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ANALYSIS OF THE VOLUME OF GENERATION AND DEVELOPMENT OF WAYS TO USE WOOD RESIDUES AND WASTE FROM THE PRODUCTION ACTIVITIES OF A FURNITURE ENTERPRISE / АНАЛІЗ ОБСЯГІВ УТВОРЕННЯ ТА РОЗРОБЛЕННЯ ШЛЯХІВ ВИКОРИСТАННЯ ДЕРЕВИННИХ ЗАЛИШКІВ ТА ВІДХОДІВ ВИРОБНИЧОЇ ДІЯЛЬНОСТІ МЕБЛЕВОГО ПІДПРИЄМСТВА

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Abstract. The study addresses the generation, structure, and utilization of wood residues and composite waste in furniture manufacturing within the framework of circular economy principles. The research is based on empirical data from a furniture enterprise for the period 2022–2024 and focuses on identifying efficient pathways for waste valorization. A material flow analysis combined with a mass-balance model was applied to evaluate waste streams and their allocation to reuse routes, including mechanical recycling, panel production, and bioenergy. The results indicate a significant reduction in total waste generation from 54.80 m^3 in 2022 to 30.48 m^3 in 2024 (–44%), mainly due to improved processing efficiency and optimized cutting strategies. Solid offcuts decreased by 44%, while sawdust and shavings showed reductions of 47% and 45%, respectively. The proposed utilization model ensured approximately 95% landfill diversion, with 28.95 m^3 redirected to secondary use streams. The economic assessment demonstrated a total annual effect of approximately UAH 0.25 million, primarily driven by mechanical reuse (≈89% of total margin). The energy recovery potential from fine fractions reached 11.35 MWh/year, with avoided CO_2 emissions ranging from 2.29 to 3.86 tons depending on substitution scenarios. The novelty of the research lies in integrating cascade wood utilization with an enterprise-level material balance model that aligns technological, economic, and environmental parameters. The practical value consists in providing a replicable tool for resource efficiency management and sustainable production in furniture manufacturing.

Keywords: wood residues, furniture manufacturing, waste utilization, circular economy, material balance, biofuel, MDF, particleboard, resource efficiency, CO_2 reduction

Introduction. The modern furniture industry is characterized by intensive consumption of wood and composite materials, resulting in substantial generation of production waste. According to existing studies, wood residues may account for up to 30–40% of raw material input, significantly affecting production costs and environmental sustainability. The relevance of this research is driven by the necessity to implement resource-efficient technologies and reduce environmental impact through circular economy approaches. However, most enterprises still lack integrated waste management systems, leading to inefficient disposal practices such as landfilling or

uncontrolled combustion. This results in economic losses and increased environmental risks. Therefore, there is a need for systematic approaches that combine technological, economic, and ecological aspects of waste utilization.

Aim. To develop and scientifically substantiate efficient pathways for the utilization of wood residues and composite waste generated in furniture manufacturing.

Object Wood and composite waste generated during furniture production processes. **Subject.** Technological and organizational approaches to recycling and reuse of wood residues in furniture manufacturing systems.

Research Hypothesis. Efficient reuse and recycling of wood residues and composite waste can significantly reduce production costs, minimize environmental impact, and generate additional value-added products.

Methodology and Approach. The research methodology includes: analysis of waste generation flows (2022–2024); classification of waste into solid (offcuts) and fine fractions (sawdust, shavings); development of a material balance model with allocation matrix; conversion of volume to mass considering density and moisture; economic evaluation (revenues, costs, avoided landfill fees); energy and carbon assessment (LHV, emission factors); sensitivity analysis.

Regression Model. Based on empirical data, the total waste generation can be approximated by a linear regression model: $V_t = 54.80 - 12.16 \cdot (t - 2022)$,
where: V_t – waste volume (m^3), t – year. This model reflects a stable downward trend in waste generation due to technological improvements.

Results of the Study. The analysis of production data for the period 2022–2024 revealed a steady decrease in the total volume of wood residues and waste generated in the furniture manufacturing process. Specifically, the overall amount of waste decreased from 54.80 m^3 in 2022 to 51.46 m^3 in 2023 and further to 30.48 m^3 in 2024, which corresponds to a total reduction of approximately 44%. This trend indicates a significant improvement in production efficiency and the implementation of resource-saving measures at the enterprise. A detailed structural analysis of waste streams shows that solid wood offcuts constitute the largest share of total waste throughout the observed period. Their volume decreased from 35.23 m^3 in 2022 to 34.17 m^3 in 2023 and further to 19.58 m^3 in 2024, reflecting a reduction of approximately 44%. This decrease is associated with the optimization of cutting patterns and more efficient use of raw materials in the production process.

