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ORIGINAL PAPER

ADAPTATION OF SUPPLY CHAIN MANAGEMENT METHODS WITHIN REVERSE SUPPLY CHAINS OF WOOD BIOMASS

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ABSTRACT. Background: This paper is devoted to identifying supply chain management methods applicable within reverse supply chains of wood biomass. In general, sustainable supply chains are characterised by increased process efficiency. Reverse supply chains also require proper management. Hence it is necessary to verify the applicability of existing management methods and tools within chains of this type. This article is devoted to identifying management methods and tools that have the potential to be used in reverse supply chains of wood biomass. Particular emphasis was placed on the well-known green supply chain management approach (GrSC), the concept of Zero Waste Management, the product life cycle (LCA), cost-effectiveness, and environmental efficiency. The possibility of adopting the available methods in reverse wood biomass supply chains has been analysed with reference to the limitations and opportunities resulting from the methods used.

Methods: The research was divided into two stages. In the first stage, an in-depth argumentative literature review (ALR) was performed to identify methods and tools suitable for implementation within reverse supply chains of wood biomass. The second stage outlined boundaries and possibilities for implementing management methods within reverse supply chains of wood biomass.

Results: The study indicated the potential to implement available management solutions in reverse supply chains of wood biomass. However, it is necessary to consider the specificity of wood biomass material flows and the characteristic elements of supply chain infrastructure they require.

Conclusions: The results show that sustainable supply chain management methods are suitable for use in reverse supply chains of wood biomass. It is necessary to consider the specific characteristics of wood biomass and the location of its acquisition points in existing supply chains. A number of limitations, related to the availability of data, their quality, the location of biomass sourcing locations and processing centres, and the degree of integration of internal processes resulting from the size of the company dealing with wood biomass processing, are identified.

Keywords: reverse supply chains, wood biomass, reverse logistics, wood biomass management

INTRODUCTION

Supply chain management methods have to take into account the constraints associated with handling a specific type of goods. In the first step, these constraints must be identified. The role of reverse supply chains is constantly growing due to their possible contribution to the reduction of carbon footprints. Hence a proper method of calculating carbon footprints is essential to obtain an accurate emissions record for reverse distribution supply chains [Dubisz et al., 2022]. Wood biomass is indicated as a way to reduce CO2 emissions. According to the conducted research, based on the example of the 27 European community members, using wood biomass as a reused raw material can significantly contribute to the reduction of greenhouse gas emissions. This illustrates the significant role of wood biomass as a raw material in European economies [Shabani and Sowlati, 2013]. Wood biomass has relatively low logistic requirements. With proper storage conditions in terms of temperature and humidity, wood biomass can be successfully used to produce active carbon, which can purify and separate chemical-origin impurities, as shown in

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tests [Danish and Ahmad, 2018]. Research has shown that the proper location of accumulation centres and processing facilities in the reverse wood waste supply chain can affect its efficiency. Mathematical modelling that considers the effect of process scalability can affect a supply chain's efficiency level [Egri et al., 2021]. The sustainable supply chain management approach is similar to the management of reverse supply chains of wood biomass in terms of its capacity to increase efficiency in the consumption of renewable resources and minimise the environmental carbon footprint of processes. The readiness to optimise a network should be precisely verified based on known and validated methods. Contemporary supply chains are based on the principles of sustainable development [Werner-Lewandowska and Golinska-Dawson, 2021]. This approach is also supported by the conception of triple bottom line reporting (3BL), taking into consideration the sole profit of an enterprise and social and environmental perspectives [Kleindorfer et al., 2009]. Simultaneously, other researchers have pointed out the advantage of lean management (LM) methods when implementing green supply chain management (GrSCM) solutions. Research on increasing environmental efficiency in reverse supply chains using LM tools focuses on production processes and transport [Zhu and Sarkis, 2004]. Nevertheless, the optimisation of GrSCM could be used within reverse supply chains to mitigate their environmental impact. Influencing the shape of the supply chain by indicating the optimal location of process participants impacts the efficiency of the entire reverse supply chain of wood biomass. For this purpose, Langarian heuristic algorithms can be introduced to obtain an optimised supply chain design [Elhedhli and Merrick, 2012]. It can be observed that supply chains identified as production and transport are subject to similar optimisation trends and management methods [Kara et al., 2007]. A similar SC management approach is noticeable in wood pellet supply chains [Mobini et al., 2013]. Due to similar goods specificity, most findings from research on production and transport may be introduced within biomass reverse supply chains. As a result, wood biomass reverse supply chain design should be considered in terms of coherence with transportation and production optimisation processes. Hence, in modelling the design of reverse supply chains of wood biomass in a similar way to standard supply chains, their environmental performance is analysed to minimise their environmental impact [Mobini et al., 2013; Murphy et al., 2014]. Research shows that the basis for a well-configured and designed reverse supply chain design may be proper management of change and risk in a business. In order to achieve total efficiency in the supply chain, it is necessary to ensure proper supply chain visibility (SCV). Difficulties in maintaining the correct identification of the quality of processes are also the subject of research in scientific analyses [Freichel et al., 2022].

