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EFFICIENCY OF REVERSE WOOD BIOMASS SUPPLY CHAINS – A QUALITATIVE APPROACH TO IDENTIFYING KEY PARAMETERS

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The strive for a efficiency improvement of logistics processes also affects the wood biomass industry. A numerous areas within the reverse supply chains of wood biomass show potential for optimization in the context of the circular economy development. Concerning the reverse supply chain of wood biomass, it is important to precisely identify the essential parameters that determine the overall efficiency of supply chain. The aim of this study is to identify the control parameters that determine the efficiency of processes related to the processing of wood biomass, as well as the problems and solutions that occur within the reverse supply chains of wood biomass. An attempt was made to understand the specifics of the management process through the use of a qualitative approach – focus group interview (FGI). The FGI was conducted among both operational and process managers. The results obtained have been classified according to specific groups of codes and have been analysed in depth. The results obtained show that the wood biomass industry revels potential for logistics processes optimalization throughout a proper management and key process parameters identification. The application of elements of the Circular Economy (CE) in the handling processes shows a great potential for process optimization. This is consistent with the wood-biomass industry's natural drive to solve problems, minimize waste and have a high degree of adaptation within the dynamic and changing environment of reverse supply chains. Conclusions and recommendations formulated can be incorporated into existing reverse supply chains of wood biomass.

Keywords: wood biomass, process digitalization, reverse supply chain, focus group interview

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1. INTRODUCTION

The improvement of process efficiency is always at the forefront of supply chain management (Abdullah et al., 2018; Dahmus, 2014; Handfield et al., 1997; Hervani et al., 2005). The efficient use of resources (Dahmus, 2014), the correct modelling of processes (Croxton et al., 2001) and the precise definition of the functions of each actor in the supply chain (Lee, Joo, 2020) have attracted the attention of researchers. Both researchers and managers have been prompted to review the efficiency of their own supply chains by the emergence of sustainability-oriented management concepts (Javied et al., 2015). One approach can be to digitize supply chains to support the processes involved (Nowak et al., 2022). Reverse supply chains of wood biomass often use aspects of supply chains with a closed loop structure. A number of studies have analyzed the impact of the efficiency of closed-loop supply chains on the development of the circular economy concept, particularly in the context of its potential disruptions such as the war in Ukraine or the COVID-19 pandemic (Sosnowski, Cyplik, 2022). However, the perspective of the representatives of supply chains handling wood biomass was rarely explored. Instead, the impact of the digitalization of processes on their efficiency has been examined in the context of the circulation of logistical documentation accompanying order fulfilment in maritime ports (Kristiyanti et al., 2024). At the same time, there are indications of elements of wood biomass handling processes that could be made much more efficient with the appropriate level of digitization.

Wood is a versatile material that is increasingly used in a wide range of applications, including rapidly growing sectors of wood construction and bioenergy. Its renewability and carbon storage properties make it a good substitution for fossil-based materials. However, amid increasing demand and growing pressure to preserve natural ecosystems, it is necessary to further improve the processing efficiency and advance the development of circular economy practices in the wood sector. The efficient utilization of wood (or other biomass), which prioritizes the material use of residues and waste before energy use, is referred to as material cascading (Mair, Stern, 2017; Vis et al., 2016). Wider circular economy literature focuses rather on circular strategies, such as the 10R framework (Potting et al., 2017), which encompasses strategies related to smarter product use and manufacture (Refuse, Rethink, Reduce), extending lifespan of products and its parts (Re-use, Repair, Refurbish, Remanufacture, Repurpose) and useful application of materials (Recycle, Recover). The strategies are prioritized according to the level of circularity, with Recover (energy use) being the last , which makes the framework consistent with the cascading use dominant logic. Generally, it is implied that that more circularity means better environmental performance due to the fact that fewer virgin resources are used, but this heavily depends on the technologies used and material flow organization, i.e., the efficiency and impact of logistic processes.

A literature review conducted by Suárez-Eiroa et al. (2019) shows that elements of the circular economy (CE) are now widely implemented in global supply chains.

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Simultaneously, there is a lack of practical information on which elements of the circular economy are most relevant. In addition to dynamically adjusting the volume in and out of the SC, it is important to model the supply chain design accordingly. Awareness of the stakeholders involved in the process, who are present at each stage of handling the flows, also plays an important role (Co, Barro, 2009). The study carried out by Werner-Lewandowska et al. (2024) on the transition of supply chains to sustainable models identifies the most relevant groups of elements using the example of electrical and electronic equipment (EEE). The conclusions of the study are indirectly applicable to the handling of wood biomass, as this type of supply chain is characterized by a low level of technological complexity. Therefore, proper planning is required from the outset to ensure that all elements of the reverse supply chain of wood biomass would be sustainable once the improvements are implemented.

Opportunities for the re-use of wood biomass residues are in line with the concepts of sustainability and circular economy (Keefe et al., 2014; Krstić et al., 2022). However, as stated above in (Hofmann, 2017) research, an increase in the amount of wood biomass within a reverse supply chain may not yield the desired effects. That is why an accurate understanding of the specifics of handling woody biomass in reverse supply chains is essential (Keefe et al., 2014).

In identifying ways to improve the efficiency of reverse supply chains for wood biomass, the work of other researchers on sustainability concepts and management methods in supply chains can provide valuable insights (Danish, Ahmad, 2018; Keefe et al., 2014; Kogler et al., 2021; Kogler, Rauch, 2018; Mobini et al., 2013). However, it is necessary to understand the constraints and opportunities associated with the wood biomass itself (Desing et al., 2020; Zapp et al., 2021). The aim of this study is to identify the parameters that determine the efficiency of wood biomass processing, as well as the problems and solutions within its reverse supply chains. To achieve this objective, a qualitative research approach, and focus group interview (FGI) were adopted. It has been recognized that there is a lack of sufficient qualitative research in the area of reverse supply chains of wood biomass. While a qualitative approach may not provide a complete overview of reverse supply chains, it will provide information that cannot be obtained through quantitative research. The analysis of the literature presented in the next paragraphs revealed that there is a knowledge gap on the awareness of wood company employees on circular economy strategies and current trends in the reverse logistics network of wood biomass. The results allowed to verify the adaptability of circular economy principles within the organization of wood biomass supply chains.

