italy, Greece and Bulgaria. The countries were chosen based on two criteria: the structure of environmental taxation and the forestry sector's capacity to absorb carbon dioxide, as measured by official LULUCF (Land Use, Land Use Change and Forestry) data.

The countries were selected for their representativeness of different geographical areas, economic models and institutional frameworks for forest management. Sweden and Finland have a relatively low share of green taxes, but their forestry sectors are highly efficient in terms of CO₂ absorption. It is the result of long-term targeted investments in sustainable forest management and digitisation (Kostova, 2024) and regulations. In contrast, Greece and Bulgaria have high levels of green taxation relative to their total tax revenues, but significantly lower levels of carbon absorption capacity, which raises questions about the effectiveness of reinvesting tax revenues in the forestry sector. Germany, France, and Italy are included as representatives of countries with average values and a balanced policy combining fiscal and regulatory frameworks.

Figures 1 and 2 illustrate the relationship between green tax intensity and real climate benefits, as measured by forest ecosystems' carbon absorption. These figures provide an empirical basis for further interpretation and critical analysis of the effectiveness of green fiscal policy in the context of sustainable forestry within the EU.

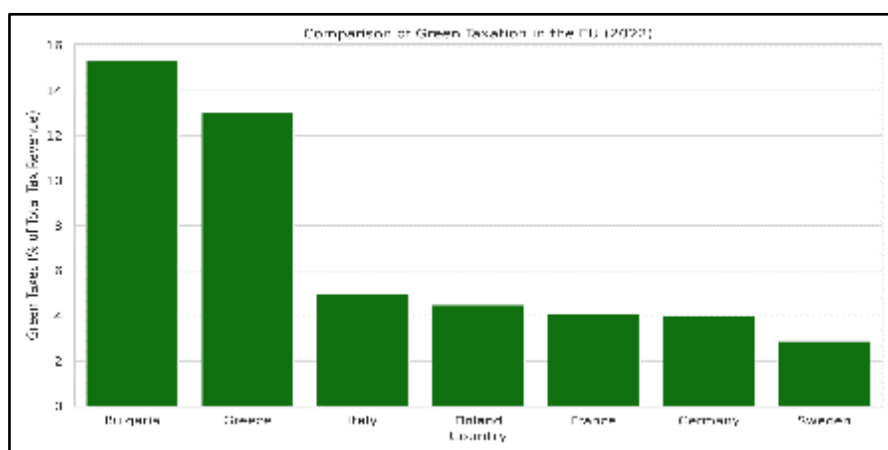


Figure 1. Comparison of Green Taxation in the EU
Source: Eurostat

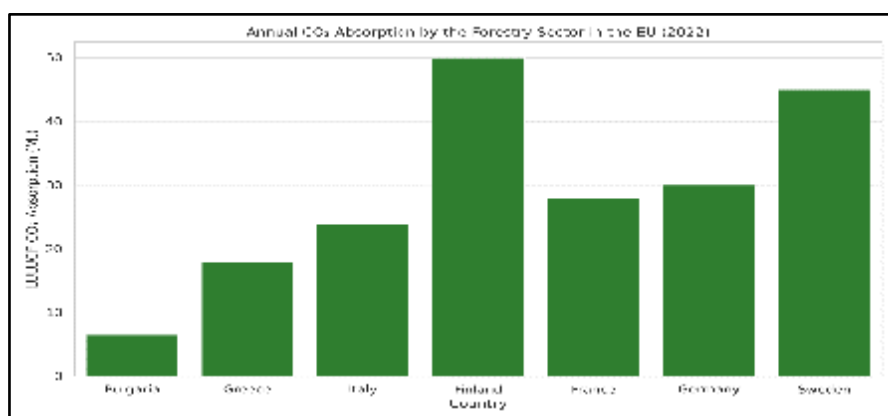


Figure 2. Annual CO₂ Absorption by the Forestry Sector in the EU
Source: Eurostat

To assess the true impact of such taxation, it is necessary to analyse the relationship between green tax levels and environmental performance indicators in the forestry sector. The following Figure 3 presents empirical data from seven EU Member States in 2022. The horizontal axis shows the proportion of green taxes in total tax revenue, expressed as a percentage, while the vertical axis shows the amount of CO₂ absorbed by the forestry sector according to the LULUCF methodology, expressed in megatonnes of CO₂ equivalent (Mt CO₂e).

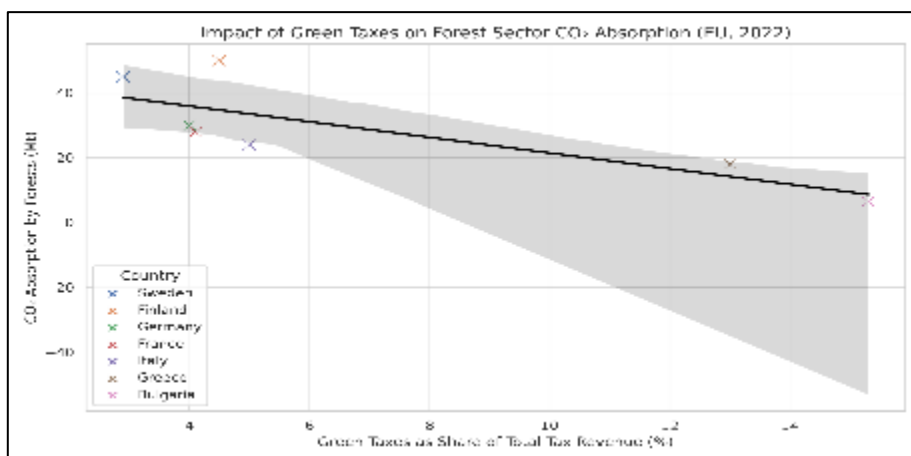


Figure 3. Impact of Green Taxes on the Forest Sector CO₂ Absorption

As can be seen from the graph, there is no clear positive correlation between high shares of green taxes and the amount of CO₂ absorbed by the forestry sector. Countries such as Bulgaria and Greece have some of the highest shares of green taxation (15.3% and 13.0% of all taxes), but relatively low levels of carbon absorption (6.5 and 18.0 Mt CO₂e, respectively). At the same time, Sweden and Finland, with relatively low shares of green taxes (2.9% and 4.5%), demonstrate the most significant forest absorption – 45.0 and 50.0 Mt CO₂e.

Scientific analysis of the regression relationship shows a negative correlation between the two indicators. However, the result should not be interpreted as evidence of the ineffectiveness of green taxation, but rather as a reflection of differences in forest policy, economic structure, climatic conditions, and the institutional framework of each country. In Northern Europe, countries such as Sweden and Finland have long-standing sustainable practices, modern management, and digital control over forest resources, which contributes to their high absorption capacity despite relatively low green taxation. On the other hand, the high share of green taxes in countries such as Bulgaria and Greece is often due to a general fiscal structure in which energy and transport taxes are significant but are not directly reinvested in forestry. The highlights need not just to introduce green taxes, but to target them effectively towards environmental impact and the sustainability of industrial practices.

The analysis suggests that green taxation in the EU has significant potential to impact the forestry industry by putting fiscal pressure on harmful practices and encouraging sustainable investment. However, real effectiveness depends on political will, institutional capacity, and the degree of private sector engagement. To achieve sustainable transformation, green taxes need

to be integrated into national strategic frameworks that combine fiscal policy, regulation, and real ecosystem interventions.

4. CONCLUSION

The article shows that green taxation is a strategic tool that can promote sustainable development within the EU's forestry sector. An analysis of empirical data from seven countries reveals a weak negative correlation between the proportion of green taxes in total fiscal revenue and the forestry sector's carbon absorption. However, it should not be taken as an indication of the ineffectiveness of green taxes, but rather as a reflection of differences in institutional capacity, national policy priorities and the extent to which natural capital is reinvested.

High effectiveness in the forestry sector is not achieved through fiscal burden, but rather through the coordinated implementation of long-term management policies, digital transformation and active stakeholder participation. Therefore, to be sustainable and effective, green taxation must be integrated into a broader environmental governance framework that includes monitoring, reporting and transparent public spending if it is to be sustainable and effective. It will ensure that fiscal instruments contribute to reducing the EU's carbon footprint and protecting forest ecosystems.

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WOOD INDUSTRY IN THE SLOVAK REPUBLIC

Anna Šatanová

Abstract: One of the features of a mature economy is a sustainable way of using and capitalizing on domestic raw materials. Wood is considered by experts to be one of the most promising raw materials that is environmentally friendly, and a material for the future. In advanced countries, the use of wood is increasingly being promoted as it does not pose a threat to the environment like commonly used non-renewable materials. The interest in wood is increasing all over the world. The wood processing industry is a very important economic sector because its domestic raw material base is permanently renewable. The wood processing industry is the basic pillar of primary wood processing. Wood is one of few materials that accompany man throughout his life. It is one of the most versatile and most useful raw materials available. As a natural material, it has a wide range of properties. Thanks to its unique qualities, wood is still an irreplaceable material that is used in many different areas of human life. The aim of the article is to present the historical development of the organization of the wood industry and current state of the wood industry of the Slovak Republic.

Keywords: wood, wood industry, historical development, organization of the wood industry, current state, Slovak Republic

INTRODUCTION

The woodworking industry is a very important economic sector. This is mainly because its domestic raw material base is permanently renewable. The wood processing industry is the basic pillar of primary wood processing. Wood is one of the few materials that accompanies man throughout his life. It is one of the most versatile and most useful raw materials available. As a natural material, it has a wide range of properties. Thanks to its unique properties, wood is still an irreplaceable material that is used in many different areas of human life (Gaffová, 2017).

The woodworking industry is bound to produce forestry. The carpentry industry includes the installation of floor and ceiling beams, the production of additional structures, etc. Joinery, on the other hand, focuses on the manufacture and repair of furniture, windows, doors and other wooden products. Sawing machines for cutting material are very important tools in the woodworking industry.

Semi-finished wood products, such as lumber, boards, planks and prisms, are an indispensable part of the woodworking industry. Widespread wooden houses are called eco-houses (new technologies enable lowering heating costs).

In this chapter we will describe the woodworking industry, its importance to national economy and its relation to forestry, provide an overview of the historical development and organization of the woodworking industry in the Czech Republic and Slovakia, and present the current state of the woodworking industry in the Slovakia and the quality of production of this industry.

1. HISTORICAL DEVELOPMENT OF THE ORGANIZATION OF THE WOOD INDUSTRY IN THE CZECH REPUBLIC AND THE SLOVAK REPUBLIC

Sawmill processing is one of the oldest trades. The state and development of production capacities, their frequency and deployment were historically based on forest land and the layout of raw woody materials. Other factors of development included sectoral and organizational arrangement – mainly within Czech industry, investment equipment and the production activity of timber companies (Kupčák, 2002).

Pre-war sawmill production was fragmented, its major part was of a small-scale, craftsmanship nature and there were only relatively few large industrial enterprises (Sprock, 1950).

Post-war development of the wood industry can be divided into 3 stages, namely from 1945 to 1948, the development after 1948 after the end of nationalization and development after 1989. In the period of 1945–1948, nationalized plants belonged to the national companies “České pily”, “Moravsko-slezské pily”, “Českomoravské impregnační závody” and “Českomoravské překlízkárny a dýhářny”. However, most of the companies were still privately owned and grouped into two economic groups: a group of sawmills and a group of woodworking industries. According to statistics, after the war 3,650 sawmills were registered, of which 15 were state-owned sawmills.

After 1948, further companies were nationalized down to units with a daily capacity of 8 m³ of sawn logs, which meant virtually every sawmill. However, war mining and wood consumption significantly exceeded the increase, and after the war they were reduced. This resulted in a lack of raw materials and many establishments disappeared. Within a short time, about 70% of sawmills were suggested for liquidation. Nevertheless, in 1949 the average capacity of sawmill operation was 2,500 m³ per year, although the average amount of sawn wood was only 800 m³. The first period after 1948 also developed relatively favourably. Production concentration, better utilization of capacities, rapid labour productivity growth, and rationalization of operations took place.

Between 1949 and 1960, 37 new businesses were created, and in 1960 a total of 1,509 enterprises were represented by the wood industry, of which 841 were national enterprises, 206 local industry enterprises and 462 cooperative enterprises. The trend was moving towards further concentration. In 1965 a production unit was established Dřevařský průmysl Praha (VHJ DP Praha), a trust that brings together 8 core national companies, according to the regions of the Czech Republic. After 1971, due to the pressure to increase production, systematization and modernization began.

Modernization and concentration of production **in the 1970s and 1980s** resulted in substantial capacity changes with a similar number of production units. The concepts adopted in the 1970s and 1980s provided for a substantially gradual and practically complete concentration of sawmill production, based on a worldwide change in sawmill technology by the use of milling aggregates, thereby accelerating the transformation of the branch structure. In 1986 there were 168 sawmills in the Czechoslovakia; the sawmills were divided according to the companies.

The Czechoslovak Republic was at the forefront of the wood industry (Drábek and Merková, 2010). The developed cooperative relations and civic amenities were very high up to 1989 (Drábek and Volčko, 1998). With a change in regime and the abandonment of central management, there was a decline in the development of the woodworking industry, both in the

Czech Republic and in the Slovak Republic (Kovalčík et al., 2009). The historical and current development of the woodworking industry in the Czech and Slovak Republics is full of changes both in the size and performance of the plants, as well as in the structure, technical equipment, organization and property structure (Pražan, 2010). Especially the latest developments since 1989 and the arrival of privatization have brought about dramatic changes both in the ownership structure and in the development of the number of these sawmills and their focus on different segments of the market.

At the beginning of the 1990s, state-owned enterprises were divided into smaller units in the first stage, and they entered into changing economic conditions. They later became independent with restitution and privatization. Each company that requested to be removed from a large business was granted this request regardless of whether it had a chance to survive a month or a year or two. This political decision resulted in the fact that very soon most of these state-owned enterprises disappeared, not surviving to subsequent privatization (Hrubec, 2002). In 1992, a decline in timber trade and all its products began in Western Europe. The decrease in production also caused a decrease in logs prices – on average by 30% between 1992 and 1993. However, there was no recovery in the production and trade of lumber – some companies ended, others gradually became indebted to financial institutions and to suppliers of raw materials. In debt, they were unable to fulfil their obligations and ceased their activities and their existence. Small and medium-sized factories and unilateral manufacturing operations were even worse off, and after the wave of independence, restitution, and overall pressure on the disposal of large units, this was the case of most factories (Kupčák, 2002).

At present, the wood industry in Slovakia makes up 2.6% of the value added in total production in Slovakia, bringing the Slovak Republic to the 6th place among EU countries (Kupkovič et al., 2003). The Czech Republic has a 2.1% share in added value, thanks to which it has achieved a remarkable 8th place among EU countries.

The question is what caused the drop from the top of the timber industry to the 6th and 8th position, and what are the possibilities get the Czech Republic and the Slovak Republic back where they belong. Most of the harvested wood in Europe is destined for further industrial processing; only about a quarter is used as fuel (Lesáková, 2004). Most of the wood harvested in Slovakia (91%) and in the Czech Republic (86%) is used as industrial wood; on the contrary, in Greece (72%), Italy (70%) and Cyprus (60%) most of the wood is used as fuel.

Timber harvesting is sustainable in most EU countries. Every year, around 1.5–2.5% of the stock of wood in European forests is usually circulating. This means that if forests did not recover, they would average about 50 years.

Statistics show that the amount of exported wood out of the total wood logged in the Czech Republic was 29%, and in Slovakia it was 39% (Suchomel et al., 2010). The Slovak wood industry could achieve even better results. More than one third of harvested trees are exported abroad. This brings about a large part of the added value that other processors earn outside the borders.

If Slovakia or the Czech Republic were able to process the wood in the same way efficiently, the share of the woodworking industry in value added could increase further (Vysušil and Fotr, 1993). Scandinavian countries, namely Sweden and Finland, but also Italy, Romania, and Austria – are at least initially processed by domestic production capacities, and less than 5% of wood is exported.

2. CURRENT STATE OF THE WOOD INDUSTRY OF THE SLOVAK REPUBLIC

The timber industry in the Slovak Republic is incorporated under the woodworking industry, which has a rich tradition in Slovakia. It is represented by the wood, furniture and pulp-paper industries, which are based on the processing of domestic, ecological raw material, i.e. wood. After the change of the economic system in 1989, the wood and furniture industry in Slovakia was faced with the need to restructure their production program with product innovation and exports to EU countries.

In parallel with structural and ownership changes, market disintegration with countries of the former CMEA in the 1990s, suspension of massive housing construction financed from the state budget, devaluation of currency and a gradual decrease in the population's purchasing power occurred in Slovakia. These facts have led to the collapse of domestic and foreign markets and to the deterioration of the stability of industrial production and the sale of timber products.

Another serious problem was the interruption of forestry and timber processing industries. In 1992, organizational integration of these sectors into two ministries shared responsibility for optimal wood evaluation, and conditions for an ongoing search for the bases for supporting domestic woodworking in the market environment. The commercial and pricing policy applied to timber in the internal market did not contribute to harmonizing relations in terms of volume, quality indicators and maturities with rules common in market economy countries. Demand for coniferous raw material began to outweigh the supply and generate rising production costs for production activities in state forest enterprises, which was mainly reflected in prices of lumber. At the same time, exports of raw wood increased to 20% of annual wood harvesting.

However, the level of future development is directly dependent on the implementation of the program for the construction of housing, apartment buildings, the renovation of housing stock resulting from the state housing policy concept, implementation of public work projects and industrial construction. It can be said, however, that this sector is well-placed for further development by ensuring the modernization and replenishment of technological equipment to increase the quality and share of final products with higher added value. Current high material costs, which sometimes exceed 70% of the total cost, are a disadvantage of the woodworking industry.

Because coniferous lumber will remain a significant commodity in the future, in order to increase the monetization of exports and expand export territories to countries with a wood deficit, it is necessary to introduce the mass production of dried timber.

An advantage for the further development of the industry is the interest of foreign partners, such as Swedwood Slovakia, s.r.o. (IKEA, Sweden), which realized the construction of a chipboard production line with a capacity of 125 thousand m³/year in 2000. Since the launch of the production line, at least 100 thousand m³ of pine and poplar is consumed.

The development of the wood industry is largely dependent on the size of investments and, above all, on the effective management methods. Without effective management methods, which include controlling, the objectives of the "Wood – raw material of the 21st century" program (elaborated in 1999 by the Slovak Government, the basic task of which is the elaboration of a common concept of forestry and timber policy in wood production, processing and utilization in the Slovak Republic in order to overcome persisting deformations between wood suppliers and processors) cannot be fulfilled.

The wood industry has a specific position within the Slovak economy due to its comparative advantages. It is relatively independent on imports of raw materials (based on a renewable domestic raw material base), and it is permanently capable of generating an active balance of foreign trade. The development of the entire woodworking industry is also reflected in other factors:

- 41% forest of the SR, total forest area 1.99 million ha
- Average wood reserves of 196 m³/ha, which places the SR in 7th place in Europe
- Logging per capita – 5th place, and mining per ha – 13th place in Europe

A major problem is the low rate of wood utilization and the high share of exports of products with low added value, as well as the export of raw wood, which is contrary to the objectives of restructuring and revitalization of the industry as a whole. At present, the main problem is low valuation raw material. Slovak wood and its products are promoted in overcrowded foreign markets at a price with low economic returns (Drábek, Volčko, 1998).

If we use average consumption indices for the rate of timber valuation based on wood production, which is essentially the average raw material consumption per product, Slovakia, in comparison with countries with an advanced wood processing industry, values raw wood by 33%–50% less (Tunák, 1996).

The raw material base of the SR is quite comparable to other advanced woodworking states. The species composition of our forests fully meets the requirements of the current woodworking product market. The most problematic area in the level of raw material valuation is primarily the state of the technical base of wood industry. Most businesses in the Slovak wood industry have exceptionally obsolete machinery and inefficient management systems.

There are several different factors in the level of raw material valuation. Above all, it is the current level of technology base used in the product making process, the quality of the raw material itself, the quality of the final products and the efficiency of the company's business processes.

Every enterprise in the field of industry, commerce and services has to deal with the level of these three factors. As far as management is concerned, as many foreign companies have shown by coming to Slovakia, the time has come for innovation that greatly affects the quality of production in Slovakia.

The following is a summary of the basic economic indicators of the woodworking industry in Slovakia.

The development of the woodworking industry in Slovakia from 1990 to 2025 has undergone significant changes and transformations. After the fall of communism and gaining independence in 1993, the woodworking industry in Slovakia had to adapt to new market conditions and competition. In the 1990s, many enterprises were privatized, e.g. enterprises of the former state-owned enterprise Bučina Zvolen or Smrečina Banská Bystrica, production was marked by a decline due to the loss of traditional markets (mainly in the countries of the Common Market for Economic Cooperation and Development), the recovery was brought by the orientation towards new markets, mainly Western Europe, and the number of employees in the sector was significantly reduced.

Slovakia's entry into the EU (2004) opened up new possibilities: free trade, investment and standardization of production. Foreign investments increased (e.g. IKEA invested in wood processing, also through partners). Exports of wood products like timber, furniture and wood panels mainly to Germany, Austria and Italy grew. New segments were developed, such as

the production of glued beams, DTD boards, pallets and briquettes. Environmental standards (FSC certification) became an important part of production.

These factors significantly influenced efficiency and environmental sustainability in this segment.

The years 2010-2020 were mainly focused on adding higher value to the sector. There is growing pressure to increase the share of domestic processors compared to raw wood exports (frequently criticised export of logs without processing), making Slovakia a major producer of sawn timber in Europe, by investing in automation and digitalisation of production. But this period is also characterised by a shortage of skilled labour, increasing prices of raw materials (wood) and growing demands for environmental sustainability.

The years 2020-2025 are characterised mainly by greening, crises and new trends. The COVID-19 pandemic caused short-term production interruptions and problems in logistics. There has been an increased interest in wooden structures and ecological products (wooden houses, CLT panels). Climate change and bark beetle disasters in Slovak forests (mainly in the spruce area) significantly affected the availability of quality wood. Green transformation is taking place to greater extent, especially to the support of wood recycling and thus the so-called circular economy. The years 2023-2025 are characterised by greater emphasis on domestic processing and use of wood in construction (wooden structures, green buildings) and the development of the bio-economy, wood is used as raw material for new products (bioplastics, insulation).

The development of important indicators of the wood processing industry of the Slovak Republic is presented in the following table 1.

Table 1 Development of wood processing industry of the SR

Period	Characteristics	Sales (average)	Employment	Notes
1990–2000	Transformation, privatisation, decrease of production	500–750 mil. €	Decreases ~40%	Loss of eastern markets
2000–2010	Modernisation, entry in the EU	750–1200 mil. €	Stabilisation	Development of export, new investments
2010–2020	The increase in added value, automation	1200–1800 mil. €	Lack of employees	Export of finished products
2020–2025	Greening, technologies	green 1800–2100 mil. €	Digitization	Climate challenges. Bio-economy

The woodworking industry in the Slovak Republic has come a long way in 35 years – from a state-run sector to a modern industry oriented towards exports, innovations and ecological solutions. The challenge remains to ensure enough raw materials, qualified labour and adaptation to climate change. Nowadays, the woodworking industry has moved to modern technologies such as CNC machines, robotic production lines and advanced methods.

CONCLUSION

In this paper, we have focused on the historical development as well as the current state of the timber industry in the Slovak Republic. At the same time, we also listed important economic indicators that characterize this industry in the current conditions of the market economy.

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ESG AND THE FOREST-BASED INDUSTRIES IN SLOVAKIA: THEORETICAL BACKGROUND AND IMPLEMENTATION CHALLENGES

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Abstract: This paper focuses on the theoretical aspects of ESG (Environmental, Social, and Governance principles) in the forest-based industries in Slovakia. ESG is becoming a key element of sustainable business practices, with its significance increasing due to the Global initiatives and European regulations and market demands. This paper examines the definition and development of ESG and analyses the crucial factors influencing its implementation within the forest-based sector. Particular attention is given to the environmental aspects, such as the use of certified wood, emissions reduction, and waste management. Social factors comprise working conditions and employee safety, while governance processes emphasize transparency and ethical business practices. Additionally, the paper discusses potential strategies needed for the effective integration of ESG principles in business practices in alignment with European and global sustainability trends.

Keywords: ESG, sustainability, innovations

1. INTRODUCTION

Environmental, Social, and Governance (ESG) principles have emerged as essential components of sustainable business conduct, particularly within the European Union, where regulatory instruments such as the European Green Deal and the Corporate Sustainability Reporting Directive (CSRD) have transformed ESG from a voluntary initiative into a binding framework. ESG encompasses three pillars: environmental (climate action, resource use), social (labour rights, diversity), and governance (corporate ethics, transparency) (Alamillos, 2022). ESG is now instrumental in enhancing corporate resilience, stakeholder confidence, and environmental accountability (Chernysheva, 2024). In Slovakia, ESG adoption is still in its formative stages, characterised by an uneven implementation across sectors. Given their intrinsic connection to natural resources, biodiversity, and rural livelihoods, forest-based industries - comprising forestry, wood processing, and pulp and paper - present both a challenge and an opportunity for ESG integration. This paper investigates the theoretical foundations, institutional context, and implementation barriers of ESG in the Slovak forest-based sector, with particular emphasis on environmental stewardship, social responsibility, and transparent governance.

2. THE REGULATORY CONTEXT OF ESG IN THE EUROPEAN UNION: THE 2025 ESG OMNIBUS SIMPLIFICATION PACKAGE

The European Union (EU) plays a pivotal role in shaping the ESG landscape by embedding sustainability into corporate and financial frameworks. Core legislative instruments—including the Corporate Sustainability Reporting Directive (CSRD), the EU Taxonomy Regulation, and the Corporate Sustainability Due Diligence Directive (CSDDD)—aim to enhance transparency, channel capital towards sustainable activities, and advance the

European Green Deal and the Sustainable Finance Action Plan (European Commission, 2018, 2019).

