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Logistics Analysis of the Supply Chain for Forest Biomass in Slovakia

Miloš Gejdoš[1*] and Miloš Hitka[2]

[1]*Technical University in Zvolen, Department of Forest Harvesting, Logistics and Ameliorations, T. G. Masaryka 24 Zvolen, Slovakia; Email: gejdos@tuzvo.sk*
[2]*Technical University in Zvolen, Department of Economics, Management and Business, T.G. Masaryka 24 Zvolen, Slovakia; Email: hitka@tuzvo.sk*

***Corresponding Author:** Miloš Gejdoš

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Abstract: The demand for renewable energy sources and the construction of new consumer capacities for forest biomass, combined with increasing demands for nature protection and disturbances caused by global climate change, present several technological and logistical challenges. This study aims to analyze the main logistical problems in the production and transportation of forest biomass for energy use. The input data for the study were obtained from the databases of the National Forest Center and the Ministry of Agriculture and Rural Development. In the production cycle, harvesting operations related to forest management, including tending felling and main felling, were considered. Service prices were sourced from the public price lists of both private and state forest managers, as well as forestry machinery operators. Costs were calculated for three key points in the logistics flow: the skid way in the forest, the biomass supplier's warehouse, and the heating plant utilizing the biomass. Our results indicate that, regardless of the production location or the age of the forest stand, the largest cost component is primarily the transportation of biomass to the point of consumption. After establishing the optimization structure, it is also necessary to ensure the operational functionality and continuous biomass supply.

Keywords: Logistics, forest biomass, heating plants, wood chips, biomass transport

1. Introduction

The growing demand for renewable energy sources and the development of new capacities utilizing forest biomass as a primary energy source bring several technological and logistical challenges. In addition to the rising demand for biomass and increasing prices due to the global crisis and conflicts, there are also significant technological challenges related to harvesting, processing, transportation, and use of biomass.

Supporting the use of renewable energy sources based on forest biomass processing from a forestry perspective involves addressing a wide range of technical, technological, economic, and environmental challenges. These challenges are interconnected and interdependent, leading to a limited set of optimal technological options for the entire process, from biomass collection (harvesting) to energy recovery. Therefore, a critical task in the decision-making process is to select the best option for the given conditions from these specific alternatives [1].

Through conceptual differentiation, logistics has evolved into a system composed of several subsystems. [2-4]. A subsystem represents a specific logistics activity involved in the flow or transfer of goods, cargo, deliveries, or information from the beginning to the end of the logistics chain [5-6].

Cost calculation plays a crucial role in optimizing specific activities within the logistics system. The most effective solution is considered to be the one that minimizes implementation costs. The main categories of logistics costs include [7]:

- Variable costs: These are performance-related logistics costs incurred during the execution of logistics activities, particularly through the consumption of certain production factors (e.g. fuel, energy, etc.).
- Fixed costs: These are readiness-related logistics costs arising from the use of logistics capacities. They remain relatively constant regardless of the number of logistics services provided and are incurred by maintaining and preparing capacities for use (e.g. employees, transport and handling equipment, warehouse buildings).

Existing scientific studies have developed specific proposals for simulations and models aimed at supporting sustainable forest management [1,8]. The primary goals include increasing the economic efficiency of management, reducing negative environmental impacts on forest ecosystems, and enhancing the overall humanization of work through automation of procedures. However, one of the most significant challenges in expanding the use of biomass for energy purposes is the high cost of transportation and the often complex technology required to convert biomass into usable forms of energy, such as electricity and heat. These costs can be reduced by optimizing logistics operations. For instance, an analytical model of the supply network for five types of biomass revealed that 20-50% of delivery costs are associated with the transportation and handling of biomass [9]. In Slovakia, significant logistical optimizations have been achieved through the application of geoinformatics [10,11].

The utilization and logistical optimization of forest biomass production are fundamentally influenced by various limiting factors. One of the most significant factors is the slope of the terrain, which affects the selection of appropriate harvesting and transport technologies. Another limiting factor is the category of forest use, as protected forests and those under the highest levels of nature protection are not considered productively available [12].

The aim of this study is to analyze the main logistical challenges in the production and transportation of forest biomass for energy use under the conditions in Slovakia. This objective is influenced by primary factors such as natural conditions, the species and age composition of forest stands, the age and structure of technologies, and the profile of potential customers and their installed capacities.

2. Data and Methods

The Ministry of Agriculture and Rural Development of the Slovak Republic, in cooperation with the National Forestry Center, regularly collects summary data on Slovak forests and available biomass resources on an annual basis in the Reports on Forestry in the Slovak Republic [13]. Input data on volumes and availability of wood biomass were obtained from these sources.

