LogForum

> Scientific Journal of Logistics <

http://www.logforum.net p-ISSN 1895-2038 e-ISSN 1734-459X

2023, 19 (2), 295-302

http://doi.org/10.17270/J.LOG.2023.799

ORIGINAL PAPER

REVERSE SUPPLY CHAIN OF RESIDUAL WOOD BIOMASS

Arkadiusz Kawa

Łukasiewicz Research Network – Poznań Institute of Technology, Poznan, **Poland**

ABSTRACT. Background: Awareness of environmental or, more broadly, sustainable development is becoming an increasingly important issue, and questions of recycling and reuse have been getting more and more attention lately. Biomass is an important renewable resource and can take many forms, ranging from agricultural residues to food waste, forestry residues, and wood processing residues. A particular example is woody biomass such as forestry residues, wood-processing residues, or construction and municipal wastes that can be recycled and reused, providing a more environmentally friendly alternative to bioenergy production. This requires reverse supply chains in which the processes of collection, sorting, and transportation are efficient. The aim of this paper is to characterise the reverse supply chain of residual wood biomass and to indicate the main challenges related to it.

Methods: For the needs of the paper, the research was conducted using the methods of analysis of secondary and primary sources. The materials included data obtained from scientific papers, reports, studies, and internet sources. We conducted focus groups interviews (FGIs) in three cities in Poland.

Results: The article characterizes the details of the supply chain processes in woody biomass. Moreover, challenges, threats, and opportunities for reverse biomass supply chains are indicated.

Conclusions: Wood biomass can be derived from various residues and has a very wide range of industrial applications. Several factors must be considered when organising and conducting logistics processes for wood residues, such as origin, structure, and composition of woody biomass. The reverse supply chain of residual biomass consists of many different entities between which many different processes take place. The well-organized logistical and technological processes are vital parts of the supply chain because they result in size reduction, moisture adjustment, cleaning, fractionation, densification etc., which reduces transport and storage costs. There are many challenges related to biomass supply chains, e.g. the seasonality of biomass, the different requirements for handling and transport equipment, as well as storage space configuration.

Keywords: reverse supply chain; biomass; wood; residual wood

INTRODUCTION

In the past ten years, the EU countries have collectively produced between 40 and 60 million tonnes of wood waste yearly [Cocchi et al. 2019]. Recovery rates depend on both the country and the type of wood waste, but it can be seen that there is room for improving the current amounts [Garcia and Hora 2017]. This issue was recognized, and as a result, the amount of research dealing with residual wood biomass has increased over the past few years [Daian and Ozarska 2019].

Circular economy and sustainability of supply chains have received extremely relevant attention in the past years. Companies invest in optimizing their logistics processes and aim to reduce their environmental impact at the same time. These expenditures can reduce the companies' costs while also decreasing the amount of their environmental waste. One of the most important bottlenecks in increasing the use of biomass is the cost of logistics operations and technology for converting biomass into useful forms of energy. 20-50% of the cost of biomass supply is due to transport and handling operations [Rentizelas et al. 2019].

While the studies of the availability, life cycle, potential reuse of wood waste, and backward biomass streams [Sharma et al. 2013, Nunes 2020] have become more widespread in

Citation: *Kawa A., 2023. Reverse supply chain of residual wood biomass. LogForum 19 (2), 295-302,* http://doi.org/10.17270/J.LOG.2023.799

Received: 21.12.2022, Accepted: 06.06.2023, on-line: 02.07.2023

the past few years, the papers dealing with processes in reverse supply chains of residual wood biomass are still scarce [Sokhansanj and Hess 2009]. A brief analysis of the leading databases with the most important publications confirmed this. A search using the keywords "biomass" and "supply chain" or "logistics" in the Emerald database revealed 308 articles, in Sciencedirect (Elsevier) – 3517, and in Taylor & Francis – 431. Additionally, the keyword combination: "wood biomass" and "supply chain" or "logistics" gave the following results: 2, 166, and 17, respectively. When combined with the notion of a reverse process ("wood biomass" and "reverse supply chain" or "reverse logistics"), the results were even weaker: 1, 0, and 0.