By early 2025, mounting concerns over the administrative burden of ESG reporting, particularly for SMEs and mid-sized enterprises, led the European Commission to propose revisions to streamline the framework (European Commission, 2025). The updated CSRD limits mandatory reporting to large companies exceeding 1,000 employees and specific financial thresholds, thereby aligning more closely with CSDDD applicability criteria and exempting most listed SMEs.

The European Sustainability Reporting Standards (ESRS) will undergo simplification, with proposed changes including a reduction in mandatory data points, prioritisation of quantitative metrics, and elimination of sector-specific standards. This is especially relevant for resource-intensive sectors such as forestry, where reporting requirements had been projected to be disproportionately complex.

Assurance remains at the "limited" level, delaying stricter audits. The revised CSRD limits value chain reporting by capping data requests to firms with under 1,000 employees. EFRAG's voluntary SME standard provides tailored ESG tools for smaller forestry suppliers. Firms with turnover under 450 million € may opt into voluntary EU Taxonomy disclosures. Under the CSDDD, due diligence on indirect partners applies only where credible risks exist.

Together, these adjustments preserve the EU's sustainability objectives while addressing the implementation challenges faced by complex, resource-dependent sectors such as forestry, where administrative capacity and data accessibility remain critical constraints (European Commission, 2025).

3. ESG CHALLENGES AND INNOVATION PATHWAYS IN THE FORESTRY AND WOOD-BASED SECTOR

The integration of ESG principles within Slovakia's forest-based and wood-processing sectors reveals a landscape marked by inconsistency and overall low adoption. While certain firms - particularly those that are state-owned, large-scale, or research and development intensive - demonstrate relatively advanced ESG engagement, broader implementation remains hindered by structural, financial, and informational barriers (Slastanová et al., 2021; Brodrechťová, 2024).

ESG (Environmental, Social, and Governance) is becoming increasingly important for forest-based industries in Slovakia due to a combination of persistent sustainability challenges, emerging opportunities, and the transformative potential of new technologies and market demands (Schubert et al., 2022).

3.1. Structural barriers to sustainability

One of the most pressing systemic challenges is the variability and insecurity of raw material supply, exacerbated by climate change and biodiversity decline (Schubert et al., 2022). These ecological disruptions threaten not only the availability but also the consistency of wood quality, necessitating adaptive sourcing strategies and the valorization of a broader spectrum of wood species (Rusanen et al., 2024). In the Slovak context, this complexity is compounded by limited state support, which impedes the transition toward low-impact production models (Melichová et al., 2021).

The environmental footprint of processing technologies further undermines wood's reputation as a sustainable material. Conventional thermal and chemical treatments rely on

intensive inputs of energy, water, and hazardous substances, generating emissions and post-processing waste that contradict the sector's ecological narrative (Akpan et al., 2021). Despite a growing consensus around green chemistry, many small and medium enterprises (SMEs) in Central Europe cite high costs and limited technical capacity as key barriers to adopting clean innovations (Šulyová & Koman, 2020).

A further challenge lies in the misalignment between academic sustainability goals and industrial priorities, where climate-related benefits are often perceived as peripheral rather than integral to business performance (Iliescu et al., 2025). Moreover, short product life cycles, particularly in low-end furniture and panel production, reduce long-term carbon storage, which is crucial for climate mitigation (Paluš et al., 2020).

3.2. Circularity, technological innovation, and bioeconomic integration

The wood-based sector, despite existing constraints, offers strong potential for sustainability through circular economy principles such as cascading use, waste reduction, and the valorization of residues and post-consumer wood (Hasegawa et al., 2022). Technological and organizational innovations - like machine learning, low-emission adhesives, and nanotechnologies - are driving more efficient, low-impact production (Schubert et al., 2022; Akpan et al., 2021).

In Slovakia, although implementation is uneven, stakeholder awareness is increasing, and companies often exceed regional benchmarks in areas e.g. machinery planning (Loučanová et al., 2020). However, consistent ESG integration remains contingent on targeted R&D support and clearer policy incentives. Engineered wood products such as CLT and LVL further support decarbonization by offering structurally sound, carbon-storing alternatives to traditional materials, with early use cases reporting high energy efficiency and user satisfaction (Brödner & Fürst, 2024; Švajlenka & Kozlovská, 2020). Their broader adoption could accelerate the transition toward low-carbon construction in both urban and rural environments.

3.4. The role of certification and policy frameworks

An enabling regulatory environment and credible sustainability certification systems -such as FSC and PEFC -are central to advancing environmental, social, and governance (ESG) outcomes. Certification improves market access, corporate reputation, and stakeholder trust (Leite et al., 2025), though evidence suggests that their economic benefits may vary depending on firm size and target market (N'Doua, 2023). As an example of its significance to ESG principles, PEFC has identified 14 areas relevant to ESG and developed an ESG Reporting Guide that provides guidance to companies as to how they can reference PEFC when reporting against relevant requirements from different ESG standards (PEFC, 2025). In Slovakia, a stronger policy push is required to mainstream such frameworks and align them with innovation incentives and public procurement strategies (Melichová et al., 2021).

Investment returns also influence ESG uptake. For example, the expected rate of return on investment in Slovakia is higher in the furniture sector (7.84%) compared to the forest and paper sectors (6.04%), though both present similar risk levels - highlighting strategic investment opportunities within ESG-related development (Kánová et al., 2023). Moreover, foreign direct investment has demonstrated measurable positive impacts on economic value added, supporting the economic rationale for promoting sustainable practices (Rajnoha & Kánová, 2022).

3.5. Social and governance aspects of ESG in the Slovak forestry

Despite their importance, social and governance aspects are often overlooked in ESG efforts across Slovakia's high-risk forestry sector, where felling operations pose recurring hazards - especially for subcontractors, older, and less experienced workers (Kallová & Kozáková, 2023). Although safety has improved, gaps persist between in-house and outsourced staff.

At the organizational level, Slovak companies often exhibit "clan" cultures emphasizing trust, loyalty, and employee wellbeing - factors that support social sustainability when backed by effective institutional frameworks (Šajbidorová et al., 2021). Traditional forest communities in mountainous regions, managing collectively owned land, exemplify grassroots ESG practices through democratic governance and long-term stewardship (Louda et al., 2023).

Some Slovak wood-processing enterprises have adopted modern process management tools such as benchmarking, process controlling, and quality management systems. Although their overall use remains limited, these tools contribute to improved efficiency and cost optimization, indicating potential for enhanced operational performance. As these instruments fall under internal management processes, they may be considered part of the broader framework of corporate governance (Simanová & Gejdoš, 2019). Yet integrated ESG strategies require more than operational excellence they call for transparency, stakeholder inclusion, and the embedding of social and environmental values into governance systems. Evidence shows that ESG, especially the social and governance pillars, positively correlates with corporate performance and resilience (Zeng & Jiang, 2023). ESG-aligned forestry investments yield competitive returns without compromising profitability, while certification and legality attributes enhance compliance and market value (Löf et al., 2023; Klinger et al., 2022). Although Slovak-specific ESG data remain limited, international findings affirm ESG's strategic relevance for the sector's sustainable transformation.

4. CONCLUSION

The integration of ESG principles into Slovakia's forest-based industries remains an evolving but increasingly critical endeavour. While the European Union provides a robust legislative and strategic foundation through instruments such as the CSRD, EU Taxonomy, and the CSDDD (European Commission, 2019, 2025), the practical implementation at the national and sectoral level continues to face structural, financial, and informational barriers (Melichová et al., 2021; Schubert et al., 2022).

Forest-based industries, by virtue of their environmental interdependencies and social embeddedness, are uniquely positioned to pilot ESG innovation. Case studies from Slovak forest communities and selected enterprises demonstrate the potential of grassroots governance, circularity strategies, and technological adoption in aligning operational practices with ESG objectives (Louda et al., 2023; Loučanová et al., 2020).

However, ESG mainstreaming demands more than isolated success stories. A systemic shift will require targeted capacity building, simplified reporting frameworks for SMEs, and stronger policy coherence across environmental, social, and economic domains (Beckmann et al., 2020; Klarić et al., 2023). Integrating ESG into core decision-making processes - not merely as a compliance tool but as a strategic asset - may enhance the sector's resilience, innovation potential, and long-term global competitiveness (Brödner & Fürst, 2024).

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KEY INDICATORS FOR ASSESSING DOUBLE MATERIALITY IN THE WOOD INDUSTRY

Silviya Kostova

Abstract: Double materiality is established as a core principle in the regulatory framework for sustainable corporate governance implemented through the Corporate Sustainability Reporting Directive (CSRD) and the European Sustainability Reporting Standards (ESRS). In this context, the wood industry, characterized by high dependence on natural resources, significant environmental impacts and social engagement, is faced with the need to integrate robust financial and non-financial reporting mechanisms. The objective of the article is to identify key indicators that can be applied in the double materiality assurance process, tailored to the specificities of the timber sector. Identifying key indicators in the double materiality assessment process supports systematic assessment of environmental and social risks, providing a basis for informed management decisions in the forest industry.

The methodological approach includes a systematic review of relevant regulatory frameworks and voluntary standards (GRI, ISSB, ESRS), as well as an analysis of ESG reports of leading companies in the sector. Qualitative data is complemented by expert interviews with auditors and sustainability specialists from countries with developed forest industries. The study provides a structured indicator framework to assess the impacts and financial risks associated with environmental and social factors. The results contribute to the development of a useful toolkit for the audit of non-financial information and to the improvement of sustainability assessment processes in wood industry companies.

Keywords: double materiality, audit, wood industry, ESG, non-financial reporting

1. INTRODUCTION

The concept of double materiality is essential to the European regulatory framework on sustainable corporate governance. It requires companies to report not only financially material factors ("outside-in") but also how their activities impact the environment and society ("inside-out"). In this context, the forestry and timber industries are among the sectors with the highest sustainability exposure due to their frequent use of natural resources, their impact on biodiversity and their dependence on the population (Moratis & Van Liedekerke, 2024). The EU Regulation against Deforestation (EUDR) (Regulation (EU) 2023/1115) requires increased control of supply chains and greater transparency along the entire value chain dependent on sustainable forest management. The implementation of these new obligations poses significant challenges for auditing practice, especially on the validation of non-financial impacts.

Companies have difficulty applying double materiality analysis due to a lack of clearly defined processes, sustained stakeholder engagement and objective impact criteria (Mezzanotte, 2023). An analysis of Iberian companies shows that only a limited proportion of organizations provide detailed and auditable information related to the materiality process.

There is also a significant legal risk associated with incomplete or misleading reporting, including the danger of greenwashing, especially in the absence of consistency in the definition

of indicators and commitment to external audits (Martinčević, Primorac, & Dorić, 2024). Regulators, as well as organizations such as GRI and ISSB, are pushing for the inclusion of quantitative and comparable indicators to enable adequate impact analysis and provide a basis for sustainable investment and oversight. Specific indicators in the forest industry, aligned with the value chain, ecological footprint and social dependencies, should be based on sustainable management and auditing systems. Therefore, the application of double materiality in this sector requires the development of standardized, quantitative and controllable indicators (Zhelev, 2024). It is important for the credibility of sustainability reporting and for reducing regulatory and legal risk in the timber sector (Merková, Drábek, & Jelačić, 2013).

2. IMPORTANCE OF DOUBLE MATERIALITY IN THE FOREST INDUSTRY

The principle of double materiality is a fundamental element as it involves a two-way assessment - of both the external environmental impact on the enterprise and the environmental and societal impact of the enterprise (Dragomir, Dumitru, Chersan, Gordan, & Păunescu, 2025). In the forest industry, the approach is strongly linked to ecosystem services, carbon balance and microclimate resilience. Indicators such as greenhouse gas (GHG) emissions, biodiversity loss, water resource use and social impacts are most used (Morganho, Milánes-Montero, & Pérez-Calderón, 2025). Effective reporting of these requires the application of established frameworks such as GRI, ISSB and the EU taxonomy. The analysis of impacts through the so-called PAI-indicators mandated by the SFDR requires systematic screening for adverse effects along the entire value chain, especially in the primary biomass sector (Filtikaki, Vastardi, & Adam, 2023). Companies must demonstrate not only compliance but also adequacy of processes for double assessment (Bhatnagar, Taneja, & Özen, 2025).

The study found that the key indicators that capture double materiality in the forest industry are CO₂ uptake, biodiversity loss and PAI 1 and PAI 7, which are consistent with regulatory requirements for SFDR reporting and sustainable investment assessment. Table 1 shows the data for the period 2015-2024 to give an idea of their numerical values.

Table 1. Double Materiality Indicators in the Forest Industry (2015-2024)

Year	CO ₂ Sequestration in Forests (Mt CO ₂ /year)	Biodiversity Loss/Degradation (%)	PAI 1 - GHG Emissions (tCO ₂ e)	PAI 7 - Biodiversity (% investments in sensitive areas)
2015	74.1	-	-	-
2016	72.5	-	-	-
2017	70.0	-	-	-
2018	65.0	-	-	-
2019	60.0	73%	-	-
2020	55.0	70%	-	-
2021	50.0	68%	-	-
2022	37.8	65%	-	-
2023	-	-	3,217,630	30%
2024	-	-	-	28%

The lack of consistent and comparable data for ESG and PAI indicators in the forest industry over the 2015-2022 period is due to several structural and methodological factors. First, until the Corporate Sustainability Reporting Directive (CSRD) and Sustainable Finance Reporting Regulation (SFDR) came into force, companies were not legally obliged to disclose information on uniform indicators. Reporting was mostly voluntary, with low harmonization and limited coverage of non-financial indicators. Second, until 2022 there was no clearly defined methodology for applying PAI indicators, especially for more complex aspects such as biodiversity and social impact. Thirdly, much of the forest industry consists of small and medium-sized enterprises, which are often outside the scope of binding regulations. An additional difficulty is the complexity of measuring Scope 3 emissions and value chain impacts. Until the introduction of ESRS standards in 2023, there was no comprehensive mechanism for public reporting and verification (Dyczkowska & Szalacha, 2025).

The application of double materiality implies a significant role for auditors who need to validate non-financial information and prevent greenwashing by providing confidence in the reporting process (Appelbaum, Duan, Hu, & Sun, 2023). In this context, their role is transformed into mediators between data, regulations and stakeholders (Al Amosh, 2025).

In the forestry sector, companies often focus on economic and environmental aspects, neglecting social indicators, creating risks of non-compliance and legal vulnerability (Li, Toppinen, Tuppur, Puumalainen, & Hujala, 2011). Therefore, the integration of double materiality in the forest industry is not only a regulatory requirement, but a prerequisite for sustainable transformation that requires reliable measurability and cross-sectoral alignment of ESG practices with strategic objectives and regulatory expectations.

3. KEY INDICATORS FOR AUDITING AND ASSESSING DOUBLE MATERIALITY

Assessing double materiality within non-financial reporting requires an understanding of ESG risks, applying clearly defined and measurable indicators. The methodology requires a combination of European regulations (CSRD, SFDR, EUTR, CSDDD), voluntary frameworks (GRI, ISSB) and expert assessments applicable to sustainability auditing in the forest industry. The leading indicators used in the audit assessment of double materiality in the forest industry have high regulatory and practical relevance as they cover critical impact areas - climate, biodiversity, social responsibility and economic sustainability. They are directly linked to the requirements of the CSRD, the EU taxonomy and the SFDR and provide comparability and verifiability of non-financial reporting. Auditors use them as a basis for validating sustainable investments and for assessing the risk of non-compliance and greenwashing (Wang, Shen, Zhang, Asif, & Shahzad, 2025). On this basis, the following aspects of evaluation can be derived: (1) measurement of GHG emissions by activities defined within the EU taxonomy; (2) assessment of impacts on water resources and biodiversity; (3) indicators related to human rights and labor standards, according to ILO and UNGPs; (4) financial parameters such as sustainable turnover, investment and operating costs (CAPEX, OPEX); and (5) compliance with the principle of "Do No Significant Harm" (DNSH), which is central in determining eligibility for sustainable finance.

Linking these indicators to the forest industry highlights their practical relevance. The auditor's assessment of CO₂ emissions under the EU taxonomy should correspond to the

actual levels of carbon sequestration in forest stands, which according to CITEPA and BNP Paribas data show a significant reduction over the last decade. Water and biodiversity impact indicators need to be benchmarked against risk investments defined under PAI 7, which in 2023 exceed 30% for leading ESG funds.

Assessing social indicators related to forest governance and labor rights compliance in timber companies requires comparability with non-financial practices under UNGPs and ILO standards. Financial indicators (sustainable turnover, green CAPEX) should be verified in relation to the eligibility of investments under the taxonomy, which directly affects access to green finance and ESG funds. The DNSH principle is essential in assessing the forest industry's compliance with European sustainable legislation. Integrating these indicators into the audit framework allows validation of non-financial reporting as a reliable sustainability and risk management tools. Table 2 presents a system of indicators through which an objective and comparable audit assessment can be structured.

Table 2. Relationship between audit indicators and double materiality in the forest industry

Audit Indicator	Application in the Forest Industry	Relevant PAI/ESG Indicator	Source of Risk	Relevance for Sustainable Finance	Audit Indicator
CO ₂ Emissions (EU Taxonomy activities)	Measurement of forest carbon sequestration	PAI 1 - GHG Emissions	Climate risk, operational inefficiency	Eligibility for green bonds and EU taxonomy funds	CO ₂ Emissions (EU Taxonomy activities)
Impact on Water and Biodiversity	Investments in biodiversity-sensitive zones	PAI 7 - Biodiversity	Ecosystem degradation, DNSH non-compliance	Assessment of green CAPEX and OPEX	Impact on Water and Biodiversity
Human Rights and Labor Standards (ILO, UNGPs)	Local community inclusion, workplace safety	PAI 9 - Social Norms Violations	Reputational and legal risk	Social value contribution under SFDR	Human Rights and Labor Standards (ILO, UNGPs)
Sustainable Turnover, CAPEX and OPEX	Certified wood product investment, eco-efficiency technologies	SFDR Articles 8 & 9	Financial risk due to ineligibility under ESG portfolios	Criteria for inclusion in sustainability-linked funds	Sustainable Turnover, CAPEX and OPEX
DNSH (Do No Significant	Avoidance of deforestation, environmental compliance	DNSH - EU Taxonomy	Non-alignment with EU	Prerequisite for ESG-compliant investments	DNSH (Do No Significant

Harm) Principle			sustainability regulation		Harm) Principle

The integration between the analytical toolkit for assessing double materiality and specific audit mechanisms serves to validate sustainability in the forest industry. On the one hand, the sector is characterized by high environmental and social exposure, which requires specific approaches to identify significant impacts. On the other hand, auditing practice requires clearly defined indicators consistent with the regulatory expectations applicable to sustainable financing.

4. CONCLUSION

The article confirms the need to apply the principle of double materiality in the timber sector, not only as a regulatory requirement, but as a tool to ensure transparency, effective risk management and compliance with sustainable finance standards. Due to its strong dependence on ecosystem services and sensitivity to environmental and social impacts, the sector emerges as a priority for the application of an integrated assessment of double materiality.

The development of an indicator framework allows for functional linkages between key audit indicators - such as CO₂ emissions, biodiversity impacts, labour rights compliance and compliance with the Do No Significant Harm (DNSH) principle - and key aspects of sustainability in the forest industry. It ensures traceability of impacts back in time and predictive risk assessment. The lack of unified standards, prior to the CSRD and ESRS coming into force, highlights the need to establish comparable, quantifiable and measurable indicators. The proposed audit verification mechanisms provide a basis for reliable non-financial reporting. In conclusion, the implementation of the key indicator measurement framework supports the sector in meeting regulatory requirements, facilitates access to green finance and contributes to the sustainability of both forest ecosystems and the economic models operating within them.

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INFORMATION FROM THE CASH FLOW STATEMENTS AND SUSTAINABLE BANK LENDING: INSIGHTS FROM THE WOOD- BASED SECTOR IN BULGARIA

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Abstract: As sustainability becomes a core concern for financial institutions, the integration of environmental, social, and governance (ESG) considerations into lending practices is reshaping credit assessment criteria, especially in resource-intensive industries. This paper explores how information derived from cash flow statements influences sustainable bank lending decisions within the wood-based sector in Bulgaria. By focusing on the intersection of financial transparency and corporate sustainability, the study highlights the importance of cash flow data in evaluating a company's financial resilience, investment in sustainable practices, and long-term viability. Our study investigates how cash flow indicators such as operating cash flows, capital expenditures, and liquidity metrics interact with ESG disclosures to support or hinder access to green financing. The paper contributes to the growing dialogue on sustainable finance by emphasizing the role of traditional financial statements in complementing ESG information. Implications for regulators and financial institutions are also discussed, with recommendations for integrating cash flow-based and non-financial metrics into sector-specific credit risk frameworks.

Keywords: IAS 7, cash flow statements, banks' analysis of creditworthiness, cash flow ratios, ESG reporting, sustainability, wood industry, natural wood furniture production

1. INTRODUCTION

Against the backdrop of dynamic global changes in every aspect—economic, social, environmental, technological, etc.—corporate bank lending faces new and increasingly complex issues to resolve. This is particularly evident in connection with public, institutional, and regulatory measures related to so-called sustainability reporting (ESG reporting). In 2022, the EU adopted the European Parliament Resolution on a New EU Forest Strategy for 2030 – Sustainable Forest Management in Europe (2022/2016(INI)). The National Strategy for the Development of the Forest Sector in the Republic of Bulgaria for the period up to 2030 shares a similar goal. The purpose of these documents, linked to the Green Deal, is to provide the framework and guidelines for transforming forests into a key factor in the fight against changing climate conditions and the preservation of biological diversity. This, along with several other measures and activities, would help reduce gas emissions by up to 55% by 2030 and achieve climate neutrality across the EU by 2050.

The development of the forest sector and the related woodworking industry, particularly furniture production, including that from natural wood materials (solid wood furniture), is directly linked to the problems of sustainability and its financing, including through bank lending. All this determines the motives and relevance of the chosen topic in this study. The main research question is: Is there sufficient quantitative and qualitative public information disclosed by enterprises (e.g. annual financial statements, including cash flow statements, management reports, etc.), which, together with other sources of information, can be used by banks as creditors when assessing the credit risk and solvency of borrowers in the furniture manufacturing sector in Bulgaria? And to what extent does public company information,

including that from their annual cash flow statements, reveal certain dependencies with the size and conditions of bank lending from the point of view of the strategies of banks and stakeholders, towards sustainable development?

The main author's thesis is that the vast majority of enterprises in Bulgaria engaged in furniture production and trade are micro and small enterprises that do not publish a sufficient volume and quality of publicly-available information that banks can use and which could guide them in assessing the main policies, impacts, measures, and results of these enterprises from the standpoint of sustainable development and the green transition. The information related to their cash flows is also insufficient to be linked to the size, type, and conditions of the bank lending provided.

2. LITERATURE REVIEW

The literature on the usefulness of financial statement information is extensive, with growing emphasis on sustainability reporting's objectives, principles, regulations, and requirements. However, empirical studies specific to industries, particularly in Bulgaria's furniture production sector, are scarce. Research on bank lending practices and influencing factors in this environmentally linked sector in Bulgaria is also lacking.

A relevant study by Bobeva et al. (2023) examines green finance and the banking system's role in sustainability, emphasizing banks' strategies toward greening corporate finance over retail banking. The study highlights banks' significant challenge of limited client information necessary for evaluating creditworthiness and compliance with green transition requirements (Bobeva et al., 2023). Stoyanov (2024) emphasizes that banks require comprehensive ESG information from enterprises' sustainability reports to meet sustainability challenges. Similarly, Zhelyazkova (2023) asserts the essential role of banks and capital markets in transitioning to a circular economy, advocating improved accounting and reporting of environmental aspects to support decision-making.

These findings align with our view that high-quality financial reporting and standardized corporate sustainability information are vital for banks linking enterprise financing with sustainability objectives.

Rink (2024) finds that sustainable lending to small businesses can support global sustainability goals, yet banks show more progress in sustainable financing for larger, capital-market-oriented clients. He also highlights that sustainability risks in small business credit portfolios are expected to grow (Rink, 2024). These findings are relevant to the industry structure typical of Bulgaria.

ESG factors are considered essential for assessing the future performance of the borrower and complement traditional financial indicators. This is regulated in Delegated Regulation (EU) 2021/2178, supplementing Regulation (EU) 2020/852, according to which credit institutions must classify their exposures under the Taxonomy for Sustainable Finance. A key indicator is the Green Asset Ratio (GAR), which reflects the share of taxonomy-aligned exposures in the total assets of banks. The EU Taxonomy directs capital flows towards sustainable activities to achieve climate neutrality by 2050 and fulfil the environmental priorities of the Green Deal.

Significant regulatory changes in the EU related to ESG policies seriously affect the furniture industry. As of July 18, 2024, new ecodesign rules (ESPR, 2023) are in effect, requiring furniture to be energy-efficient, durable, repairable, and recyclable, with the

introduction of a mandatory digital product passport for environmental sustainability. The regulation comes into force in 2028-2029 and covers all stages of production and trade (Regulation (EU) 2024/1781).

In Bulgaria, the furniture industry includes about 4,000 companies, creating over 3% of the GDP and employing about 55,000 people, with production valued at over BGN 1.5 billion (BBCWFI, 2023). Despite high quality, Bulgarian furniture is mainly exported due to lower domestic demand, driven primarily by price factors. All this presents the furniture manufacturing sector in Bulgaria as significant, with very good traditions, but at the same time, it faces complex challenges and fierce competition from the import of cheaper, but not as high-quality, furniture.