The analysis of costs resulting from logistical processes in wood biomass supply chains was discussed in previous studies (Kamimura et al., 2012). The example of energy plants in Japan was used to verify the optimal number of suppliers. The analysis considered the cost of raw material delivery and transport. The proposed model referred to the use of specialized forestry machinery for harvesting the raw material and larger truck containers. The case study allowed to determine

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how improvements in dedicated forestry machinery and the cubic capacity of loading units can improve overall efficiency in reverse supply chains of wood biomass. A survey of Polish companies in 2011-2013 and 2015 indicated that the efficiency of production processes was inadequately tested (Koliński et al., 2016). The efficiency assessment factors identified in the study can be attempted to be adapted to the needs of reverse wood biomass supply chains. The multivariate simulation model emerged from the study enables efficiency simulations. A similar management approach may also be beneficial for optimizing reverse supply chains.

The impact of reverse supply chain processes identified within the Circular Economy has been recognized in many industries. Potentially, each of them can, under certain specific circumstances, handle the flow of post-consumer raw material that can be converted to wood biomass. This has been extensively addressed in the context of the automotive industry (Golinska, 2014). The management methods of resource recovery in the computer industry also provide an interesting perspective (Kawa, Golinska, 2010). The concept of 'two way economy' points to the need for changes in management processes and is closely linked to defining the environmental impacts of product's life cycle (LCA) and carrying out proper forecasting. The results of the study indicate a high degree of efficiency in supply chains suitable for dynamic configuration. This characteristic of the supply chain has also been shown in other studies as highly beneficial (Torrisi et al., 2017; Yuan, 2012). Research on supply chain efficiency is not limited to the specifics of the transported raw material. The impact of standardized loading units is also relevant, as this can have a significant impact on the efficiency of the logistics model while reduce its carbon footprint. The use of appropriate standardized loading units increases the use of the loading space of the means of transport and facilitates faster turnover within the logistics model (Dubisz et al., 2023). The main challenges facing carbon management within sustainable supply chains are an important part of process efficiency.

A study conducted by Dubisz et al. (2022) showed that interviews of transport managers may be an important source of information to supplement the state of knowledge on the key parameters driving flows within the logistics chain. A further survey among representatives of participants of reverse supply chains of wood biomass can provide important information on the correlations between the parties involved (Dubisz et al., 2022).

A five step methodology was proposed for analyzing the efficiency of wood based biomass material flows within supply chains (Marques et al., 2020). Identification of terminology, estimation of flow volumes, indication of raw material source balance, scenario analysis and stakeholder validation were indicated. It has been noted that the correct identification of the resource balance allows the wood biomass supply chain to be aligned with the circular economy concept. Proper management and monitoring of data at regional and country level is a way to support business decision making. The importance of using wood biomass in the context of developing a circular economy has also been recognized (Sherwood, 2020). The use of wood

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by products and post-consumer wood in the production of materials and as a raw material for energy production fits into the concepts of the circular (bio)economy. Researchers point to the need to raise awareness among stakeholders of the reverse supply chains of wood biomass. In order to increase the reuse of recycled raw materials, they identify this as a key area. The review of the literature shows the important role and the impact on the overall efficiency of the factors that regulate the reverse supply chains of wood biomass.

A research gap has been identified in the area of improving the efficiency of logistics processes within reverse supply chains of wood biomass. The process knowledge of wood biomass chain managers will also be verified. This knowledge is crucial for the implementation of optimization solutions directly related to process efficiency improvement. Following an analysis of the available literature, it was identified that there is a lack of research that investigates both the awareness of those involved in the management of wood biomass flows and the use of circular strategies in the handling of wood biomass streams. Simultaneously, there is a lack of proper research on current trends in the development of reverse supply chains of wood biomass.

The chosen research method, presented in the next section of this publication, allows to improve the knowledge related to handling wood biomass flows, as it takes into account the business perspective provided by the interviewed research participants.

2. MATERIALS AND METHODS

In the utilitarian layer of the study, the focus was put on the both the core logistics operations of wood biomass processing (identification of residues, reprocessing, repurposing, change of the material physical characteristics) and the supporting operations of the core business (storage and transport elements). Simultaneously, among these operations, attention was paid to the handling of raw materials in terms of storage conditions. All these elements are essential for the subsequent adaptation of circular strategies and the efficiency of the whole process of handling wood biomass flows. Despite of this utilitarian goal of the research that led to the practical implications, a scientific goals were outlined. Reaching those has been achieved by providing an answers to the three following research questions.

Based on the literature review, a number of potential issues were outlined which could be verified during the FGI study, which guided the formulation of the research questions:

RQ1: How wood biomass flow within reverse supply chains can be improved?

RQ2: How circular strategies can be implemented within wood sector?

RQ3: How current market trends affect the reverse supply chains of wood biomass?

Obtaining an answer to the first RQ could influence the area defined at initial stage of this research specified as a potential for improving the efficiency of the reverse

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supply chains of wood biomass. The emphasis of the research was placed on ways to improve the efficiency of the wood biomass flow process within reverse supply chains. The following research step was to test whether the circular strategies presented in the literature, which are a subset of sustainability approach within modern supply chains, could be implemented in reverse supply chains of wood biomass. Furthermore, in order to maintain the market driven character of the research carried out, an attempt was made to verify current market trends within reverse supply chains of wood biomass. Based on this, the third research question was formulated. Hence qualitative research was necessary to provide answers to these questions. For this purpose, a focus group interview (FGI) was used to obtain answers to the defined questions.

Answering the research questions posed was the purpose of the interview. A total of three separate meetings were held online, and the groups consisted of 4-7 participants and the moderator. The duration of an FGI interview was between 1.5 and 2 hours. Interviewees worked in companies associated with wood industry, sawmills and handling and recycling of residual biomass. A qualitative method was chosen to verify supply chain efficiency, to provide answers to the questions about biomass flows, possible usage, difficulties and origins within a chain. The data collected in this way can be used to carry out further research based on quantitative methods. The fundamental differences between qualitative and quantitative approaches clearly determine the subsequent course of the study. Quantitative methods provide precise information about trends, values, magnitudes of the issues under study, whereas qualitative methods allow us to understand the way and characteristics of the area under study(Chambers, 1997) Qualitative methods, which originated in the 1940s, make it possible to add to the state of knowledge in areas that are difficult to cover with quantitative methods (Musab, Christian, 2014). A qualitative research approach was used to investigate the reverse supply chains of wood biomass. Qualitative research allows to examine the perspective of individuals involved in the process and is based on non-numerical data. Thus, experience of specific individuals can be examined during the research (Pathak et al., 2013). Three approaches to qualitative research were identified: observational studies, interview studies, and documentary data analysis (Musa, Christian, 2014). The interview-based study analysis approach was chosen for this study. An example of a study carried out with qualitative methods (FGI) on the interrelationships between elements of circular economy and Industry 4.0 approaches shows the positive results of this research method in analyzing sustainable supply chains (De Mattos Nascimento et al., 2024). Due to the many common elements with the reverse wood biomass supply chains, it is expected that the applied qualitative method will provide valuable results in the current research. In parallel with the qualitative FGI research, an in-depth literature review was carried out to examine other developments in this area of science. In the preparation for the analysis of the data gathered through focus group interviews, a three stage coding technique was used. The first step involved initial coding, based on the literature review and transcription screening. Then, a final coding frame was developed (focused and theoretical coding), using MS Excel software (Charmaz, 2006).