Given the similarities related to the management of sustainable supply chains and reverse wood biomass supply chains, the primary logistic parameters have to be identified. The current research is tailored to the specific characteristics of wood biomass, so the obtained results have a practical character.

An effective logistic model of wood biomass has to consider key logistics parameters and predict each identified parameter's impact on its effectiveness.

The aim of this article is to identify existing management methods and accompanying tools suitable for use in reverse supply chains of wood biomass. The need to verify the possibility of their use results from the specificity of wood biomass and the shape of the supply chains supporting its flows. Using a suitable method or management support tool requires consideration of the specificity of the organization of flows of a given commodity, in this case, wood biomass. It is also necessary to properly understand the mechanisms determining the method's effectiveness. For this purpose, it is necessary to precisely identify the available approaches and verify their applicability and limitations.

This paper is divided into three main sections and a conclusion containing research findings and a proposal for further research. In the first section, a literature review is conducted. The overarching aim is to verify other research and its scope to ensure the novelty of the current research. In this step, emphasis is placed on identifying the main methods used to optimise reverse supply chains. In the next step, the appropriate tools used in the indicated methods are verified. The primary goal of this study is to identify the main methods and tools used to optimise reverse supply chains that can be adopted within reverse supply chains of wood biomass. Considering wood biomass's physical form and specificity, at the end of the research, in the Conclusions and Recommendations section, an attempt is made to indicate probable methods suitable for implementation in reverse biomass supply chains.

Based on the existing literature, the following research questions have been formulated:

Research Question 1 (RQ1): Is it possible to implement known and widely used methods of reverse supply chain management, considering the specificity of wood biomass?

Research Question 2 (RQ2): Are there any limitations in managing the wood biomass supply chain resulting from its specific characteristics?

For the literature review in this publication, the argumentative literature review (ALR) guidelines proposed by McCullough et al. [2004] were used. For this purpose, a research area was first identified: supply chain management methods and tools that would be suitable for use within reverse supply chains of wood biomass. The next step was to conduct a comprehensive literature review, during which the limitations associated with using the identified methods were demonstrated. In the next step, based on the conducted study, several limitations in the identified methods which may significantly interfere with their use were demonstrated. On this basis, further conclusions were also formulated.

The research methodology applied in this research is presented in Fig. 1.

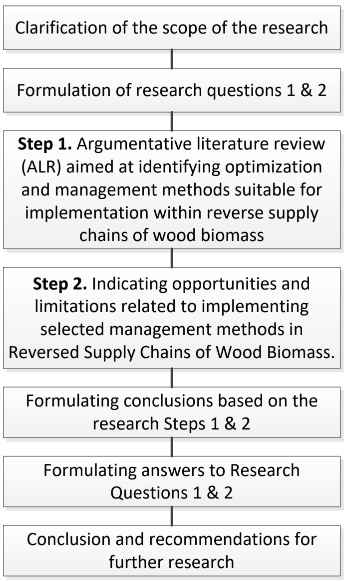

Fig. 1 Course of the research applied in this study.
Source: own elaboration

LITERATURE REVIEW

Following the adopted ALR method, the literature review identified various approaches to managing and optimising reverse supply chains. To commence a review, the Scopus and Google Scholar databases were used during the study. The keywords that were used included: "reverse supply chain", "optimisation of reverse supply chains", "supply chain management", and "operational management of supply chains".