The reverse supply chain redesign problem for wood waste from the construction industry was investigated in Trochu et al. [2018], and a MILP (mixed integer linear programming) model was proposed as its solution. A use-case on a scenario from Quebec, Canada, was also presented. In turn, Kot, S., & Ślusarczyk, B. [2013] drew attention to the relationship between the location of the biomass sources, the organization of the supply chain, and the economic and ecological results of energy production. Moreover, they analyzed the different biomass delivery methods [4]. There are also some works on biomass storage problems in the supply chain [Allen et al. 1998, Tatsiopoulos, Tolis 2003].

However, articles on circular economy are more numerous. For example, Araujo et al. [2019] assessed the literature on circular economy in wood panel production. The conclusion was that while circular economy as a concept was being investigated with regard to waste production in this sector, LCA (life cycle assessment) studies had mainly been carried out [Kim, Song 2013]. Daian and Ozarska [2009] studied a sample group of six SMEs in the wood furniture sector of Australia and collected data about the current state of their wood waste and its reuse, recycling and disposal. Based on this, they formulated suggestions for wood waste management. Studies comparing wood waste management in selected European countries were also conducted by Garcia and Hora [2017] and the BioReg Project [2017].

A good example of a business dedicated to circular economy is the global home-furnishing company IKEA. It was announced that they would develop circular capabilities in all their products by 2030 [2022]. This means that they would use only renewable or recycled materials, as well as give their products a longer lifespan through reuse, refurbishment, remanufacturing, and recycling. Evaluating the availability of residual wood biomass is also becoming more and more important, which can be seen from the multiple recent studies that have dealt with this issue. Research by Verkerk et al. [2019] and Borzecki et al. [2018] assessed the potential availability of forest biomass from European forests and its spatial distribution, focusing on the biomass hotspots.

Given the indicated scarcity of the research on reverse supply chains for woody bio-mass, the aim of this article is to characterise the reverse supply chain of residual wood biomass and to indicate the main challenges related to it.

RESEARCH METHODOLOGY

The research presented in this paper was carried out for a project which aims to develop a model of reverse supply chain of residual wood biomass. Achievement thereof is possible by conducting several stages of research, consisting of a literature review, empirical studies, and mathematical modelling. The empirical research was divided into two parts: research using a qualitative method and research using a quantitative one. The former aimed to analyse the issues related to the reverse supply chain of residual wood biomass and to provide information necessary for the appropriate design of the quantitative research, including, above all, the design of a survey questionnaire. This article uses the former type of research. A focus group interview (FGI) was applied as a technique for collecting information. Like other qualitative methods, it does not need to be conducted on representative samples of the population. For this reason, the selection of respondents for the study was purposive. The main criterion was to ensure that the participants were as diverse as possible in terms of experience. In addition, each participant in the study had to meet the condition of being familiar with the topic of residual wood biomass.

In July 2022, we conducted FGIs in three cities in Poland using questionnaires concerning working in companies related to the wood industry, sawmills, or involved in handling and recycling. The sample size was three groups, each of which consisted of 7 people.

The interview was conducted according to a prepared scenario, which was based on a literature analysis and collaboration with experts in wood (3 people) and logistics and supply chains (3 people). As a result, a scenario was prepared which consisted of questions and tasks for the respondents. The tasks were divided into 2 main parts, which, in turn, included several tasks: sources and uses of residual wood biomass (forms, sources, and use of residual wood biomass), reverse supply chain (essence, processes, actors, and problems). Some of these were carried out independently in order to activate all participants in the study, whereas others required joint effort in order to achieve synergies.

In the following part of the article, selected conclusions from the research have been presented. At the same time, their reference to the literature on the issues discussed has been shown.

WOODY BIOMASS

Wood is a raw material that has been used by humans almost since time immemorial. This is because it is relatively easy to obtain compared to other raw materials. Its wide range of applications is impressive. In fact, it is difficult to imagine industry and our daily life without it. Generally speaking, it is a raw material that is obtained from felled trees and shaped differently by processing. It also has other very important properties. Wood is a renewable, reusable, and recyclable material. Wood waste can therefore be reused and minimise the negative impact on the climate and the environment [Burnard et al. 2015].

