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Drivers and Barriers for Sustainable and Efficient Biomass Valorization Processes

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Abstract

This abstract presents the key findings and implications of a systematic literature review and cross-case analysis on supply chain mapping studies and the drivers and barriers for residual agroforestry biomass valorization. The key findings emphasize the importance of supportive government policies, socio-economic benefits, market acceptance, financial challenges, and stakeholder empowerment. Supportive policies incentivize biomass valorization, while job creation and rural development drive socio-economic benefits. Market pressure for conventional products and limited financial support present barriers. Empowering stakeholders, such as farmers and industry associations, is crucial for fair pricing practices. Decision-makers can utilize this research to make informed decisions and develop strategies. It highlights the need for supportive policies, market acceptance, and financial support to enhance the viability of residual biomass valorization projects. It also emphasizes the importance of addressing market demand for traditional products and limited financial support mechanisms. Stakeholder empowerment through knowledge-sharing and collaboration improves their bargaining power. Understanding the drivers and barriers aids in addressing financial challenges, creating supportive policies, promoting market acceptance, optimizing material flows, addressing transportation costs, and enhancing stakeholder bargaining power. This research contributes to the development of sustainable and efficient biomass valorization processes that benefit the environment and society as a whole.

Keywords

Drivers of residual agroforestry biomass, Barriers of residual agroforestry biomass, supply chain, residual biomass supply chain, supply chain mapping

Introduction

The growing concerns about climate change and the pursuit of sustainable energy and materials have sparked significant interest in utilizing biomass as a renewable resource. Forest residues, including branches, twigs, trunks, bark, and leaves, hold great potential as biomass feedstocks to produce energy, biofuels, bioplastics, and other bio-based products (Nerlich et al. 2012). Moreover, reducing woody residues from forests not only contributes to sustainable biomass utilization but also significantly mitigates the risk of wildfires (Casau et al. 2022). Despite the abundance of woody residues, their limited monetary value necessitates cost-efficient valorization processes along the entire supply chain. This includes harvesting residual biomass, collection, transportation, storage, and subsequent conversion for various end uses (Karras et al. 2022). The valorization process involves multiple stakeholders, such as forest and farm owners, loggers, logging companies, and biofuel and energy producers, all forming the residual forestry biomass supply chain and it can benefit all these stakeholders (Ymeri et.al. 2020). This study aims to address these knowledge gaps by integrating a systematic review and exploratory case studies to assess the drivers, barriers, and opportunities for the valorization of residual biomass in agroforestry and forestry systems and a better understanding of the supply chain.

The specific research questions driving this study are: i) How is the residual forestry biomass supply chain organized and what are its material and information flows? ii) What are the main drivers and barriers for the valorization of residual agroforestry biomass? To address these questions, two exploratory case studies focusing on the valorization of residual forestry biomass in Portugal were conducted. Portugal's significant forestry area, susceptibility to wildfires, and urgent need for sustainable biomass management make it an ideal context for studying the residual forestry biomass supply chain. Additionally, a systematic literature review was conducted to identify the drivers and barriers of residual agroforestry biomass valorization through a theoretical lens.

This extended abstract presents a comprehensive approach to understanding and optimizing the valorization of residual biomass in agroforestry and forestry systems. It is structured in the following manner: theoretical background, research methodology, results, and conclusion.

Theoretical background

Biomass, including residual agroforestry and forestry biomass, offers a sustainable solution to reduce greenhouse gas emissions and decrease dependence on fossil fuels. Woody biomass, derived from residual forest biomass, has gained

traction as a raw material for energy production and polyurethane manufacturing. Polyurethane is utilized in various applications such as adhesives and foams.

The valorization of residual biomass holds significant potential for energy production. However, large-scale implementation faces challenges such as high logistics costs and the need for suitable biomass composition. Residual agroforestry biomass represents another valuable source of lignocellulose with applications in various sectors. Understanding the supply chain for residual biomass is essential for effective implementation. Mapping the supply chain helps identify potential inefficiencies and improve collaboration. To develop a sustainable business model for residual biomass valorization, understanding the drivers and barriers is crucial. The Institutional Theory and Autopoiesis Theory offer theoretical frameworks to analyze these factors.

Supply Chain Mapping

The supply chain (SC) map of residual forestry biomass will include links and nodes connecting suppliers, storage, transportation, production, distribution, and customers. These links represent the flows between different entities and processes (Gardner & Cooper 2003). Different types of arrows can represent different types of links within the SC. The nodes in the map would represent the different entities and processes themselves. The SC map can also include relational links between entities, management policies and lead times, and their state variables (MacCarthy et al. 2022). The mapping conventions consist of graphical elements representing the SC entities, transportation modes, links, and others, as shown in figure 1. This study follows a case studies research approach to analyze the residual forestry biomass supply chain and create a supply chain map based on the case studies. The findings contributed to the design of a supply chain map illustrating material, economic, and information flows in the respective supply chains.