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The third step was the cross-check of the coded data by another author to improve the overall reliability of the research and minimize author-induced bias. In the end, a two-level hierarchical code tree was obtained. The next stage of the research was to draw conclusions from both the qualitative FGI research and the literature review. The final stage of the study was to develop a set of recommendations to support the proper modelling of effective reverse wood biomass supply chains. The results and conclusions of the research are presented in the final sections of the publication. Adopted research methodology is presented in figure 1.

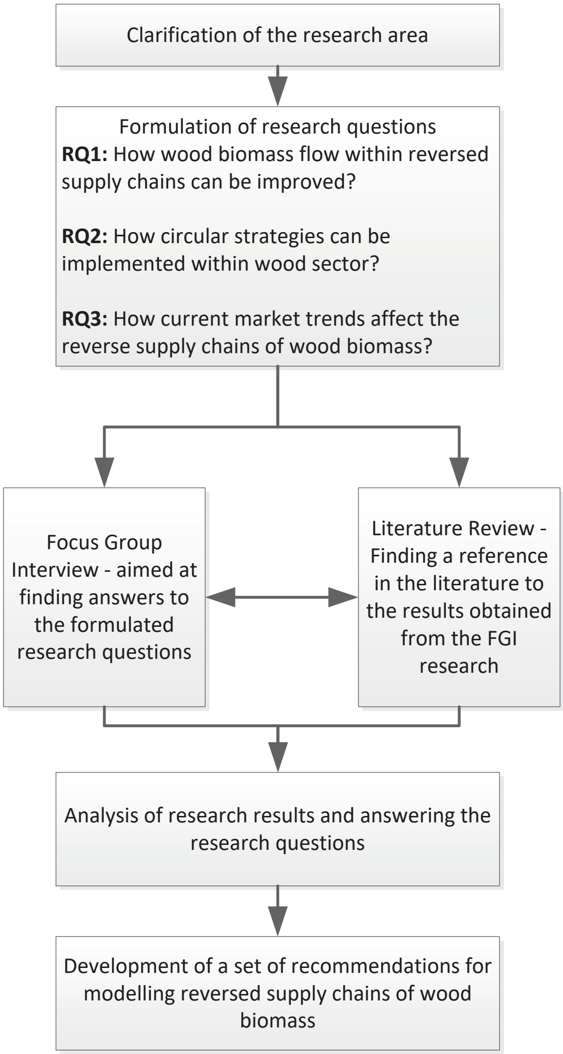

Fig. 1. Research methodology implemented within this research (own elaboration)

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3. RESULTS

The qualitative study was conducted with representatives of wood biomass processing enterprises, particularly with people in charge of management challenges and operational activities in the reverse supply chain. The representatives from different positions in the production companies, whose activities result in the generation of waste wood biomass, took part in the interview. Thus, it was possible to gain an insight into the perspectives of both: those who are involved in the primary processes of the reverse wood biomass supply chains and those who are in charge of modelling these processes. The data collected in this way is helpful to validate the research area from both operational and management perspectives.

The study was divided into several phases presented in the figure 2.

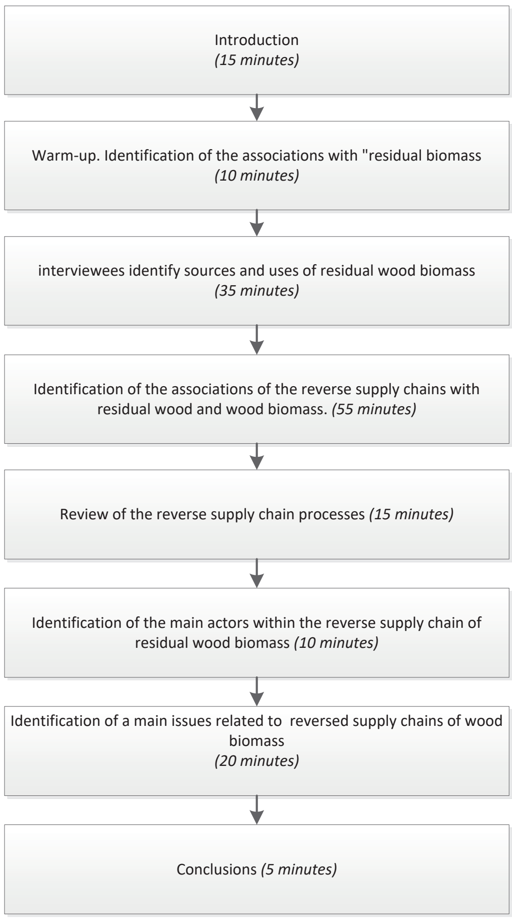

Fig. 2. Phases of the FGI research conducted among wood biomass professionals (own elaboration)

Group 1 (FG1) consisted of 6 participants, group (FG2) consisted of 7 participants, and group 3 (GF3) consisted of 4 participants. To better characterize the interviewees, their function within the company was defined, as well as the company's specialization. The characteristics of the participants are presented in table 1 and table 2.

Table 1. Characteristics of participants position in a company

Position in a company	Number of participants
general manager	12
project manager	1
logistics specialist	1
quality control specialist	1
customer advisor	1
n/a	1
In total	17

Source: own elaboration.

Table 2. Characteristics of participants – type of the company

Type of company	Number of participants
sawmill	11
wooden packaging	3
wood construction	1
garden architecture	1
carpentry	1
SUM	17

Source: own elaboration.

Figure 3 shows the geographical distribution of research participants. However, due to the research methodology, it is not possible to identify the exact location of each company. The companies, from which the participants were recruited, were randomly selected from a market research company's database on the basis of their activity in the wood biomass processing sector.

