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Article

Circular Economy of Medium Density Fiberboard (MDF) and Medium Density Particleboard (MDP): Challenges and Advances in Sustainability and Production Processes

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ABSTRACT

The wood-based panel industry, MDF (*Medium-Density Fiberboard*) and MDP (*Medium-Density Particleboard*), plays a key role in the construction and furniture industries, as well as contributing to waste utilization and carbon storage. However, challenges such as the environmental impact of production, the use of toxic synthetic resins, and limitations on the reuse of these materials have generated growing interest in more sustainable measures. This study aims to review the literature from 1945 to 2024 on the environmental, technological, and sustainability aspects of these materials, seeking to identify measures to optimize reuse, minimize environmental impacts, and innovate with circular economy practices. A narrative review was conducted using the Web of Science platform of studies that evaluate the life cycle of MDF and MDP. The study highlighted aspects such as environmental impacts, technical feasibility, and innovation with the use of applied technology, using an integrative and critical approach to the results achieved. The results highlighted that replacing synthetic resins with biodegradable alternatives, such as Ulva algae-based adhesives, and using paper waste in MDF proved to be effective strategies for reducing carbon emissions and environmental toxicity. The reuse of MDF waste through processes such as thermal hydrolysis allowed for the recovery of usable fibers, despite technical challenges related to maintaining mechanical properties. The analysis showed that MDF and MDP have great potential for development through the application of circular economy practices and technological innovations. Strategies such as fiber recycling, the use of biodegradable adhesives, and the recovery of industrial waste are promising solutions for reducing environmental impacts and meeting the demands of the sustainability plan and the 2030 agenda.

Keywords: medium-density fiberboard; medium-density particleboard; life cycle; reuse.

RESUMO

A indústria de painéis à base de madeira, MDF (*Medium-Density Fiberboard*) e o MDP (*Medium-Density Particleboard*), tem um papel fundamental no setor da construção civil e indústria moveleira, bem como contribuindo para o aproveitamento de resíduos e o armazenamento de carbono. Entretando, desafios como o desgaste ambiental da produção, uso de resinas sintéticas tóxicas e limitações na reutilização desses materiais têm gerado crescente interesse por medidas mais sustentáveis. O presente estudo visa revisar a literatura no período de 1945-2024 sobre os aspectos ambientais, tecnológicos e de sustentabilidade destes materiais, buscando a identificação de medidas para otimizar a reutilização, minimizar os impactos ambientais e inovar com práticas de economia circular. Foi realizada uma revisão narrativa, utilizando a plataforma Web of Science, de estudos que avaliam o ciclo de vida de MDF e MDP. O estudo destacou aspectos como impactos ambientais, viabilidade técnica e inovação com uso de tecnologia aplicada, fazendo uso de uma abordagem integrativa e crítica dos resultados alcançados. Os resultados destacaram que a substituição de resinas sintéticas por alternativas biodegradáveis, como adesivos à base de algas Ulva, e a utilização de resíduos de papel no MDF, mostraram-se estratégias eficazes para reduzir emissões de carbono e toxicidade ambiental. A reutilização de resíduos de MDF por meio de processos como a hidrólise térmica permitiu recuperar fibras utilizáveis, apesar de desafios técnicos relacionados à manutenção de propriedades mecânicas. A análise evidenciou que MDF e MDP possuem grande potencial de desenvolvimento por meio da aplicação

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das práticas de economia circular e novidades tecnológicas. Estratégias como a reciclagem de fibras, o uso de adesivos biodegradáveis e a valorização de resíduos industriais são soluções promissoras para diminuir os impactos ambientais e atender às demandas do plano de sustentabilidade e a agenda 2030.
Palavras-chave: painéis de fibra de densidade média; painéis de partículas de média densidade; ciclo de vida; reutilização.

Introduction

The *Medium-Density Fiberboard* (MDF) and Medium-Density Particleboard (MDP) industry plays an important role in the sustainable development of forests, contributing to the valorization of wood waste and species of irrelevant economic value. Panels such as MDF have been fundamental for carbon storage, with applications that allow the retention of this element for decades, depending on the end use (Garcia et al. 2024).