3. METHODOLOGY

This research provides a qualitative analysis of a selected sample consisting of the six largest enterprises by revenue in 2023 from the "Manufacture of other furniture" sector (NCEA-code 3109) in Bulgaria. These enterprises account for 52.23% of the total revenues of the sector's 1034 enterprises. The analysis utilizes data from their annual financial statements and management reports published in the Commercial Register, focusing on financial indicators relevant to bank lending and sustainability disclosures.

Notably, none of these enterprises are mandated by the 2023 NFRD to disclose non-financial or sustainability information. Disclosures related to sustainability (if any) should be considered voluntary and made at the discretion of the enterprises' management.

The sample consists of the following enterprises: Grammer AD; Paralel EAD; Irim OOD; Veleya Home EOOD; Em Ko Design EOOD; Mebel Stil OOD.

4. RESULTS AND DISCUSSION

General information related to the format of the financial statements, the existence of bank lending, and the disclosure of specific sustainability information is shown in Table 1.

Table 1. General information about corporate reporting and financing of the activity

Entity	Type of report	Financial Audit	Bank loans (Creditor, terms) As of 31.12.2023 (BGN '000)	Disclosure of ESG information (Sust. KPI)
Grammer AD	Fin. Statement + Management report	Yes, Big4	No loans	No
Paralel EAD	Fin. Statement + Management report	Yes	No loans	No
IRIM EOOD	Fin. Statement + Management report	Yes	Amount: 9871 Bank: n.a. Type: Investment, Overdraft, working capital loan Collateral: Non-current tangible assets	No
Veleya Home EOOD	Fin. Statement + Management report	Yes	Amount: 1224 Bank: UniCredit Type: Investment	No

			Collateral – n.a.	
EmKo Dizain EOOD	Balance Sheet, Profit and Loss Statement	No	na	No
Mebel stil OOD	Fin. Statement + Management report	Yes	Amount: 12653 Bank: DSK Bank Type: n.a. Collateral: Non-current assets, Inventories	No

Source: Financial statements and Management reports of the entities for 2023

The analysis of Table 1 regarding cash flows and sustainable bank lending in the "Furniture Manufacturing" sector in Bulgaria highlights the following:

- 83% (5 of 6) of enterprises publish full financial statements, based on National Accounting Standards in Bulgaria, with management reports.
- 67% underwent financial audits; one was audited by a Big 4 firm, indicating high-quality reporting.
- One enterprise publishes only a balance sheet and income statement, lacks full financial statements (including cash flow and management reports), and has not been audited.
- 50% (3 of 6) have bank loans, primarily collateralized by non-current tangible assets; one also includes inventories as collateral.
- Loan terms are not disclosed by any enterprise, which violates the requirements of the relevant accounting standards.
- No enterprise provides sustainability (ESG) information, presenting challenges for banks assessing sustainability.

Thus, while traditional financial data (revenues, expenses, profit, liabilities, cash flows, liquidity, indebtedness) is generally available, specific sustainability indicators such as "green" investments, energy efficiency, raw material sources, or environmental compliance which can improve for the so-called "green" analysis, which is the focus of banks' taxonomy for sustainable lending, is completely absent

Previous research (Filipova et al., 2025) indicated that banks in Bulgaria find Cash Flow Statements particularly useful in assessing credit risk. Another study (Filipova et al., Forthcoming) identifies the current and operating cash flow ratios as banks' preferred liquidity indicators, informing the choice of financial metrics examined in Table 2.

Table 2. Main indicators relevant to assessing creditworthiness

Entity	Operating cash flows (BGN '000)	Capital expenditures (CapEx)	Free Cash Flow (FCF)	Current ratio	Quick ratio
Grammer AD	7271	(1482)	5789	16,72	10,09
Paralel EAD	15209	(4631)	10578	3,94	1,95
IRIM EOOD	5825	(1242)	4583	1,74	0,93
Veleya Home EOOD	8171	(6479)	1692	0,61	0,02
EmKo Dizain EOOD	na	na	na	na	na
Mebel stil OOD	3015	(1256)	1759	1,12	0,14

Sources: Author's calculations based on the financial statements for 2023

From a traditional creditworthiness perspective based on financial indicators, Grammer AD and Paralel EAD demonstrate excellent financial conditions, with stable net operating cash flows (BGN 7.3 million and BGN 15.2 million) and high liquidity ratios (current liquidity 16.72 and 3.94), ensuring their ability to meet short-term obligations.

Irim OOD and Mebel Stil OOD present mixed signals; despite stable operating cash flows, their liquidity ratios are lower, with quick ratios below 1.0 (0.93 and 0.14, respectively), indicating potential short-term liquidity risks. Veleya Home EOOD, although generating high operating cash flow (BGN 8.2 million), has critically low liquidity ratios (current 0.61, quick 0.02), highlighting substantial short-term financial risks despite long-term stability.

Purely based on liquidity indicators, Irim, Mebel Stil, and Veleya Home would receive unsatisfactory creditworthiness assessments. However, these companies exhibit stable operating and free cash flows (FCF). The cash flow statement provides more objective analysis, showing significant capital expenditures (CapEx), indicating strong investment activity. For instance, one company reported CapEx of BGN 4.6 million with operating cash flow of BGN 15.2 million, while another invested BGN 6.5 million.

We found a significant issue in bank lending assessments - the lack of disclosure of sustainability indicators. Cash flow statements alone do not clarify whether these substantial investments are "green" and comply with the EU Taxonomy. The absence of ESG-related disclosures prevents banks from accurately assessing sustainability and classifying investments correctly for the Green Asset Ratio (GAR). Consequently, despite potentially financing "green" projects, loans provided by banks are negatively or neutrally reflected in their GAR.

This analysis aligns with observations by Bobeva et al. (2023) and Stoyanov (2024), highlighting that banks face substantial difficulties in sustainable financing due to limited non-financial ESG disclosures by enterprises. Banks, pressured by Green Deal regulations, require active and voluntary disclosure of ESG data by enterprises. In Bulgaria, where bank lending dominates external financing, the lack of ESG disclosures forces banks to rely on internal questionnaires, underscoring the need to integrate sustainability indicators into credit assessment frameworks.

5. CONCLUSION

The present study highlights the specific characteristics of furniture production in Bulgaria, which is dominated by micro and small enterprises. Despite the good financial stability demonstrated by positive operating cash flows and capital investments, these companies do not publish information related to sustainability. The lack of disclosures regarding ESG indicators makes it difficult for banks to assess sustainability and limits the firms' access to "green" financing. This calls for stimulating more active ESG disclosure to improve the sector's sustainability and competitiveness.

The main limitation of this study is its small sample size, which includes only six of the sector's largest enterprises. Although these enterprises generate over half the sector's revenues, results cannot be generalized to the entire industry, which primarily comprises over 1,000 enterprises, most of which are micro and small. Additionally, the analysis covers only the "Manufacture of other furniture" sector for 2023, relying solely on publicly available data. This restricts the applicability of the findings to longer periods or other wood-based industries.

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EUROPEAN STANDARDS AND MARKET PLACEMENT RULES FOR CORK FLOORING IN THE EU

Slavica Petrović

Abstract: This article analyzes the relevant European standards that define the properties and quality of cork flooring. The analysis of the requirements prescribed in the standards was carried out depending on the type of cork flooring. In this context, the basic standard for the quality of cork tiles EN 12104:2023 and standard EN ISO 20326:2018 for the quality of cork floor panels were analyzed. In addition, other relevant standards were analyzed that prescribe requirements that are assumed to have a direct influence on the scope of application of this type of flooring. In this group, two standards stand out, namely EN ISO 10874, which defines the classes of floor coverings, and EN 15398, which specifies the pictograms for floor coverings. The quality of cork flooring on the European market is confirmed by ecolabels, so the requirements for their award are also analyzed in the paper. As cork flooring is a construction product, the most important articles of the EU Construction Products Regulation No. 305/2011 were included in the analysis. This regulation governs the placing of this type of product on the EU market. Knowledge of the properties of cork flooring is crucial when choosing this flooring for installation in a particular room. If market players do not know these well, they can easily make the wrong choice and later judge the product as inferior.

Keywords: cork, floor coverings, properties, requirements, regulations

1. INTRODUCTION

We live in a time in which ecology is one of the most important topics we deal with in various areas of research. The preservation of the environment and, in this sense, the mitigation of the effects of climate change, requires responsible behavior from society in the use of all types of resources. Natural, ecological, renewable, and recyclable materials have been promoted for years in the manufacturing of various items, and cork is a notable example. Although it has been used since centuries BC, cork is still a very attractive raw material today. Due to its favorable properties, cork has also been used for the production of floor coverings. However, in order to properly position this type of floor covering on the market, it is necessary to know and promote its desirable qualities. The fact that this raw material is only available in some countries in Europe and the world severely restricts and affects the implementation of the above-mentioned activities.

In Europe, the Portuguese Association for the Promotion of the Cork Products Manufacturing Industry (APCOR) is actively involved in the promotion of cork and cork products. Information on all manufacturers of cork products, including flooring, can be found on the association's website. The Cork Forest Conservation Alliance is also engaged in the promotion of cork as a raw material. At the European level, the European Resilient Flooring Manufacturers' Institute (ERFMI) is committed to supporting the resilient flooring industry. "ERFMI represents the interests of the resilient flooring industry by helping to maintain high ethical standards within the industry" (<https://erfmi.com/>). The European Resilient Flooring Manufacturers' Institute is part of the European Floor Coverings Association – EUFCA. This "Association represents the European floor coverings industry at both European and international levels and ensures the maintenance of high standards in social, environmental,

economic, ethical, technical, and other perspectives in the broadest possible sense" (<https://eufca.org/>). On a global level, the National Floor Covering Association of Canada has the task of "promoting industry standards for resilient, carpet, hardwood, laminate, cork and bamboo floor covering installations" (<https://www.nfca.ca/>).

2. METHODOLOGY

This study was performed using the following general scientific methods: content analysis, induction, and deduction. The content analysis method was used to analyze the content of the relevant European standards, the requirements for obtaining the ecolabel and the requirements of the European regulations for cork flooring. The induction and deduction methods were used to form opinions and conclusions about the research conducted.

European EN, EN-ISO and ISO standards were used for research purposes. In this sense, the EN and EN-ISO standards developed and adopted by Technical Committee CEN/TC 134/WG4: Resilient, textile, laminated and modular mechanically interlocked floor coverings have been used. A list of valid EN standards for cork flooring can be found under the link: <https://standards.cencenelec.eu/dyn/www/f?p=205:105:0:::> The analysis also included ISO standards defined and adopted by Technical Committee ISO/TC 219/WG 2: Resilient floor coverings. A list of ISO standards for resilient floor coverings, including cork flooring, can be found at the link: <https://www.iso.org/committee/54988/x/catalogue/p/1/u/0/w/0/d/0>. Certain ISO standards related to cork as a raw material and cork products are defined and adopted by Technical Committee ISO/TC 87. The list of this group of standards can be found at the link: <https://www.iso.org/es/contents/data/committee/05/04/50400/x/catalogue/>. The analysis of standards for cork flooring revealed that some ISO standards are equivalent to EN standards. In this sense, the Serbian Institute for Standardization (the national standards body of Serbia) has maintained certain EN standards and indicated that they are identical to certain ISO standards.

3. RESEARCH RESULTS

This part of the study analyzes the requirements of the main European standards for cork flooring, as well as the requirements of the most commonly used European ecolabels applicable to them. Since cork flooring is a construction product, the most important articles of the EU Construction Products Regulation No. 305/2011 were included in the analysis. This directive sets out the requirements that these products must meet when they are placed on the EU market.

3.1. European standards for cork flooring

The key European standards that define the quality requirements for cork flooring are:

- EN 12104: 2023: "Resilient floor coverings – Cork floor coverings – Specification" and
- EN ISO 20326: 2018: „Resilient floor coverings – Specification for floor panels/assembly for loose laying”.

When choosing cork flooring, it is important to know the purpose of the room in which the floor is to be used.¹ In this sense, the classes and properties of flooring for rooms with intensive use differ from those for rooms with moderate or low use. The designation and intended uses of the classes of resilient flooring, including cork flooring, intended for use in households, commercial and industrial use are defined in standard ISO 10874:2009 - "Resilient, textile and laminate floor coverings - Classification". Cork flooring intended for use in households is classified into classes 21, 22 and 23. A class 21 cork flooring is intended for rooms with moderate/light use (bedroom), a class 22 cork flooring for rooms with general/medium use (hobby room) and a class 23 cork flooring for rooms with intensive use (living room). Cork flooring in classes 31, 32, 33 and 34 is intended for commercial facilities with moderate (small offices), medium (schools), general (hospitals) and intensive use (post offices). Flooring in classes 41, 42 and 43 is intended for industrial use.

According to the requirements of the EN 12104:2023 standard, class 21 flooring must have an overall thickness greater than or equal to 3.2 mm, while class 22, 23, 31, 32, 33, 34 and 41 flooring must have a total thickness of at least 4.0 mm. The total thickness and the apparent density of the cork flooring are the basic parameters used to define the class of the flooring (Danish industry). According to the requirements of the EN 12104:2023 standard:

- flooring coverings in classes 21 to 41 are classified into three groups based on the value of apparent density, while according to the value of residual indentation they are classified into two groups;
- the effect of a chair castor is not defined for flooring in classes 21 to 23, while the other flooring classes are classified into two groups according to the same parameter;
- wear resistance is not defined for flooring class 21, but it is defined for the other flooring classes, provided that they are not factory sanded, oiled or waxed;
- the flooring class, the nominal dimensions and the area of the tiles must be indicated on the packaging in addition to the other data specified;
- the packaging must also indicate that the packages should not be exposed to sunlight and humidity during storage.

The EN ISO 20326:2018 standard specifies general requirements and test methods for cork panel used in households and commercial applications. The standard defines the requirements for the classification of the upper layer of the panel, which is made of cork (also of other materials such as linoleum, rubber, polyvinyl chloride, synthetic thermoplastic polymers and heterogeneous polyurethanes).² The general requirements of the standard define the deviation values of the dimensions of the cork panel from the nominal dimensions as well as the deviation values for certain properties of the panel. In this sense, deviation values have been defined for: side length in square panels, width and length in rectangular panels, overall thickness, squareness, straightness measured at the surface layer, flatness of the panel - length (concave/convex) and width (concave/convex), openings between panels, height difference between panels and dimensional deviations due to changes in atmospheric humidity.

The requirements for residual indentation and color fastness to artificial light are defined by the general requirements for the upper layer of the panel. The classification defined in

¹ When installing cork floors, as well as other types of flooring, cork purchased in rolls is often used as an underlay. The quality requirements for this type of product are laid down in a specific standard designated EN 12103:1999, titled "Resilient Floor Coverings – Agglomerated Cork Underlays – Specification".

² The standard does not apply to panels made of heterogeneous polyvinyl chloride for floating installation or to panels intended for rooms with a high moisture content (bathrooms, laundry rooms, saunas).

standard EN ISO 10874:2009 applies to panels with a cork upper layer. According to the EN ISO 20326:2018 standard, the following requirements are tested when classifying cork panels: effect of a furniture leg, effect of a castor chair, locking strength and thickness swelling. For cork floor panels in classes 21, 22 and 23, which are intended for use in households, there are no requirements for the effect of a furniture leg and locking strength. For class 23 there are requirements for the effect of a castor chair and for classes 21-23 for thickness swelling. For cork panels with a cork top layer intended for commercial facilities, requirements are specified for the effect of a furniture leg, the effect of a castor chair, locking strength and thickness swelling. An exception is class 31, for which the requirement for locking strength is not prescribed. According to the requirements of the ISO 20326:2018 standard, the nominal thickness of the cork upper layer must be greater than or equal to 2.5 mm for floors in classes 21-23 and no less than 3.0 mm for classes 31-34. The standard also lays down the rules for marking, labeling and packaging the panels. The packaging of the panels contains the usual information such as manufacturer's identification, floor class, nominal dimensions of the panels, total area of the panels in the packaging, etc. The standard also contains six normative annexes. The first amendment to this standard, introduced in 2020, removed class 22+ from the classification of household flooring.

To help consumers understand the technical characteristics of flooring, including cork flooring, pictograms have been created to graphically represent certain properties of flooring. The pictograms are defined in standard EN 15398:2016: "Resilient, textile, laminate and modular mechanically interlocked floor coverings (MMF) - Standard symbols for floor coverings - Complementary element". In addition to the floor classes, pictograms have been created in the standard for the following floor properties, including cork flooring: electrical behavior (antistatic flooring, vertical resistance - static dissipative flooring, vertical resistance - conductive floor covering), fire classes, slip resistance, watertightness, resistance to chemicals, content of pentachlorophenol, emission of formaldehyde, thermal resistance - thermal conductivity, castor chair suitability, fraying behavior, light fastness, acoustic properties, resistance (impact resistance, staining resistance and abrasion resistance), locking strength, swelling, flexibility, dimensional stability, residual indentation, effect of a furniture leg, enhanced slip property, horizontal electrical resistance, roll length and roll width, total thickness, tile size, total mass, light reflection, environmental product declaration and CE labelling. The pictograms are created in a special font and can be downloaded free of charge from the website www.floorsymbols.com. The symbols and pictograms used for floor coverings are referred to as Floor Covering Standard Symbols - FCSS.

3.2. Ecolabels for cork flooring

For cork flooring in the form of tiles and panels, the most commonly applied ecolabels in Europe are the EU Ecolabel, the Nordic Swan, and the German Blue Angel. Eco-labels for cork floors are a confirmation of their quality. In this sense, attention is paid to the materials used in production and to the substances that may be emitted during the use of the floor covering. It is essential that pollutant emissions from the floor covering remain low during its use, as it is used indoors and thus has a direct impact on human health. The Nordic ecolabel applies not only to the cork flooring, but also to the cork underlays that are placed under the flooring.

The above ecolabels have similar requirements that are tested in the certification process, namely: the content of renewable or recycled materials used in flooring production, the testing

for hazardous substances harmful to human health, the energy consumption during production, and the product's reparability and recyclability. If certified material is mixed with non-certified and/or recycled material in the production of cork flooring, at least 70% must be FSC or PEFC certified, in accordance with the EU and Nordic eco-certification requirements (European Commission, 2017; Nordic Council of Ministers, 2023). The eco-certification requirements do not allow the use of GMO materials in the production of flooring. The requirements for obtaining the analyzed ecolabels explicitly list the categories of dangerous, carcinogenic, mutagenic and reprotoxic substances that cork flooring must not contain. In addition, the presence of certain substances in cork flooring - such as pollutants in recycled cork, biocidal products, heavy metals in varnishes, plasticizers, halogenated organic compounds, flame retardants, etc. - as well as formaldehyde emissions from floor coverings and HDF boards, are examined (European Commission, 2017; Nordic Council of Ministers, 2023; Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2011). Limit values for the specified substances are defined in the requirements and must not be exceeded. In addition to the energy consumption during the production of the floor covering and its reparability, it is also tested whether the floor covering of a certain quality class is suitable for use in the intended room. Cork flooring coverings that are to be eco-certified in accordance with the requirements of the EU and the Nordic ecolabels must comply with at least class C23 if they are intended for use in households, or at least class C32 if they are intended for commercial facilities (European Commission, 2017; Nordic Council of Ministers, 2023).

To apply for the EU Ecolabel, the technical specification of the product (technical data sheets), the environmental product declaration (EPD) and the safety data sheets (SDS) must be submitted.³ The technical specification contains a detailed technical description of the floor covering and the product's area of application. The EPD provides information on the environmental impact of the floor covering during its life cycle.⁴ The safety data sheets, which are regulated by the REACH directive, contain information on product safety.

3.3. European regulations for cork flooring

Flooring, including cork flooring, falls under the scope of the Construction Products Regulation (EU) No. 305/2011 (CPR 305/2011), as it is considered a construction product. This means that construction products placed on the European market must be manufactured in accordance with the requirements of the relevant harmonized European standards. Harmonized European standards are standards whose requirements are adapted (harmonized) to the requirements of CPR 305/2011. According to the requirements of CPR 305/2011, construction products, including cork flooring, must be CE marked before they are placed on the EU market. The manufacturer or importer of the cork flooring is responsible for the CE marking, which is documented by the Declaration of Performance (Danish industry). By affixing the CE marking to the product, the party responsible guarantees that the product's properties comply with the requirements of the relevant harmonized European standards. In accordance with Article 9(2) of Regulation (EU) No 305/2011, the CE marking shall be

³ The design of the EU Ecolabel and how it is applied to the product can be found at the following link:
https://ec.europa.eu/environment/ecolabel/documents/logo_guidelines.pdf

⁴ <https://erfmi.com/wp-content/uploads/EPD-9-Cork-floor-tiles-according-to-EN-12104-6Cork-floor-tiles-according-to-EN-12104.pdf>

accompanied by the last two digits of the year in which the product was first CE marked, the name and address of the manufacturer, the identification code of the product type, the number of the declaration of performance, the level or class of the declared performance, the reference of the harmonized standard applied and the intended use of the product in accordance with the reference standard (product for external or internal use). The declaration of performance, which is an essential part of the Construction Products Regulation, is drawn up by the manufacturer before the product is placed on the EU market.⁵ With this document, the manufacturer confirms that the product has been manufactured in compliance with the harmonized European standards. In the declaration of performance, the manufacturer specifies the values of the essential characteristics of the product. According to Article 3 of EU Directive No. 305/2011, the essential characteristics of construction products are defined in the harmonized reference standards in accordance with the basic requirements for construction works.

The content of the declaration of performance is laid down in Article 6(2) and (3) of the same Directive. The model for drawing up the declaration of performance is contained in Annex III CPR 305/2011. The essential characteristics of resilient, textile, laminate and modular floor coverings are defined in standard EN 14041:2018: "Resilient, textile, laminated and modular multilayer floor coverings - Essential characteristics". According to this standard, the essential characteristics of cork flooring stated in the declaration of performance are: fire response, formaldehyde emission, pentachlorophenol (PCP) content, waterproofness, slip resistance, antistatic properties, thermal conductivity and area of application (indoors/outdoors). Annex I of this standard also contains pictograms that can be used for cork floors. If no data is available for an essential performance of the floor, the symbol NPD (No Performance Determined) is used in accordance with CPR 305/2011. Cork floors are generally assigned to flammability class Cfl - s₁ (radiation intensity of 4.5 kW/m² = flame-retardant construction products; EN 13501-1:2018).⁶ Cork floors must not contain pentachlorophenol and the formaldehyde emission into the air is less than 0.124 mg/m³ (0.1 ppm), which means that they belong to class E1 (EN 717-1:2004).⁶

4. CONCLUSION

The requirements for cork flooring manufactured in the form of tiles and panels are specified in the relevant EN, EN ISO and ISO standards. The general requirements as well as the requirements for the classification, marking, labeling and packaging of cork floor tiles are listed in standard EN 12104: 2023: "Resilient floor coverings - Cork floor coverings - Specification". The basic standard according to whose requirements cork floor panels are manufactured is EN ISO 20326:2018: "Resilient floor coverings - Specification for floor panels/assembly for loose laying". Cork flooring in the form of tiles and panels is subject to the EU, Nordic and German ecolabels. As cork floorings are construction products, they are also subject to the provisions of the Construction Products Regulation (EU) No. 305/2011.

⁵ https://single-market-economy.ec.europa.eu/sectors/construction/construction-products-regulation-cpr/declaration-performance-ad-ce-marking_en;

⁶ https://prod1.farveringen.no/globalassets/inriver/resources/nobbm-60162205-_yte_wo-st-na_dop91.00-cork-d-pr-uv-varnish-in-ire_en_ms3.5.24_dop.pdf?ref=92391;
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 24. *** <https://standards.cencenelec.eu/dyn/www/f?p=205:105:0::::>
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 26. *** <https://www.iso.org/es/contents/data/committee/05/04/50400/x/catalogue/>

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GIS-BASED INDICATORS FOR MONITORING THE IMPACT OF RECREATIONAL TRAILS ON FOREST HABITATS

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Abstract: The negative ecological impacts of recreation and tourism, along with their effective monitoring, are increasingly crucial in the context of sustainable tourism development and sustainable forestry, respectively. With the rising importance of preserving natural habitats, understanding these impacts becomes essential. Despite advancements in recreational ecology and trail science, the condition and characteristics of tourist trails remain underestimated in established monitoring systems, particularly for forest-based tourism destinations. This study presents and visualizes preliminary results from a GIS-based assessment of trail-related indicators to identify negative spatial impacts of recreational activities on forest habitats within Vitosha Nature Park. The findings justify the use of trail spatial characteristics as appropriate indicators for monitoring recreational pressure, emphasising their potential for establishing sustainable management practices.

Keywords: recreation-induced habitat fragmentation, trail-based spatial indicators, GIS-based assessment, forest habitat vulnerability, Vitosha Nature Park

1. INTRODUCTION

Recreational trails provide critical access to natural landscapes, supporting outdoor activities and nature-based tourism, but can also impose significant ecological pressures on forest ecosystems. The impacts include vegetation loss, habitat fragmentation, soil compaction, and shifts in microbial community composition (Kissling et al., 2009; Ballantyne & Pickering, 2015). The spatial extent of such disturbances can be substantial, often reaching 10 meters (Godefroid & Koedam, 2004), and, in some cases, extending up to 50 meters from the trail edge (Malmivaara-Lämsä et al., 2008), resulting in reduced biodiversity, loss of forest litter, and altered microclimatic conditions. Informal trails tend to cause more severe disturbance due to their unplanned nature and intensive use (Ballantyne et al., 2014). Additionally, various recreational activities, such as hiking, horseback riding, and mountain biking, impose similar pressures, including soil compaction, erosion, trail widening, and hydrological changes, while also facilitating the spread of invasive species and pathogens (Pickering et al., 2010; Buckley et al., 2003).