We compared the production costs of biomass for energy purposes across different technological systems and the availability of resources in various regions of Slovakia. This comparison was based on limiting criteria such as terrain slopes and forest management methods. The price of wood per stump was not included in the calculations. The structure of supplier production procedures and the basic work phases are illustrated in Figure 1.

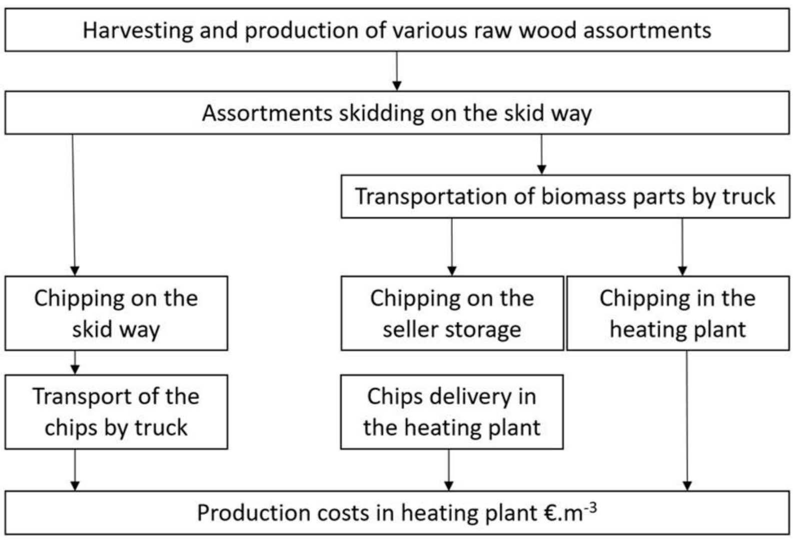

Fig. 1 A scheme of analyzed technological procedures. Source: modified according to [12]

Biomass transport costs were calculated for trucks equipped with large-volume superstructures for transporting wood chips and special superstructures for hauling uncut logging debris, such as branches and slash.

The cargo volume for transporting wood chips was set at 26 m³ (equivalent to 65 m³ of filled wood chips), while the volume for uncut biomass transport was 19 m³. In both cases, the average transport speed was calculated at 45 km/h. The hourly cost for truck operation was set at €95/h, and the cost for loading and stacking cargo was €52/h. The time required for loading chips was 0.85 hours (with a mower capacity of 75 m^3 of loaded chips per hour), the unloading time at the heating plant was 0.26 hours, and the auxiliary loading time was 0.4 hours. For uncut biomass transport, the driving cost was €49/h. The time for loading was 1.04 hours, unloading at the heating plant took 0.89 hours, and the auxiliary loading time was 0.4 hours.

The chipping costs were calculated for a chipper mounted on a truck chassis, with a purchase price of approximately €500,000. The transport calculations assumed a distance of 8 km between the supplier's warehouse and the heating plant, with the chips being transported by a standard truck.

In the production cycle, logging operations related to forest management, including tending felling (thinning for stands under 50 years old and over 50 years old) and main felling, were considered. Costs were calculated for three key points in the logistics flow: the removal point in the forest, the biomass supplier's warehouse, and the heating plant utilizing the biomass.

The development of a method to rapidly estimate the total available volume and price of dendrimers suitable for energy purposes in forest stands was largely based on existing methodological procedures. Specifically, it involved the methodology for creating assortment tables of tree species, categorized by storeys and stand components, and further classified into thickness and quality classes, as outlined in [14]. Data collected by the National Forestry Center [13] were used as a basis for determining the available biomass volume. This included data on forest stand stocks and planned silviculture operations. The available biomass volume for energy purposes was calculated based on the percentage share in the assortment structure of supplies from the previous year. Limiting criteria such as management practices and slope accessibility (up to a 50% slope) were also applied.

Service prices were sourced from public price lists provided by both private and state forest managers, as well as forestry technique operators.

The established hypothesis aimed to identify potential points in the biomass supply chain for energy use and assess whether it was possible to optimize costs and improve the overall efficiency of the process.

3. Results

In the results section, we focused on analyzing biomass availability and calculating handling, production, and transport costs, with consideration of the production location within the logistical flow.

3.1 Available Biomass Sources within the Slovak Republic

The wood stock in Slovakia's forests has grown significantly over the past twenty years. In 2021, it reached its highest volume of 483.9 million m³, with an average of 248 m³ per hectare of forest land. However, a downward trend, which started in 2022, is expected, primarily due to the cyclical nature of the uneven age composition of forests. This decline is projected to be more pronounced for coniferous trees and more moderate for deciduous trees. The distribution of wood stock by age classes (where one age class equals 10 years) in Slovakia's forests is shown in Table 1.