Drivers and Barriers of Residual Agroforestry Biomass Valorization

The sustainable development paradigm offers a framework for understanding the valorization of residual agroforestry biomass. It aims to balance economic growth, environmental protection, and social equity (Abad-Segura et al. 2021). Converting residual agroforestry biomass into value-added products can enhance resource efficiency and reduce waste. Institutional Theory and Autopoiesis Theory can be employed to analyze the drivers and barriers to residual agroforestry biomass valorization. Institutional Theory focuses on the influence of external factors on organizational behavior (Meyer and Rowan 1977). Autopoiesis Theory suggests that systems generate and maintain their own organization through closed processes of production (Magalhaes & Sanchez 2009; Luis 2003).

Drivers have been classified into six categories: coercive, normative, mimetic, economic and financial, environmental, and technological. While the barriers were categorized as normative or coercive within Institutional Theory or process, structural or human resource related within Autopoiesis Theory. By understanding the drivers and barriers within these theoretical frameworks, stakeholders can identify effective strategies to promote the valorization of residual agroforestry biomass while advancing sustainable development goals.

Research Methodology

This extended abstract incorporates and analyses the findings of two studies: a systematic literature review on the drivers and barriers of residual agroforestry biomass valorization and a supply chain mapping of residual forestry biomass in Portugal through case studies. The systematic literature review aimed to identify and analyze the main factors influencing the valorization of residual agroforestry biomass as a value-adding feedstock. The research process involved four phases: identification, refinement, analysis, and presentation of data. The review included peer-reviewed articles, conference proceedings, and book chapters published between 2000 and March 2023. Initially 280 studies were identified, which were reduced to 194 after removing duplicates. Further screening resulted in the inclusion of 7 relevant studies. To broaden the scope, the search keywords were revised, leading to 407 papers. All sections of each study were examined and systematically analyzed to identify and define the main drivers and barriers of residual agroforestry biomass valorization. The review provides a comprehensive overview of the current state of research in this area and serves as a valuable resource for future studies.

In addition to the systematic literature review, two case studies were used to examine the upstream supply chain and the processes involved in sourcing raw materials for manufacturers and producers. Data collection for the case studies utilized various methods, including interviews, observation, content analysis, and survey questionnaires. This information was used to capture information on supply chain entities, links, material and informational flows, policies, and lead times. Through careful analysis of the collected data, a comprehensive map of the residual forestry biomass

supply was developed. This contributes to the sustainable management of biomass resources and the reduction of wildfire risks.

Results

Summary of Findings from the Systematic Literature Review:

Among the frequently appearing drivers, favorable government policies emerged as a prominent factor. Studies consistently highlighted the importance of supportive policies that incentivize and regulate the valorization of residual biomass. Such policies play a vital role in encouraging sustainable practices and attracting investment in this sector. Additionally, the increased interest in biobased products was identified as a significant driver. Stakeholders across the agricultural value chain have demonstrated a growing demand for environmentally friendly alternatives derived from residual biomass. This driver reflects the market's inclination towards sustainable and renewable solutions. Job creation also emerged as a notable driver, particularly in rural areas. The valorization of residual biomass has the potential to generate employment opportunities, contributing to the socio-economic development of local communities. Figure 1 shows the drivers and their respective categories.

Figure 1. Drivers of residual agroforestry biomass valorization

On the other hand, the most frequently appearing barriers were the lack of financial support, market pressure for conventional products, and the food versus fuel debate. Insufficient financial support mechanisms hinder the widespread adoption of biomass valorization projects. Limited access to funding and high investment costs poses significant barriers to initiating and scaling up such initiatives. The dominance of conventional products and markets creates challenges for the acceptance of biobased alternatives. The market demand for traditional fossil-based products can limit the competitiveness and market penetration of biomass-derived alternatives. Additionally, concerns over the impact of biomass production on food security and prices present a contentious debate. Balancing the use of agricultural resources for food production versus energy production requires careful consideration and sustainable land-use planning. Learning about these, these drivers and barriers is crucial for guiding policy development, research

efforts, and industry strategies aimed at overcoming obstacles and leveraging drivers for sustainable and efficient biomass valorization. By addressing financial challenges, creating supportive policies, and promoting market acceptance, the utilization of residual agroforestry biomass can be maximized, leading to environmental, economic, and social benefits. Figure 2. Illustrates the barriers in their respective categories.

