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Correlation Between Key Parameters of Wood Biomass Reverse Supply Chains and Their Impact on Total Biomass Acquisition Levels

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Effectiveness is the prism through which supply chains are defined. Different management methods can be used to measure supply chain effectiveness, such as life cycle assessment or sustainable supply chain management. In order to properly model and manage reverse supply chains for wood biomass, the structure of the supply chains was examined. For this purpose, a correlation analysis of the basic parameters of wood biomass reverse supply chains was carried out. After their identification, the level of mutual correlation was verified using Pearson's correlation coefficient. The coefficient of determination r^2 was also verified for the two parameters with the highest degree of interaction – the sales of wood chips and the purchase of wood biomass. To improve the verification, scatter plots were made to further confirm the degree of interaction. As a result of the analysis of the parameter interdependencies and a discussion of the results of other international studies, the parameters were found to be applicable in modelling effective reverse supply chains of wood biomass.

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Introduction

The degree of supply chain complexity impacts its design to correspond to the specificity of the distributed products [Leeuw et al. 2013]. Accurate design of the supply chain significantly enhances the effectiveness of the whole supply chain. Based on research, this conclusion can be applied to reverse supply chains [Accorsi et al. 2015; Fernández Campos et al. 2019]. Appropriate supply chain planning based on the mathematical modelling of distribution and return logistics processes enable the creation of sustainable supply chains that exhibit high effectiveness [Lee et al. 2016]. Different studies indicate a specific methodology for managing a reverse supply chain from the perspective of the transported goods, supported with mathematical modelling [Al-Babtain 2010]. An interesting approach is the LCA method covering the

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entire product life cycle. Hence, both the forward distribution supply chain and reverse supply chain are adjusted to specify the transported goods within the SC. Due to this approach, supply chain effectiveness might be optimised [Abejón et al. 2020; Accorsi et al. 2015; Cordella et al. 2008]. Kogler and Rauch [2018] indicate the complexity of transport processes in supply chains handling wood biomass flows. They indicate a research gap in verifying the effectiveness of a combination of process optimisation and its simulation. A potential solution may be the inclusion of discrete-event simulation (DES) in modelling and managing reverse wood biomass logistics networks. However, the modelling of the network should take into account the different types of transport modes used in handling the flows, including road, rail and water transport. The processes within the supply chains that operate on wood biomass include its cultivation, harvesting, transport, short-term storage, processing and recycling. This requires the inclusion of multi-level planning at strategic, tactical and operational levels [D'Amours et al. 2008]. The result of the Väätäinen et al. [2021] literature research on the organisation of roundwood and biomass logistics in Finland and Sweden in the 21st century demonstrates significant interest in this research area. The largest increase in the number of publications on this topic took place between 2011 and 2017. The paper revealed that more than 50% of the available research is concerned with issues related to the organisation and management of wood biomass supply chains. The remaining studies deal with roundwood and residual wood biomass. The collected papers were structured according to the employed transport, handling and processing infrastructure elements. Each area was reviewed for current management trends in the literature. Based on a study of wood biomass within reverse supply chains in Austria, the potential to increase their efficiency by as much as 24% as a result of implementing integrated supply chain solutions was identified [Kogler et al. 2021]. The proper coordination of processes and establishing management strategies can help maintain the competitive character of the entire supply chain. Selection of the appropriate parameters of a reverse supply chain of wood biomass should take place in the areas of production, harvesting and transportation of wood biomass. Thus, it is possible to optimize the cost of logistics services at the level of all the participants in the process. To achieve increased process efficiency in handling wood biomass, the introduction of solutions that characterize integrated supply chains is crucial.

Adjustment of the appropriate parameters of the logistics model to the specificity of the product involves utilisation of the available means of transport in the chain and other elements of the logistics infrastructure [Mouronte-López 2021]. Therefore, the final shape of reverse supply chains must be able to handle the estimated distribution volumes [Kolinski et al. 2017]. Based on the Taiwanese fresh-fruit sector, it was outlined that the impact of essential logistics parameters significantly affects supply chain management. The same approach may be applied to reverse supply chains [Do et al. 2022]. Consequently, it is crucial to know the interdependencies between the individual elements of the reverse supply chains of wood biomass:

- There are reverse supply chains of wood biomass parameters that affect the sales volume of wood biomass.
- There are model parameters that do not directly statistically correlate with the volume of wood biomass sold.