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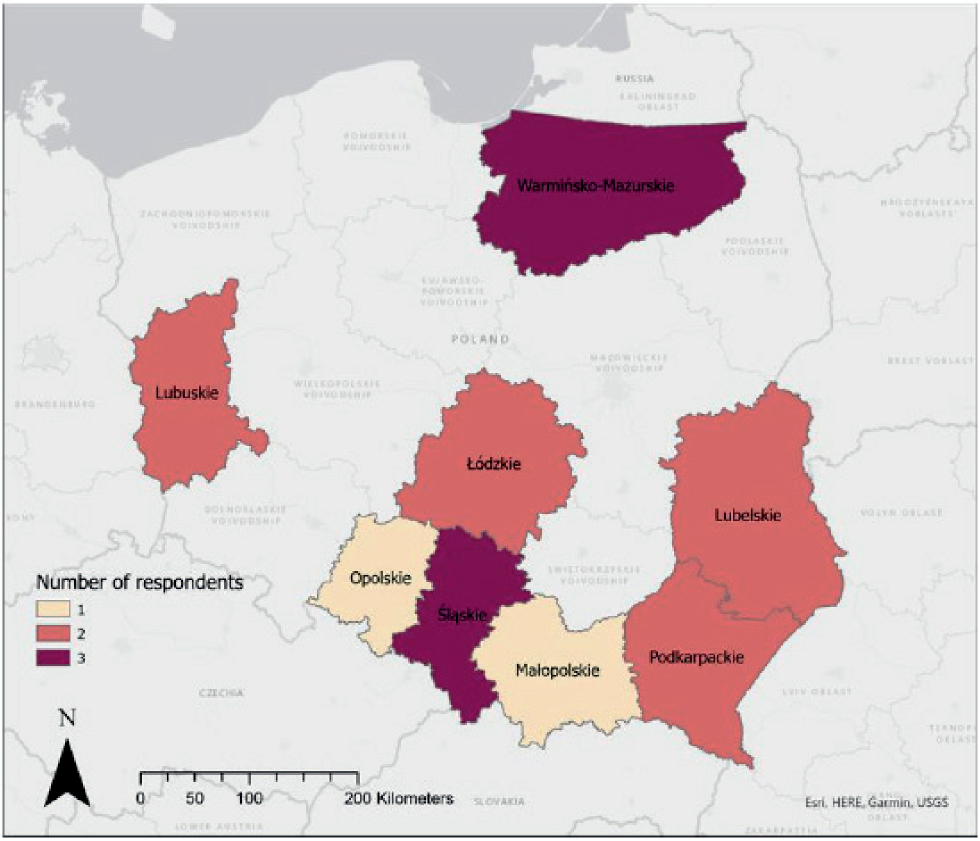

Fig. 3. Geographical spread of research participants (own elaboration)

Table 3 indicates a detailed overview of the study participants, including the voivodeship, the type of company, and the professional area of the respondents.

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Table 3. Characteristics of the people taking part in the interview, with indication of location

FGI no.	Professional area	Position	Company type	Voivodship
1	wood technology	general manager	sawmill	N/A
1	management	general manager	carpenter's workshop	Łódzkie Voivodship
1	management	general manager	sawmill	Lubelskie Voivodship
1	management, logistics	general manager	sawmill	Warmińsko-Mazurskie Voivodship
1	management, customer service	general manager	sawmill	Lubuskie Voivodship
2	management, logistics	general manager	sawmill	Podkarpackie Voivodship
2	construction	project manager	wood construction	Lubelskie Voivodship
2	quality control	quality control specialist	garden architecture	Lubuskie Voivodship
2	logistics	logistics specialist	sawmill	Łódzkie Voivodship
2	management	general manager	sawmill (structural timber)	Śląskie Voivodship
2	management	general manager	sawmill	Podparpackie Voivodship
3	production management	general manager	sawmill	Śląskie Voivodship
3	management, logistics	general manager	wooden packaging	Śląskie Voivodship
3	N/A	N/A	wooden packaging	Warmińsko-Mazurskie Voivodship
3	customer service	customer advisor	wooden packaging, furniture, straw products	Warmińsko-Mazurskie Voivodship
3	management	general manager	sawmill	Małoposkie Voivodship
3	management	general manager	sawmill	Opolskie Voivodship

Source: own elaboration.

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The interview was carried out in the form of an online meeting. The interview participants were divided into three groups to facilitate communication. Respondents were randomly assigned to each group without prior analysis of their function or affiliation to a particular organization. The duration of each interview was approximately 120 minutes. The respondents had different functions in their companies. Participants in each group had a free choice to respond to the questions.

As mentioned earlier, the responses given were coded. The resulting code tree is presented in the table 4. Based on the identified content, the study proposed a division into 4 groups of codes. Group 1: Problems and Challenges referred to all issues and obstacles related to handling, collection, identification and processing of biomass. Each example described by interviewees was assigned to this group. A second group, Solutions, consisted of responses in which participants indicated ways to resolve identified problems classified under group 1 (Problems and Challenges). The third group, Trends, encompasses items referring to business trends, which affect the scope and direction of wood biomass utilization and the cascading use of wood. The fourth category: Circular Strategies refers to statements that indicated possible ways to apply circular strategies in the management of wood biomass flows.

Table 4. The code tree used in the data analysis

Main code group	Detailed code within a group
1. Problems	1.1. Difficulties in identifying material and mixing different materials
	1.2. Degradation
	1.3. Flammability
	1.4. Lack of economic effectiveness
	1.5. Cargo size
	1.6. Lack of demand
	1.7. Limited supply of raw material
	1.8. Insufficient labor force
	1.9. Insufficient investment in infrastructure and machinery
	1.10. Lack of/inadequate communication
	1.11. Environmental pollution (transport)

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Main code group	Detailed code within a group
2. Solutions	2.1. Purification of raw material
	2.2. Distance to customer
	2.3. Segregation
	2.4. Storage
	2.5. Moisture measurement
	2.6. Fire protection
	2.7. Appropriate transportation
	2.8. Quality control
	2.9. Drying
	2.10. Packaging
	2.11. Tax preferences for environmentally friendly products
3. Trends	3.1. Increase of energy prices
	3.2. Restrictions in foreign trade
	3.3. Vintage fashion
	3.4. Increasing popularity of prefabricated construction
	3.5. Ecology
	3.6. Renewable energy sources
4. Circular Strategies	4.1. Reduce
	4.2. Reuse
	4.3. Repair
	4.4. Refurbish
	4.5. Remanufacture
	4.6. Repurpose
	4.7. Recycle
	4.8. Recover
	4.9. Not specified

Source: own elaboration.

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When coding the collected responses, a total of 272 items were identified. Table 5 summarizes the coded items in reference to each interview.

Table 5. Summary of a FGI responses assigned to specific main code group classification

FGI no.	1. Problems	2. Solutions	3. Trends	4. Circular strategies	99. Other	Total
FGI 1	25	30	19	54	10	138
FGI 2	21	23	7	24	5	80
FGI 3	18	12	1	20	3	54
Total	64	65	27	98	18	

Source: own elaboration.