Despite these well-documented impacts, many studies rely on localized observations or labor-intensive field measurements, often focusing on individual trails or small sections of trail networks, without addressing broader ecosystem effects (Ballantyne & Pickering, 2015). While Geographic Information Systems (GIS) have been introduced as a powerful tool for quantifying these impacts, their application remains limited. When used, such methods often involve complex, data-intensive procedures that, despite their scientific value, are challenging for practitioners to implement (Sahani & Ghosh, 2021). Established monitoring frameworks rarely include indicators that capture the cumulative impacts of trails and related infrastructure, leaving key ecological disturbances under-addressed.

This study focuses on forest habitats in Vitosha Nature Park, a prominent peri-urban protected area in Bulgaria with a diverse forest landscape and extensive trail network. The research aims to carry out a GIS-based assessment of the impacts of recreational trails on forest habitats using indicators that reveal habitat fragmentation and other recreational pressure processes. By integrating spatial data on forest habitats and trail networks, this study seeks to provide a preliminary assessment of trail-induced forest habitat fragmentation, thus supporting the development of more sustainable management practices.

2. STUDY AREA

Vitosha Nature Park, established in 1934, is the oldest in Bulgaria and the Balkans. (Fig. 1) It lies just south of Sofia and spans over 27,000 hectares, covering nearly the entire Vitosha Mountain. Park's boundary follows the lower forest line, underlining the ecological importance of its forest ecosystems. Vitosha is the fourth-highest mountain in Bulgaria (Cherni Vrah – 2,290 m). The spatial distribution of habitats and vegetation in the mountain reflects the influence of its dome-shaped morphology, characterized by steep slopes and an extensive upland plateau, combined with an alpine-type climate, clearly expressed altitudinal zonation, and a pronounced asymmetry between the north-facing and south-facing slopes.

The park is part of the Natura 2000 network (SPA and SCI, code BG0000113). About 64% of its area is forested, 69% of which are natural (mainly beech), and 31% are artificial plantations (Vitosha NP Management Plan, 2005–2014). It hosts 31 habitat types, including 10 forest habitats of high conservation value. Their distribution is uneven due to historical human impacts, leading to fragmentation and secondary forests, as discussed in studies by Dyakov (2012), Bozhkov (2022), and Dimitrov & Dimitrova (2023).

Vitosha is also a major peri-urban recreation area, attracting around 1.3 million visitors annually (2013–2014), mostly in summer. Common activities include hiking, winter sports, biking, and horseback riding. The densest visitor infrastructure is in the northern part: 22 accommodation facilities, 85 food establishments, 3 museums, a visitor center, 324 km of hiking trails, and 30 ski slopes (total length: 31 km) (Mitova, 2020). Though three passenger cableways exist, they were inactive during the study, making the trail network essential for visitor access to the park.

Given the park's ecological significance and high visitor pressure, understanding the spatial distribution and impact of recreational trails is critical for effective habitat management.

3. DATA AND METHOD

Habitat fragmentation is a major driver of biodiversity loss, often leading to habitat degradation, isolation, and reduced species richness (Fahrig, 2003; Debinski & Holt, 2000). It is a complex, multidimensional process involving not only habitat loss but also changes in spatial structure, connectivity, and ecosystem function (Lindenmayer & Fischer, 2007). This complexity demands careful data selection and interpretation (Fletcher, 2018).

This study focuses on recreation-induced habitat fragmentation in Vitosha Nature Park, where a dense trail network intersects diverse forest habitats. To assess these impacts, a GIS-based approach was developed, prioritizing practical applicability for conservation managers.

The analysis utilized official spatial data on forest habitats from the Ministry of Environment and Water, combined with trail data from the Vitosha Nature Park Directorate.

Table 1 summarizes key forest habitats in Vitosha Nature Park with their areas, trail presence, and conservation status. Using overlay analysis (intersection) in a GIS environment, key indicators were derived, including the number of fragmented forest patches, trail density (m/ha), and trail dispersion (count/ha) within habitat areas.

Table 1. Forest Habitat Types and Their Basic Characteristics

Habitat Type (Code)	Area (ha)	Polygons	Trail Count	Trail Length (m)	Habitat Status
91D0 Bog woodland	1.42	20	2	221.39	U/U
91E0 Alluvial forests	55.05	37	53	7453.41	U/U
91H0 Pannonian woods	144.26	47	29	3358.91	U/U
91M0 Pannonian-Balkan oak forests	757.28	107	180	23757.02	U/U
9110 <i>Luzulo-Fagetum</i> beech forests	2279.14	424	472	71872.36	U/U
9130 <i>Asperulo-Fagetum</i> beech forests	972.08	190	237	37010.13	U/U
9150 Medio-European limestone beech forests	168.84	42	26	3417.69	U/U
9170 <i>Galio-Carpinetum</i> oak-hornbeam forests	651.13	181	229	27088.86	U/U
9180 <i>Tilio-Acerion</i> forests	35.77	25	16	2070.89	U/U
9410 Acidophilous <i>Picea</i> forests	1234.92	181	216	30746.25	U/B

Legend: U/U – Unfavorable, Unsatisfactory; U/B – Unfavorable, Bad; **Source:** The table is compiled by the authors based on information provided by the Vitosha Nature Park Directorate and the Ministry of Environment and Waters.

4. RESULTS AND DISCUSSION

The results presented in Table 2 (see also Figure 1) demonstrate substantial variation in the degree of recreation-induced habitat fragmentation across the forest types in Vitosha Nature Park. Habitat 9110 is most affected in terms of horizontal structural change, with the emergence of 770 new patches resulting from trail intersections. A similar notable, though less pronounced, effect is observed in habitats 9130, 9170, 9410, and 91M0. These are also among the most widespread and extensive forest habitats in the park, which likely increases their exposure to visitor use and associated infrastructure.

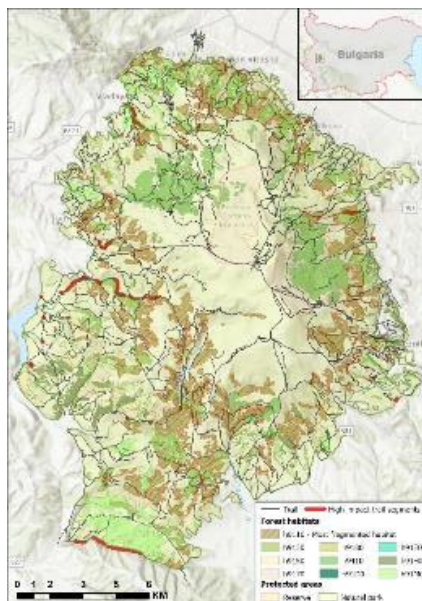


Figure 1. Vitosha Nature Park location, the spatial distribution of forest habitats and trails, and the most endangered habitat areas.

Other habitats exhibit moderate levels of fragmentation, while 91D0 remains the least fragmented, with only four new patches detected. Despite this, the spatial structure of the trail network reveals that trail density and dispersion are highest in 91D0 and 91E0, with values of 155.65 m/ha and 1.41 trails/ha, and 135.39 m/ha and 0.96 trails/ha, respectively. These two habitats are characterized by small area coverage and a pre-existing fragmented configuration, making them especially sensitive to additional disturbance. Moderate trail density and dispersion are also found in habitats 9170 and 9180, though their ecological context differs: 9170 spans a large area, while 9180 consists of smaller, already fragmented patches.

These findings emphasize that the ecological impact of trails depends not only on the absolute number or length of trails but also on the structural characteristics of the habitats they intersect. Extensive and relatively continuous habitats may show high fragmentation values due to sheer scale, while rare or limited-area habitats may experience concentrated pressure in smaller, ecologically critical zones. The contrast between structural fragmentation (e.g., number of patches) and spatial trail intensity (e.g., density and dispersion) calls for a dual-perspective assessment that considers both the extent of physical alteration and the intensity of recreational use.

Overall, the GIS-based indicators developed in this study offer a spatially explicit and ecologically meaningful basis for identifying areas of concern. They provide conservation managers with a practical tool to distinguish between habitats with high levels of structural fragmentation and those facing intense recreational pressure. Most importantly, the results highlight priority habitats and locations where field-based ecological assessments should be focused. This enables a more targeted and resource-efficient monitoring approach, bridging remote sensing diagnostics with on-the-ground evaluation of ecological impacts.

Table 2. Fragmentation Indicators and Trail Pressure by Habitat Type

Habitat Type	Output Polygons	Intersected Polygons	New Polygons	Trail Density (m/ha)	Trail Dispersion (trails/ha)
91D0	22	2	4	155.65	1.41
91E0	94	20	77	135.39	0.96
91H0	89	18	60	23.28	0.20
91M0	297	56	246	31.37	0.24
9110	991	203	770	31.53	0.21
9130	464	93	367	38.07	0.24
9150	70	13	41	20.24	0.15
9170	426	90	335	41.60	0.35
9180	51	8	34	57.90	0.45
9410	424	87	330	24.90	0.17

5. CONCLUSION

This study illustrated the effectiveness of applying a GIS-based assessment of indicators for habitat fragmentation caused by recreational trails. The analysis revealed two key patterns: (1) large forest habitats such as 9110 and 9130 are structurally fragmented by trails; and (2) small, already fragmented habitats like 91D0 and 91E0 face the highest trail density and dispersion. These findings highlight areas under the greatest recreational pressure.

The method provides a practical tool for preliminary assessment in conservation planning, helping to prioritize habitats for monitoring and management. It also serves as a spatial guide for future field assessments of ecological impact, ensuring more targeted and efficient conservation actions under growing recreation demand.

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TECHNOLOGICAL INNOVATIONS IN PRODUCTION AND CONSTRUCTION

STRENGTH ANALYSIS OF THE END-TO-END GRAIN PUZZLE JOINT

Seid Hajdarevic, Murco Obucina, Ibrahim Busuladzic, Alen Ibrisevic, Sandra Martinovic

Abstract: In this paper, the end-to-end grain puzzle joint assembled with PVA-c glue was tested and numerically analysed. The strength and stiffness of this type of joints were tested and compared with the finger joint, which is widely used in the solid wood furniture industry today. Numerical stress and strain analyses were performed by the finite element method for an orthotropic linear-elastic model and an orthotropic nonlinear model. The experimental results showed that puzzle joints achieved much lower strength than the common finger joints with the same dimension of wooden elements cross-section. However, the results of the E modulus do not demonstrate a significant difference between these two types of joints. The load-displacement graph of the joints obtained by numerical and experimental methods indicates that both numerical models, within the used constitutive relation, are suitable for validating the test results and capable of predicting the behaviour of loaded joints. The stress distribution of loaded puzzle and finger joints indicates that the profile of the adhesive surface of the joint has a dominant influence on the joint strength. Although puzzle joints are less commonly used for longitudinal assembly, and have lower bending strength compared to finger joints, they can achieve the appropriate strength for non-load-bearing furniture elements made of solid wood.

Keywords: wood, end-to-end grain joint, finger joint, puzzle joint, numerical analysis, strength

1. INTRODUCTION

General requirements for furniture design are functionality, structural safety, durability, and aesthetics. The defined concept of requirements for furniture design is the starting point in the design process for a product's constructive solution. The structural safety of furniture includes both, the strength of furniture joints and the strength of the construction as a whole. Wooden furniture usually does not fail in the construction member, but in the joint (Grič *et al.*, 2017). For this reason, the improvement of manufacturing methods and constructive solutions of furniture is the main subject of research nowadays. Contemporary furniture design requires, not only the strength and stiffness of furniture joints, but also high aesthetic value. Therefore, designers are experimenting with nontraditional types of joints or connections, according to the required assembly principle, which contribute not only to the strength and structural safety of the construction but also to the aesthetics and originality of newly designed furniture. In a preindustrial era, traditional woodworking required exceptional craftsmanship. Today, computational systems for designing wood structures and CNC machining facilitate the creation of custom joints with complex geometries with high degree of precision, which is beneficial, not only for the aesthetic quality of a joint, but also for its structural capability. One of the nontraditional joints used in contemporary furniture design is the end-to-end grain puzzle joint that resembles traditional Asian puzzle joints, but with much simpler geometry and uses adhesive for assembly. This joint is appealing for its high aesthetic value. The problem with nontraditional joints is that the properties determination of such joints is challenging because of the geometric complexity and unspecified joint behaviour (Larsson *et al.* 2020). The effect of numerous variables, such as wood properties, geometry of a joint profile, adhesive used, joining

process, and an interaction between these variables on joint mechanical properties is complex (Ibrisevic *et al.* 2021).

In this paper, the results of numerical stress and strain analyses of the end-to-end grain puzzle and finger joints, using the finite element method for both an orthotropic linear-elastic model and an orthotropic nonlinear model, are presented. Numerical results were compared with experimental results of strength and stiffness tests of this type of joint. This paper aimed to explore the mechanical properties of the puzzle joint and capabilities for application in the construction of solid wood furniture.

2. MATERIALS AND METHODS

The physical models of the puzzle and finger end-to-end grain joints had the same beam geometry configurations. The dimensions of the beam and elements of both types of joints, as well as the diagram of joint loading, are shown in Figure 1.

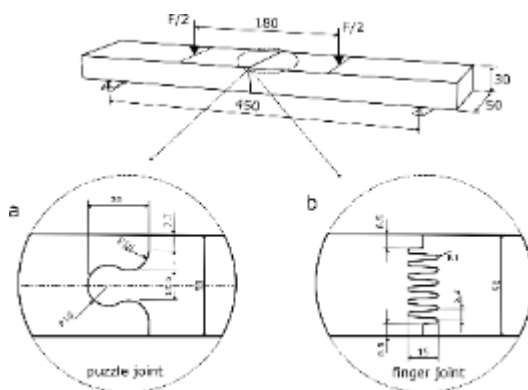


Figure 1. Physical models of the end-to-end grain joints: a) puzzle joint, b) finger joint

The numerical 3D nonlinear model for both the orthotropic material (wooden parts of the joint) and the isotropic material (adhesive) was solved by a method based on the finite elements, Figure 2. The numerical results were obtained using Abaqus software. The 3D hexahedral solid element was used to build the FE mesh. The global coordinates were used to define the grain direction, as well as radial and tangential cross-section directions of the wooden parts of the joints. The adhesive layer (0.1 mm) was connected with other elements by the TIE-type constraint.

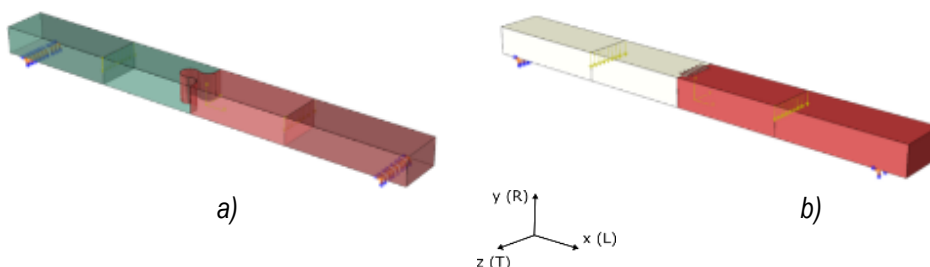


Figure 2. Numerical models of the end-to-end grain joints: a) puzzle joint, b) finger joint

Calculation was carried out for common oak wood (*Quercus robur* L.). The orthotropic elastic properties of the oak wood are presented in Table 1 (Tippner *et al.* 2022). The isotropic modulus of elasticity of adhesive (PVA-c glue) was 707.9 Mpa, and Poisson's ratio $\nu = 0.3$ (Jain *et al.* 2017). The Hill's function was applied to represent the anisotropic plastic flow of wood material after reaching a yield point (Kawecki and Podgorski 2020, Kawecki 2021). The yield stress for oak wood was 62 MPa, and for the adhesive was 8 MPa for the puzzle joint analysis and 10 MPa for the finger joint analysis.

Table 1. Elastic properties of oak wood (Tippner *et al.* 2022)

Modulus of elasticity (MPa)			Modulus of rigidity (MPa)			Poisson's ratio		
E_L	E_R	E_T	G_{LR}	G_{LT}	G_{RT}	ν_{LR}	ν_{LT}	ν_{RT}
14 669	656	494	1900	2015	127	0.037	0.028	0.326

The numerical results are compared with experimental results from the paper that investigated the bending strength and E-modulus of the same types of end-to-end grain joints (Hajdarevic *et al.*, 2024).

3. RESULTS

The deformation–force diagrams obtained by testing the bending strength of the five oak wood beam specimens with the end-to-end grain puzzle and five oak beams with the finger joints are shown in Figure 3. The experimental results are comparable with the numerical results of linear and nonlinear analyses of stress and strain, as they were obtained using the same physical models described in this paper, and by determining the displacement of the same point at a distance $x=150$ mm from the left support.

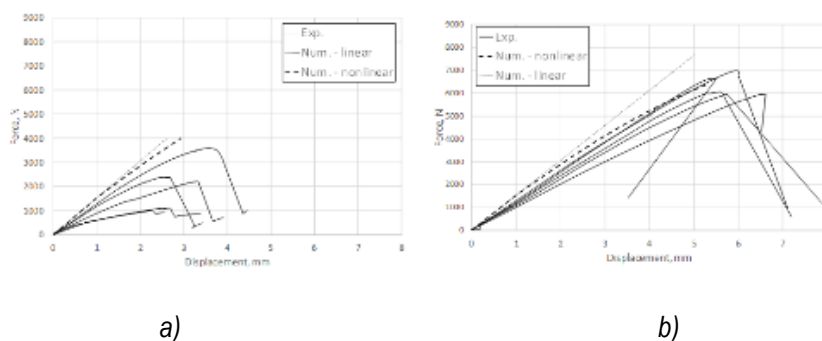


Figure 3. Force-displacement diagrams - experimental and numerical results: a) puzzle joint, b) finger joint

The average value of bending strength of puzzle joints (19.4 MPa) reaches 32.4% of the bending strength value (59.8 MPa) of the finger joints. The puzzle joints (CV 45.7%) turned out to exhibit very high variability, whereas the finger joints (CV 6.0%) were characterised by low variability (Hajdarevic *et al.*, 2024). The curve pattern of the numerical nonlinear model agrees

well with the curves obtained by the test. However, the numerical curves indicate that the numerical joint models are stiffer than the experimental results, which is a consequence of the use of literature values of the elastic properties of oak wood and adhesive, and the influence of the anatomical cross-section of the adhesive surface on the mechanical properties of the adhesive joint, which was neglected in the numerical model. The result of the linear numerical model does not demonstrate a significant difference in the E modulus between these two types of joints. Likewise, the results of the nonlinear numerical model show that the force at the limit of proportionality, compared to the linear numerical model, is about 2000 N for both types of joints.

The distribution of normal stress S_{11} for the wooden parts of puzzle joint (Figure 4a) loaded with highest value of specimens failure forces ($F_{\max}=3640$ N; puzzle joint strenght 33.64 MPa) shows that the highest values of this normal stress (dominant component stress in beam bending) occurred in the upper and lower grains of the cross section and that the stress value is less than yield stress for oak wood. However, the distribution of normal stress S_{11} and the Von Mises stress for the adhesive layer (Figure 4b and 4c) shows that the stress values are higher than the yield stress for the adhesive and occur on most of the adhesive surface.

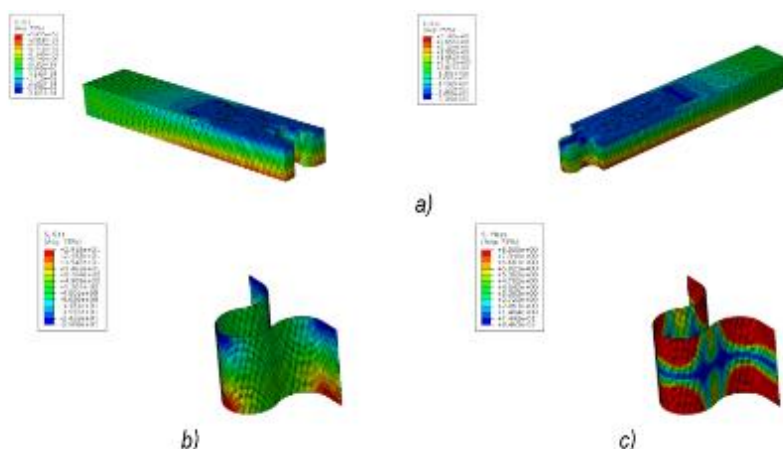
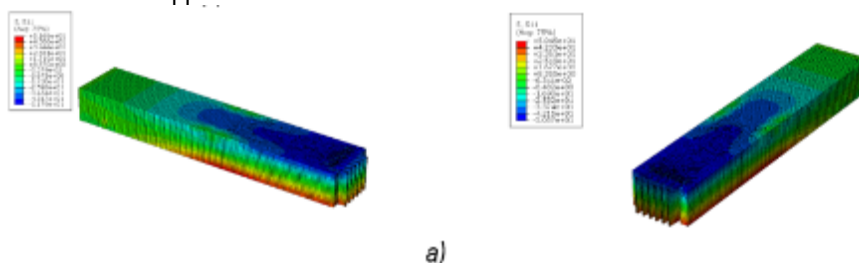


Figure 4. The puzzle joint: a) normal stress S_{11} in the wooden part of the joint, b) normal stress S_{11} in the adhesive layer, c) Von Mises stress in the adhesive layer

The distribution of stresses for the wooden part and adhesive layer of the finger joint loaded with average values of experimental failure force ($F_{\max}=6390.2$ N; finger joint strength 59.8 MPa) is shown in Figure 5. Stress in the adhesive layer is also higher than the yield stress for the adhesive on the upper and lower zones of the adhesive surface.



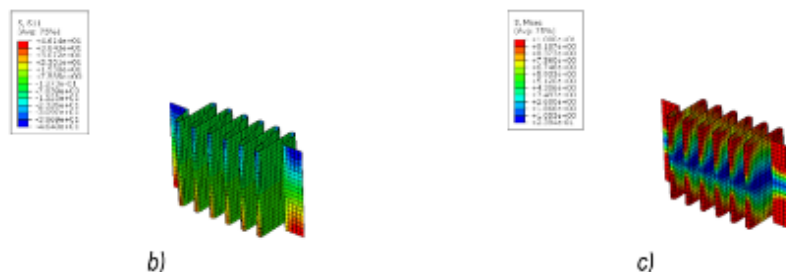


Figure 5. The finger joint: a) normal stress S_{11} in the wooden part of the joint, b) normal stress S_{11} in the adhesive layer, c) Von Mises stress in the adhesive layer

The distribution of normal stresses S_{11} and characteristic patterns of the fractures of the puzzle and finger joints caused by the bending are shown in Figure 6.

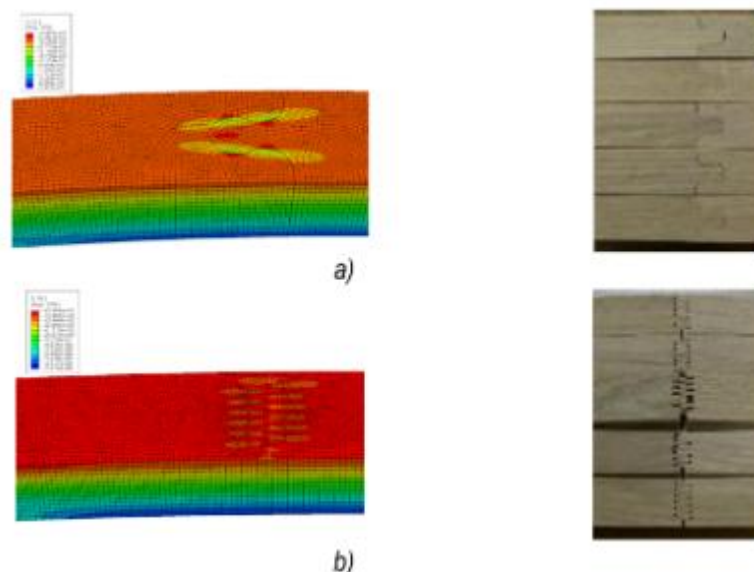


Figure 6. Normal stresses S_{11} and characteristic patterns of the fractures: a) puzzle joint, b) finger joint

The fracture mode of the puzzle joint is a fracture along the adhesive surface, in particular on the end grain surfaces. For the finger joint, in addition to a fracture along the adhesive surface, fractures can also occur in the wood in the width zone of the fingers.

4. CONCLUSION

This paper analyses the bending of the end-to-end grain puzzle and finger joints that are made of oak wood and assembled with PVA-c glue. Numerical results, performed by the finite element method for an orthotropic linear-elastic model and an orthotropic nonlinear model, were compared with the experimental results. The results of the numerical nonlinear joint models are stiffer, but the force-displacement curve pattern agrees well with experimental

results. The stress values and distribution indicate that the adhesive surface and profile of the adhesive surface of both joint types have a dominant influence on the joint strength. Numerical linear and nonlinear models, within the used constitutive relation, are capable of describing the mechanical properties of loaded joints. Although puzzle joints have lower bending strength compared to finger joints, they can achieve the appropriate strength for furniture construction.

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ANALYSIS OF WOOD CUTTING USING DIFFERENT CIRCULAR SAWS AT DIFFERENT PROCESSING PARAMETERS

Ibrahim Busuladzic, Seid Hajdarevic, Murco Obucina, Alen Ibrisevic, Sandra Martinovic

Abstract: Circular saws are the indispensable tools used in wood industry plants, in the sawmill and in the final processing of wood. They are used for cutting plywood, chipboard and solid wood.