On this basis, statistical analyses are carried out in the following research steps. Pearson's correlation coefficient and the coefficient of determination are calculated. Because of the limited nature of the source data, ETS – exponential smoothing was used to obtain estimated data determining the nature of distribution within the reverse supply chains of wood biomass. Identifying the degree of dependencies between individual components of the reverse supply chain is essential owing to the increasing importance of mathematical modelling based on a statistical approach [Kannegiesser and Günther 2014; Lee et al. 2016]. It is a solid basis for the proper optimisation of reverse supply chains.

Referring to the conducted literature study, the following research questions were formulated:

- Are there parameters of reverse supply chains of wood biomass that affect an increase or decrease in the amount of harvested wood biomass?
- By modelling the parameters of the reverse supply chain in an appropriate way, can we increase its efficiency in terms of the amount of harvested wood biomass?

The following part of the study attempts to answer the formulated research questions.

Materials and methods

Based on historic data from 2015–2018, an analysis of the amount of wood biomass produced for the area of Poland is performed. A relationship between historical data defining the level of obtaining wood biomass and the quantities sold needs to be verified to determine the demand for transport services of the reverse supply chain of wood biomass. For this purpose, the data published in the Statistical Yearbook of Forestry

2020 was gathered. The data analysis is carried out for the years 2015–2018 resulting from the subsequent change in the statistics, according to which, after 2018, wood biomass began to be included in the category of small-sized wood.. This is important because wood biomass is a natural waste occurring during the acquisition of wood and its processing. By verifying the trend between the general level of obtaining wood from forests and the level of obtaining wood biomass and its further resale, it can determine the intensity of flows in the designed reverse supply chains of wood biomass. Table 1 presents the amount of harvested, wood biomass and their sales volumes in 2015–2018 to enterprises that utilise wood biomass as a resource for further production processes.

Table 1. Sourcing and sales of timber, including residual wood biomass for biomass purposes [in thousand m^3]

Volume parameter in thousand m^3	2015	2016	2017	2018
Total timber sales	37 971.10	39 457.10	40 420.90	44 694.80
Acquisition of wood	193.00	265.00	245.00	255.00
Sales of wood biomass	192.70	265.40	243.70	255.20

Source: authors' own elaboration based on Statistical Yearbook of Forestry 2015, 2016, 2017, 2018

According to the statistical data collected from the Statistical Yearbook of Forestry Poland 2022, the key factors were listed for further research. Identifying key factors and conducting proper statistical analysis is the basis for indicating the fundamental parameters affecting the shape of the targeted logistics model. The obtained information can outline the mutual interdependencies between the main factors determining the effectiveness of the entire wood biomass transport chain. Owing to the lack of primary statistical data for total timber sales, the acquisition of wood biomass, sales of wood biomass and the identified deficiencies in years 2019 and 2020, they were supplemented with a forecast considering ETS – exponential smoothing [Pardoe 2012]. Simultaneously, in the case of limited data on the value of technical and transport equipment, the value of stock and the level of financial investments, linear regression was introduced to fill a data gap for the years 2016-2018. The complete dataset was calculated and is presented in Table 2.

Table 2. Key basic data related to wood biomass sourcing

Years	2015	2016	2017	2018	2019	2020
Forest land in thousand ha	9420.1	9433.55	9447.00	9459,50	9462.90	9464.20
Total timber sales in thousand m^3	37971.1	39457.10	40420.90	44694.80	46269.13	48624.66
Acquisition of wood biomass in thousand m^3	193	265.00	245.00	255.00	280.80	281.97
Sales of wood biomass in thousand m^3	192.7	265.40	243.70	255.20	280.58	281.85
Technical equipment and machinery in million PLN	232.3	224.25	216.20	208.15	200.10	187.80
Transport equipment in million PLN	95	99.73	104.45	109.18	113.90	105.70
Stock - unfinished production of wood in million PLN	6.3	7.0	9.50	11.10	12.70	9.00
Stock - finished production of wood in million PLN	161.7	168.93	176.15	183.38	190.60	205.20
Short term investments in million PLN	2516.1	2350.65	2185.20	2019.75	1854.30	2356.50

*data marked in blue and underlined are authors' own calculations
Source: Statistical Yearbook of Forestry 2021 and authors' own calculations of forecast and historic data.