Figure 2. Barriers of residual agroforestry biomass valorization

Summary of Findings from the cross analysis of the case studies

A cross-case analysis of two case studies was conducted to examine the operations and challenges within the supply chains of residual forestry biomass valorization. The analysis revealed insights into transportation expenses and the bargaining power between farmers and logging companies. Regarding operations, both case studies had the necessary resources for harvesting and collection of residual biomass. However, Case Study 2 had a greater geographic dispersion and more resources for exploiting forest lands compared to Case Study 1. Pre-treatment involved chipping or baling in both cases. Storage arrangements also differed, with Logger X having one open-air park while Logger Y had two. Transportation was mainly direct to customers for both loggers, with Logger X benefiting from lower transportation costs due to proximity to its customer while Logger Y faced higher costs due to suppliers' dispersion. The material flow analysis provided insights into the quantity and distribution of biomass in the supply chains. It facilitated decision-making on production planning and resource allocation.

Transportation cost disparities were observed, with Logger Y incurring higher costs due to the geographic diversity of its suppliers. Strategies to optimize transportation efficiency were suggested to reduce costs and improve profitability. The analysis also highlighted the limited bargaining power of farmers and forest owners in negotiating biomass prices, leading to unfair trade practices. Empowering farmers and forest owners through knowledge-sharing initiatives can enhance their bargaining power. Collaboration among stakeholders and engagement with industry associations and policymakers are essential for advocating fair pricing practices. Understanding these findings can guide decision-making and strategies in the residual forestry biomass valorization sector. Optimization of material flows, addressing transportation cost disparities, and enhancing the bargaining power of farmers and forest owners are

crucial for sustainable and efficient biomass valorization processes. Figure 3 shows the supply chain map designed through the cross-case analysis.

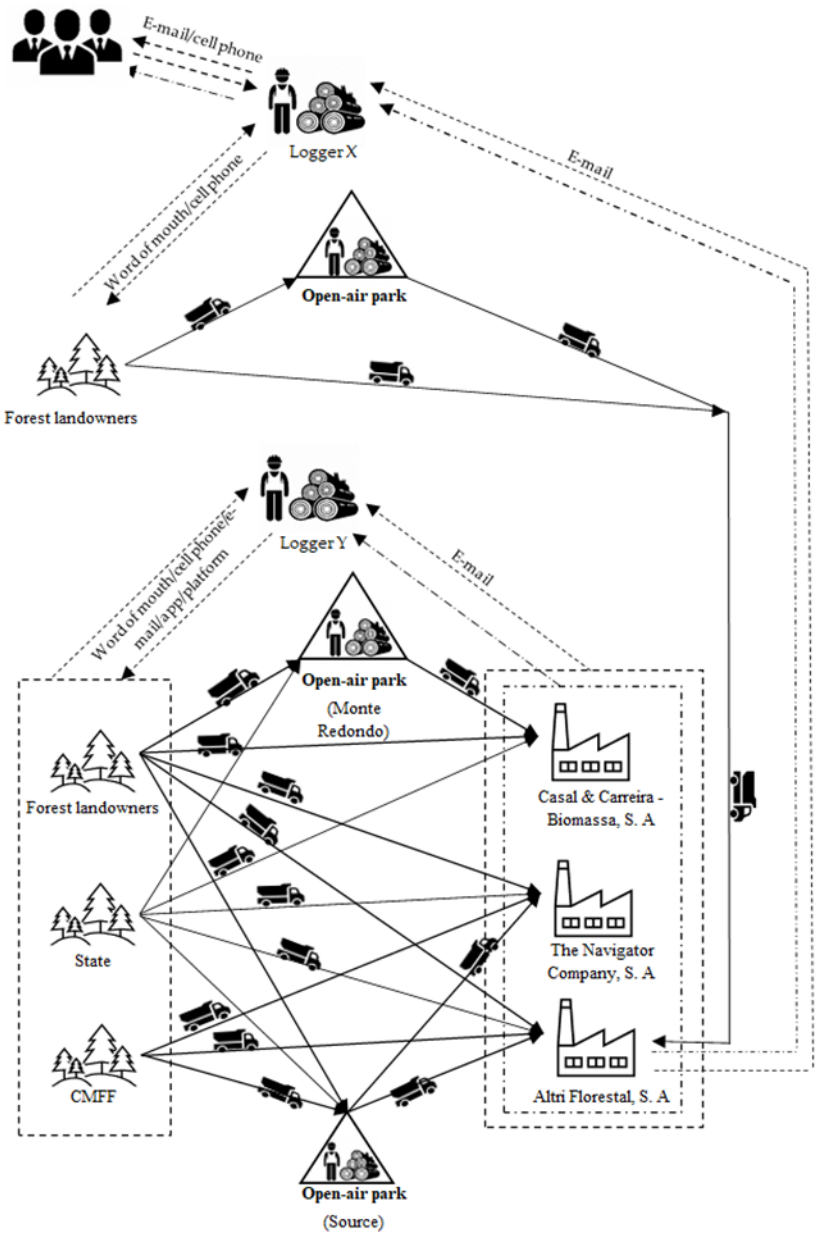

Figure 3. Supply chain map of residual forestry biomass

Analysis of the findings from the systematic literature review and the cross-case analysis for supply chain mapping studies