In order to conduct the study, the following inclusion criteria were adopted:

- Articles published in English in a defined research area
- Articles on the research area published in the years 2011–2021
- Simultaneously the following exclusion criteria were defined:
  - Publications describing non-product-specific methods within supported supply chains were excluded.
  - Articles referring to the use of various different management methods whose effectiveness for wood biomass it would be impossible to verify were also excluded.

Twenty-six papers describing the results of research on supply chain management were identified. Eleven articles from 2011–2021 relating to research on chain management methodologies were divided into five categories: green supply chain management, cost-effect approach, LCA approach, environmental efficiency, and the concept of zero waste management. The following 16 articles were used to determine the possibilities and boundaries for applying supply chain management tools within reverse supply chains of wood biomass. The method adopted for the literature review is presented in Fig. 2.

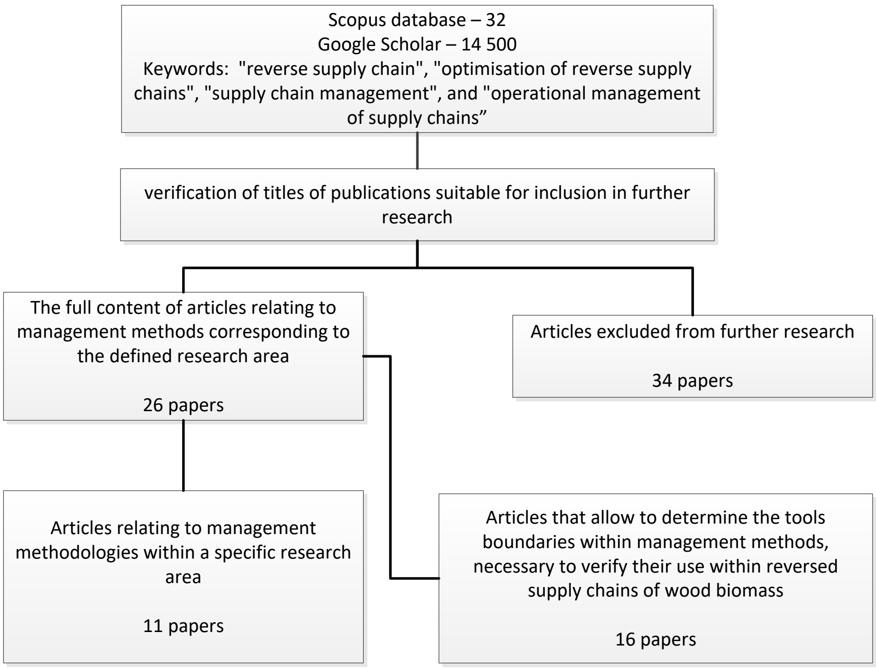

Fig. 2 Course of the argumentative literature review conducted within this study.
Source: own elaboration

A number of challenges related to the management of supply chains have been outlined in various scientific studies [Zhu and Sarkis, 2004; Barbosa-Póvoa, 2009; Mobini et al., 2013; Freichel et al., 2022]. For example, an organisation's success is not only due to profits but also to its resource management approach, striving to maintain the sustainable development of its processes and care for people and the planet's future [Barbosa-Póvoa, 2009]. A management approach dedicated to the transport organisation of wood biomass supply must reflect the specificity of the primary goods transported within the supply chain. Based on other scientific research, several common challenges were pointed out. Those mainly related to operational running costs, organisation of the reverse supply chain and energy consumption [Morrissey and Browne, 2004]. The common denominator for various approaches seems to be the determination of the economic size of the delivery [Condeixa et al., 2022].

Another approach to the management of reverse logistics chains indicates the need to ensure a short transportation or production lead time, flexibility, and economic efficiency. Using the best-worst method (BWM) and the innovative concept of comprehensive distance-based ranking (COBRA), a Multi-Criteria Decision Making (MCDM) organisational model was created that considers the functional needs identified above [Krstić et al., 2022]. There are also noticeable barriers to quick access to information due to a company's financial capabilities. Large international enterprises can obtain advanced IT tools, enabling efficient information management within the supply chain. Smaller companies, which include companies related to the production, transport, and management of wood biomass flows, can use shared solutions. This approach indicates the potential to minimise the costs associated with logistics services and should be considered when managing reverse supply chains of wood biomass [Kawa, 2012].