The answer to the research question, which can prove valuable in determining the potential volume of wood biomass to be transported, can be based on the collected data. The correct identification of this relationship can be of great importance to determine the demand for means of transport and the support of transport processes.

Results

The difference between the amount of wood biomass purchased and the amount of wood biomass sold, shown in Table 1, indicates the short-term storage of wood biomass in the forests where it was harvested. The unsold volume was carried over to re-sell in the following year. Nonetheless, this is a marginal value and it can be assumed that the majority of the wood biomass harvest will be directly transferred for further distribution. It was observed that within the reverse supply chain model, wood biomass is incidentally stored. There is a small gap between the amount of wood biomass purchased and sold based on the data in Table 2. Thus, this indicates the high absorptive capacity of the market for the acquisition of processed wood raw material. From the conducted analysis, two important interdependencies can be highlighted from the perspective of the supply chain design:

– Increasing timber harvesting will result in a further increase in the amount of wood biomass.
– The small difference between the harvested and sold wood biomass indicates the expected high effectiveness of wood biomass reverse supply chains.

The collected data was analysed in the context of their interdependencies in order to determine the importance of individual parameters in wood biomass reverse supply chains. Thus, the parameters that have an impact on the two main criteria of wood biomass production and wood biomass sales were identified. From the perspective of organising the process, these two parameters significantly determine the shape of the model and the total demand for logistics services. The results of calculating the obtained correlation coefficients are presented in Table 3.

Table 3. Wood biomass control parameters correlation matrix

	Acquisition of wood biomass in thousand m^3	Sales of wood biomass in thousand m^3	Technical equipment and machinery in million PLN	Transport equipment in million PLN	Stock - unfinished production of wood in million PLN	Stock - finished production of wood in million PLN	Short term investments in million PLN
Acquisition of wood biomass in thousand m^3	1						
Sales of wood biomass in thousand m^3	0.999	1					
Technical equipment and machinery in million PLN	-0.800	-0.798	1				
Transport equipment in million PLN	0.741	0.737	-0.752	1			
Stock - unfinished production of wood in million PLN	0.670	0.666	-0.633	0.986	1		
Stock - finished production of wood in million PLN	0.785	0.782	-0.997	0.708	0.582	1	
Short term investments in million PLN	-0.559	-0.556	0.466	-0.933	-0.979	-0.408	1

Source: authors' own elaboration

The result of the Pearson index calculations of the parameters of wood biomass acquisition and sales of wood biomass is r=0.99. It indicates a high degree of correlation. According to the Person coefficient scale, it shows a positive correlation between the amount of harvested wood and the volume of wood biomass. Hence, the amount of harvested wood within a forest can be treated as a significant factor affecting the volume flow of biomass reverse supply chains.

The coefficient of determination r^2 for those two parameters is 0.9997. It indicates a high magnitude of association between those two variables, further confirming the importance of these factors. Mutual dependencies between the parameters of the reverse supply chain of the wood biomass logistics model were additionally verified on scatterplots concerning the parameter of wood biomass acquisition. The results are shown in Fig.1 below.