Wood is one of the key elements of biomass. It accounts for around half of the European Union's total renewable energy consumption [Burnard et al. 2015]. Biomass has received a great deal of definitions. It is understood as "any organic material derived directly or indirectly from the process of photosynthesis by plants and algae, except for fossilized materials" [da Silva et al. 2018]. The range of possible uses for biomass is quite wide due to the very many existing materials that fit this definition [da Silva et al. 2018]. Another says that it "is one of the renewable energy sources on which policy makers are greatly based to reduce the greenhouse gas emissions" [Rentizelas et al. 2009]. The former definition focuses on the sources of biomass, while the latter emphasises the use of biomass.

Wood biomass can be derived from various residues. The respondents surveyed during the FGIs identified a number of these, which can be classified into three groups: agricultural and forestry residues, post-production residues, and post-consumer wood. In turn, the above can be divided into further categories [Kot, Ślusarczyk 2013, Burnard et al. 2015]:

1. Agriculture and forestry wood residues
   a. Stumpwood
   b. Forest chips
   c. Bark
2. Post-production residues
   a. Solid piece production residues
   b. Wood-based piece production residues
   c. Sawdust and chips
   d. Wood dust
   e. Bark as post-production waste
3. Post-consumer wood
   a. Wooden packaging
   b. Wooden elements of window and frame-woodwork
   c. Wooden interior elements
   d. Furniture / furniture elements
   e. Wooden waste from buildings and structures demolition
   f. Wooden elements of infrastructure/small architecture objects
   g. Wooden auxiliary elements for construction work

Biomass has a very wide range of industrial applications, and the respondents surveyed during the FGIs identified many of them. They can be classified according to use for, among others: production of wood materials, wood products, energy carriers, pharmaceuticals, cosmetics, chemical products, and even clothing and footwear [Tripathi et al. 2019, Khoddami et al. 2021]. Wood biomass is most commonly used for energy and particleboard production. However, according to European projects examining the topic (e.g. DEMOWOOD 2015, CaReWood 2015; FPS COST Action E31 2011), there is great potential to expand wood recovery for [Burnard et al. 2015] other uses [Khoddami et al. 2021].

The classifications indicated show that biomass has very different origins and uses. This poses major challenges for logistics [Kot, Ślusarczyk 2013].

REVERSE SUPPLY CHAIN

Reverse logistics and supply chain are fairly well-recognised concepts in the literature. There are several different definitions of reverse logistics. It is often referred to as the direction of the flow: “the process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal" [Burnard et al. 2015]. Another approach pays attention to the type of thing that is the subject of the flow. It is “the continuous logistic process through which used products move from the consumer back to the producer or recycling enterprises” [Burnard et al. 2015].

The main goal of reverse logistics is to recover the value of returned materials or provide the means to dispose of them properly [Burnard et al. 2015]. It can be integrated with the traditional process of supply chain to guarantee both forward and reverse flows of resources (closed-loop supply chain) [Kazemi et al. 2019].

The reverse supply chain of residual biomass consists of many different entities. According to the respondents surveyed and literature [Rentizelas et al. 2009, Tripathi et al. 2019], the most common ones include:

1. Sawmills
2. Manufacturers of wood-based panels
3. Woodwork manufacturers
4. Manufacturers of wooden houses
5. Manufacturers of wooden packaging
6. Manufacturers of flooring materials
7. Furniture manufacturers
8. Cellulose plants
9. Recycling companies
10. Demolition companies
11. Transportation and logistics companies
12. Municipal waste collection companies
13. Land reclamation companies
14. Distributors of materials and/or final wood products

Many different processes take place between the actors indicated. Reverse logistics processes involved in residues according to the respondents surveyed and literature [Rentizelas et al. 2009, Burnard et al. 2015, Dekker et al. 2004] are as follows:

1. Field/forest transportation
2. Transportation (road, rail, sea, etc.)
3. Transshipment
4. Identification and marking/labeling of the type of raw material/wood biomass residue and product
5. Storage/warehousing

They refer to the processes throughout the handling of the raw material – both in-house and those outsourced to other companies.