Simultaneously, there is a need to define a precise logistics model that provides complementary reverse logistics services considering the specificity of the transported product [Brown, 2021]. For this purpose, it is necessary to determine the influence of individual logistic parameters on the reverse supply chain's design, its bottlenecks and detailed result parameters outlining the quality of the logistics model in general. The accompanying supply chain should correspond to the entire product life cycle to maximise the benefits of the company's operations. Hence an appropriate LCA approach needs to be reconsidered when designing the reverse supply chain [Cordella et al., 2008; Finnveden et al., 2009; Murphy et al., 2014]. Closed Loop Supply Chains (CLSCs) complement the concept of lean management and fit into the solutions specified in the Circular Economy [Govindan et al., 2015] The need for conscious optimisation of existing processes is also evident in this research area. Hence the multi-objective optimisation method can be supportive, especially in CLSCs [Amin and Zhang, 2012b; Barker and Zabinsky, 2011; Mogale et al., 2022].

Based on an analysis of the literature regarding challenges that reverse supply chains of biomass may face, many similarities with other reverse logistics chains can be identified. Another study points out the importance of product specificity in supply chain design in the case of the natural gas supply chain [Dujak et al., 2019]. The parameters to be assessed are the same when organising the transport of wood biomass [Danish and Ahmad, 2018]. It is essential to check how the available methods can be suitably implemented in existing reverse supply chains. The aspect of biomass flow organisation should be considered.

Based on the literature analysis, there have been many studies on the efficiency of supply chains, and some of their methods could be implemented in the qualitative assessment of wood biomass return processes. However, the research gap still consists in determining the degree of dependence on individual parameters of the supply chain and their impact on the design of a reverse wood biomass supply chain. According to waste management models, the LCA approach is the most important. The importance of the LCA assessment method within reverse supply chain management has been outlined in various studies [Morrissey and Browne, 2004; Mukherjee et al., 2020]. Researchers point out multiple difficulties that may occur while modelling a reverse supply chain for different sorts of waste [Abejón et al., 2020; Murphy et al., 2014]. In Abejón et al., the heterogeneous nature of research on Municipal Solid Waste (MSW) is pointed out, which provides a better perspective for the design of reverse logistics chains, taking into consideration the specific details of a product (or waste). In other research related to the LCA approach in reverse supply chains, the arrangement of other supporting processes is shown to be crucial for maintaining proper goods flow [Rehl and Müller, 2011].

An approach pointing to the environmental efficiency of global reverse supply chains (GRSC) is also worth noting. One study analyses quantitative models [Seuring, 2013]. Other researchers point to the importance of properly defining the location of raw material collection points within the chain, measuring and managing carbon dioxide emissions related to logistics processes and global challenges affecting the shape of supply chains [Egri et al., 2021; Tao et al., 2018]. Another study focuses on sea transport and cost-effectiveness resulting from fluctuating exchange rates [Xu et al., 2017].

A reverse supply chain management approach based on the concept of the circular economy is consistent with the desire to minimise the amount of waste sent to landfill. According to the idea of Zero Waste (ZW) management, waste is a resource that should be adequately processed, managed, and reused. The proposed approach also points to the synergy of LCA and the maximisation of process efficiency in GRSC [Gaur et al., 2022]

IDENTIFICATION OF SUPPLY CHAIN MANAGEMENT TOOLS

Based on the analysis of the literature, the main factors determining the shape of reverse supply chains and influencing their effectiveness were identified:

- The cost-effect approach that determines the economic viability of the applied design [Wang et al., 2019; Dev et al., 2020].
- The LCA approach, in which product life cycles are precisely defined, and the method of obtaining, processing, and reusing the product after the end of its life is determined [Morrissey and Browne, 2004; Mukherjee et al., 2020; Rehl and Müller, 2011].
- An environmental approach that verifies the quality of reverse processes in terms of their energy intensity and emissivity. This approach is also related to the planning of the reuse of product waste as a raw material in subsequent processes [Abdullah et al., 2018; Chen and Chen, 2017; Reddy et al., 2022].

The identified approaches recommended for managing reverse supply chains could be adopted within reverse supply chains of wood biomass. They are presented in Table 1.