Analyzing the frequency of responses within all three interviews, 36% of statements were related to wood biomass applications supported by circular strategies (fig. 4). Both 24% of the responses were related to the 'problems' and 'solutions' categories. Additionally, 10% of responses pointed to external market trends that resulted from the behavior of end users of wood biomass residues. Lastly, 7% of contributions were related to the 'other' category.

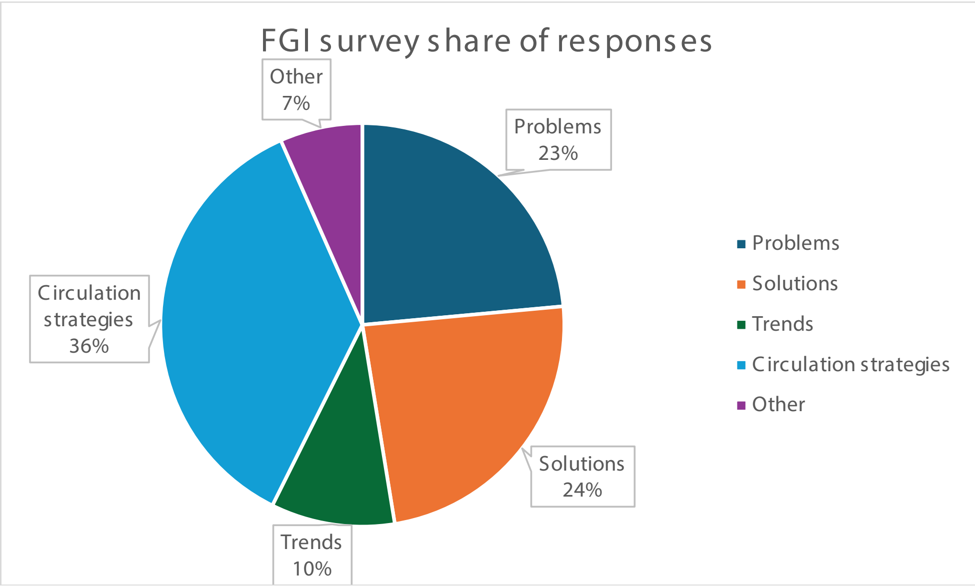

Fig. 4. A summary of the responses provided by research participants (own elaboration)

The results of the interviews indicate similar number of problems and solutions. This can point to the adaptability of the wood biomass industry within reverse chains to changing external conditions. The flexibility of wood biomass reverse supply chains may be one of the key common elements that characterize their participants. This characteristic of supply chains was verified based on the responses received from interviewees. According to research participants, the most pressing problems and challenges affecting the creation and effectiveness of the reverse wood biomass supply chains are lack of economic viability, wood degradation, difficulties in identifying materials, and dealing with complex products composed of different materials. In relation to the cost-effectiveness, the interviewees mostly referred to high costs of transportation and storage, especially in relation to the prices of the processed post-consumer wood. These financial burdens undermine the implementation of the circular economy in the wood sector. One of the factors influencing these costs is the susceptibility of wood to abiotic and biotic degradation (i.e. fungi), which was also frequently mentioned by the participants.

"I would like to say as well that the storage time is relevant. […] It is a cost. Surely, we will cut on costs, [storage] space, providing appropriate storage conditions. And for sure on the raw material quality. The longer we store any wood, wood waste, the worse their quality, because they start to deteriorate, to rot, the mould and fungi appear".

Another issue is the possible mixing of waste, which includes different types of wood-based materials but also other raw materials, e.g., metal elements of used wood construction materials. Moreover, there may be difficulties in waste sorting and identification, particularly in the presence of chemical wood preservatives, which inhibit the reuse of such materials. Waste sorting, in turn, requires usually manpower (especially in small enterprises, which make up the biggest group of wood processing companies and do not have adequate financial resources to invest in automatized segregation lines).

In each of the problem analyzed, interview participants indicated how the problem could be solved. The interviewees did not identify any problems that critically disrupt and block the functioning of the wood biomass supply chain. They, however, indicated that the biomass storage is a key process both in terms of costs and quality preservation. Biomass waste may be stored in covered storage areas, or, for a longer periods and best conditions, in warehouses, which provide adequate level of humidity, temperature and ventilation. Some companies pointed to the necessity of monitoring humidity on an ongoing basis, but they have assigned a responsible person to oversee this process rather than using automatic sensors. Several interviewees have underlined that the minimization of the storage time is the best strategy to deal with potential loss of biomass quality.

Both lower costs and better quality may be also assured when the companies involved are geographically close to each other, keeping the supply chain at the local level.

"These firms are next to each other. […] that is why the transport costs are minimized. In consequence the products, raw material, from which the pellet is

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manufactured, is of good quality, because it is fresh, dry and is transported from one place to another in several hours".

In wood waste transport, the use of adequate vehicles and/or packaging is very important. In the companies interviewed, this included big bags, containers and covered trailers. Additionally, some of the companies were using mobile wood chippers when collecting waste biomass from farmers and forest. Another important process identified was waste sorting. The interviewees stated that in their companies, this process was done manually. Main criteria were the size of wood pieces, type of wood (coniferous vs. non-coniferous) and quality (discarding wet and/or rot pieces). Sometimes post-consumer wood waste is cleaned by removing all metal pieces, such as nails. However, this is usually done by the biomass buyer. In case of wet biomass, drying also may be necessary before further use. To sum up, the companies underlined in the discussion that the right management of the reverse supply chain is a key competence in making this type of activity profitable.

"But the biggest challenge is to assure such a supply chain that would be seamless, form the wood harvesting, through all the recipients, so that it isn't store too long and doesn't rot, get wet. So the stages between one and other customer were very short".

The interviewees identified several trends that influence reverse biomass supply chains. Among them, rising energy prices of energy were mentioned very often, especially in the context of market opportunities for bioenergy products manufacturers, such as pellet producers, and for wood companies, because the increased demand for wood has resulted in the creation of the market for wood by-products, which were previously given away for free. Besides, this topic is connected to other trend: ecology and the increasing adoption of renewable energy.

The growing demand for ecological products was indicated as an opportunity to develop new value-added products from wood waste, such as bio-based lacquers, and boost the circularity in the wood sector. Next, the vintage trend is also popular among the consumers. This results in an increased demand for high-quality old demolition wood, which is repurposed and used, i.e., for floors, furniture, and decorative elements. One of the FGI participants also mentioned the increasing popularity of wood construction. However, compared to other European countries, this type of construction still faces many barriers in Poland.

Last but not least, a recurring topic was also the wood import ban from Russia and Belarus, as well as the export cap from Ukraine, which are the consequences of the Russia-Ukraine war. Because these markets were a considerable source of raw materials for Polish companies, this restriction has increased competition for wood in the Polish market, at the same time presenting an opportunity for wood waste providers.