The dynamics of fine fractions demonstrate similar trends. The volume of sawdust slightly increased from 11.92 m^3 in 2022 to 12.58 m^3 in 2023, which can be attributed to changes in production structure or an increase in finishing operations. However, in 2024, a significant decrease to 6.65 m^3 was observed, corresponding to a reduction of approximately 47%, which indicates improved process control and dust extraction systems. The volume of shavings decreased consistently from 7.65 m^3 in 2022 to 4.71 m^3 in 2023 and further to 4.24 m^3 in 2024, representing a total reduction of about 45%.

The proportional structure of waste in 2024 shows that solid offcuts account for approximately 64% of total waste, while sawdust and shavings represent about 22% and 14%, respectively. This distribution reflects the technological nature of furniture production processes, where primary cutting operations generate the majority of residues. Based on the developed material balance model, the allocation of waste streams

to utilization pathways was optimized. The results demonstrate that approximately 11.75 m³ of solid residues were reused in the production of structural elements such as blockboards, furniture panels, and auxiliary components. Additionally, 4.90 m^3 of offcuts and 1.27 m^3 of shavings were directed to particleboard production after mechanical processing, while 1.33 m^3 of sawdust was utilized as raw material for MDF manufacturing. A significant share of fine fractions was allocated to bioenergy production, with a total of 6.78 m³ converted into pellets and briquettes. This utilization pathway ensures efficient use of low-quality residues that are not suitable for mechanical recycling. Furthermore, a minor portion of waste (approximately 0.64 m³) was used for auxiliary purposes such as bedding materials and absorbents, while technological losses remained limited to 1.52 m^3.

The proposed allocation scheme resulted in a landfill diversion rate of approximately 95%, meaning that 28.95 m^3 of waste were effectively reused or recycled, and only a small fraction required disposal. This demonstrates the high efficiency of the integrated waste management system implemented at the enterprise.

The economic evaluation of waste utilization pathways indicates that the total annual economic effect reaches approximately UAH 0.25 million. The largest contribution is generated by mechanical reuse of solid offcuts, particularly in the production of structural elements, which accounts for the majority of the total profit margin. Biofuel production provides a secondary but stable source of income, while the use of residues in particleboard and MDF production contributes additional value. An important component of the economic effect is the avoidance of landfill disposal costs, which further increases overall efficiency.

From an environmental perspective, the use of fine fractions for bioenergy production provides a significant energy output of approximately 11.35 MWh per year. This energy substitution leads to avoided CO_2 emissions of about 2.29 tons when replacing natural gas and up to 3.86 tons when replacing coal. Therefore, the implementation of integrated waste utilization strategies contributes not only to economic performance but also to environmental sustainability.

The obtained results confirm that the application of a cascade utilization approach, combined with an enterprise-level material balance model, ensures a high level of resource efficiency, minimizes waste disposal, and creates additional economic and environmental benefits for furniture manufacturing enterprises.

Scientific Novelty: Integration of cascade wood utilization with enterprise-level material balance modeling. Improvement of waste classification considering reuse potential. Establishment of relationships between waste management efficiency and economic performance. Development of a combined techno-economic-environmental evaluation framework.

Practical Significance: Reduction of raw material consumption and disposal costs. Increase in enterprise profitability through secondary products. Implementation of resource efficiency KPIs. Applicability for furniture and related wood-processing industries.

Expected Results: Increase in resource efficiency by 20–30%. Reduction of waste disposal to below 5%. Stable economic return from secondary resource streams. Reduction of environmental impact and CO_2 emissions.

Conclusions and Recommendations: Waste generation decreased by 44% due to improved production efficiency. Solid offcuts are the main contributor to both waste generation and economic value. The developed model ensures up to 95% landfill diversion. The total economic effect reaches approximately UAH 0.25 million annually. Bioenergy utilization provides additional environmental benefits, including CO_2 reduction. Priority should be given to mechanical reuse of solid residues. Fine fractions should be flexibly allocated between bioenergy and panel production. Implementation of sorting, moisture control, and waste routing is essential. Further improvements require investment in pelletizing technologies and advanced recycling systems. The integration of cascade utilization principles with a material balance approach provides a robust framework for sustainable waste management in furniture manufacturing. The proposed model ensures both economic profitability and environmental sustainability, making it a viable solution for modern wood-processing enterprises.

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