In this experimental study, cutting with different circular saw tools was tested, measuring the roughness of the processed surface. The wear of the tool, the geometry and the speed of rotation of the circular saw blade were considered. Also, for the experiment, two types of cuts were made, namely transverse and longitudinal cuts, and two types of wood are processed: oak and fir. These materials were chosen because of their different structural properties. For both materials and different configurations of cutting, the measurements of surface roughness were analyzed. The roughness of the surface was measured on twelve samples when each parameter was changed (number of revolutions of circular saw, type of processed material, type of saw, wear of the saw).

An analysis of variance (ANOVA) was used to analyze the data of this experiment, to compare them and to determine if there are significant differences between them.

Keywords: circular saw, wood cutting, ANOVA, surface roughness

1. INTRODUCTION

Circular saws can be used for different purposes, ie. for cutting materials such as wood, metal or plastic. They have different types of blades for different purposes, for fast and rough or precise and fine cutting. It is also important to choose the size and type of saw depending on the material being processed. Analysing the use of different tools of circular saws in wood processing, attention should be paid to the following key factors: type of wood, material thickness, type of processing, fine or precise cutting, cutting speed, and tool maintenance, which are of key importance in order to achieve the desired processing parameters.

The aim of this work is to study the influence of most important factors that affect the quality of wood cutting. These factors are the type of circular saw, the bluntness of the teeth, the type of wood to be cut, the direction of cutting, as well as the tool rotation speed. Roughness measurements were performed to quantify the quality of cutting [3,4,5]. Roughness measurements were performed on samples for each change in parameters (rotation speed, type of material, type of saw, bluntness of the saw) [1].

2. MACHINING AND MATERIALS

In the experimental part of this work, cutting was performed with a format circular saw. An important feature of this special circular saw is the sliding table, which allows precise cuts in one operation. Subsequent processing and finishing of the piece are no longer necessary, which saves a lot of time compared to cuts with a regular circular saw. In this experimental part different combinations of materials and tool types, as well as processing parameters, were used to obtain finished samples, on which the roughness was then measured. Twelve samples were produced for each combination of chosen cutting parameters.

Cutting was performed with different blades, i.e. saws with fine and coarse teeth (figure 1). The geometry of the teeth is determined mainly by the hardness of the wood. This geometry reduces the cutting force to the lowest possible value, and it can be achieved by increasing the

angle of engagement of the material. Tool wear, geometry and speed of rotation of the circular saw blade were also considered (3000 and 5000 rpm).



Figure 1. Saws with fine and coarse teeth

Two types of solid wood are used for the experiment, namely oak and fir. These materials are chosen because of the different properties they possess.

Oak is a hardwood that is often used in construction and the wood industry due to its durability and attractive appearance (figure 2. left). There are different types of oak, but the most commonly used are red and white oak due to their strength and availability.

Fir is a softer wood compared to oak, but it is also a popular material in the woodworking industry (figure 2. right). It is used to make furniture, building structures, floors, panels, doors and other items. Fir is known for its ease of processing, which makes it popular for a variety of purposes.



Figure 2. Samples of oak and fir wood

3. SURFACE ROUGHNESS MEASUREMENT

For roughness measurement, the ISR-C002 device (figure 3.) was used. This device uses various methods for roughness evaluation, including the return wave method, which makes it suitable for a wide range of industrial applications.



Figure 3. ISR-C002 roughness measuring device and its accessories

Table 1 and 2 shows the results of all measurements of the roughness parameters Ra and Rz, where:- Ra – mean absolute deviation, i.e. average deviation of the surface profile from its middle line - Rz – represents the sum of arithmetic mean of the heights of the five maximum peaks and arithmetic mean of the values of the five largest valley depths on the length l.

Table 1. Results of roughness measurement (Ra and Rz) after longitudinal cutting

		File		1	2	3	4	5	6	7	8	9	10	11	12	
3000 rot/min	blunt tool	coarse toothing	Ra	2.354	2.291	2.022	2.008	4.246	2.2	2.719	2.284	2.245	1.991	1.783	2.69	
			Rz	13.863	13.762	12.085	11.218	23.632	12.205	14.503	12.529	12.571	10.786	10.081	18.554	
	fine toothing	Ra	2.47	2.34	2.513	1.737	1.868	2.317	1.961	2.243	1.789	1.983	2.028	1.821		
		Rz	12.592	10.978	15.924	9.395	10.894	15.215	11.129	15.052	11.041	10.855	11.349	10.198		
	sharp tool	coarse	Ra	4.713	4.761	4.026	3.725	3.895	5.672	3.27	3.526	3.288	2.891	2.835	3.345	
			Rz	24.794	24.901	24.511	22.515	24.05	28.888	17.961	17.6	17.818	18.175	18.624	18.117	
5000 rot/min	blunt tool	coarse	Ra	4.139	4.979	2.576	2.526	2.063	1.579	1.637	2.227	1.899	2.485	1.405	2.139	
			Rz	23.507	30.573	13.976	16.248	13.568	7.275	12.145	15.783	13.008	14.702	9.866	13.01	
	fine	Ra	3.174	2.716	2.73	2.478	4.524	2.617	1.668	3.744	2.928	3.136	1.277	2.752		
		Rz	19.042	11.836	17.37	15.172	24.431	15.954	15.787	21.718	11.556	19.657	19.042	12.67		
	sharp tool	coarse	Ra	1.695	1.729	1.711	2.736	2.768	1.48	1.84	1.458	1.789	2.035	2.212	1.551	
			Rz	9.808	9.359	8.983	14.32	14.367	8.566	10.8	8.502	11.558	11.631	13.077	9.469	
3000 rot/min	blunt tool	coarse	Ra	3.087	2.918	3.02	3.348	3.549	3.992	2.876	2.34	2.564	3.082	3.778	4.095	
			Rz	16.738	16.54	17.031	21.731	21.914	22.254	18.669	15.858	15.665	17.818	22.792	22.815	
	fine	Ra	2.585	2.693	1.581	1.894	1.905	3.804	1.136	1.502	3.061	1.915	3.222	3.417		
		Rz	14.492	14.958	8.854	12.294	12.118	21.9	19.308	18.504	12.988	12.056	18.196	19.7		
	5000 rot/min	blunt tool	coarse	Ra	3.613	2.89	1.672	2.796	3.026	2.896	2.75	3.134	2.846	1.977	1.955	3.581
				Rz	16.462	14.216	9.902	15.892	15.804	16.195	14.404	15.904	13.046	10.811	11.511	19.493
fine		Ra	2.999	2.095	1.844	2.589	2.139	3.122	2.725	2.031	3.392	3.552	3.988	1.768		
		Rz	15.45	10.409	11.088	15.036	10.712	17.425	15.072	10.492	16.158	7.954	10.748	12.785		
sharp tool		coarse	Ra	5.417	5.766	3.858	4.061	4.494	5.625	5.923	5.907	3.35	4.444	4.155	3.636	
			Rz	27.476	32.704	20.558	20.154	24.217	19.504	28.265	28.585	17.854	28.408	21.481	20.849	
3000 rot/min	blunt tool	coarse	Ra	5.122	4.53	4.459	5.789	4.54	2.168	4.774	4.611	4.59	5.855	4.153	4.709	
			Rz	25.40	21.157	22.478	18.587	19.768	13.37	18.284	23.695	23.758	27.67	18.137	23.669	
	fine	Ra	3.987	3.843	3.481	3.882	3.973	4.408	3.82	5.68	5.287	5.507	5.447	3.762		
		Rz	24.353	30.417	22.056	19.026	19.057	27.506	14.78	27.758	27.095	15.895	30.526	23.899		
	sharp tool	coarse	Ra	3.706	2.688	2.533	3.529	3.424	2.329	3.604	3.931	3.545	3.04	2.267	2.282	
			Rz	17.05	14.541	15.088	17.381	19.141	11.564	18.363	17.329	17.262	16.477	14.117	13.82	
5000 rot/min	blunt tool	coarse	Ra	4.124	2.865	3.078	3.108	4.511	4.249	4.517	2.632	2.227	5.888	5.982	4.184	
			Rz	20.744	14.567	14.817	14.472	22.306	21.219	21.799	14.279	13.859	19.726	18.721	18.055	
	fine	Ra	3.212	3.288	3.8	3.728	3.255	3.713	2.842	3.091	3.811	3.006	3.889	2.167		
		Rz	14.942	18.06	20.955	18.405	18.248	15.788	18.021	18.274	17.088	18.874	15.795			

Table 2. Results of roughness measurement (Ra and Rz) after transverse cutting

Oak			1	2	3	4	5	6	7	8	9	10	11	12	
3000 rot/min	blunt tool	coarse	Ra	5.155	5.889	5.151	8.901	4.801	3.574	6.201	8.277	4.925	4.291	8.868	5.472
		Rz	30.444	41.3	30.374	44.674	32.311	26.129	38.36	41.498	24.473	25.718	30.562	35.08	
	fine	Ra	2.321	2.154	1.892	2.478	2.987	3.194	2.411	3.145	1.801	2.156	2.887	1.713	
		Rz	14.743	14.644	11.251	18.678	22.145	23.967	16.855	18.692	12.889	13.594	19.509	11.058	
	sharp tool	coarse	Ra	6.934	6.881	4.528	4.058	6.65	4.91	4.593	5.145	5.9	4.513	5.797	5.543
		fine	Ra	18.82	40.136	18.172	27.163	51.625	28.693	35.958	38.718	38.829	29.593	35.891	36.428
5000 rot/min	blunt tool	coarse	Ra	2.476	3.761	4.559	4.485	4.195	3.497	2.559	3.687	4.823	4.045	2.782	2.85
		Rz	20.044	24.108	28.525	31.889	30.276	23.946	18.608	36.517	32.521	28.996	18.522	20.635	
	fine	Ra	5.526	6.082	3.872	6.017	5.797	5.73	6.125	6.678	6.166	4.466	3.905	6.74	
		Rz	31.263	34.694	24.348	35.702	35.561	36.493	23.82	31.076	30.498	27.638	24.458	40.23	
	sharp tool	coarse	Ra	2.771	2.859	3.213	2.578	2.043	1.854	2.198	3.218	2.087	2.125	3.658	3.911
		fine	Ra	19.595	21.295	17.48	15.866	14.2	14.531	15.852	17.981	15.886	15.527	21.958	23.078
3000 rot/min	blunt tool	coarse	Ra	5.675	5.574	5.709	3.628	5.591	5.092	4.973	4.818	4.956	5.405	5.15	5.133
		Rz	26.985	28.636	29.027	27.878	27.032	36.25	35.576	30.108	31.236	45.473	40.151	40.172	
	fine	Ra	3.772	4.14	2.729	2.586	2.812	2.769	3.197	3.135	3.362	2.076	2.717	5.548	
		Rz	14.228	22.39	17.477	16.195	19.016	17.904	19.685	15.788	19.655	19.886	15.872	20.473	

Fir			1	2	3	4	5	6	7	8	9	10	11	12	
3000 rot/min	blunt tool	coarse	Ra	5.243	5.37	6.254	5.824	4.468	5.293	6.735	5.7	4.864	5.17	6.701	4.795
		Rz	30.672	32.366	38.808	36.505	24.777	27.57	36.579	27.904	25.474	29.252	27.024	29.943	
	fine	Ra	2.856	2.856	4.504	3.975	3.32	4.256	2.226	2.728	4.74	4.965	2.907	2.925	
		Rz	14.865	16.504	24.755	21.24	24.288	24.646	15.315	26.861	29.356	29.175	26.876	16.876	
	sharp tool	coarse	Ra	7.354	6.882	7.282	4.673	5.009	5.211	5.305	5.484	5.508	5.698	5.755	5.229
		fine	Ra	31.853	27.211	30.406	22.509	25.173	26.695	35.74	28.881	28.811	28.553	27.873	21.884
5000 rot/min	blunt tool	coarse	Ra	5.719	4.198	5.491	6.108	5.549	5.944	5.745	5.548	5.084	5.907	5.806	5.795
		Rz	35.712	27.189	31.011	31.743	35.159	32.423	33.885	30.244	29.215	20.911	21.862	25.863	
	fine	Ra	5.15	5.543	5.153	5.081	6.542	5.429	4.955	4.667	5.021	7.153	4.463	5.298	
		Rz	26.095	29.545	28.648	28.207	35.623	28.103	27.711	23.267	25.341	24.063	21.983	27.164	
	sharp tool	coarse	Ra	4.245	4.17	4.173	3.82	5.188	4.012	3.75	5.679	5.334	5.234	5.15	5.131
		fine	Ra	21.157	17.585	20.174	20.755	25.265	27.283	39.125	26.686	26.416	25.144	25.742	24.922
3000 rot/min	blunt tool	coarse	Ra	6.027	3.771	5.021	3.557	4.75	4.386	4.879	4.707	4.695	6.577	5.053	5.733
		Rz	35.750	34.533	35.262	33.249	27.528	25.032	22.027	21.585	21.878	34.375	25.64	26.395	
	fine	Ra	5.155	4.686	6.151	4.737	5.462	5.046	4.91	4.742	4.532	4.463	6.163	5.833	
		Rz	23.004	24.858	24.531	22.752	33.487	25.467	22.474	22.871	22.264	21.488	35.538	31.933	

Fir			1	2	3	4	5	6	7	8	9	10	11	12	
3000 rot/min	blunt tool	coarse	Ra	5.248	5.37	4.284	5.828	4.468	5.293	4.735	5.71	4.864	5.12	4.701	4.744
		Rz	30.875	32.585	30.818	30.552	24.777	27.527	36.578	27.904	26.476	28.252	32.014	22.951	
	fine	Ra	2.256	2.256	4.324	3.875	3.225	4.256	2.205	4.728	4.474	4.993	4.077	2.937	
		Rz	14.889	18.394	24.755	21.24	24.285	24.646	13.251	26.891	29.356	29.179	26.876	16.107	
	sharp tool	coarse	Ra	7.352	6.892	7.282	4.673	5.029	5.211	5.320	5.496	5.508	5.598	5.752	4.325
		Rz	31.851	27.241	30.456	22.509	25.173	25.695	25.744	28.881	28.911	28.552	30.573	21.888	
5000 rot/min	blunt tool	coarse	Ra	5.719	4.198	5.492	6.028	5.548	5.944	5.745	5.548	5.084	5.502	5.806	5.759
		Rz	35.712	27.189	31.921	31.745	35.125	32.429	33.885	30.244	28.235	20.911	21.862	21.862	
	fine	Ra	5.25	5.343	5.153	3.083	6.542	5.429	4.955	4.687	5.021	4.751	4.462	5.298	
		Rz	29.095	29.545	28.948	28.107	35.623	28.103	27.711	23.267	22.541	24.061	21.190	27.168	
	sharp tool	coarse	Ra	4.245	4.12	4.171	3.82	5.188	6.012	5.73	5.372	5.334	5.234	5.153	
		Rz	21.157	17.585	20.175	20.755	25.585	27.285	29.125	26.655	26.416	25.144	25.742	24.922	
3000 rot/min	blunt tool	coarse	Ra	6.017	5.771	5.012	5.597	4.72	4.386	4.878	4.707	4.692	6.577	5.005	4.718
		Rz	35.782	34.533	35.242	33.249	27.528	25.052	22.027	21.858	21.878	34.375	25.664	26.395	
	fine	Ra	5.159	4.686	4.518	4.737	4.562	5.046	4.91	4.742	4.532	4.463	6.186	5.831	
		Rz	23.004	24.848	24.531	27.272	23.497	25.627	12.974	25.813	22.064	21.448	36.563	31.343	

4. STATISTICAL ANALYSIS AND DISCUSSION

For data analysis in our work, analysis of variance ANOVA was used as a statistical technique used to compare data to determine whether there are significant differences between them [2]. Software JASP allows to perform different types of ANOVA analyses, including one-way ANOVA, multi-way ANOVA, ANOVA with repeated measures and others.

The results of the statistical analysis of the given parameters, based on which will be determined whether there is significant difference between the surfaces processed by different saws, i.e. cutting with sharp or blunt teeth, large or small teeth, where the rotation speed and

the type of material are taken into account are presented in figures 4-7. Also, the type of cutting, i.e. transverse and longitudinal cutting, was taken as a parameter.

At the beginning, the roughness parameters R_a and R_z , data obtained by measuring the surface roughness after longitudinal cut of solid oak and fir wood are analysed. Using the one-way ANOVA method, the parameter p is obtained, which shows if there is any difference between the processed samples. In the case where the parameter $p < 0.05$, a significant statistical difference is obtained, while in the case where the parameter $p > 0.05$, there is no statistical difference.

Figures 4 and 5 show diagrams of the parameters R_a and R_z that were statistically analysed in the software JASP. The designations OKH3000 or TSJ5000 represent the label of the samples group where the letters and numbers correspond:

O – sharp saw, K – large teeth, H – material oak and 3000 – number of revolutions, T – blunt saw, S – small teeth, J – material of the wood and 5000 – number of revolutions.

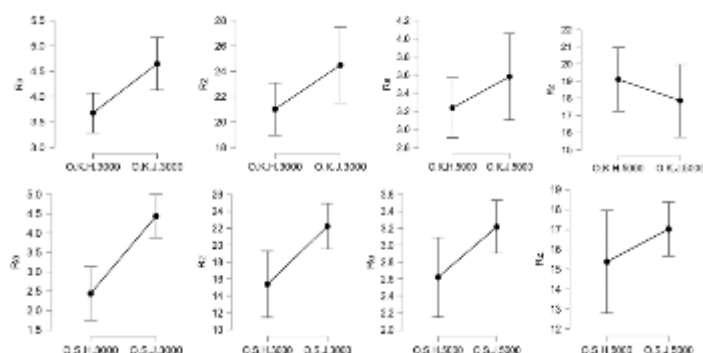


Figure 4. Analysis of parameters R_a and R_z using a sharp saw with large and small teeth on longitudinal cut

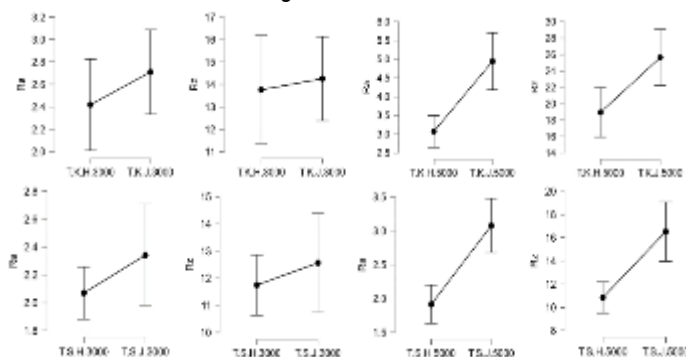


Figure 5. Analysis of parameters R_a and R_z using a blunt saw with large and small teeth on longitudinal cut

Analysing the samples, where a sharp saw with large teeth was used according to parameter p , it can be seen that when the saw rotates at 3000 rpm, for the roughness parameters R_a and R_z , there is significant difference between the samples, while there is no significant difference when the saw rotates at 5000 rpm. Regarding the sharp saw with small teeth, when analysing the roughness parameter R_a , there is no significant difference in roughness at 3000 rpm or at 5000 rpm saw speed. The analysis of the roughness parameter

Rz shows a difference in the surface roughness of the sample processed at 3000 rpm, while there is no significant difference at 5000 rpm. Compared to a sharp saw with large teeth, a blunt saw with large teeth has the opposite sequence of results, where for the roughness parameter Ra and Rz, differences in surface roughness occur at a saw blade speed of 5000 rpm, and there is no difference at 3000 rpm. As with this saw, it can be also noticed that changes in roughness occur at a saw blade speed of 5000 rpm and are absent when cutting at 3000 rpm.

The data obtained by measuring the surface roughness after transverse cutting of booth materials are also analysed. The same parameters (sharpness, saw speed, etc.) are taken into consideration, using the same criterion with parameter p. Figures 6 and 7 show diagrams of the parameters Ra and Rz that were statistically analysed in the software JASP.

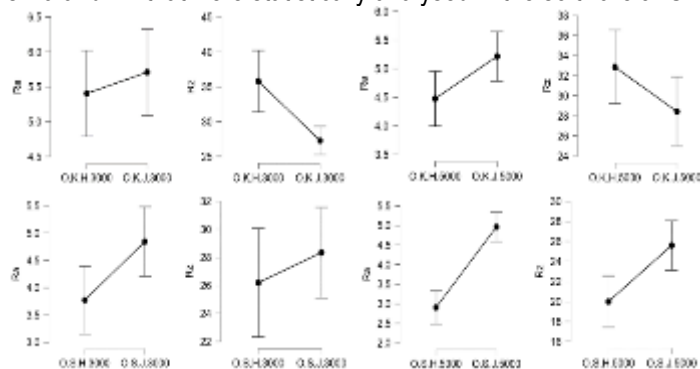


Figure 6. Analysis of roughness parameters Ra and Rz using a sharp saw with large and small teeth on transverse cutting

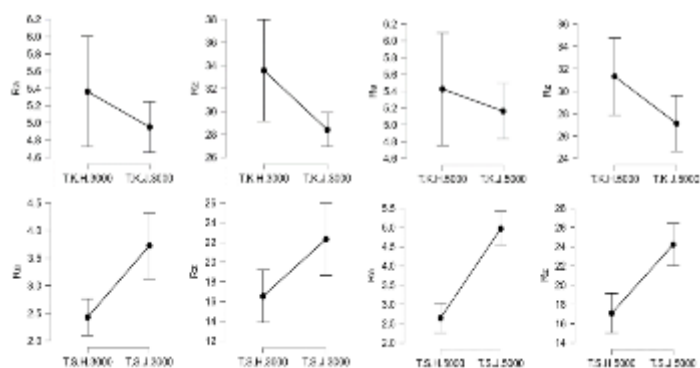


Figure 7. Diagrams of the analysis of parameters (Ra and Rz) due to transverse cutting with a blunt saw with large and small teeth

By analysing the samples where a sharp saw with large teeth was used according to the parameter p, at a saw speed of 3000 rpm for roughness parameter Ra there is no significant difference between the samples, while at a saw speed of 5000 rpm there are more significant differences. When analysing parameter Rz at 3000 rpm, there is difference in surface roughness, and at a saw speed of 5000 rpm there is no significant difference. When analysing the sharp saw with fine teeth, considering the Ra roughness parameter, there is a significant difference in roughness on the surfaces of the samples for booth saw speeds.

For a blunt saw, with large teeth, there is no difference in the surface roughness results for the roughness parameter Ra for booth saw rotation speeds. For the parameter Rz, there is difference in surface roughness when using both speeds. For a blunt saw with fine teeth, it can be seen that changes in surface roughness occur at a saw blade speed of 5000 rpm, as well as at 3000 rpm.

5. CONCLUSION

Ultimately, properly matched tools and cutting parameters are key to achieving high cutting quality and user satisfaction in the woodworking industry. The quality of the processed surface depends on the number of revolutions of the circular saw, the material of the circular saw, the type of cut, the type of circular saw, as well as the geometry and wear of the blade of the circular saw. The type of material plays also important role in the quality of the finished surface, i.e. characteristics of the material being processed, in this case oak and fir. When cutting longitudinally, the blade follows the direction of the wood fibers, while when cutting crosswise, the blade goes perpendicular to the direction of the wood fibers. In this regard, with longitudinal cutting, a higher quality of the processed surface is obtained, i.e. less roughness.

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FROM DESIGN TO IMPLEMENTATION: DEVELOPMENT OF 3D-PRINTED FASTENING SYSTEMS FOR MODERN FURNITURE CONSTRUCTIONS

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Abstract: The creation of a fastening system or fasteners is an iterative and complex process that requires thorough analysis and optimization during the design, testing, and manufacturing phases. This study presents an analysis of the development of an innovative, demountable fastening system for the furniture industry using modern additive manufacturing technologies. The fastener was produced from PETG CFJet Carbon and PLA materials and tested in corner joints made from 18 mm thick MDF. The joints were subjected to bending moments in the angular plane, as well as tensile and compressive forces. Compared to the fastener made from PLA, the PETG CFJet Carbon fastener achieved approximately 28% higher $F_{\max}$ under compressive loading (107.05 N) and about 42% higher $F_{\max}$ under tensile loading (285.78 N). The results indicate a significant improvement in mechanical performance when using the composite PETG CFJet Carbon material. In the conclusion of the study, we provide a comparison of the obtained mechanical properties with traditional furniture joints, demonstrating the potential of additive manufacturing and modern materials in developing innovative solutions for the furniture industry.

Keywords: 3D printing, furniture connectors, additive manufacturing, mechanical testing

1. INTRODUCTION

The development of a furniture connector is a complex, iterative process requiring continuous analysis and optimization. Each design decision influences later steps, and testing often reveals earlier issues that must be systematically addressed to meet safety and performance standards.

3D printing enables the creation of precise, complex, and efficient furniture joints, supporting rapid prototyping, single-piece production, and the use of recyclable or bio-based materials (Song et al., 2017; Jarža et al., 2023). Despite challenges in integrating additive manufacturing into existing workflows, its potential for innovation and sustainability is considerable.

Several studies highlight the importance of connector geometry and print parameters. For instance, Hajdarevic et al. (2022) found that an ABS connector lacked sufficient strength due to poor shape and thin walls. In contrast, a double self-compression fastener showed superior performance in Podskarbi and Smardzewski's (2019) analysis. Similarly, Nicolau et al. (2022, 2023) emphasized that proper connector shape and print quality are key to mechanical performance.

Additive manufacturing supports sustainable furniture production through reduced material waste and efficient use of resources. Studies by Krapež et al. (2022) and Kariž et al. (2021) demonstrated that printing directly onto wood, combined with appropriate surface treatments, can improve bonding strength and expand design possibilities.

Our research contributes to this effort by developing 3D-printed connectors for wooden furniture that combine mechanical efficiency with environmental responsibility. Using recyclable

and eco-friendly materials like PETG and PLA, we support circular design principles and demonstrate how additive manufacturing can advance sustainable practices across the furniture and construction sectors.