In addition to the logistical processes, technological ones can be distinguished, which are closely related to the former. They are [Rentizelas et al. 2009, Burnard et al. 2015]:

1. Quality control
2. Sorting/selection
3. Drying
4. Cleaning
5. Processing
6. Composting
7. Combustion with energy recovery
8. Disposal

Both logistical and technological processes are vital parts of the supply chain because they result in size reduction, moisture adjustment, cleaning, fractionation, densification etc., which reduce transport and storage costs [Sokhansanj, Hess 2009].

Each of the logistics processes identified is important, but from the cost point of view, transport and storage are key issues [Rentizelas et al. 2009, Sokhansanj, Hess 2009, Kot, Ślusarczyk 2013]. In the case of transport, a distinction is made between short and long-distance transport. The former involves transport at the location of the biomass [Sokhansanj, Hess 2009]. Road transport is most often chosen because it is most flexible and has the greatest accessibility (a car can go almost anywhere, such as fields or forests). Heavy goods vehicles [Allen et al. 1998, Huisman et al. 1997] and agricultural/forestry equipment [Rentizelas et al. 2009, Tatsiopoulos, Tolis 2003] are primarily used here. When biomass needs to be transported over longer distances, it is done by other transport means, such as ship or train. Road transport is also used here, particularly when delivery times are important [Hamelinck et al. 2004]. While biomass is no more challenging than other things as far as transport is concerned, the situation is more complicated in the case of storage. Biomass is very often seasonal, i.e. it is produced at a specific time, e.g. after harvesting or felling. Due to the different forms of woody biomass residues, a different configuration of storage space is often required. Sometimes drying, cleaning, or composting processes are required. This creates a need for a storage point located on the farm or in the forest. They may then be stored at an intermediate site or with recycling companies, distributors of materials, and final products or other entities [Rentizelas et al. 2009].

Several factors must be considered when organising and conducting logistics processes for wood residues. According to the respondents surveyed, among the most important ones are the following:

- sources and sourcing of woody biomass residues (e.g. type of raw material supplier and number of receiving locations)
- origin, structure, and composition of woody biomass residue (e.g. contamination with post-consumer elements, chemical content, and presence of metals)
- required moisture content of the woody biomass residue and/or product
- required temperature of the woody biomass residue and/or product
- physical form of the woody biomass residue (dimensions, volume, weight, etc.)
- degree of risk of ignition of the woody biomass residue

CHALLENGES, THREATS AND OPPORTUNITIES FOR REVERSE BIOMASS SUPPLY CHAINS

In addition to the aforementioned seasonality of biomass and the different requirements for handling and transport equipment, as well as storage space configuration, other challenges of biomass supply chains can be distinguished. According to the respondents surveyed and literature [Kot, Ślusarczyk, 2013, Burnard et al. 2015], these include:

- large variety of types and forms of woody biomass residues
- high dispersion of woody biomass residues sites
- low utilisation value, low quality of woody biomass residues
- high purchase price of woody biomass residues
- high cleaning and processing costs of woody biomass residues
- relatively high cost of transport, handling, and storage of woody biomass residues
- lack of an information system on the availability of woody biomass residues
- high and very different requirements for combustion equipment with energy recovery
- low awareness (among producers and the community) of the potential for reuse of woody biomass residues
- In addition, many countries lack systemic and institutional solutions for the recovery of woody biomass residues, especially post-consumer wood, and a national classification of woody biomass residues to guide its use.