In Brazil, one of the world's largest MDF manufacturers, the importance of this sector is clear (Piekarski et al. 2017). Based on information from the 2019 report by the Brazilian Tree Industry (IBÁ), Brazil ranks 8th in the world in MDF manufacturing, with remarkable growth in the last decade, driven by increased domestic consumption and expansion in the international market (Figure 1).

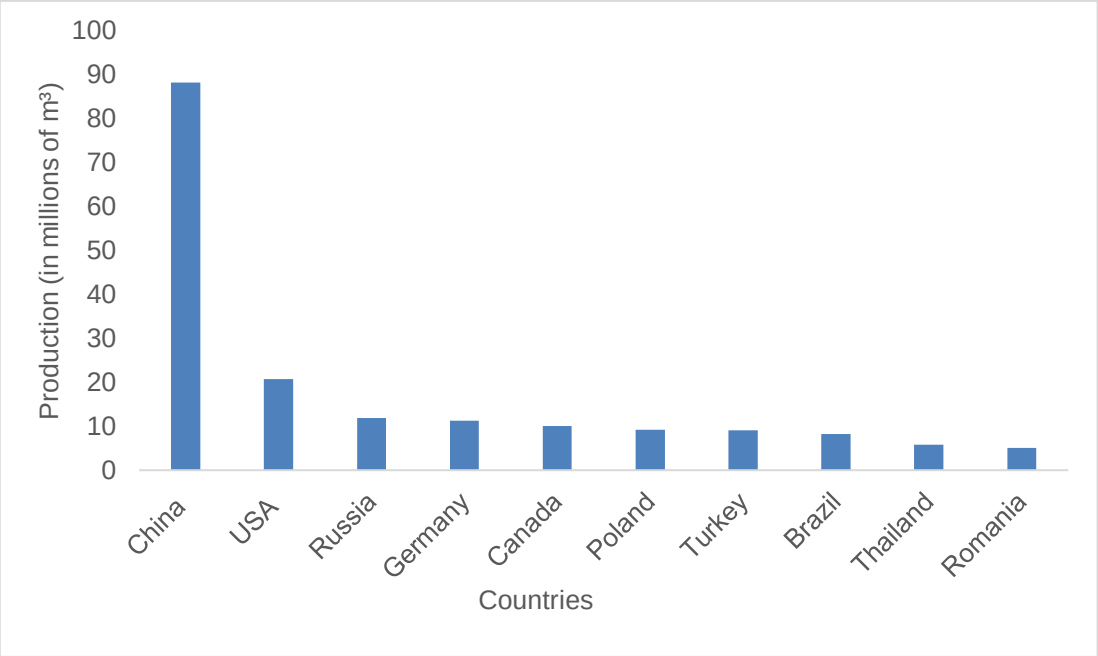

Figure 1 - Leading Global Producers of Reconstituted Wood Panels. Source: 2019 Report of the Brazilian Tree Industry (2019).

Given the high demand, the production of these panels currently faces significant challenges, mainly related to energy efficiency and the use of chemical materials, such as formaldehyde-based resins, which have an impact on the environment and human health. The MDF manufacturing process in Brazil is still highly dependent on fossil fuels in the wood fiber drying stage, which contributes significantly to greenhouse gas emissions (Piekarski et al. 2014).

In this regard, Farage et al. (2013) point out that the waste generated during manufacturing and disposal at the end of the life cycle lacks integrated reuse strategies, representing a significant environmental liability. In line with this understanding, Chu and Kumar (2020) highlight that industrial pollutant emissions, including volatile organic compounds (VOCs) and dust, are critical aspects to be addressed in the wood panel production chain, especially in the context of emerging economies. In this sense, the application of methodologies such as Life Cycle Assessment (LCA) has been widely discussed in the literature, especially in studies that seek to

identify critical environmental points throughout the production chain (Piekarski et al. 2013; DAL Silva, RP Garcia, FMCS Freire 2013; IA Simões 2021). The application of LCA enables the identification of critical points in the production process, allowing for the proposal of technological improvements and more sustainable strategies, such as the replacement of fossil energy sources with renewable alternatives and the use of resins with less environmental impact (Costa et al. 2024).