2. MATERIAL AND METHODS

The design of furniture connectors is a complex and iterative process influenced by multiple interrelated factors. Key elements include the connector's geometry, which affects tool selection and its compatibility with various materials (e.g., wood, plastic, metal), and the type of joint, whether permanent or detachable, and whether it is corner, central, or continuous.

The manufacturing phase is equally critical, involving material selection for 3D printing, the printing technology, internal structure design, and tolerance adjustments for wood components. The connector's stiffness, load-bearing capacity, and deformation resistance are essential for ensuring reliability. Assembly method tool-based or tool-free also plays a key role.

Since new materials, technologies, and user-specific requirements continually emerge, the connector design process remains dynamic and adaptable, requiring ongoing optimization.

The proposed connector shape was inspired by the keyhole form, enabling simple insertion and secure locking, and incorporates elements of the traditional dovetail joint for mechanical stability. During development, several internal refinements were made while maintaining the outer geometry, progressively improving the connector's performance through successive prototypes. The figure 1 illustrate the progression of the connector's components, leading up to the final prototype used for mechanical testing. The technical design of the connector we developed consists of three parts – a sleeve (1), a wedge element (2), and a screw (3) – intended for production using 3D printing technology, specifically FDM (Fused Deposition Modelling). The sleeve has a longitudinal cross-section composed of an upper circular hole with an internal thread and a lower isosceles trapezoid (dovetail) with a continuous slot. The wedge element has a trapezoidal shape, featuring a wedge-shaped rectangular tongue at the bottom and a concave semi-circular surface with a thread at the top. The screw has a metric thread and a head with a hex socket for an Allen key. The connection to the wood is ensured by frictional and clamping forces generated by the wedge element and the screw.

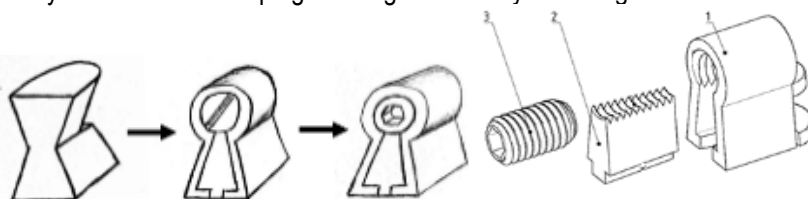


Figure 1. Design and shape of the prototype of a new mechanical fastening element for furniture constructions

2.1. Preparation and Manufacturing of Test Specimens

The test specimens were made from 18 mm thick MDF, which was conditioned in a standard climate (20°C and 65% RH) to achieve an equilibrium moisture content of 12%. The loading rate was set to 5 mm/min, and the load was applied to the specimen until failure occurred. Two types of router bits were used to create the openings for installing the connector.

A dovetail router bit CMT C918 was used for the lower trapezoidal section. For the circular hole, a roughing spiral router bit IGM 197 with chip breakers, positive Z2+2 – D16x35 L90 S=16, was applied. Two types of materials were used to produce the connector. The first material, PETG CFJet Carbon, is based on PETG (polyethylene terephthalate glycol) and contains 17% carbon fibers, which gives it higher strength and stiffness compared to standard PETG. It is ideal for mechanical components and features an attractive matte surface finish. Printing was carried out at a nozzle temperature of 255 °C, bed temperature of 90 °C, with a 0.4 mm nozzle diameter, and in an open print chamber. The second material was PLA (polylactic acid), a bioplastic derived from renewable resources such as corn starch. It is biodegradable and has good mechanical properties. Printing was done at a nozzle temperature of 210 °C, bed temperature of 70 °C, with a 0.4 mm nozzle diameter, also in an open print chamber. For both furniture fasteners, a 5% infill was used, meaning the connectors were printed as shells with internal lattice structures providing 5% material density. For both types of connectors, the layer height was 0.15 mm. Furniture joints in constructions are most heavily loaded by bending moments in the angular plane, specifically in compression or tension. This is also reflected in the loading scheme of the joints shown in Fig. 2. Based on the geometric characteristics and the maximum force reached F_{max} (N), we determined the mechanical properties of the joints: their load-bearing capacity M_{max} (N·mm), joint stiffness T (N·mm/deg), and angular deformation at ultimate load φ_{max} (deg). These were calculated using the equations and loading schemes.

For load-bearing capacity under compressive loading: $M_{max} = F_{max} \cdot l$ (1)

For load-bearing capacity under tensile loading: $M_{max} = F_1 \cdot l_1$ (2)

Joint stiffness: $T = \frac{\Delta M}{\Delta \varphi}$ (3)

where: $\Delta M = M_{max} \cdot 0.3$ (4)

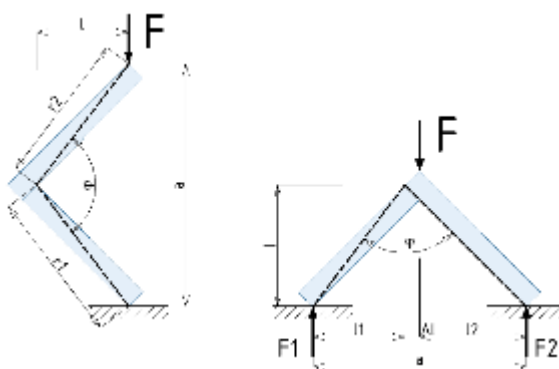


Figure 2. Loading schemes and determination of geometric parameters of corner joints subjected to bending moment in the angular plane under compression and tension.

3. RESULTS AND DISCUSSION

Table 1 presents the average values of the measured and calculated mechanical properties of the tested joints.

Table 1. Measured and calculated values of the mechanical properties of corner joints

Material of fastener	Type of joint loading	Coefficient of variation ν (%)	F_{max} (N)	M_{max} (N.mm)	T (N.mm/deg)	Φ_{dmax} (deg)
PETG-carbon	Compression	5.49	107.05	8563.60	3387.61	98.52
PETG-carbon	Tension	10.21	285.78	22461.20	9715.52	86.62
PLA	Compression	7.30	83.71	6683.68	1455.02	94.46
PLA	Tension	7.12	201.28	16234.96	8219.24	88.43

The maximum forces, i.e. the failure load and the deformation at failure, were recorded, as shown in Figure 3.

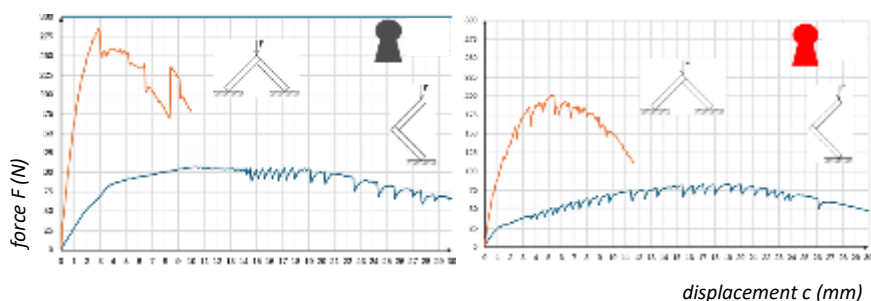


Figure 3. Force–displacement diagram for the fastener made of PETG CFJet and PLA;
orange curve – tension, blue curve – compression

The evaluation of mechanical tests of joints made from MDF boards and fasteners produced from PETG CFJet (with 17% carbon fiber) and PLA is based on average values (Table 1). For each testing group, six specimens were manufactured. The lowest coefficient of variation was observed for PETG CFJet under compression (5.49%), indicating precise and consistent measurements. The highest variation occurred in PETG CFJet under tension (10.21%), suggesting a slightly higher dispersion, likely due to greater loading. The joints made with PLA showed similar coefficients around 7%, confirming good repeatability of the tests.

The force–displacement diagrams (Fig. 3) show the loading behaviour of joints under compression and tension for the fastener made from PETG CFJet. In the compression test, the average maximum force at which joint failure occurred was $F_{max} = 107.05$ N, with a corresponding displacement of $c_{max} = 10.34$ mm. In the tensile test, a higher maximum load of $F_{max} = 285.78$ N was recorded, but with a lower displacement value of $c_{max} = 2.9$ mm. The results clearly confirm that the tensile joint exhibits higher stiffness and can transfer higher loads with smaller deformation. In contrast, under compressive loading, the joint was more compliant, which manifested in greater displacement before failure. This phenomenon highlights the different behaviour of the joints depending on the type of loading. Lower stiffness allows the joint to absorb deformation without immediate failure.

In the tests of joints made from PLA, the following average values were recorded: under compression, $F_{max} = 83.71$ N and $c_{max} = 19.02$ mm; under tension, $F_{max} = 201.28$ N and $c_{max} = 5.42$ mm. These results are consistent with the previous analysis, higher load values in tension,

but with lower deformation. An interesting observation during the PLA tests was the repeated fluctuation of the loading force, which was caused by material densification and microcracks forming in the MDF structure. These "jumps" in force indicate the gradual delamination of MDF layers and suggest localized damage in the contact area between the fastener and the base material.

A comparison of the results from the compression tests shows that PETG CFJet achieved approximately 28% higher maximum load than PLA, while also exhibiting significantly lower displacement 46% less. In the tensile test, the difference was even more pronounced: the PETG CFJet joint withstood 42% higher load than the PLA joint, with approximately half the displacement, representing a 46% lower deformation. These results clearly confirm that PETG CFJet exhibits higher stiffness and strength under both loading conditions. Moreover, the lower displacements at higher loads indicate more efficient force transfer with a reduced risk of deformation.

The joints with PETG CFJet exhibited stiffer behaviour, and the load progression was smooth up to the point of failure, whereas the PLA joints showed repeated drops and rises in force. This difference can be attributed to the varying surface roughness of the fasteners, manufacturing precision, and the microstructural properties of the materials themselves. The results show that PETG CFJet has significantly higher stiffness than PLA in both compression and tension. This higher stiffness results in less deformation under the same load, which is advantageous for strong and stable joints.

4. CONCLUSION

The research confirmed that 3D-printed connectors are a viable alternative to conventional solutions in furniture construction. PETG CFJet carbon fibres connectors demonstrated higher stiffness, strength, and load stability, while PLA connectors were more flexible, suitable for applications where joint elasticity is preferred.

Additive manufacturing allows for rapid shape and material adjustments and offers a wide range of properties due to filament diversity. It supports customization and design integration. Developing a functional fastener requires systematic testing, iterative feedback, and a high level of responsibility from both designers and manufacturers.

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EFFECT OF THE FINENESS OF THE SEWING THREAD AND STITCH LENGTH ON THE STRENGTH OF THE SEWN JOINT: IMPLICATIONS FOR SUSTAINABLE UPHOLSTERED FURNITURE MANUFACTURING

Anna Vilhanová, Nadežda Langová, Katarína Zigová

Abstract: Textiles play a crucial role in the furniture industry, particularly in the production of upholstered furniture, where durability and sustainability are key considerations. In the manufacturing process, flat textiles are divided into individual components and joined using sewing techniques. The sewn joints represent critical points in upholstery, directly influencing the longevity, mechanical performance, and aesthetic quality of furniture products. This study focuses on the upholstery fabric of a sandwich structure composed of two plain-weave fabrics. The research investigates the impact of sewing thread fineness (135, 90, 70 tex) and stitch length (3, 4, 5, 6 mm) on the strength and rigidity of sewn joints in both warp and weft directions. To ensure reliability, the methodology followed the EN ISO 13935-1 standard, analyzing maximum force (Fmax) and joint failure types. The findings indicate that increasing thread fineness results in lower seam strength in both directions, with the highest strength observed in seams using 135 tex thread. At Fmax, fabric rupture occurred at these joints. Additionally, shorter stitch lengths (3 mm) produced the strongest joints, while longer stitches distributed stress more evenly, leading to higher thread load-bearing capacity. These results provide valuable insights for sustainable furniture manufacturing, guiding producers in optimizing seam parameters for enhanced durability and resource efficiency. By improving seam strength, manufacturers can extend the lifespan of upholstered products, contributing to waste reduction and more sustainable material utilization in the industry.

Keywords: upholstery seams, upholstery fabric, sewing thread, seam strength, seam quality

1. INTRODUCTION

Upholstered furniture plays a vital role not only in comfort and aesthetics, but increasingly in sustainability, in line with current EU requirements for circularity and extended product life cycles (Skorupińska et al., 2021; Joščák and Langová, 2018). Upholstery constructions are typically composed of multi-layered systems, where textile covers, often of synthetic origin, are exposed to significant mechanical stress during use (Zubauskienė, 2017). This makes seam quality a key factor in both product durability and environmental impact. High seam strength not only extends the service life of furniture but also allows the use of a wider range of textile materials, including residual or recycled fabrics. The transformation of flat textile materials into three-dimensional upholstery shapes is mainly achieved through sewing, a critical process that influences final product quality (Hunter and Cawood, 1979; Bharani and Mahendra Gowda, 2012). Seam performance depends on multiple factors: fabric properties, thread type and fineness, stitch configuration, and technological parameters such as needle size and stitch density (Hayes and McLoughlin, 2013). Studies show that core-spun and multifilament

polyester threads generally yield stronger seams (Behera et al., 1997; Ünal, 2012; Sular et al., 2015). However, research focused on sewn joints in upholstery applications remains limited.

2. MATERIAL AND METHODS

The test samples were made of an upholstery fabric with a sandwich two-layer construction composed of two plain-weave fabrics. The warp system of the face fabric consisted of multifilament yarns, while the weft system was a combination of multifilament and chenille yarns (Fig. 1a). The backing fabric had both the warp and weft systems made of multifilament yarns (Fig. 1b).

The tested upholstery fabric exhibited an areal density of 300 g/cm², with a tensile strength of 898 N in the warp direction and 801 N in the weft direction.

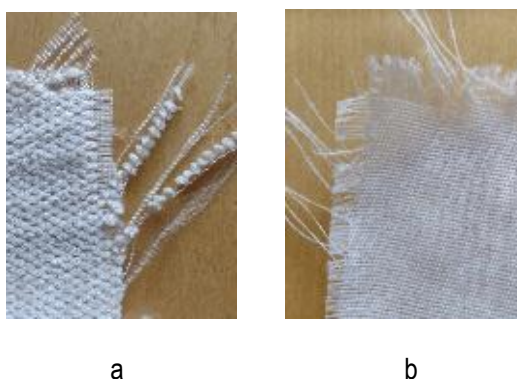


Figure 1. Upholstery fabric (a) facing side, (b) back side

The joining materials were multifilament sewing threads marketed under the trade names Synton 20, Synton 30, Synton 40 and the staple fiber thread Belfil 30.

Test samples of the sewn joints were prepared using a Groz-Beckert 100/16 sewing needle with an R-point tip, which is recommended for joining woven fabrics. The parameters of the sewn joints of type 1.01.01 and stitch type 301 (ISO 4915:1991) were tested, with stitch lengths of 3 mm, 4 mm, 5 mm, and 6 mm. The test samples were produced on a Juki 185 industrial sewing machine operating at a sewing speed of 4000 stitches per minute. The strength of the sewn joints was determined using the strip method in accordance with ISO 13935-1. During the tensile test, the clamping length was set to 200 mm $\pm$ 1 mm, and the loading speed was 100 mm/min. The sewn joints were tested under load in both the warp and weft directions of the fabric, with eight test samples prepared for each direction. The loading scheme of the sample and the test procedure are shown in Figure 2. The maximum force was recorded, and the failure type of the sample was evaluated.

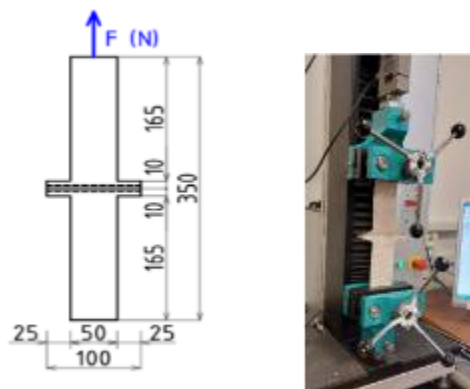


Figure 2. The sample dimension and loading scheme

3. RESULTS AND DISCUSSION

The experimental part of the study focused on investigating the influence of sewing thread fineness and stitch length on the mechanical properties of the sewn joint in the selected upholstery fabric. The experimentally determined mechanical properties of the sewn joints, in which the loading force was applied in the weft direction of the fabric, are presented in Table 1.

Table 1. The average tested mechanical properties of the seams upholstery fabric in direction weft

Type of sewing thread	Stitch length (mm)	Seam strength $\overline{F_{max}}$ (N)	CV (%)	Slip modulus (N/mm)
SYNTON 20	3	704,43	2,66	20,65
	4	682,43	2,56	20,42
	5	675,88	2,39	19,65
	6	609,54	5,05	17,67
SYNTON 30	3	650,36	5,46	21,08
	4	540,98	3,27	22,01
	5	451,57	6,08	20,01
	6	398,28	4,98	13,24
BELFIL 30	3	706,57	3,54	21,08
	4	531,56	5,66	19,09
	5	412,8	5,14	19,7
	6	386,17	6,1	16,09
SYNTON 40	3	573,6	2,58	20,75
	4	451,8	8,83	20,01
	5	403,92	1,88	19,27
	6	338,58	5,11	17,89

The highest F_{max} (704.43 N) was recorded for the seam made with SYNTON 20 sewing thread and a stitch length of 3 mm. As the stitch length increased, F_{max} and the stiffness of the joints decreased for all tested sewing thread types. The loading of the joint with the force F_{max} causes its mechanical failure. Mechanical damage to seams affects both the aesthetics and the functionality of the upholstery cover and, consequently, the entire upholstered product. When loaded in the weft direction, rupture of the yarns in the bonded material occurred in the seams made with Synton 20 thread and stitch lengths of 3 mm and 4 mm (Fig. 3a). Slight damage to the joined material and complete rupture of the sewing thread occurred in the seam with a stitch length of 5 mm (Fig. 3b). In the other seams loaded in the weft direction, the sewing thread broke (Fig. 3c).

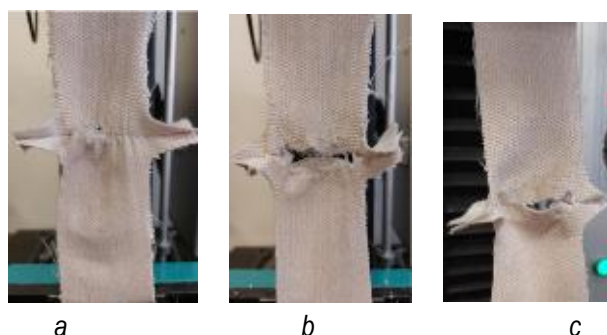


Figure 3. Damage to joints loaded in the weft direction
a) Synton 20, 3 and 4 mm; b) Synton 20, 5 mm; c) Synton 30, 5 mm

The experimentally determined mechanical properties of sewn joints in which the loading force acted in the warp direction of the fabric are shown in Table 2.

Table 2. The average tested mechanical properties of the seams upholstery fabric in direction warp

Type of sewing thread	Stitch length (mm)	Seam strength $\overline{F_{max}}$ (N)	CV (%)	Slip modulus (N/mm)
SYNTON 20	3	778,09	1,95	22,54
	4	766,66	3,11	20,19
	5	758,2	4,23	20,72
	6	623,64	4,87	19,64
SYNTON 30	3	700,93	4,07	20,87
	4	581,65	4,37	20,7
	5	448,86	4,42	19,44
	6	370,42	5,96	13,93
BELFIL 30	3	691,69	4,03	22,08
	4	518,14	2,07	21,09
	5	452,01	5,34	20,00
	6	399,29	2,03	16,08

SYNTON 40	3	607,45	3,01	19,96
	4	468,13	5,72	20,01
	5	375,35	3,42	18,9
	6	316,43	5,58	17,02

The highest Fmax (778,09 N) was recorded for the joint with SYNTON 20 thread and a stitch length of 3 mm. The strength and stiffness of the joints decreased with increasing stitch length. The type of seam damage at Fmax was similar to that observed in the weft direction. Rupture of the joined material occurred in the seams with Synton 20 thread and stitch lengths of 3 mm and 4 mm (Fig. 4a). A rupture of the sewing thread along with minor tearing of the joined material yarns was observed at the seam with Synton 20 thread and a stitch length of 5 mm (Fig. 4b). In the remaining seams loaded in the warp direction, the sewing thread ruptured upon reaching Fmax (Fig. 4c).

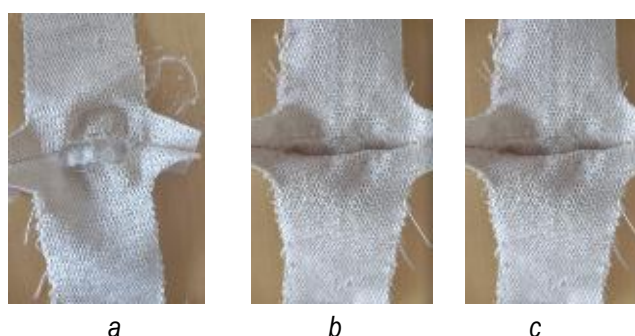


Figure 4. Damage to joints loaded in the warp direction
a) Synton 20, 3 and 4 mm, b) Synton 20, 5 mm, c) Synton 30, 4 mm

Based on the evaluation of the experiments, it can be concluded that the fineness of the sewing thread is a significant factor influencing the strength of sewn joints. As the thickness of the sewing thread increases, the strength of the seam increases. The strength of the sewn joints of the tested upholstery fabric decreased with increasing stitch length.

4. CONCLUSIONS

The production of three-dimensional upholstery covers can be defined as a process in which two-dimensional upholstery material is transformed into three-dimensional shapes by assembling individual cover components. This transformation is achieved through sewn joints, which represent one of the critical quality points of an upholstered product. This study focused on investigating the influence of selected factors of sewn joints and their combinations on the strength and stiffness of the seam.

Based on the results of this experiment, it can be concluded that the strength of the seam in the upholstery fabric selected for the experiment depends on the direction of loading,

the fineness of the sewing thread, and the stitch density. Higher F_{max} values were observed in joints loaded along the warp direction of the fabric compared to those loaded along the weft direction. Among the factors of sewn joints examined in this study, the fineness of the sewing thread was identified as the most significant. As the fineness of the sewing thread increased, the F_{max} of the sewn joints of the selected upholstery fabric decreased. From the analysis of the relationship between joint strength (F_{max}), joint stiffness (N/mm), and stitch length, it can be stated that both strength and stiffness of the joint decreased with increasing stitch length.

Acknowledgements: This work was supported by the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic under the research project VEGA 1/0450/25 Furniture joint innovations: Use of 3D printing and gluing in the development of joint components.

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LOG HOUSES – AIR TIGHTNESS IN RELATION TO VARIOUS LOG JOINT ARRANGEMENTS

Pavol Sedlák, Marek Kirner, Dominika Búryová, Daniel Bebej, Patrik Štompf, Rozália Vaňová

Abstract: This study investigates the air tightness of log houses in relation to various log joint arrangements, with a focus on the impact of excessive infiltration on energy efficiency and heating performance. Infiltration in log houses is a significant concern, as it can lead to increased heating energy consumption and exceed minimal ventilation requirements. A series of blower door tests were conducted on several log houses to measure the extent of air leakage and assess the performance of different log joint configurations. The results revealed that excessive infiltration was common, not only in the log joints but also in the non-log portions of the upper floor structures, pointing to significant defects in those areas. The study also highlighted that current methods of evaluation tend to favour larger houses due to the building envelope/volume ratio, as well as the use of standard construction details that do not account for variations in house size or design. These findings suggest that improvements in both log joint arrangements and overall building construction, particularly in the upper floor sections, are necessary to reduce infiltration and improve energy efficiency in log houses. Further research into tailored evaluation methods is also needed to ensure accurate assessment across different house sizes and structures

Keywords: log house, log joint, air tightness, air permeability, blower door test

1. INTRODUCTION

In log houses with a log structure on the bottom and a timber frame above—both equally important elements—ensuring air tightness requires careful attention to the movement of the log walls, especially around windows. As logs naturally settle over time, rigid components like window frames must be installed with flexible detailing. Settling gaps above windows, concealed by interior and exterior trim, allow for vertical movement without stressing the frame. Floating window boxes or slip joints let the logs compress while maintaining a tight seal. Log joints themselves must be precisely cut and tightly fitted to minimize air leakage, while flexible membranes and compressible gaskets should be used around openings to preserve air tightness during and after settlement.



Figure 1. Difficult window detail (not sealed)



Figure 2. Log joint during manufacturing

Poor airtightness of a building can lead to significant energy losses and reduced indoor comfort. When a house is not properly sealed, uncontrolled air infiltration allows cold air to enter in winter, forcing heating systems to work harder. This results in higher energy consumption and increased utility bills. Additionally, drafts, uneven temperatures, and cold spots can make living spaces uncomfortable. Moisture carried by air leaks can also affect indoor air quality and damage building materials over time [1], especially in roof structures.

The air infiltration relates to result of Blower Door Test (see below), app. $n_i = 12\% \cdot n_{50}$ (1/h) [2] depending on wind exposure. It must be noted the infiltration should be lower than ventilation demand $n_v = 0.5$ (1/h) for dwellings, as ventilation is primarily provided by openable windows or ventilation system - usually mechanical ventilation with heat recovery (MVHR), otherwise higher infiltration would make these systems useless.

While developing log joint details, 3D printing offers a promising way to produce custom sealing components. It enables precisely shaped inserts that fit specific joint geometries, maintaining elasticity as the structure settles. These solutions could supplement or replace traditional materials like sheep wool or foam, helping reduce air permeability.