The situation in the wood biomass supply chain has been complicated by various events such as the pandemic, the war in Ukraine, and high inflation. As a result, a number of distinctions can be made here:

- problems with access to timber (e.g. harvesting restrictions)
- increase in timber prices
- increase in labour costs

- limited availability of staff with the required skills
- increase in transport costs (e.g. increase in fuel costs, vehicles, drivers' salaries)
- increase in processing costs (e.g. high energy costs)
- limited investment opportunities (e.g. lack of access to funds for infrastructure purchase)
- lack or long lead times for delivery of parts and equipment

Despite the current complex economic and social situation, it is worth identifying opportunities for reverse supply chains for woody biomass residues, namely:

- increasing the share of wood biomass in energy production
- innovative technologies and products using recycled wood raw material
- the development of a collection and recycling system for wood waste, especially post-consumer wood waste
- legislative changes to promote recycling, including putting into practice the classification of wood waste for recycling
- education of the community on the environmental benefits of wood products
- improvement/development of the EU's environmental policy and creation of new growth opportunities for wood biomass products
- new markets after the end of the war (reconstruction of Ukraine)
- introduction of segregation of waste from construction
- limiting (in some areas) the substitution of wood by its non-wood (less environmentally friendly) equivalents
- search for new possibilities and unique solutions in architectural design which take into account environmental aspects
- striving to reduce the unit cost of production by maximising the use of the raw material

CONCLUDING REMARKS

The management of residual wood biomass is an important field, and not many studies have dealt with the reverse supply chain. There are multiple problem classes that can be studied in the reverse logistics processes of wood. Optimizing the activities of this supply chain and identifying their special characteristics is a relevant issue both for reducing the environmental impact and for increasing the efficiency and profit of companies.

The goal of this paper was to identify the processes in the woody biomass supply chain and to indicate the main challenges and opportunities facing it. The conclusions in the article can therefore be regarded as a kind of state of the art. The next step will be to conduct empirical research in the form of computer-assisted telephone interviews (CATI). The results of such a study will allow new phenomena to be confirmed or rejected in the form of research hypotheses. Next, we plan to develop efficient models for the problems that will be investigated. There is a need for a study of reverse logistics problems connected to residual wood biomass and the development of efficient optimization algorithms for these problems. This is usually a very hard task for new domains, and innovative ideas for modeling will be needed. The optimisation of activities in this supply chain and the identification of their specific characteristics is an important issue both from the point of view of reducing environmental impacts and for increasing the productivity and performance of wood biomass businesses.

ACKNOWLEDGMENT

This paper has been written with financial support of the National Center of Science [Narodowe Centrum Nauki] – grant number DEC-2020/39/I/HS4/03533.

REFERENCES

Allen, J., Browne, M., Hunter, A., Boyd, J., & Palmer, H. (1998). Logistics management and costs of biomass fuel supply. International Journal of Physical Distribution & Logistics Management. https://doi.org/10.1108/09600039810245120

Borzecki, K, Pudelko, R., Kozak, M., Borzecka, & M, Faber, A (2018).. Spatial distribution of wood waste in Europe. Sylwan, 162:563–571, 2018. https://doi.org/10.26202/sylwan.2018008

Burnard, M., Tavzes, Č., Tošić, A., Brodnik, A., & Kutnar, A. (2015). The role of reverse logistics in recycling of wood products. In Environmental implications of recycling and recycled products (pp. 1-30). Springer, Singapore. http://doi.org/10.1007/978-981-287-643-0_1

Carlos A. Garcia and Guido Hora. State-of-the-art of waste wood supply chain in Germany and selected european countries. Waste Management, 70:189 – 197, 2017. https://doi.org/10.1016/j.wasman.2017.09.025

Cocchi, M., Vargas, M. & Tokacova K., State of the art technical report. Technical report, Absorbing the Potential of Wood Waste in EU Regions and Industrial Biobased Ecosystems — BioReg, 2019.

da Silva, C. M. S., Carneiro, A. D. C. O., Vital, B. R., Figueiró, C. G., de Freitas Fialho, L., de Magalhães, M. A., ... & Cândido, W. L. (2018). Biomass torrefaction for energy purposes–Definitions and an overview of challenges and opportunities in Brazil. Renewable and Sustainable Energy Reviews, 82, 2426-2432. https://doi.org/10.1016/j.rser.2017.08.095

Daian, G., & Ozarska, B. (2009). Wood waste management practices and strategies to increase sustainability standards in the Australian wooden furniture manufacturing sector. Journal of Cleaner Production, 17(17), 1594-1602. https://doi.org/10.1016/j.jclepro.2009.07.008

de Carvalho Araújo, C. K., Salvador, R., Moro Piekarski, C., Sokulski, C. C., de Francisco, A. C., & de Carvalho Araújo Camargo, S. K. (2019). Circular economy practices on wood panels: a bibliographic analysis. Sustainability, 11(4), 1057. https://doi.org/10.3390/su11041057