Table 1 Timber resources according to age classes of Slovakian forests. Source: [13]

Age Class of Forest Stand	Millions m^3
1	0.1
2	1.6
3	7.2
4	15.9
5	30.5
6	29.8
7	28.7
8	41
9	49.2
10	43.3
11	38.5
12	34.3
13	19.7
14	7.9
15+	5.9

The distribution of wood stock is highly uneven across individual regions (Table 2), largely correlating with the forest cover in each region. The Banská Bystrica Self-Governing Region has the highest supply. Since 2010, the Prešov Region has seen the most significant growth in forest stock, with an increase of 10.4 million m³.

Table 2 Timber resources according to Slovakian Self-Governing Regions. Source: [13]

Self-Governing Region	Thousands m^3
Banská Bystrica	115574
Prešov	97826
Žilina	94572
Košice	63802
Trenčín	59334
Nitra	19361
Bratislava	17112
Trnava	15261

In contrast, the largest decrease occurred in the Žilina Self-Governing Region, particularly due to the dominance of spruce in this area. The wood supply also declined in the Bratislava Region.

In the last year, total harvest amounted to 7.68 million m³ (3.70 million m³ of coniferous and 3.97 million m³ of deciduous). This was nearly 2 million m³ less than the planned harvesting volume. Of the total volume, assortments for energy use represented approximately 7.9%, equaling 608.5 thousand m³. Over the next ten years, a slight decrease in planned intentional harvesting is expected due to climate change and the gradual shift in the structure and age of forest stands in Slovakia. The planned harvesting volume for next year is 9.29 million m³, even considering a higher proportion of incidental felling. Of this, approximately 734.4 thousand m³ is expected to be used for energy purposes, based on the current share of biomass assortments.

3.2 Calculation of Costs for the Production of Wood Chips and their Transport

The costs of producing and transporting energy biomass to the consumer were evaluated across nine basic production technologies. Fig. 2 illustrates the percentage breakdown of individual costs for each technological variant. These costs represent average conditions, calculated for wood collection from stands with a 20-30% slope and a transport distance of 40 km. The lowest costs occur in the production of wood chips from the main felling at the removal site, followed by direct transport to the customer. In contrast, the cost of producing wood chips from tending felling is 50-60% higher due to the increased costs associated with logging and wood concentration. The most significant differences between the analyzed technological schemes are found in transport costs.