The results of the interview indicate the important role of circular strategies among the respondents. This is followed by the problems faced by those working in reverse wood biomass supply chains.

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4. DISCUSSION

4.1. Theoretical Implications

The results of this study indicating a high degree of application of circular strategies in reverse wood biomass supply chains show a positive impact of digitization on operational efficiency. This is consistent with the approach presented in empirical studies on the efficiency of blockchain-based supply chains in India and the USA (Queiroz, Fosso Wamba, 2019).

A study carried out on Hungarian companies (Nagy et al., 2018) evaluated selected elements of the digitalization of logistic processes with the focus on big data solutions, the Internet of Things (IofT), and Industry 4.0. Identifying the right path for the development of the supply chain may affect its final efficiency and determine organizational success. The study indicated that a lack of awareness regarding the use of circular economy solutions does not necessarily have a negative impact on the efficiency of biomass processing. The result of the study suggests that awareness of the CE concept could influence changes in reverse supply chains, but this is not a mandatory condition for achieving efficiency.

The lack of awareness of the full process of handling wood biomass flows, identified during the FGI interview, potentially adversely affects the decision making process of managers of reverse supply chains of wood biomass. This conclusion is also supported by the results of the research on the sustainability of digitalization in logistics (Kayikci, 2018). Similarly, within this FGI study, it is identified that the lack of adequate vertical and horizontal integration within an organization can negatively affect its efficiency.

4.2. Practical Implications

The practical implications of the research indicate the potential for developing the application of circular strategies supported by digitalization solution within wood biomass reverse supply chains. The sector is presently applying elements of circular strategies related to the reuse of raw materials, the reuse of raw materials, processing and the minimization of the carbon footprint of products throughout their life cycle as a result of their recycling. These activities are partly undertaken without full awareness and are carried out by the participants within the reverse supply chain of wood biomass, due to the nature of the material associated with the raw material being processed. Improving the level of awareness can bring significant improvements to the efficiency of the process and increase the level of application of process handling elements specific to the circular economy.

The results indicate the important role of circular strategies in handling wood biomass flows within reverse supply chains. Respondents often unconsciously use circular strategies in their operations, which is a positive trend. The problems

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identified in all supply chains are consistent with the approaches described in the literature, but the biomass industry shows great adaptability to the changes and challenges encountered. Unlike other types of supply chains, where the decision-making processes are stretched between operational employees and the managers, the wood biomass sector has short communication structure. Proper involvement of digitalization of communication flow within an entire reverse supply network may support decision making processes and improve wood biomass reprocessing processes.

4.3. Limitations and Future Research

Limitations identified within this research are:

- It is not possible to have complete information on which of the participants in the study will be answering the questions. This is mainly due to the FGI's chosen methodology.
- Limiting the study to qualitative only proposed within this research. The process has been explained, but it is not possible to determine the overall trend and generalize the results.
- Limitation of the study due to the participation of mainly sawmill representatives. Lack of a broader perspective from representatives of other wood industries.
- The interview focused on biomass processing companies and not on companies that collect, intermediate and distribute the result of raw material processing. Therefore, the scope of the study is narrow.

Recommendations for further research may be related to conducting extended interviews based on the different research methods. The current research is limited to a qualitative approach. In order to fully understand the challenges of managing wood biomass flows, it is necessary to properly plan and conduct quantitative studies. A large-sample quantitative survey (e.g. CAWI or CATI survey) is recommended for this purpose.

5. CONCLUSIONS

The research revealed that the vast majority of respondents lacked knowledge of the overall process and its downstream steps which could be related with relatively poor level of digitalization of wood biomass handling processes. The preliminary findings suggest that this lack of knowledge and familiarity with the process may lead managers to draw inappropriate conclusions and influence overall effectiveness of reverse wood biomass supply chains. Knowledge of only a narrow part of the wood biomass processing is not conducive to the optimization of the overall performance. It is necessary to incorporate dynamic process measurement based on digital big data solutions, due to the potentially large amount of data extracted from wood biomass processing.

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The results of the study indicate that the physical form of the wood biomass plays an important role in its handling and processing. Researchers point to the characteristics of biomass that affect the way it can be used during processing. One of the most frequently cited reuses of wood biomass are combustion and its use as a raw material for the production of garden fertilizers.

The characteristics of the raw material should also be taken into account when establishing reverse supply chains for wood biomass and analyzing their efficiency. According to respondents, wood biomass is vulnerable to weather conditions. The high level of moisture absorption is a serious problem for its storage, transport and processing. Additionally, material contamination was also a problem highlighted by the interviewees. For large-scale processing, there is a need for the development of effective means of identification of the type and quality of raw material. This creates the potential for automation in this stage of processing.

The results indicate that storage space, human resources, available infrastructure, and technology are the main constraints associated with processing wood biomass in reverse supply chains. Due to the nature of the unprocessed raw material, it is necessary to provide large storage areas for wood biomass. The parameters of the raw material determine specific storage conditions to maintain the expected moisture levels.

Due to the nature of the processing process, a significant amount of human resources is required, which implies high labor intensity and low operational efficiency. The findings also indicate that there is significant potential for the industry to adopt advanced technologies to help identify both the type and parameters of wood biomass. The study also found that the supply of raw material is highly dependent on a number of variables. Depending on how the wood biomass is harvested, this can be influenced by:

- The location of the forest stock, if the sourcing location is a forest area.
- The life cycle of the products and their design if post-consumer biomass is used for processing.
- Other production processes controlled by the wood biomass processing center.

The characteristics of the raw material supply also affect its demand. Irregularity of supply and high seasonality mean that recovered material can only be used as a raw material for reuse in a narrow range of industries, e.g., horticulture, pellet production, and reuse in other production processes. Therefore, the amount of processed biomass obtained can sometimes only be an addition to the basic raw material engaged within production processes. The research indicated that one of the main reasons for the low level of investment in wood biomass processing is the low profit margins. High profits depend on large volumes of processed wood biomass. Therefore, it is even more important to provide the industry with relatively cost-effective technology to increase processing within reverse supply chains of wood biomass. Improving the flow of digital information between supply chain participants will help to better control supply volumes, determine production needs, and more

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efficiently plan the transportation of processed raw materials. Measures taken to increase the degree of digitalization of processes will help to benefit the minimization of the carbon footprint of wood biomass reverse supply chains. The conducted research showed that some respondents understand the purpose of processing wood biomass. However, the vast majority did not have a comprehensive understanding of the detailed process of wood biomass flow. The respondents focused on a limited section of the technological process of raw material processing. Simultaneously, they demonstrated a general idea of the purpose of harvested and processed wood biomass. Interviewees indicated that they have knowledge of the processes required to handle the wood-based raw material, to change its functionality, and to influence the conversion and further use in the supply chain.