Table 1. SC management approaches suitable for reverse supply chains of wood biomass

Identified methodologies	Main research references
Green supply chain management	[Seuring, 2013], [Xu et al., 2017]
Cost-effect approach	[Dev et al., 2020; Wang et al., 2019]
LCA approach	[Morrissey and Browne 2004; Mukherjee et al. 2020; Rehl and Müller 2011]
Environmental Efficiency	[Abdullah et al., 2018; Chen and Chen, 2017; Reddy et al., 2022]
The concept of Zero Waste Management	[Gaur et al., 2022]

Source: own elaboration.

MANAGEMENT BOUNDARIES WITHIN REVERSE SUPPLY CHAINS OF WOOD BIOMASS

Mathematical modelling can effectively support the supply chain design process. This approach shows implementation potential within the reverse supply chain of wood biomass [Brandenburg et al., 2014]. In other studies, the importance of defining the general framework in the context of the organisation of reverse supply chains is outlined as a significant supply chain design factor [Fleischmann et al., 1997]. The framework used for mathematical modelling should be used for distribution planning, inventory control and production planning. Each indicated element affects the result of the mathematical modelling of the reverse supply chain. The conclusions from these studies indicate the need for holistic planning of entire supply chains to maintain a sustainable framework for further optimisation of the reverse supply chain [Kannegiesser and Günther, 2014]. The approach presented in the research is consistent with the LCA management method, because it involves planning the entire life cycle of products. All the critical elements of every supply chain, such as manufacturing, goods collection, repairs, disassembly, recycling, and disposal, must be considered. Hence the related initial simulations must consider the specific characteristics of wood biomass management [Amin and Zhang, 2012a]. A lack of planning can affect the effectiveness of the reverse chain. Thus, proper support from mathematical modelling has to be employed in the supply chain design process.

According to the conducted research, various control parameters influencing overall model effectiveness were identified:

- The geographical locations of the significant processing centres within the supply chain [Tao et al., 2018; Redmer, 2022]
- Limitations resulting from the capacity of individual chain elements [Abdullah et al., 2018]
- The impact of changes in the supply chain and the impact of their application on the continuity of processes [Dahmus, 2014]
- The need for proper goods flow planning in order to maximise process efficiency while maintaining relatively low unit costs [Kolinski et al., 2017; Golinska-Dawson, 2019]

According to other researchers, management techniques based on the multi-criteria decision-making (MCDA) approach are among the most effective [Barker and Zabinsky, 2011]. This method considers various control parameters that may influence the reverse supply chain flow's overall effectiveness in terms of planning and management [Morrissey and Browne, 2004; Mukherjee et al., 2020].

Multi-criteria analysis can be used when modelling a reverse supply chain of wood biomass to select the best SC participants [Amin and Zhang, 2012b]. Obtaining the information required to conduct an analysis using this method is crucial for further mathematical simulation modelling within the chain. All the approaches indicated in the literature are used to optimise and simulate the most favourable scenario for handling biomass return flows [Kara et al., 2007]. The choice of management strategy must consider the organisation's goals, information flow, key resources, the level of integration of management processes, and holistic approaches to the analysis of internal and external factors. The chosen strategy also has to consider the balance between the goals and expectations of the stakeholders [Miller et al., 1996]. Hence, the Gray Stratified Decisions Model has potential for implementation when choosing the most suitable management method within reverse wood biomass supply chains [Mierzwiak, 2023].

A summary of the identified approaches is provided in Table 2.

Thepresented set of approaches is enhanced with a comment based on the analysed literature indicating potential limitations and possibilities of their use in handling reverse logistics chains of wood biomass.

The main obstacles that may prevent the use of management tools within reverse supply chains of wood biomass were also identified. During the research, data quality was identified as a major concern. Another element is the identification of mutual dependencies between the components in the model. Due to the specific characteristics of wood biomass, it may be impossible to control all centres responsible for obtaining biomass.

Based on the research, the identified supply chain management methods have the potential to increase the efficiency of wood biomass supply chains. What is more, the limitations related to the specific properties of wood biomass do not exclude their implementation.

CONCLUSIONS AND RECOMMENDATIONS

The identified management methods can all be used to increase the effectiveness of logistics processes. This can be seen as their common goal. However, each of the presented methods draws attention to different areas of logistics management in supply chains. The emphasis is variously placed on: supply chain participants' geographical location, product life cycle, environmental aspects, and waste minimization. Implementing elements of these management methods within reverse supply chains of wood biomass can achieve a synergy effect that benefits logistics processes.

Table 2. Boundaries and possibilities of management within Reverse Supply Chains of Wood Biomass.