The systematic literature review and cross-case analysis reveal crucial aspects related to residual biomass valorization. The synthesis of these two sources provides valuable insights into driving factors and barriers within biomass supply

chains, including supportive government policies, market acceptance, socio-economic benefits, financial challenges, and stakeholder empowerment.

Policy Support: Both the systematic literature review and cross-case analysis emphasize the importance of favorable government policies in driving the valorization of residual biomass. Supportive policies incentivize and regulate biomass valorization, attract investments, and create a favorable environment for sustainable practices.

Socio-economic Benefits: Biomass valorization has the potential to generate employment opportunities and foster socio-economic development in local communities, particularly in rural areas. Both the systematic literature review and cross-case analysis highlight job creation and rural development as drivers of biomass valorization.

Market Acceptance and Financial Challenges: Market pressure for conventional products and lack of financial support are frequently appearing barriers to biomass valorization, as identified by the systematic review. The cross-case analysis also discusses challenges related to market demand for traditional products and limited financial support mechanisms. Addressing these market barriers and financial challenges is crucial for enhancing the viability and competitiveness of biomass valorization projects.

Empowerment of Stakeholders: Empowering stakeholders, including farmers, forest owners, and industry associations, is important for overcoming barriers and promoting fair pricing practices. The systematic review emphasizes the need to address the food versus fuel debate and promote market acceptance of biobased alternatives, while the cross-case analysis highlights the limited bargaining power of farmers and forest owners in negotiating biomass prices. Knowledge-sharing, training, and collaborative initiatives can enhance stakeholders' bargaining power, address market challenges, and drive the adoption of biomass valorization.

Understanding these key factors can help policymakers, researchers, and industry stakeholders make informed decisions and develop strategies to promote sustainable and efficient biomass valorization processes.

Conclusion

The analysis of the findings from the systematic literature review and the cross-case analysis provides a comprehensive understanding of the drivers and barriers in supply chain mapping studies for biomass valorization. Supportive government policies that incentivize and regulate the valorization of residual biomass promote sustainable practices and attract investment in the sector. The market's inclination towards sustainable and renewable solutions is reflected in the increasing interest in biobased products. Job creation, particularly in rural areas, contributes to the socio-economic development of local communities.

However, several barriers hinder the widespread adoption of biomass valorization projects. Insufficient financial support mechanisms and high investment costs pose significant challenges. The dominance of conventional products and markets creates obstacles for the acceptance of biobased alternatives. Concerns over the impact of biomass production on food security and prices further complicate the debate. Balancing the use of agricultural resources for food production and energy production requires careful consideration and sustainable land-use planning.

The cross-case analysis focuses on the operations and challenges within the supply chains of residual forestry biomass valorization. It reveals insights into transportation expenses and the bargaining power between farmers and logging companies. Material flow analysis facilitated decision-making on production planning and resource allocation. Strategies to optimize transportation efficiency were suggested to reduce costs and improve profitability. The limited bargaining power of farmers and forest owners in negotiating biomass prices leads to unfair trade practices. Empowering these stakeholders through knowledge-sharing initiatives can enhance their bargaining power.
By understanding these findings, decision-makers can develop effective strategies to address financial challenges, create supportive policies, promote market acceptance of biomass valorization, optimize material flows, address transportation cost disparities, and enhance the bargaining power of stakeholders.

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Biographies

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Prabalta Rijal is a dedicated researcher and PhD applicant in industrial engineering and management. She has a keen interest in sustainable economic drivers, the bio circular economy, and agroforestry. Prabalta began her research journey in Portugal in January 2022 when she was awarded the Master Fellowship at Nova.id.FCT. She is currently working under the guidance of Professor Dr. Helena Carvalho from Nova School of Science and Technology, Professor Dr. Susana Garrido from the University of Coimbra and Professor Dr. Carina Pimentel. Building upon her master's degree from Vistula University in Warsaw, Poland, Prabalta pursued a Ph.D. at the University of Aveiro. Her research interests revolve around sustainability impacts and sustainable business models. Prabalta possesses a diverse range of skills and abilities that complement her research expertise. She is skilled in management, has excellent communication skills, and has experience as a lecturer and curriculum developer. Prabalta has an impressive media background and has exhibited strong research, evaluation, and analytical skills.