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LITERATURE

Abdullah, M.I., Sarfraz, M., Qun, W., Javaid, N. (2018). Drivers of green supply chain management. *Logforum*, 14(4), 437-447, https://doi.org/10.17270/J.LOG.2018.297.

Chambers, L.W. (1997). Qualitative and quantitative research methods. *Canadian Journal of Public Health*, 88(1), 9-10, https://doi.org/10.1007/BF03543069.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. Sage Publications.

Co, H.C., Barro, F. (2009). Stakeholder theory and dynamics in supply chain collaboration. *International Journal of Operations & Production Management*, 29(6), 591-611, https://doi.org/10.1108/01443570910957573.

Croxton, K.L., García-Dastugue, S.J., Lambert, D.M., Rogers, D.S. (2001). The Supply Chain Management Processes. *The International Journal of Logistics Management*, 12(2), 13-36, https://doi.org/10.1108/09574090110806271.

Dahmus, J.B. (2014). Can Efficiency Improvements Reduce Resource Consumption? A Historical Analysis of Ten Activities. *Journal of Industrial Ecology*, 18(6), 883-897, https://doi.org/10.1111/jiec.12110.

Danish, M., Ahmad, T. (2018). A review on utilization of wood biomass as a sustainable precursor for activated carbon production and application. *Renewable and Sustainable Energy Reviews*, 87, 1-21, https://doi.org/10.1016/j.rser.2018.02.003.

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De Mattos Nascimento, D.L., De Oliveira-Dias, D., Moyano-Fuentes, J., Maqueira Marín, J.M., Garza-Reyes, J.A. (2024). Interrelationships between circular economy and Industry 4.0: A research agenda for sustainable supply chains. *Business Strategy and the Environment*, 33(2), 575-596, https://doi.org/10.1002/bse.3502.

Desing, H., Brunner, D., Takacs, F., Nahrath, S., Frankenberger, K., Hischier, R. (2020). A circular economy within the planetary boundaries: Towards a resource-based, systemic approach. *Resources, Conservation and Recycling*, 155, 104673, https://doi.org/10.1016/j.resconrec.2019.104673.

Dubisz, D., Golińska-Dawson, P., Koliński, A. (2022). Measuring CO2 emissions level for more sustainable distribution in a supply chain. *Engineering and Applied Science Research*, 49, 804810, https://doi.org/10.14456/EASR.2022.78.

Dubisz, D., Golinska-Dawson, P., Kolinski, A. (2023). Impact of Standardized Reusable Packaging on a Supply Chain Design and Environmental Efficiency. In: V. Ivanov, J. Trojanowska, I. Pavlenko, E. Rauch, J. Piteľ (eds.). *Advances in Design, Simulation and Manufacturing VI*. Springer Nature Switzerland, 102-112, https://doi.org/10.1007/978-3-031-32767-4_10.

Golinska, P. (ed.) (2014). *Environmental issues in automotive industry*. Springer.

Handfield, R.B., Walton, S.V., Seegers, L.K., Melnyk, S.A. (1997). 'Green' value chain practices in the furniture industry. *Journal of Operations Management*, 15(4), 293-315, https://doi.org/10.1016/S0272-6963(97)00004-1.

Hervani, A.A., Helms, M.M., Sarkis, J. (2005). Performance measurement for green supply chain management. *Benchmarking: An International Journal*, 12(4), 330-353, https://doi.org/10.1108/14635770510609015.

Hofmann, E. (2017). Big data and supply chain decisions: The impact of volume, variety and velocity properties on the bullwhip effect. *International Journal of Production Research*, 55(17), 5108-5126, https://doi.org/10.1080/00207543.2015.1061222.

Javied, T., Rackow, T., Franke, J. (2015). Implementing Energy Management System to Increase Energy Efficiency in Manufacturing Companies. *Procedia CIRP*, 26, 156-161, https://doi.org/10.1016/j.procir.2014.07.057.

Kamimura, K., Kuboyama, H., Yamamoto, K. (2012). Wood biomass supply costs and potential for biomass energy plants in Japan. *Biomass and Bioenergy*, 36, 107-115, https://doi.org/10.1016/j.biombioe.2011.10.020.

Kawa, A., Golinska, P. (2010). Supply Chain Arrangements in Recovery Network. In: P. Jędrzejowicz, N.T. Nguyen, R.J. Howlet, L.C. Jain (eds.). *Agent and Multi-Agent Systems: Technologies and Applications*, vol. 6071. Springer Berlin Heidelberg, 292-301, https://doi.org/10.1007/978-3-642-13541-5_30.

Kayikci, Y. (2018). Sustainability impact of digitization in logistics. *Procedia Manufacturing*, 21, 782-789, https://doi.org/10.1016/j.promfg.2018.02.184.

Keefe, R., Anderson, N., Hogland, J., Muhlenfeld, K. (2014). Woody Biomass Logistics. In: D.L. Karlen (ed.). *Cellulosic Energy Cropping Systems*. John Wiley and Sons, Ltd., 251-279, https://doi.org/10.1002/9781118676332.ch14.

Kogler, C., Rauch, P. (2018). Discrete event simulation of multimodal and unimodal transportation in the wood supply chain: A literature review. *Silva Fennica*, 52(4), https://doi.org/10.14214/sf.9984.

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Kogler, C., Schimpfhuber, S., Eichberger, C., Rauch, P. (2021). Benchmarking Procurement Cost Saving Strategies for Wood Supply Chains. *Forests*, 12(8), 1086, https://doi.org/10.3390/f12081086.

Koliński, A., Śliwczyński, B., Golińska-Dawson, P. (2016). Evaluation model for production process economic efficiency. *Logforum*, 12(2), https://doi.org/10.17270/J.LOG.2016.2.3.

Kristiyanti, M., Rosita, N.D., Hermawati, R., Khamdilah, A., Kundori, K., Mawardi, K. (2024). Logistics digitalization on import document activities: Electronic delivery orders and service quality in maritime ports. *International Journal of Data and Network Science*, 8(1), 227-236, https://doi.org/10.5267/j.ijdns.2023.9.029.

Krstić, M., Agnusdei, G.P., Miglietta, P.P., Tadić, S., Roso, V. (2022). Applicability of Industry 4.0 Technologies in the Reverse Logistics: A Circular Economy Approach Based on COmprehensive Distance Based RAnking (COBRA) Method. *Sustainability*, 14(9), 5632, https://doi.org/10.3390/su14095632.