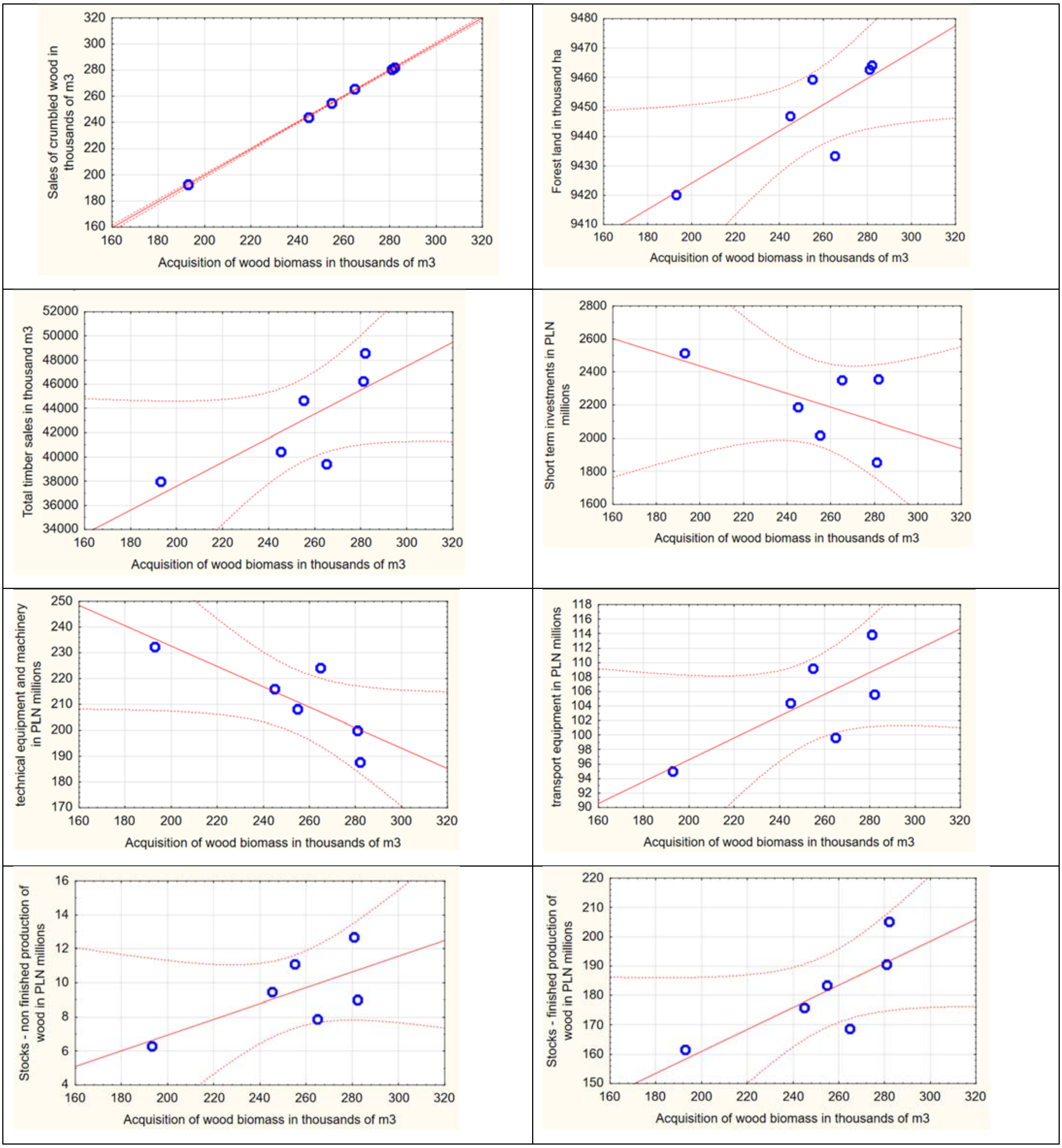

Fig. 1. Scatterplots showing relationship between analysed factors and parameter acquisition of wood biomass

As a result of this analysis, it was confirmed that the sales of wood biomass and the acquisition of wood biomass are strongly mutually dependent. It also indicates that the places where the wood biomass is acquired do not store it. What is more, the entire obtained volume is transferred for further distribution. Therefore, it directly impacts the shape of a reverse supply chain of wood biomass. Those findings are concurrent with the previous conclusions revealed in Table 3.

The analysis showed that technical equipment investments do not affect the amount of acquired biomass or its level of sales. Similar to short-term investments, they do not affect the handled volumes of wood biomass but only increase the value of the technical equipment and machinery.

The collected data was analysed in the context of their mutual dependencies to determine the importance of individual parameters of the reverse supply chains of wood biomass. Hence, it was determined which parameters affect the two essential factors of reverse supply chains of wood biomass: the amount of acquired wood biomass and the volume of wood biomass sales.