Figure 3. Ceiling/floor-to-ext. wall detail



Figure 4. Membrane sealed to post/beam

2. TYPICAL STRUCTURE AND COMMON AIR-LEAKAGE SCHEME

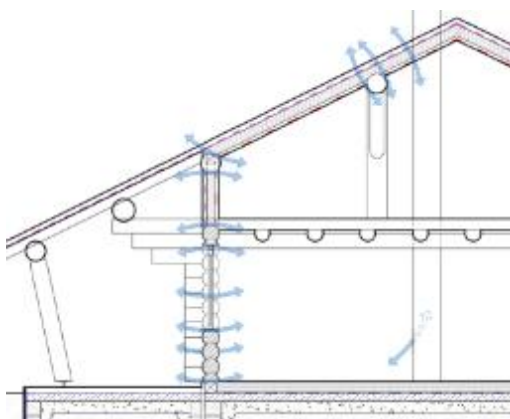


Figure 5. Typical path of air flow caused by air infiltration

The critical details are depicted on Fig. 5, based on in-situ testing:

- Base beam and first row of logs
- Joints between logs
- Window installation
- Penetrations and outlets
- Connection of log and timberframe structure
- Penetrations of roof vapour/air barrier
- Chimney installation

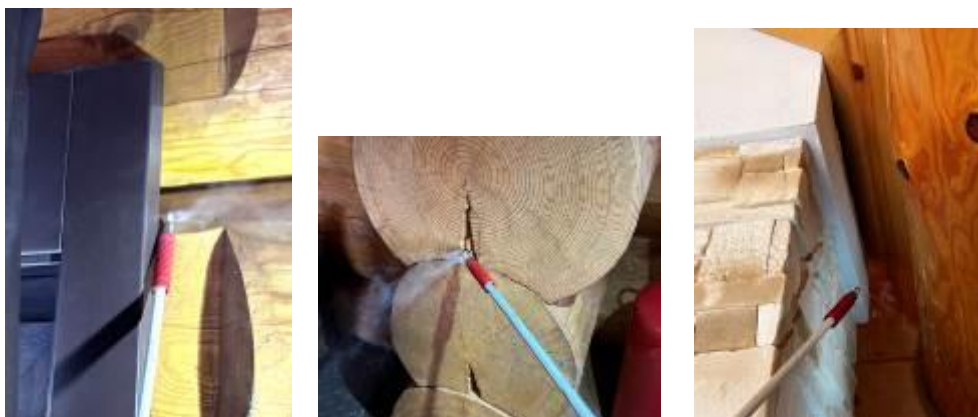


Figure 6. Selected details from tested houses, where considerable air leakage occurred (window jamb, cracks, around chimney through roof)

3. METHODS OF EVALUATION

A blower door test is used to quantify the amount of air leakage through a building's enclosure. Its main advantages include quick setup of the portable equipment, near-instantaneous results, and the ability to detect air leaks using tools such as a smoke pen, anemometer, or—in some cases—an infrared camera.

The airflow rate is described by a power-law relationship, where the parameters C_{env} and n (exponent) characterize the airtightness of the building. The purpose of the testing process is to determine these parameters. They are obtained using the method of least squares, allowing accurate calculation of the airflow rate through the building envelope, Q_{env50} , at the standard pressure difference of 50 Pa.

The overall result is typically expressed as n_{50} [1/h]—the air change rate at 50 Pa—calculated from Q_{env50} [m³/h] and the building volume [m³] [3]. Lower values are desirable, as they indicate reduced thermal losses due to air infiltration. Maximum allowable values are defined in national standards (see Tab. 1). However, n_{50} tends to favor larger buildings due to their lower envelope-to-volume ratio A/V [m²/m³]. Therefore, when comparing only the performance of different building envelope structures, it is more accurate to use the air permeability of the envelope, q_{a50} [m³/(m²·h)].

Table 1. Permitted values n_{50} describing building air tightness, in selected countries

air change rate n_{50}	Germany (DIN 4108-7)	Austria (Önorm, OIB-R6)	Czech Republic (ČSN 73 0540-2)	Slovakia (STN 73-0540)
houses with natural ventilation	max. 3,0 h ⁻¹	max. 3,0 h ⁻¹	max. 4,5 h ⁻¹	not stated
houses with MVHR	max. 1,5 h ⁻¹	max. 1,5 h ⁻¹	max. 1,0 h ⁻¹	not stated
passive houses (with MVHR)	max. 0,6 h ⁻¹	max. 0,6 h ⁻¹	max. 0,6 h ⁻¹	recom. 0,6 h ⁻¹

4. HOUSE TESTING – RESULTS AND DISCUSSION

There were three houses selected, that undergo blower door testing. The selection is particularly difficult task, mainly due to limited or no access, as the houses are occupied and owners rarely enable such testing on their property once the house is finished.

4.1. Log joint arrangement

The three selected houses had different log joint treatment, as shown on Fig. 7-8. House No. 1 had the wool fleece installed in double “V” groove log joint (Fig. 7 -left). House No. 2 had the same preparation as house No.1 (wool fleece in “V” groove), but there was additional sealing of gaps applied from exterior (Fig. 7 -right). In house No.3, there was special insulating composite strip used, made of sheep wool fleece and memory expansion foam in order to infill the cavity, applicated in the “V” groove joint (Fig. 8).

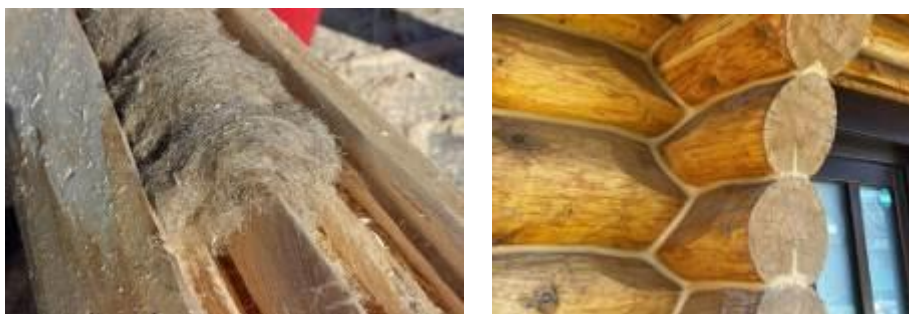


Figure 7. Wool fleece between logs (house No.1) and additional sealing of gaps (house No.2)



Figure 8. Composite strip - wool fleece and memory foam between logs (house No.3)

4.1. Results and discussion

The tested log houses varied in size and shape but shared the same basic structural details. Tab. 2 presents the house specifications, test results, and calculated values. Heating energy demand was determined using the Passive House Planning Package (PHPP), with adjustments for simplified ventilation. Estimated costs for a basic electric heating system are also included to illustrate the financial aspect of the analysis.

Table 2. Test results and calculated values for the tested houses.

	house No.1	house No.2	house No.3
			
house description	simple shape, compact, bigger	simple shape, compact, small	bigger long house with recess
log joints details	wool fleece between logs	wool fleece + sealant on gaps from exterior	special composite strip (wool fleece + memory foam)
A (building envelope)	395 m ²	252 m ²	466 m ²
V (internal volume)	460 m ³	218 m ³	397 m ³
n₅₀ (airtightness at 50Pa by Blower Door)	8,1 h⁻¹	8,5 h⁻¹	4,8 h⁻¹
Ratio A/V	0,86 m ² /m ³	1,16 m ² /m ³	1,17 m ² /m ³
q_{a50} (air permeability at 50Pa - the envelope)	9,4 m³/(m².h)	7,4 m³/(m².h)	4,1 m³/(m².h)
n_i (related air infiltr.)	0,97 h ⁻¹	1,02 h ⁻¹	0,58 h ⁻¹
n_v (required ventilation)	0,5 h ⁻¹		
over-ventilation by the air infiltration	0,47 h ⁻¹	0,52 h ⁻¹	0,08 h ⁻¹
total heating energy / y.	19 816 kW.h/a	11 460 kW.h/a	15 687 kW.h/a
total energy costs / year	2774 Eur/a	1 604 Eur/a	2 196 Eur/a
energy costs caused by over-ventilation	866 Eur/a	444 Eur/a	130 Eur/a

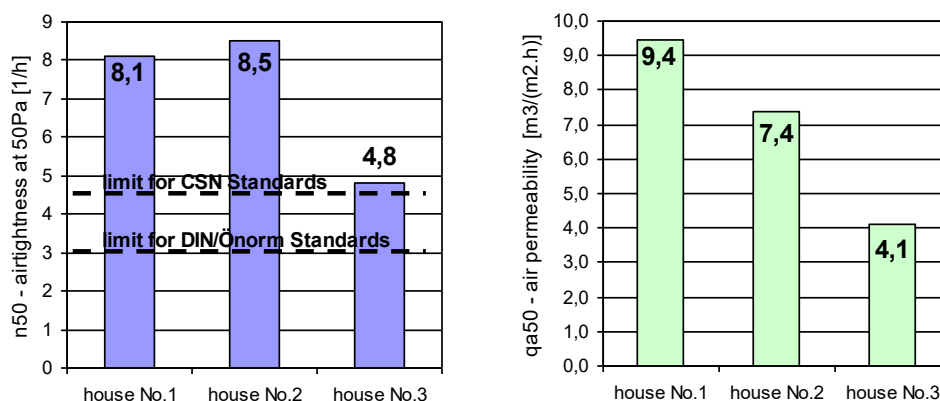


Figure 9. Air tightness n_{50} and air permeability q_{a50} of building envelope - tested houses

As seen from Fig. 9, log joint arrangement significantly affect quality and therefore air permeability of the buildings, providing best results for special composite strip. Airtightness n_{50} is not applicable criterion here, due to the shape and size variation of the houses, and due to standardized details of upper timberframe structure. Notably, none of these log cabins meet the requirements of German, Austrian, or Czech standards for permanent dwellings.

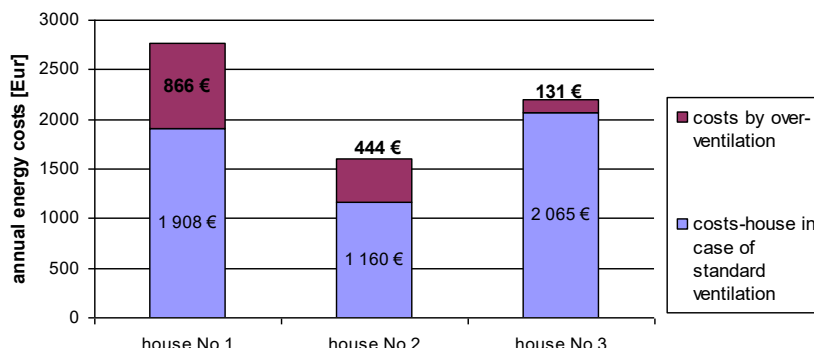


Figure 10. Annual energy costs with highlighted costs caused by over-ventilation

Fig. 10 shows a remarkable increase in operational heating costs due to poor airtightness, with heating expenses reaching up to one-third of the total energy bill. The data suggests that this cost increase is more closely related to the envelope's air permeability q_{a50} [$\text{m}^3/(\text{m}^2 \cdot \text{h})$] than to the overall airtightness expressed by n_{50} [$1/\text{h}$], as previously discussed.

5. CONCLUSION

Log houses often have poor airtightness, leading to overventilation and making mechanical ventilation systems largely unnecessary. As they are mainly used for temporary stays and rely on fireplaces for quick heating, advanced ventilation offers little or no value. However, airtightness - and thus energy efficiency - can be improved through proper construction detailing, as research shows. A promising direction is using 3D printing to create precise log joint seals where traditional methods fall short.

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SUSTAINABLE BUILDING: ASSESSING THE ENVIRONMENTAL IMPACT OF CONSTRUCTION MATERIALS

Dominika Búryová, Rozária Vaňová, Pavol Sedlák, Daniel Bebej

Abstract: Determining which components of the environment will be affected by the materials used in construction, as well as the type, size and overall extent of their impact.

It is essential that we take steps to reduce pollution and protect the environment. Investments in clean energy, improvements in technology and the implementation of appropriate environmental policies are key to reducing emissions and protecting nature. The construction industry is undeniably an industry that has the opportunity to choose a greener path. The right direction and relevant alternative solutions need to be shown.

The study examined a medium-sized building in two material-structural variants of the load-bearing system. The first system analyzed is timber construction, the second is a load-bearing system of ceramic masonry.

The chosen assessment method was IMPACT World+. IMPACT World+ provides one of the most comprehensive assessments of environmental issues among the available LCIA methods. It also offers distinctive features that allow the interpretation of LCIA results in multiple ways.

Rapid technological advances are facilitating the development and production of sustainable building materials, including recycled, low-carbon and bio-based alternatives, as well as advances in wood buildings, all of which significantly reduce impacts on the environment and human health.

Keywords: IMPACT World+, human health, ecosystem quality, wooden structures

1. INTRODUCTION

Understanding building materials is one of the fundamental prerequisites for sustainable and responsible design in the construction industry. The physical and chemical properties of materials used in both load-bearing and non-load-bearing structures exert both direct and indirect impacts on the environment throughout the entire life cycle of a building. In parallel, these properties have a substantial influence on the quality of the indoor environment, thereby affecting the health and well-being of building occupants.

For this reason, material selection in design practice must not be based solely on economic or technical parameters, but should also be informed by scientifically validated knowledge regarding environmental performance. This includes data on ecological footprint, emissions of volatile organic compounds (VOCs), impact on indoor air quality, and the biological and chemical interactions of materials with their surroundings. Scientific research in materials engineering, environmental science, and building biology provides the essential foundation for the development of comprehensive material databases and assessment tools for evaluating the environmental and health suitability of construction materials.

A thorough analysis and categorisation of construction materials in terms of their environmental impacts and effects on human health should therefore be an integral part of the decision-making process in architectural and civil engineering practice. Only in this way can construction and building operation be ensured to be not only technically efficient but also environmentally sustainable and beneficial to public health. Reducing the environmental impact of the construction sector and lowering its carbon footprint is essential and increasingly demanded by governments.

As a member state of the European Union, the Slovak Republic is obliged to reduce its carbon footprint in line with the objectives of the European Green Deal and the EU's climate commitments. The Climate Law, the Sustainable Development Strategy, and other legislative frameworks and programmes ensure that emission reductions will remain a necessary condition for the country's continued development. Current key programmes—such as the Operational Programme Quality of the Environment 2021–2027 and the Recovery and Resilience Plan of the Slovak Republic—provide concrete financial and legislative instruments to support green investments, reduce emissions, promote renewable energy sources, and improve energy efficiency nationwide.

According to the Statistical Office of the Slovak Republic, in the first quarter of 2023, residential units in family houses accounted for 70% of all completed dwellings. [2] Statistics on family house construction for the year 2024 are so far only partially available.

A common type of building for three- to four-member families is a medium-sized single-family house with a built-up area of up to 200 m².

2. MATERIALS AND METHODS

2.1. Evaluated object and typological parameters of selected structures

The built-up area of the family house is 175 m². The main structure is a one-storey building with a habitable attic, while the garage wing is designed as a single-storey annex. The overall architectural composition reflects a compact volume with a functional spatial layout optimized for residential use.

The most traditional materials for the construction of family houses in Slovakia are brick or aerated concrete, which are popular for their thermal properties, durability and availability. Wooden buildings, which have a modern and ecological character, are becoming increasingly popular.

2.2. Technical Overview of Selected Material Solutions for a Single-Family Residential

The family house is designed in two material variants: a ceramic system (Alternative A) and a timber post load-bearing system (Alternative B). The aim is to highlight universal principles applicable to both, while emphasizing their differences.

The building rests on strip foundations made of monolithic reinforced concrete C20/25 with B500 steel. Foundation strips under external walls are 1000 mm below ground level, with trench widths of 550 mm (A) and 500 mm (B). The base slab is 200 mm thick, fully reinforced with C20/25 concrete.

The pitched roof is a 30° gable with a load-bearing wooden rafter truss from C24 timber and heavy ceramic tiles. Roof structure differs: Alternative A rafters rest on a wall plate; Alternative B rafters rest on a doubled upper flange of the wall.

Load-bearing timber structures include vertical external walls of I-profile STEICOWall beams (300×60 mm) sheathed with OSB inside and diffusion-open fiberboard outside for rigidity. Internal load-bearing walls are I-profile STEICOWall beams (200×60 mm) and KVH timber (60×120 mm) sheathed on both sides. Horizontal supports include exposed ceilings of KVH beams (100×240 mm) and STEICOjoist I-profile beams (60×240 mm) elsewhere.

In the ground floor, external and internal load-bearing walls are 300 mm thick, built from Porotherm 30 Profi Dryfix ceramic blocks fixed with special mounting foam and insulated with 150 mm mineral wool. Partition walls use Porotherm 14.5 Profi Dryfix bricks. The ceiling above the ground floor is a semi-prefabricated Porotherm system, 240 mm thick. Reinforced concrete bond beams above load-bearing walls use C25/30 concrete and B500 steel.

2.3. Adopted Methodology, Inputs, and Boundary Conditions

The selected IMPACT World+ method provides a comprehensive assessment of the environmental impacts throughout the life cycle of the chosen construction, from raw material extraction, through manufacturing, to end-of-life stages. The goal was to compare alternatives and select the option with the lowest environmental impact.

The method's complexity and versatility, with its wide range of impact categories, allow for a thorough evaluation of environmental issues in a global context, providing a detailed view of the sustainability of the system. We applied normalization according to the IMPACT World+ Endpoint V1.04 method.

After normalization, environmental impact values for individual categories—such as climate change, ecosystem quality, or water use—are converted into relative units (e.g., "CO₂-equivalent emissions per person per year"). This provides a clearer understanding of how a specific product or process contributes to overall environmental problems compared to average impacts at global or regional levels.

Normalization within the IMPACT World+ Endpoint Indicator adjusts environmental impacts to a relative scale, offering context and enabling comparisons between different products or processes. This step is crucial for sustainability assessment, as it helps better understand how individual products contribute to environmental challenges on a global or regional scale.

4. RESULT AND DISCUSSION

In timber constructions (Table 1), the simulation of impacts across the evaluated categories revealed a significant contribution from the vertical structures. A substantial share of the impact in both categories is attributed to thermal insulation, as it constitutes the largest volume of material. Thermal insulation in the vertical elements of timber buildings can be substituted with various material bases, provided that the required thermal conductivity coefficient is maintained according to Decree No. 364/2012 Coll. on the energy performance of buildings, in reference to the Slovak standard STN 730540-2:2019.

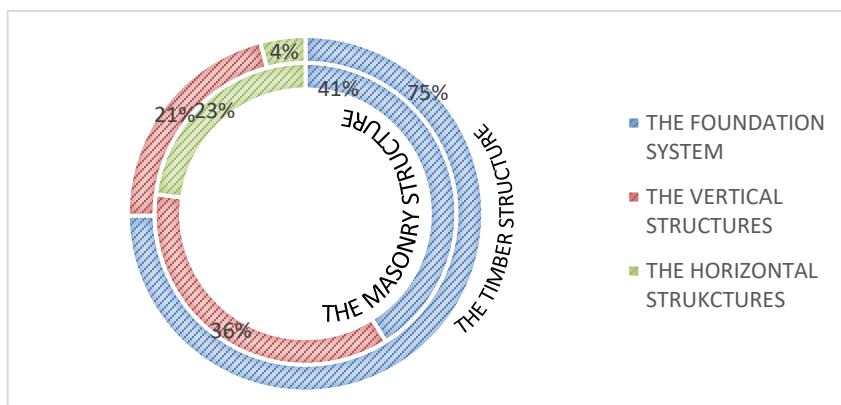


Figure 1: Comparison of the Impact of The Masonry and The Timber Structures on Human Health according to IMPACT World+ Endpoint

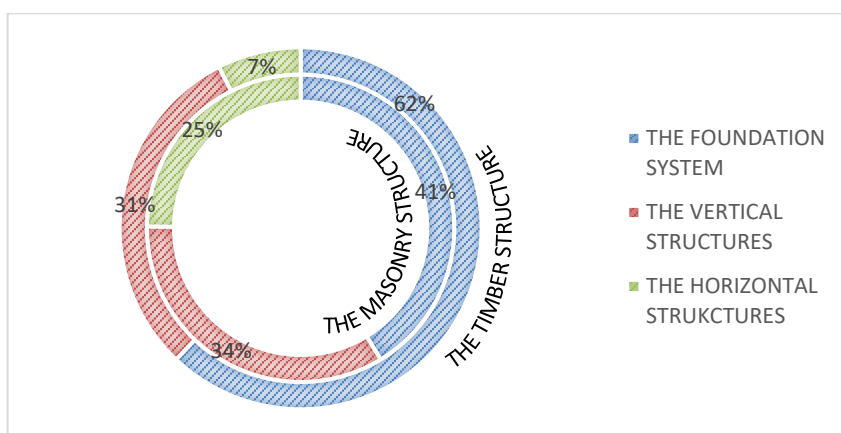


Figure 2: Comparison of the Impact of The Masonry and The Timber Structures on ecosystem quality according to IMPACT World+ Endpoint

Foundation structures represent the majority of the impact in both assessed categories for both types of constructions. For masonry constructions, modifying the foundation is not straightforward and generally involves higher investment costs from an economic perspective. In contrast, foundations for timber constructions can be adjusted more easily. The structural design of timber buildings allows such modifications, provided that the foundation conditions are thoroughly and comprehensively understood. Assessment of impacts for foundations using ground screws will be the subject of further research.

Thermal insulation properties of the selected materials play a critical role in determining the overall energy performance of the building by reducing heat transfer and consequently lowering heating and cooling demands. Furthermore, the environmental impact of these insulation materials must be carefully evaluated using life cycle assessment methodologies, such as IMPACT World+, to ensure the sustainability of the building throughout its entire life cycle.

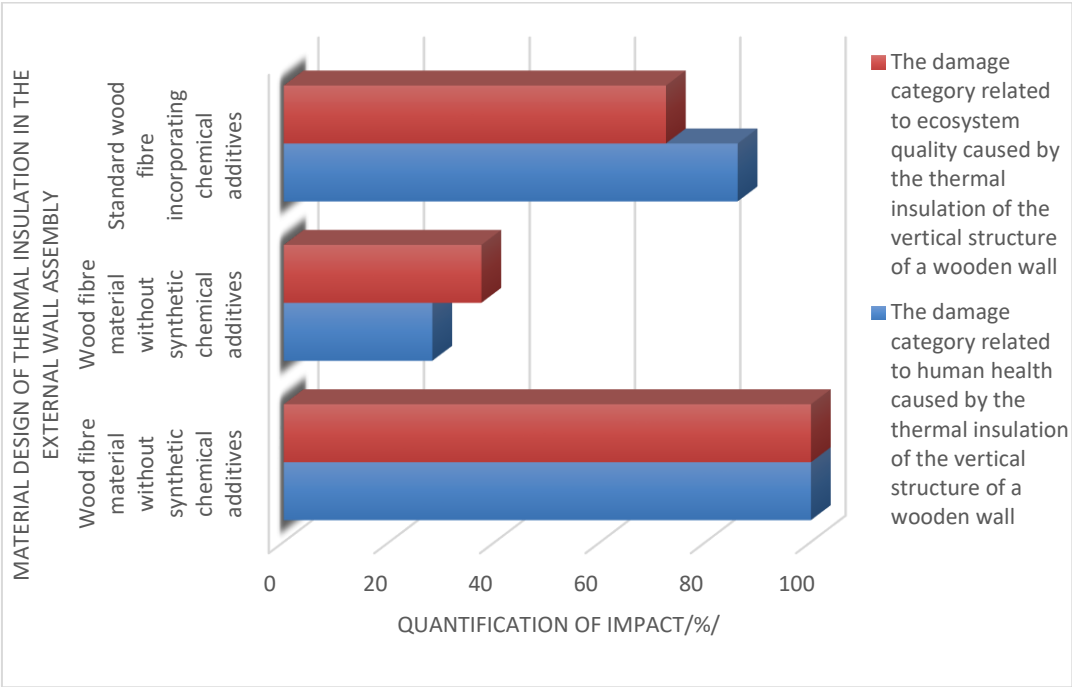
Natural or synthetic adhesives are most commonly used in wood fiber insulation to improve fiber bonding and ensure material stability. Polyurethane and lignocellulosic adhesives are commonly specified as insulating materials for timber constructions. From an ecological

perspective, thermally and pressure-bonded wood fiber insulations, which contain no added adhesives or chemical additives, are considered a more environmentally friendly alternative.

According to market offer calculations on the Slovak construction market, wood fiber insulation without chemical additives is on average about 30% more expensive than wood fiber insulation containing chemical additives. However, it is a more suitable choice, especially for environmentally focused projects.

The type of adhesive used in wood fiber insulation depends on requirements for durability, ecological properties, and manufacturing technologies. The most common adhesives are polyurethane, cement-based, and lignocellulosic adhesives, while eco-friendly solutions favor products without chemical additives that rely on heat and pressure to bond fibers.

Table 1: A comparative assessment of environmental and human health impacts of selected thermal insulation materials for external walls of a timber building



In the timber structure, the foundation is the largest contributor to impact in both assessed categories. The type of foundation depends on the type of the supported structure. Búryová, Sedlák (2022): "Terrace foundations are different for wooden terraces and natural stone plate terrace." [1]

In masonry constructions, there is limited possibility to significantly reduce the foundation volume. The only feasible options appear to be foundations on a reinforced concrete slab or, alternatively, on foam glass. Tažiková, A., et al.(2024):The growing number of constructions based on wood including, those from CLT panels, can significantly contribute to the sustainability of the construction industry, which the Slovak construction industry requires. [3]

In timber constructions, it is possible to optimize the foundation system by applying vertical foundation methods, such as reinforced concrete footings or ground screws.