Lee, J., Joo, H.Y. (2020). The Impact of Top Management's Support on the Collaboration of Green Supply Chain Participants and Environmental Performance. *Sustainability*, 12(21), 9090, https://doi.org/10.3390/su12219090.

Mair, C., Stern, T. (2017). Cascading Utilization of Wood: A Matter of Circular Economy? *Current Forestry Reports*, 3(4), 281-295, https://doi.org/10.1007/s40725-017-0067-y.

Marques, A., Cunha, J., Meyer, A., Navare, K. (2020). Contribution Towards a Comprehensive Methodology for Wood-Based Biomass Material Flow Analysis in a Circular Economy Setting. *Forests*, 11(1), 106, https://doi.org/10.3390/f11010106.

Mobini, M., Sowlati, T., Sokhansanj, S. (2013). A simulation model for the design and analysis of wood pellet supply chains. *Applied Energy*, 111, 1239-1249, https://doi.org/10.1016/j.apenergy.2013.06.026.

Musab, O., Christian, B. (2014). Qualitative Research Method Summary. *Journal of Multidisciplinary Engineering Science and Technology*, I(5).

Nagy, J., Oláh, J., Erdei, E., Máté, D., Popp, J. (2018). The Role and Impact of Industry 4.0 and the Internet of Things on the Business Strategy of the Value Chain – The Case of Hungary. *Sustainability*, 10(10), 3491, https://doi.org/10.3390/su10103491.

Nowak, P., Kirchner, M., Koliński, A. (2022). Analysis of digitalisation needs improving the supply chain efficiency for new silk road transport corridor. *Ekonomska Misao i Praksa*, 31(2), 487-503, https://doi.org/10.17818/EMIP/2022/2.7.

Pathak, V., Jena, B., Kalra, S. (2013). Qualitative research. *Perspectives in Clinical Research*, 4(3), 192, https://doi.org/10.4103/2229-3485.115389.

Potting, J., Hekkert, M., Worrell, E., Hanemaaijer, A. (2017). *Circular economy: Measuring innovation in the product chain* (no. 2544). PBL Netherlands Environmental Assessment Agency.

Queiroz, M.M., Fosso Wamba, S. (2019). Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA. *International Journal of Information Management*, 46, 70-82, https://doi.org/10.1016/j.ijinfomgt.2018.11.021.

Sherwood, J. (2020). The significance of biomass in a circular economy. *Bioresource Technology*, 300, 122755, https://doi.org/10.1016/j.biortech.2020.122755.

Sosnowski, P.C., Cyplik, P. (2022). Closed loop supply chains and circular economy – the possibilities of interplay. *Logforum*, 18(4), 413-420, https://doi.org/10.17270/J.LOG.2022.784.
Suárez-Eiroa, B., Fernández, E., Méndez-Martínez, G., Soto-Oñate, D. (2019). Operational principles of circular economy for sustainable development: Linking theory and practice. *Journal of Cleaner Production*, 214, 952-961, https://doi.org/10.1016/j.jclepro.2018.12.271.
Torrisi, V., Ignaccolo, M., Inturri, G. (2017). Analysis of road urban transport network capacity through a dynamic assignment model: Validation of different measurement methods. *Transportation Research Procedia*, 27, 1026-1033, https://doi.org/10.1016/j.trpro.2017.12.135.
Vis, M., Mantau, U., Allen, B. (2016). *Study on the optimised cascading use of wood* (Final Report No. 394/PP/ENT/RCH/14/7689). European Commission.
Werner-Lewandowska, K., Golińska-Dawson, P., Cyplik, P. (2024). Stimulators of transition toward circular supply chain – Exploratory studies in Electrical and Electronic Equipment industry. *Logforum*, 20(1), 83-96, https://doi.org/10.17270/J.LOG.000973.
Yuan, Z. (2012). A Dynamic Management Method for Fast Manufacturing Resource Reconfiguration. *Physics Procedia*, 33, 1558-1564, https://doi.org/10.1016/j.phpro.2012.05.253.
Zapp, M., Marques, M., Powell, J.J.W. (2021). Blurring the boundaries. University actorhood and institutional change in global higher education. *Comparative Education*, 57(4), 538-559, https://doi.org/10.1080/03050068.2021.1967591.

EFEKTYWNOŚĆ ODWRÓCONYCH ŁAŃCUCHÓW DOSTAW BIOMASY DRZEWNEJ – JAKOŚCIOWE PODEJŚCIE DO IDENTYFIKACJI KLUCZOWYCH PARAMETRÓW

Streszczenie

Dążenie do poprawy efektywności procesów logistycznych dotyczy również przemysłu biomasy drzewnej. Liczne obszary w ramach odwrotnych łańcuchów dostaw biomasy drzewnej wykazują potencjał do optymalizacji w kontekście rozwoju gospodarki o obiegu zamkniętym. Jeśli chodzi o odwrotny łańcuch dostaw biomasy drzewnej, ważne jest, aby dokładnie zidentyfikować istotne parametry, które określają ogólną wydajność łańcucha dostaw. Celem niniejszego badania jest identyfikacja parametrów kontrolnych, które określają wydajność procesów związanych z przetwarzaniem biomasy drzewnej, a także problemów i rozwiązań, które występują w ramach odwrotnych łańcuchów dostaw biomasy drzewnej. Podjęto próbę zrozumienia specyfiki procesu zarządzania poprzez zastosowanie podejścia jakościowego – zogniskowanego wywiadu grupowego (FGI). FGI przeprowadzono zarówno wśród menedżerów operacyjnych, jak i procesowych. Uzyskane wyniki zostały sklasyfikowane według określonych grup kodów i poddane dogłębnej analizie. Pokazują one, że przemysł biomasy drzewnej ma potencjał do optymalizacji procesów logistycznych poprzez odpowiednie zarządzanie i identyfikację kluczowych parametrów

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procesu. Zastosowanie elementów gospodarki o obiegu zamkniętym (GOZ) w procesach przeładunkowych wykazuje duży potencjał optymalizacji procesów. Jest to zgodne z naturalnym dążeniem przemysłu biomasy drzewnej do rozwiązywania problemów, minimalizacji odpadów i wysokiego stopnia adaptacji w dynamicznym i zmieniającym się środowisku odwróconych łańcuchów dostaw. Sformułowane wnioski i zalecenia można włączyć do istniejących odwrotnych łańcuchów dostaw biomasy drzewnej.

Słowa kluczowe: badania jakościowe, cyfryzacja procesów, zwrotne łańcuchy dostaw, biomasa drzewna

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