Discussion and conclusions

Kogler and Rauch [2018] highlighted in their study the possibility of using elements based on respective regression in modelling supply chains of fresh roundwood. Wood, as a consequence of weather conditions and insects, loses its original performance when it is stored for excessively long periods in a forest area. In the case study part of the research, it was possible to reduce the lead time in the supply chain by using a regression model, which contributed to maintaining the wood parameters of approximately 57% of the total volume of harvested roundwood. In addition, it was shown that the result could be increased to 73% with a 25% larger fleet of vehicles adapted to the transport of roundwood. The correlation shown in this study between the volume of harvested wood biomass and the level of sales indicates a low level of loss or waste. In the case of wood biomass harvested in the forest, it was observed that the storage event does not occur on a large scale or is very short-term. The result of the Kogler and Rauch study further confirms that the aim to shorten the lead time of handling wood biomass volumes in reverse supply chains is an approach that coincides with the approach shown in this study.

It was shown that the efficiency of supply chains operating in forested areas is affected by natural events, including windstorms and force majeure [Kogler and Rauch 2020a]. Such process conditions require adequate contingency planning to ensure process continuity. Limited transport means, terminal capacity or waiting times for timber loads require the use of advanced methods based on discrete simulation. With this approach, reverse supply chains of wood biomass can operate in an uninterrupted manner. Thus, the result of this study indicating the relationship between reverse supply chains of wood biomass parameters and their mutual relationship appears to be even more significant. The identified relationship presented by Pearson's correlation coefficients allows estimation of the volume to be shipped, planning of the appropriate amount of transport means, terminal capacity, processing centres for wood biomass and determination of the expected sales and processing volume.

As a result of the research on the correlation between the various supply chain parameters, the relationship between investment in transport equipment and the level of wood biomass procurement and sales was verified. Thus, a high correlation between both parameters was proven. Simultaneously, verification of other studies involving the use of a self-loading truck and appropriate modelling of the logistics network supported by discrete modelling revealed cost savings of between 6% and 11% in transport services, depending on the applied scenario [Kogler et al. 2020]. Furthermore, this confirms that the selection of the means of transport with the appropriate maximum permissible weight, properly used within existing reverse supply chains of wood biomass, is able to positively influence their efficiency. The calculated correlation coefficient further confirms the relevance of this parameter.

Based on the study of the correlation of individual parameters, the relationships between the various elements of the entire reverse supply chain of wood biomass were demonstrated. Therefore, it may be assumed that the key to the proper management of such a chain is to take into account many organizational aspects. It requires a multi-level analysis of reverse supply chain management and consideration of the actual parameters affecting flow levels, technological aspects and management methods. A parallel approach is seen in the presented modelling of wood supply chains conducted by Kogler and Rauch [2020b]. Discrete-event simulation (DES) makes it possible to perform cost-free verification of the dependencies of separate model parameters in different configurations.

On the basis of the conducted research focused on identification of mutual dependencies between supply chain participants presented in Table 3, it was noted that reverse supply chains of wood biomass are characterised by a low reserve factor. Most of the wood biomass collected within forests is transferred directly to the distribution network. The research showed a high correlation between the collection of wood biomass and the level of sales. Simultaneously, the coefficient of determination outlines the high interdependence between these two factors. The modelling of the reverse supply chain of wood biomass must consider the key parameters of the reverse supply chain since they affect the volumes of flows and the level of demand for logistics transport operations.

The research revealed that short-term investments and funds for the purchase of technical equipment are negatively correlated with the amount of wood biomass produced and sold. Therefore, it is recommended to put less emphasis on these parameters when modelling reverse supply chains of wood biomass. The results of this research can be used to support the proper management of wood biomass reverse supply chains. This approach can also support maximising the efficiency of transport processes within the reverse supply chains of wood biomass. The research results can additionally be used to estimate transport requirements in precision distribution models. What is more, the results of this research can be employed to forecast wood biomass procurement. Accurate forecasts need to take into account the forest area and quantitative plans for wood biomass extraction. The key limitations of the research include the poor quality historical data on the amount of harvested wood biomass. Hence, missing values require predictions.

Further research should be conducted in the area of quantitative and qualitative research among reverse supply chains of wood biomass representatives to verify the formulated assumptions and to understand the specificity of the analysed sector of the wood biomass industry. A survey of the panel of experts could be carried out among managers and executives who are responsible for the organisation of logistical processes in the supply chains of wood biomass.

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