Tools for the management of reverse supply chains of wood biomass	**Development boundaries for reverse supply chains of wood biomass**	**Possible directions for the development of wood biomass reverse supply chains**	**Main references**
Mathematical modelling	The limited amount of data sourced within the reverse supply chain of wood biomass, and its lower quality, can negatively affect the results of mathematical modelling.	The proposed approach of sharing IT tools among small and medium-sized enterprises could significantly affect the quality of data obtained for analysis [Kawa, 2012].	[Fleischmann et al., 1997; Amin and Zhang, 2012a; Kannegiesser and Günther, 2014; Egri et al., 2021]
Supply chain modelling regarding the correlation between logistics factors	The identification of dependencies between process participants may depend on the data quality, as in the case of mathematical modelling. Incorrect identification of dependencies can lead to wrong decisions.	By introducing advanced IT solutions, it is possible to track processes on an ongoing basis [Kawa, 2012]. Such a solution has the potential to improve data quality. Therefore, further analysis will support an accurate decision-making process.	[Zhu and Sarkis, 2004; Abdullah et al., 2018; Zapp et al., 2021]
Centre of gravity method for key process participants location	Due to the type of source from which biomass is obtained, it is not possible to fully control the sources within reverse chains. Forecasts play a crucial role in this area. Modelling of the supply chain to determine the centre of gravity can only indicate places of collective processing, cross docks and wholesale distribution points	A potential development direction for RSCWB is shortening the distance between the process participants. This can be achieved by combining the functionality of biomass acquisition, identification, processing and even distribution centres. The ideal solution would be to keep all the listed functionalities in the wood biomass harvesting centre – in the forest.	[Melo et al., 2006; Tao et al., 2018; Zomparelli et al., 2018; Redmer, 2022]
Multi-criteria decision making (MCDA)	In the case of small enterprises without a management hierarchy and procedures, the implementation of modern management methods may be too complex.	Based on the literature analysis, using MCDA management tools would allow for the optimal selection of service providers in the wood biomass reverse supply chain.	[Morrissey and Browne, 2004; Kara et al., 2007; Barker and Zabinsky, 2011; Amin and Zhang, 2012b; Mukherjee et al., 2020]

Source: own elaboration.

The conducted research permitted the identification of management methods from the perspective of the product – wood biomass. The identified methods make it possible to improve the efficiency of logistics processes in reverse supply chains. The publications, methods and corresponding tools analysed during the study did not consider the specific properties of wood biomass. In the conducted analysis, it was possible to verify their limitations and potential for further development from the wood biomass perspective. Management methods come with a set of recommendations for their adoption within supply chains. However, the specificity of a particular product, as in the case of wood biomass, requires managers to consider its characteristics, its places of acquisition, and its localization within current supply chains. Simultaneously, the quality and availability of data determine the actual shape of reverse supply chains. This perspective was verified during the study and supported the implementation of the identified methods and tools within reverse supply chains of wood biomass. The importance of mutual dependencies between reverse supply chain participants was identified as a major factor influencing overall wood biomass chain efficiency. It has been verified that proper management of logistics processes depends on actual logistics data quality and the capacity for processing and analysis focused on supply chain improvements. Simultaneously establishing the localization of each supply chain participant plays a crucial role in increasing the efficiency of reverse supply chains of wood biomass.

Answers to the research questions were obtained based on the conducted research. It has been shown that existing management methods are suitable for use in reverse supply chains of wood biomass. However, it is necessary to meet specific requirements related to the specific characteristics of wood biomass and elements of reverse supply chains, especially regarding the location of the participants responsible for the acquisition of raw materials and their processing. Limitations affect the choice of the appropriate supply chain management method. The identified boundaries are related to access to primary data and its quality. Other limitations are related to the specific location of biomass processing centres and their acquisition. Due to the relatively low level of complexity of enterprises responsible for handling reverse wood biomass supply chains, implementing advanced process management methods may be challenging. As a result of an in-depth literature study (ALR), it was shown that the LCA approach is crucial in modelling the design of reverse supply chains.

This study was limited to a literature review based on the Scopus and Google Scholar databases. Further research could be expanded to include other databases and include empirical research based on case studies. Simultaneously, research should be carried out to determine mutual statistical dependencies between various parameters of wood biomass reverse supply chains.

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