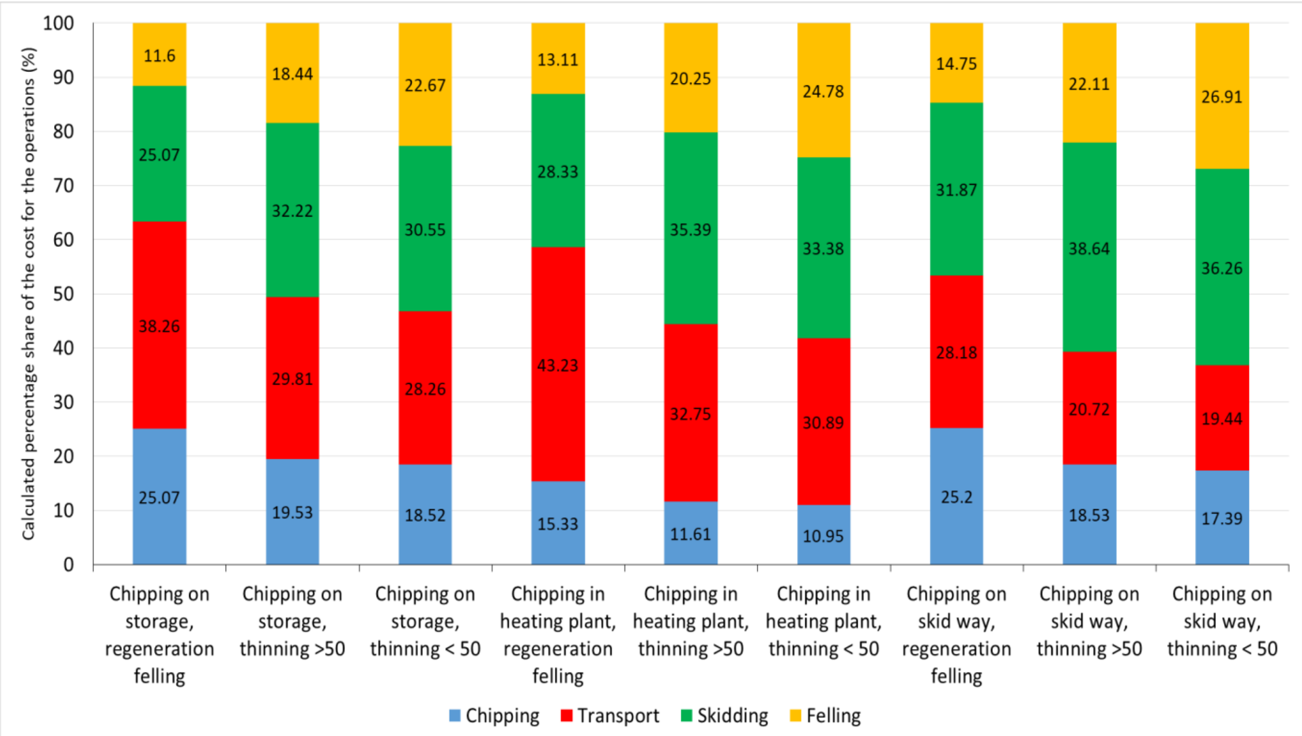

Fig. 2 Cost structure for the production and transport of wood chips in various technological alternatives. Source: the authors

They are the lowest when transporting biomass in the form of chips. Although the costs of chipping are lower when chipping is done at the supplier's central warehouse or directly at the customer's, this does not offset the higher costs of transporting uncut wood. When chipping, there are also increased costs for handling uncut wood and chips. Table 3 shows the calculated costs for the production of forest chips from main fellings from stands with slopes of 20-30% and their delivery to the heating plant using the analyzed technological schemes and for different transport distances. Here, too, it is clear that the lowest costs are in the production of chips at the skid way point and their direct transport to the consumer. It is also clear from the data that the longer the transport distance, the greater the differences in costs.

Table 3 Calculated costs of producing and transporting wood chips by different transport distances. Source: the authors

Distance to heating plant (km)	Chipping on storage (€.m^{-3})	Chipping in heating plant (€.m^{-3})	Chipping on skid way (€.m^{-3})
10	29.616	25.559	23.933
20	31.366	27.309	25.683
30	33.116	29.059	27.433
40	34.866	30.809	29.183
50	36.616	32.559	30.933
60	38.366	34.309	32.683
70	40.116	36.059	34.433
80	41.866	37.809	36.183
90	43.616	39.559	37.933
100	45.366	41.309	39.683
110	47.116	43.059	41.433
120	48.866	44.809	43.183
130	50.616	46.559	44.933
140	52.366	48.309	46.683

4. Discussion

Several domestic and international authors have explored the optimization of biomass supply for utilization plants. To optimize the cost function, a linear programming model was used to enhance logistics operations from biomass acquisition to its final use. This model also considered the costs associated with constructing and expanding storage, as well as the costs related to exceeding storage capacity and the loss of income due to biomass shortages [15]. Mitchell [16] notes that many models only focus on one aspect of the complex biomass supply issue. Our study aimed for a more comprehensive approach, particularly in terms of transport and the final processing of biomass for energy use.

Some studies incorporated models that address the work programs at biomass conversion sites, such as those for heat or electricity production. These studies demonstrated that the largest portion of total costs, ranging from 56-76%, is attributed to biomass logistics, which also offers the greatest potential for cost reduction [17-18]. Models that use multiple types of biomass have also aimed to reduce logistics and storage costs [19-20]. Our analysis found that the most significant cost reduction potential lies in the concentration and transportation of biomass, which is the largest cost component. The process of biomass conversion and whether we transport disintegrated biomass or tree parts also plays a crucial role.

It has been shown that it is most practical to assess local biomass sources alongside existing energy demand. A model designed to meet the average daily energy demand at a specific location using two biomass sources was proposed in [21].

In our previous study, we employed a mathematical iteration approach to address biomass transport logistics. This method proved relatively simple for determining the optimal transport variant when using trucks for various transport distances [8].

5. Conclusion

The logistics of securing biomass resources for energy use involve a range of complex issues [22]. This process is technically and technologically demanding, integrating multiple technical components and varying methods for handling extracted biomass [23]. Our study highlights a critical issue: the limited biomass resources, which are often overlooked in operational planning and the development of new capacities that use this renewable resource.

Regardless of production location or forest stand age, the largest cost component is the transportation of biomass to the consumption site, including concentration and transport. To achieve cost reduction, optimization efforts should focus primarily on these two aspects of the logistics chain. One potential solution is to disintegrate and produce forest chips directly at the removal site, followed by transport. However, our analysis indicates that this approach only results in minimal savings in transport costs.

A more effective strategy is to conduct a model analysis of the customer network and its requirements before biomass harvesting. This involves optimizing the network for transport routes and available resources using geoinformatics tools. Once the optimization structure is established, it is crucial to ensure operational functionality and a continuous biomass supply.

Acknowledgments

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