Thus, the main objective of this study is to review studies that have explored, over the years, the environmental, technological, and sustainability aspects related to the production of wood-based panels, with a focus on identifying opportunities for innovation and circularity that promote resource efficiency and reduce environmental impacts, especially considering the Brazilian context.

Methodology

The literature search was conducted in the international database *Web of Science*, covering the period from 1945 to 2024. The following descriptors and combinations were applied: "Medium Density Particleboard" AND "Circular Economy" "Medium Density Fiberboard" AND "Circular Economy." Articles that explicitly addressed the circular economy applied to MDP and MDF, published between 1945 and 2024, were included. Articles that did not directly address the relationship between the circular economy and the materials mentioned were not considered in this article.

Results and Discussion

The analysis of the reviewed studies demonstrates important advances in the development of MDF (Medium-Density Fiberboard) and MDP (Medium-Density Particleboard), especially from the perspective of sustainability, technological innovation, and reuse. These materials, widely used in sectors such as civil construction and the manufacture of residential or corporate custom-made furniture, stand out as efficient solutions for the use of industrial waste and reduction of environmental impacts, as well as for compliance with the United Nations (UN, 2025) Sustainable Development Goals.

The reuse of fibers from industrial waste has proven to be a promising strategy for the production of MDF and MDP. In the study conducted by Zeng et al. (2018), it was observed that recycled MDF fibers can improve the dimensional stability and water resistance of the panels. Despite a slight reduction in properties such as modulus of elasticity and flexural strength when compared to panels made from virgin materials, the use of recycled fibers reinforces the potential of industrial waste for the manufacture of new products. This method also reduces dependence on virgin raw materials, contributing to forest conservation and reducing the environmental impacts associated with the wood panel manufacturing sector.

In this sense, such practices contribute directly to the fulfillment of the Sustainable Development Goals (SDGs). The reuse of fibers promotes responsible consumption and production (SDG 12) by reducing the demand for virgin raw materials. Indirectly, this reduction in the use of natural resources can mitigate environmental impacts associated with extraction, processing, and improper waste disposal, which contributes to climate change mitigation (SDG 13), as well as the conservation of marine (SDG 14) and terrestrial (SDG 15) ecosystems by minimizing pollution and environmental degradation. These actions are also aligned with the promotion of greater productivity and economic efficiency.

Another significant advance in the reuse of materials was presented by Ashori et al. (2024), who investigated the use of paper sludge as a partial substitute for wood fibers in MDF. The research indicated that the ideal formulation, containing 20% iodine combined with 12% resin, results in a balance between cost, performance, and sustainability. This approach is a viable solution for both waste management in the paper industry and more sustainable MDF production. In addition, using by-products as raw materials reduces the

impact on natural resources and promotes the circular economy, strengthening the construction materials production chain.

In the context of energy use and waste recovery, Rodríguez et al. (2023) explored the impregnation of *phase change* materials *(PCMs)* in MDF waste. This technique aims not only to reuse waste but also to create a material with high thermal energy storage capacity, ideal for applications in buildings. By storing heat during the day and releasing it at night, PCMs can reduce the demand for heating and cooling systems, promoting greater energy efficiency in buildings. This approach illustrates how industrial waste can be transformed into high value-added products, in line with the proposal of sustainability.

Another relevant challenge in the MDF and MDP sector is the replacement of formaldehyde-based adhesives, which are widely used but associated with environmental impacts and human health concerns. Grandgeorge et al. (2024) presented an innovation by using Ulva algae (a widely available type of green algae) as a sustainable adhesive in the manufacture of wood panels. The results showed that panels bonded with Ulva exhibited significant improvements in mechanical strength, water resistance, and flame retardant properties. In addition, this natural adhesive is biodegradable, reducing the environmental impact of the final material and offering a viable and sustainable alternative to synthetic resins. This innovation highlights the potential of renewable materials in advancing the panel industry.