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IMPACT OF WOOD TREATMENTS ON INDOOR AIR QUALITY: A COMPARATIVE REVIEW OF CHEMICAL AND SUSTAINABLE COATINGS

Faton Kalisi

Abstract: Indoor air quality (IAQ) is a critical factor in human health, with volatile organic compounds (VOCs) from wood finishes significantly contributing to indoor air pollution. This study conducts a systematic literature review to compare the VOC emissions of chemical wood treatments (such as polyurethane and lacquers) with sustainable alternatives (such as plant-based oils, waxes, and UV-cured coatings). The review synthesizes findings from peer-reviewed studies between 2015 and 2025 to evaluate the impact of these treatments on IAQ and potential health risks.

Results indicate that conventional chemical coatings emit higher levels of VOCs, particularly formaldehyde and benzene, which are linked to respiratory and neurological issues. Conversely, sustainable treatments generally produce lower emissions; however, their long-term effectiveness and durability remain under-researched. Additionally, environmental factors such as humidity and temperature influence VOC emissions from both treatment types, yet studies addressing these interactions are limited.

This review identifies key gaps in the literature, including the need for long-term comparative studies, standardized VOC measurement protocols, and research into hybrid coating solutions that balance environmental safety and performance. The findings provide valuable insights for architects, manufacturers, and policymakers seeking to promote healthier indoor environments through improved material selection. Future research should focus on quantifying the real-world performance of sustainable treatments in various climatic conditions to determine their true efficacy in improving IAQ.

Keywords: Wood treatments, indoor air quality, VOC emissions, sustainable coatings, chemical finishes

1. INTRODUCTION

People spend the majority of their time inside, where they are exposed to a variety of air pollutants that can harm their health. A group of chemicals known as volatile organic compounds (VOCs) pollutes the interior environment. Building materials, flooring, composite wood products, adhesives, and other consumer goods are the primary internal sources from which they enter buildings (Harčárová et al., 2020). Because of their respiratory, mutagenic, and carcinogenic effects, VOCs such as formaldehyde, benzene, toluene, and xylene are especially dangerous, and their concentrations are sometimes much higher indoors than outside (Kaur et al., 2023).

Because wood and wood-based panels contain natural volatiles and the added chemicals like adhesives used in manufacturing, make them a substantial contributor in the air pollution (Adamová et al., 2020). Wood product coatings have the potential to directly release VOCs as well as to produce secondary emissions by reacting with indoor ozone to produce toxic byproducts such as carbonyl compounds (Ranesi et al., 2023). In order to reduce the effects, sustainable coatings are gaining attention as they not only emit less concentration VOCs but also help in reducing ozone-derived pollutants indoors, making them a more eco-efficient and healthier solution (Ranesi et al., 2023).

Coatings are essential in wood technology for enhancing the lifespan, surface performance, and aesthetics of wood goods; nevertheless, by producing VOCs and reacting with environmental oxidants, they also contribute to indoor air pollution, indoor air quality and occupant health (Adamová et al., 2020).

Sustainable coating on the other hand, such as plant oils, bio-based waxes and UV-cured aqueous solutions, are developed to cope with these issues. According to research, they release less VOCs than create less hazardous secondary byproducts (Teacă et al., 2019). But there are still concerns that regarding their behaviour in real indoor environments, long-term durability and protective capabilities, especially in different temperature and humidity conditions (Pohleven et al., 2019).

To better understand the VOCs emissions profiles of chemical vs sustainable wood coatings, their effects on health and how well they perform in indoor environments, this review will collect and evaluate peer-reviewed research that was published between 2015-2025. The study aims to highlight areas in need of further research, recommend standardised procedures, that support both indoor air quality and material performance.

2. METHODOLOGY

A systematic literature review approach was used to collect, compare, and analyze existing research on VOC emissions from chemical and sustainable wood coatings and their impact on indoor air quality (IAQ). The aim was to identify both emission patterns and associated health implications across different coating types.

An organised database search was carried out between March and June 2025 using Google Scholar, ScienceDirect, PubMed, and MDPI. Search terms including "VOC emissions wood coatings," "indoor air quality wood finishes," "sustainable coatings VOCs," "chemical polyurethane wood IAQ," and "plant-based oils wood VOCs" were among the search phrases.

The inclusion criteria were as follows: studies that were peer-reviewed and released from 2015 to 2025; studies presenting either qualitative or quantitative information on VOC emissions from wood coatings; articles addressing the importance of IAQ, chemical composition, or health impacts; studies that contrast sustainable finishes with chemical finishes or look at each separately

Exclusion criteria included: non-peer-reviewed sources (magazines, opinion articles); studies focused only on outdoor emissions or emissions from non-wood materials; duplicates or papers lacking emission data

In total, 18 papers met the requirements and were reviewed. These documents were examined to get information on: VOC levels and kinds of emissions; categorisation of coatings (sustainable or chemical); test parameters (such as temperature, humidity, and test chamber dimensions); health impacts that are stated or suggested.

3. RESULTS

The results are grouped into three topic areas:

- Emission levels from chemical coatings.
- Emission levels from sustainable or low-VOC alternatives.
- The impact of environmental factors such as, temperature, humidity, and substrate moisture content.

3.1. VOC Emissions from Chemical Coatings

Traditional chemical coatings like polyurethane, nitrocellulose lacquer, and alkyd-based finishes are still often used in interior wood applications because of their strength, durability and aesthetic appeal. Although, these coatings are among the highest emitters of VOCs (Ulker et al., 2021); (Adamová et al., 2020).

In several studies, during the curing period, chemical coatings, continuously emitted substantial amounts of VOCs. Among the most frequently found VOC types were formaldehyde, toluene, benzene, xylene, and acetaldehyde. All of these substances have known carcinogenic, mutagenic, or toxic effects (Ulker et al., 2021); (Harb et al., 2018).

According to Adamová et al. (2020), solvent-based polyurethane coatings had total volatile organic compounds (VOCs) of up to 1,200 µg/m³, especially in the first seven days following application. Also, application technique, coating thickness, and room ventilation all had a major impact on emissions. Particularly, it was also found that some coatings produced secondary pollutants with the indoor ozone. Among them were carbonyl chemicals such as acetone and formic acid that might worsen indoor air quality (Ranesi et al., 2024).

3.2. VOC Emissions from Sustainable Coatings

Plant oils (such as tung and linseed), aqueous acrylics, and UV-cured resins are examples of low-VOC or also known as sustainable coatings. They are often used as “green” or “eco-friendly” alternatives because of their health and environmental benefits. However, formulation, application techniques and curing procedure can all affect their VOC emission levels (Teacă et al., 2019); (Jabbari et al., 2025).

Compared to solvent-based chemical coatings, aqueous acrylic coatings emitted 150–400 µg/m³ of total volatile organic compounds (TVOCs) after 28 days in controlled experiments (Alapieti et al., 2021). The lowest VOC levels, frequently less than 100 µg/m³, were released by UV-cured coatings, which harden by photopolymerization and don't require solvents (Jabbari et al., 2025). However, biogenic volatile organic compounds (VOCs) such terpenes (limonene, pinene) and aldehydes (hexanal, nonanal) were created by plant-based oils and waxes. These substances may nonetheless have an impact on sensitive people or cause chemical reactions indoors, even if they are less harmful than synthetic solvents (Pohleven et al., 2019).

Also, factors such as drying time, oil saturation, wood surface preparation had significant impact on the emissions from natural coatings. Even after few days of application, some coatings have kept off-gassing (Pohleven et al., 2019). Sustainable coating may provide less resistance to abrasion, moisture, and wear despite having reduced emissions, particularly in frequent use environments (Ranesi et al., 2024).

3.3. Environmental and Performance Factors

Environmental factors including temperature, relative humidity, and wood moisture content have a big impact on the release of VOCs from wood coating, whether chemical or sustainable. A key factor in VOC volatilisation is temperature. VOCs diffuse more quickly at higher temperatures, particularly from solvent-based coatings like nitrocellulose lacquer and polyurethane. For instance, research revealed that in heated, poorly ventilated spaces the

TVOC concentrations increased significantly, speeding up the off-gassing process (Harb et al., 2018).

Relative humidity (RH) also has an influence on the emissions. Aldehyde release from chemical and bio-based coating was shown to increase with elevated relative humidity (>60%), most likely because of interactions with water molecules and slower evaporation rates (Pohleven et al., 2019). Also, relative humidity influences the production of secondary pollutants, particularly when indoor ozone and VOCs combine to create irritants like acetone or formaldehyde (Ranesi et al., 2024).

Wood moisture content (MC) is also an important factor. Higher moisture levels decreased VOC emissions, presumably by absorbing certain volatiles during drying or diminishing solvent diffusion, according (Alapieti et al., 2021) comparison of pinewood samples with 10% and 16% moisture content.

Table 1 provides a comparative summary of chemical and sustainable coatings.

Table 1. Comparative Summary of Chemical and Sustainable Coatings

Feature	Chemical Coatings	Sustainable Coatings
Common Types	Polyurethane, nitrocellulose lacquer, alkyd varnish	Waterborne acrylics, UV-cured bio-resins, plant oils (linseed, tung), natural waxes
Main VOCs Emitted	Formaldehyde, benzene, toluene, xylene, acetaldehyde	Aldehydes (hexanal, nonanal), terpenes (limonene, pinene)
Total VOC Range (7–28 days)	800–1,200 µg/m ³ (Adamová et al., 2020)	100–400 µg/m ³ (Jabbari et al., 2025)
Secondary Emissions	High (e.g., carbonyls from ozone reactions)	Moderate to Low (ozone reactions with terpenes possible)
Health Concerns	Respiratory irritation, carcinogenicity (formaldehyde, benzene)	Mild irritation in sensitive individuals
Durability	High abrasion and water resistance	Variable; may need reapplication or blending
Cost and Accessibility	Widely available; cheaper	Slightly more expensive; growing market
Environmental Impact	High (petrochemical base, persistent emissions)	Lower (bio-based, often biodegradable)

4. DISCUSSION

According to this review findings clearly indicate that wood coatings, especially those made of polyurethane, alkyd and nitrocellulose are a major source of indoor VOCs, particularly in the weeks after application. These coatings consistently emit dangerous VOCs such as formaldehyde, benzene and toluene, all of which have been connected to negative neurological and respiratory effects (Adamová et al., 2020); (Harb et al., 2018). On the other hand, sustainable alternatives, waterborne and UV-cured coating, exhibit significant reduced overall VOC emissions, less than one-third of their chemical counterparts (Jabbari et al., 2025); (Teacă et al., 2019).

However, emission levels alone do not accurately reflect a coating's environmental and health impact. Several sustainable coatings, particularly plant oil-based finishes, have been discovered to release biogenic VOCs (e.g., terpenes and aldehydes), which may nevertheless cause irritation or form secondary pollutants indoors, especially when reacting with ozone (Pohleven et al., 2019; Ramesi et al., 2024). The change in emission patterns caused by external variables, such as humidity and temperature, complicates the evaluation even more. VOC emission from paints was much higher with drier wood substrates and warmer circumstances, as demonstrated in chamber investigations on pinewood (Alapieti et al., 2021).

One major issue seen across the studies was the lack of standardisation in VOC testing and reporting. Different measurement procedures, test chamber sizes, and environmental controls, makes it difficult to compare the data from different studies. For example, some studies used 28-day test cycles, whereas others only reported 7-day emission peaks, potentially leading to underreporting or bias (Harb et al., 2018; Adamová et al., 2020).

5. GAPS AND FUTURE RESEACH DIRECTION

Even though there's in increased interest in low-emission wood treatments, this review identifies many significant gaps in existing research. First, a lack of long-term field studies comparing the VOC emissions and performance of chemical versus sustainable coating in real-world indoor environments. Most of the available data is generated from a small-scale, short-duration laboratory testing that may not accurately reflect the real-world exposure scenarios (Harb et al., 2018); (Alapieti et al., 2021).

Second, there aren't many standardised testing procedures in the field. Comparing results from other coating or studies is challenging due to the wide variations in chamber size, test duration, temperature, and humidity settings (Adamová et al., 2020). It is essential that globally recognised standards for evaluating indoor building materials for volatile organic compounds (VOCs) be developed.

Third, although sustainable coatings have potential, there is a lack of information regarding their long-term maintenance requirements and durability. For instance, the environmental impact and cost-effectiveness of plant-based oils and waxes may be impacted by their degradation or frequent need for reapplication (Ranesi et al., 2024).

The interaction between VOCs with indoor air chemistry, especially secondary emissions caused by common indoor oxidants such as ozone are not much explored. When some sustainable coatings are oxidized, they produce terpenes, which can ford aldehydes. (Pohleven et al., 2019); (Ranesi et al., 2024).

Lastly, hybrid coating solutions that combine the performance properties of conventional chemical finishes with the low emissions of sustainable materials are required. These could be essential for striking a balance between lifespan, indoor air quality, and aesthetic demands in contemporary architecture and design.

6. CONCLUSION

Using peer-reviewed research published between 2015 and 2025, this systematic review examined the performance features, health risks, and volatile organic compound (VOC) emissions of chemical and sustainable wood coatings. The results clearly show that chemical coatings, including polyurethane, nitrocellulose, and alkyd-based finishes, release notably

more toxic volatile organic compounds (VOCs), such as formaldehyde, benzene, and toluene, particularly in the initial weeks following application (Ulker et al., 2021); (Adamová et al., 2020).

Though some of them release natural compounds (like terpenes) that may still have an impact on indoor air chemistry, sustainable coatings, such as waterborne acrylics, UV-cured resins, and plant-based oils, show lower total VOC emissions and fewer health risks (Jabbari et al., 2025); (Teacă et al., 2019). Although these coatings have the potential to improve indoor air quality, they frequently lack durability data and need further real-world testing.

Future research should concentrate on standardising VOC testing procedures, carrying out long-term performance assessments, and creating hybrid coatings that strike a compromise between excellent functional performance and environmental safety to progress the area. For architects, manufacturers, and legislators to make well-informed decisions that promote healthier indoor environments, these actions are crucial.

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MECHANICAL PROPERTIES OF FINGER JOINTS, EXPOSED TO DIFFERENT ENVIRONMENTAL CONDITIONS

Alen Ibrisevic, Murco Obucina, Seid Hajdarevic, Sanin Hasanica, Goran Mihulja

Abstract: Numerous technological solutions for the longitudinal joining of wood have been developed for the better use of wood. The finger joint is one of the most widespread technological processes of longitudinal wood joining. This study aimed to determine the effect of different environmental conditions and adhesive durability classes on finger joints' mechanical characteristics. Samples from beech were bonded with polyvinyl acetate (PVAC) adhesives (D3 and D4) and exposed to different environmental conditions. The finger joint samples' bending strength and modulus of elasticity under static load were measured. An analysis of variance (ANOVA) was performed to evaluate the impact of environmental conditions and different adhesives on the mechanical characteristics of the finger joints. According to the results of this study, it can be concluded that environmental conditions influence changes in the mechanical properties of finger joints.

Keywords: finger joint, durability classes, polyvinyl acetate adhesive (PVAC), bending strength, modulus of elasticity

1. INTRODUCTION

Wood is among the oldest and most valuable materials used in various constructions and products. The poor quality of technical wood as a raw material in the wood industry is evident and occurs globally. Many technological solutions have been developed to improve the longitudinal joining of wood. The finger joint is the most common method for this purpose. This process enables better utilisation of solid wood, allowing longer element lengths and greater stability. It also uses small wood planks often discarded as waste [Kamboj et al, 2019; Muthumala et al., 2021]. The strength of the finger joint depends on several wood-related factors such as species, density, and natural defects, as well as on processing parameters like moisture content, timber temperature, finger geometry, machining settings, assembly pressure, curing time, adhesive type, and pre-treatment of the wood [Habipi et al. 2015]. Joint strength is a mechanical property that significantly influences the structure's overall strength. The most common stress experienced by structures is bending stress. Therefore, in structural finger-jointed timber, the bending strength of the joint is a critical property. Factors affecting joint strength include joint design and the adhesive used. Polyvinyl acetate adhesive (PVAC), with different durability classes, is often used in furniture manufacturing. The finger joint's geometric features and climatic factors such as moisture content and temperature significantly impact product performance [Liu et al., 2020; Liu et al., 2019]. Moisture content in the wood is a key factor influencing joint strength, as moisture levels affect the performance of some adhesives [Bomba et al. 2014]. Environmental conditions greatly influence moisture content in the wood and, by extension, the strength of finger joints. For outdoor applications, where ambient humidity is higher, the moisture content of the bonded wood should also be increased. Higher moisture levels affect the dimensional stability of the wood. This paper aims to examine the

effects of environmental conditions, adhesive durability classes, and moisture content in the wood on the bending strength and the modulus of elasticity of finger joints in beech wood.

2. MATERIAL AND METHODS

Beech wood (*Fagus sylvatica* L.) was used to test the modulus of elasticity in bending and bending strength. The testing elements were produced at the factory Secom doo (Visoko, Bosnia and Herzegovina). The wood was free of visible defects, and the elements were made using a combination of radial and tangential sections. The finger joint profiles are shown in Figure 1. The bonding process utilized polyvinyl acetate (PVAC) adhesive with two durability classes (D3 and D4 according to EN 204), with an adhesive application rate of 140 g/m². Joining was conducted in an industrial press (Weinig Grecon PJ 10/6100), with the final dimensions of the testing elements measuring 630x40x40 mm. Bonded finger joint elements were conditioned at a temperature of 20±2°C and a humidity of 65±5%. The moisture content of the conditioned finger joints were 10±2%.

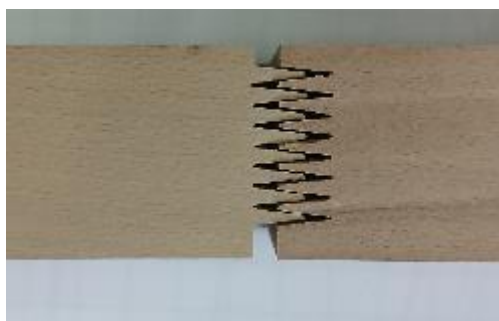


Figure 1. Geometric characteristics of the finger joint

After the condition elements were exposed to different environmental conditions, the groups were organised as follows:

Group I- temperature 23°C, humidity 30%, for 7 days;

Group II- temperature 23°C, humidity 70%, for 7 days;

Group III- temperature 23°C, humidity ranging from 30% to 70% in circular changes, as shown in Table 1;

Group IV- production condition, with temperature at 22°C and humidity at 50±5 %.

Eight groups were formed, consisting of 2 types of adhesives each tested under 4 different environmental conditions, with 10 elements per group (total of 80). The bending strength and modulus of elasticity of the finger joints were tested in accordance with the EN 408 standard. The test setup and the method for determining the modulus of elasticity in bending and the bending strength are illustrated in Figure 2. During testing, the finger joint was positioned on the lateral side of the samples, with the finger joints oriented horizontally. All tests were conducted in the Wood Science Laboratory at the Faculty of Mechanical Engineering, University of Sarajevo. Laboratory conditions were maintained at a temperature of 20 °C and a relative humidity of 55%.

Table 1: Circular changes of humidity and temperature for samples in group III

Days	Temperature (°C)	Humidity (%)
0-7	23	70
8-14	23	30
15-21	23	70
22-35	23	60

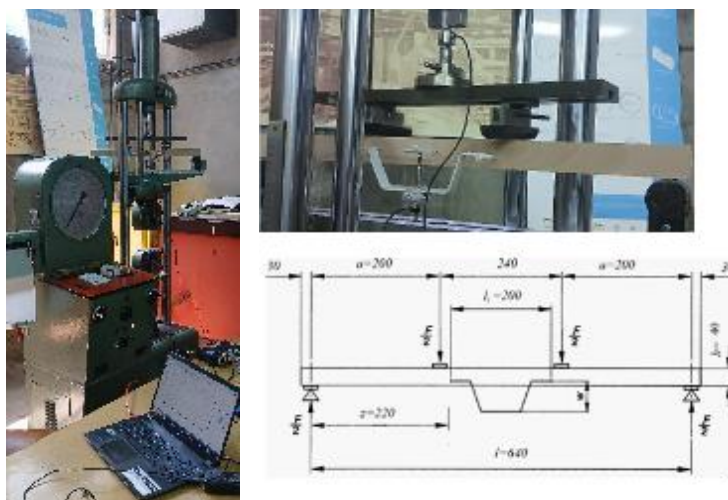


Figure 2. The test setup and experimental determination of the bending strength and modulus of elasticity

The mechanical properties were tested using a universal testing machine (Zwick—Type 1282). The displacement velocity during testing was maintained at 8.0 mm/min. The equipment and software used to collect, analyse, and visualise the measurements are a force sensor (HBM U9C, 10 kN), displacement transducer (HBM W110), QuantumX data acquisition system (DAQ), and CATMAN data acquisition software.

Statistical analysis and data visualisation were conducted using the Statistica software. Analysis of variance (ANOVA) was utilised to assess the variation in the modulus of elasticity in bending and bending strength of samples grouped by environmental conditions and adhesives used. If the one-way ANOVA indicated statistical significance, a Tukey pairwise comparison (post hoc) test was carried out.

3. RESULTS AND DISCUSSION

Figures 3 and 4 show the results of the mechanical properties of the finger joints exposed to different environmental conditions and bonded with two PVAC adhesives, categorised differently according to EN 204.

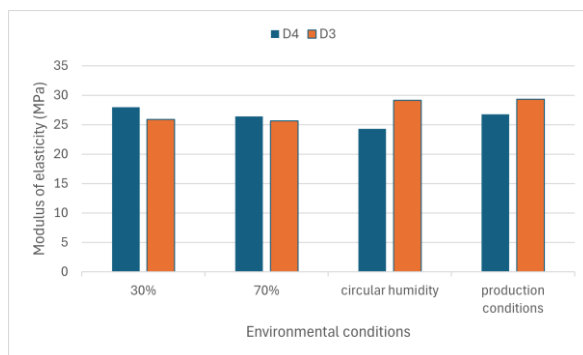


Figure 3. Bending strength of finger joints

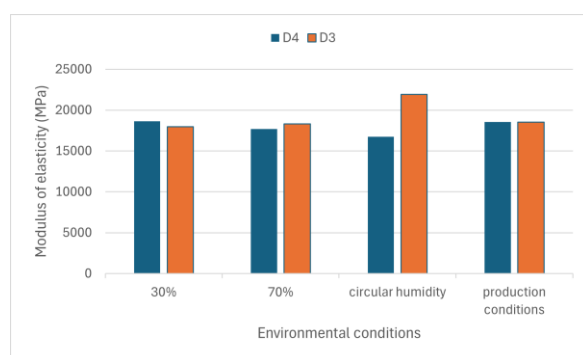


Figure 4. Modulus of elasticity of finger joints

A one-way ANOVA was performed to investigate the impact of environmental conditions on the bending strength and modulus of elasticity of finger-jointed elements bonded with D3 and D4 adhesives. A Tukey post hoc comparison was also carried out, with results in Table 2.

Table 2. The correlations between different environmental conditions for bending strength and modulus of elasticity of finger jointed elements bonded with D3 and D4 PVAc adhesive

Bending strength					Modulus of elasticity			
PVAC adhesive D3								
II	III	IV			II	III	IV	
0.058	0.546	0.879	I		0.864	0.433	0.999	I
	~~0.003~~	0.325	II			0.72	0.938	II
		0.226	III				0.622	III
PVAC adhesive D4								
II	III	IV			II	III	IV	
0.316	0.975	0.748	I		0.998	0.358	0.993	I
	0.532	~~0.020~~	II			0.375	0.999	II
		0.443	III				0.460	III

Table 2 shows no statistically significant difference in the mean bending strength and modulus of elasticity of finger-jointed elements exposed to different environmental conditions. Differences in environmental conditions influence changes in the moisture content of wood. Moisture content of wood affects the joint strength (Ibrisevic et. al, 2021; Bomba et. al, 2019). Our study shows that moisture content (environmental conditions) does not influence the changes in the mechanical characteristics of the finger joint. Elements tested in this study were exposed for a short time to different environmental conditions, and dimensions (cross-section) of the tested elements were too big, so any changes in the mechanical properties of finger joints did not occur.

A one-way ANOVA was conducted to examine the effect of adhesive durability classes (D3 and D4) on finger-jointed elements' bending strength and modulus of elasticity. The results are presented in Table 3.

Table 3. The correlations between D3 and D4 adhesives, for different environmental conditions

Conditions	Bending strength, p-value	Modulus of elasticity, p-value
I	0.444	0.730
II	0.697	0.577
III	0.044	0.038
IV	0.368	0.989

Table 3 shows that mechanical characteristics of finger joints were not affected by the PVAc adhesive class. ANOVA test shows that there is only a statistically significant difference in mean bending strength and modulus of elasticity of finger-jointed elements bonded with D3 and D4 PVAc adhesives that were exposed to a temperature of 23°C and circular humidity changes (group III). In all other cases, there is no statistically significant difference in mean bending strength and modulus of elasticity between finger-jointed elements bonded with D3 and D4.

A study conducted by Vassiliou et al. (2007) shows that the durability class of adhesive has a high influence on the mechanical characteristics of finger joints (higher classes give better results). Our study shows that the durability class does not instantly influence changes in mechanical properties. Still, as expected, the changes are noticed after joints were exposed to the circular weather conditions.

Figure 5 shows the characteristic pattern of finger joint fractures. The common fracture occurs in finger joints, i.e., finger extraction with a combination of adhesive and wood failure, with results matching data in the literature (Hajdarevic et al. 2024).



Figure 5. Characteristic joint failures

4. CONCLUSION

The test results regarding the obtained mechanical properties demonstrate that varying environmental conditions do not influence changes in the mechanical properties of finger-jointed elements within the scope of the climatic variations employed. Furthermore, the findings indicate that bonding wood with PVAc adhesives across different durability classes does not affect the mechanical properties of the finger-jointed elements, except following extended exposure to circular weather conditions designated as conditions III in the results diagrams.

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