Similarly, Czarnecka-Komorowska et al. (2024) explored the manufacture of biodegradable biocomposites using wood production waste in combination with polyvinyl alcohol (PVA) and other polymer matrices. These materials demonstrated high mechanical strength and are suitable for construction applications, replacing traditional materials with a higher environmental impact. The research highlights the importance of using industrial waste as inputs for innovative and sustainable products, promoting a closed-loop approach within the materials industry.

The implementation of circular economy strategies in the MDF and MDP panel production chain has significant benefits, especially in reducing waste and valorizing industrial waste. These panels are mainly produced from waste from the wood and paper industry and are not directly associated with the extraction of virgin wood. In this context, the adoption of circular practices, such as the reuse of discarded panels and the extension of their useful life, contributes to the mitigation of environmental impacts related to the generation of solid waste and the accumulation of environmental liabilities. In addition, the use of environmentally harmless adhesives and the incorporation of biodegradable polymer matrices can reduce the amount of carbon associated with the production of these materials, especially in processes involving intensive thermal energy consumption. Although there is no direct correlation between the circular economy in this sector and forest carbon sequestration, such practices reinforce the logic of efficient resource use and impact minimization, aligning with global sustainability goals.

Contributing to this understanding, Savov et al. (2023) investigated the impact of thermal hydrolysis regimes on MDF recycling. The results indicated that by adjusting the hydrolysis parameters, it is possible to significantly reduce the formaldehyde emissions associated with the recycling process, although technical challenges still need to be overcome to preserve the mechanical properties of recycled panels. This approach, combined with technological innovations, reinforces the role of the circular economy in transforming the wood panel industry.

The studies analyzed reinforce that MDF and MDP continue to evolve as essential materials for industries seeking to combine high performance and sustainability. Strategies such as fiber recycling, the use of natural adhesives, and the incorporation of industrial waste demonstrate the feasibility of transforming environmental challenges into opportunities for innovation. Despite challenges, such as maintaining the mechanical properties of recycled materials, the advances presented show a promising path for the sector. The adoption of more

sustainable and technological practices not only meets environmental demands but also positions MDF and MDP as protagonists in a circular economy.

Conclusion

This study reviewed recent advances in the development, reuse, and application of MDF (*Medium-Density Fiberboard*) and MDP (*Medium-Density Particleboard*), highlighting technical developments and efforts to promote sustainability in these widely used materials. The results showed that recycling practices, innovation in adhesives, and the use of waste as raw material have the potential to transform the wood panel industry, aligning it with the principles of the circular economy.

MDF recycling proved to be a promising strategy for reducing industrial waste and increasing the viability of using these materials over time. It was demonstrated that recycled MDF fibers can maintain adequate technical properties, especially when associated with processes such as thermal hydrolysis for resin removal and fiber recovery. On the other hand, the use of paper waste has shown significant results in the manufacture of panels with a balance between cost, technical performance, and sustainability. Replacing traditional adhesives with biodegradable and sustainable alternatives reinforces the possibility of reducing environmental impacts and increasing safety in the use of wood panels. Similarly, the application of materials such as Ulva algae and other natural sources has proven to be effective in improving adhesion, moisture resistance, and flame retardancy. In addition, biocomposites developed with biodegradable polymer matrices and natural reinforcements have stood out for their robust mechanical properties and low environmental impact.

The use of waste, by incorporating phase-change materials into MDF waste, represents a relevant option for creating high value-added products and increasing energy efficiency in construction applications. The advances reviewed point to a promising future in the wood panel industry, where the integration of recycling practices, the development of sustainable adhesives, and technological innovation can transform environmental challenges into opportunities. However, challenges remain, such as preserving the mechanical properties of recycled materials and the economic viability of new processes.

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