Dekker, R., Fleischmann, M., Inderfurth, K., & van Wassenhove, L. N. (Eds.). (2004). Reverse logistics: quantitative models for closed-loop supply chains. Springer Science & Business Media. https://doi.org/10.1007/978-3-540-24803-3

Hamelinck, C. N., Suurs, R. A. A., & Faaij, A. P. C. (2004, May). Large scale and long distance biomass supply chains: logistics, costs, energy consumption, emission balances. In 2nd World Conference on Biomass for Energy.

Huisman W, Venturi P, Molenaar J. Costs of supply chains of Miscanthus giganteus. Ind Crops Prod 1997;6:353–66. https://doi.org/10.1016/S0926-6690(97)00026-5

Md. Uzzal Hossain and Chi Sun Poon. Comparative lca of wood waste management strategies generated from building construction activities. Journal of Cleaner Production, 177:387 – 397, 2018. https://doi.org/10.1016/j.jclepro.2017.12.233

IKEA. Our view on inspiring a circular mindset. https://newsroom.inter.ikea.com/aboutus/our-view-on-inspiring-a-circular-mindset/s/b813c66f-2e9e-4bf6-bcd9-9409ab471f87.

Kazemi, N., Modak, N. M., & Govindan, K. (2019). A review of reverse logistics and closed loop supply chain management studies published in IJPR: a bibliometric and content analysis. International Journal of Production Research, 57(15-16), 4937-4960. http://doi.org/10.1080/00207543.2018.1471244

Khoddami, S., Mafakheri, F., & Zeng, Y. (2021). A System Dynamics Approach to Comparative Analysis of Biomass Supply Chain Coordination Strategies. Energies, 14(10), 2808. https://doi.org/10.3390/en14102808

Kim, M. H., & Song, H. B. (2014). Analysis of the global warming potential for wood waste recycling systems. Journal of Cleaner Production, 69, 199-207. http://doi.org/10.1016/j.jclepro.2014.01.039

Kot, S., & Ślusarczyk, B. (2013). Aspects of Logistics in Biomass Supply for Energy Production. In Applied Mechanics and Materials (Vol. 309, pp. 206-212). Trans Tech Publications Ltd. http://doi.org/10.4028/www.scientific.net/AMM.309.206

Nunes, L. J. R., Causer, T. P., & Ciolkosz, D. (2020). Biomass for energy: A review on supply chain management models. Renewable and Sustainable Energy Reviews, 120, 109658. https://doi.org/10.1016/j.rser.2019.109658

Rentizelas, A. A., Tolis, A. J., & Tatsiopoulos, I. P. (2009). Logistics issues of biomass: The storage problem and the multi-biomass supply chain. Renewable and sustainable energy reviews, 13(4), 887-894. http://doi.org/10.1016/j.rser.2008.01.003

Sharma, B., Ingalls, R. G., Jones, C. L., & Khanchi, A. (2013). Biomass supply chain design and analysis: Basis, overview, modeling, challenges, and future. Renewable and Sustainable Energy Reviews, 24, 608-627. https://doi.org/10.1016/j.rser.2013.03.049

Sokhansanj, S., & Hess, J. R. (2009). Biomass supply logistics and infrastructure. Biofuels, 1-25. http://doi.org/10.1007/978-1-60761-214-8_1

Tatsiopoulos IP, Tolis AJ. Economic aspects of the cotton-stalk biomass logistics and comparison of supply chain methods. Biomass Bioenergy 2003;24:199–214. https://doi.org/10.1016/S0961-9534(02)00115-0

Tripathi, N., Hills, C. D., Singh, R. S., & Atkinson, C. J. (2019). Biomass waste utilisation in low-carbon products: harnessing a major potential resource. NPJ climate and atmospheric science, 2(1), 1-10. http://doi.org/10.1038/s41612-019-0093-5

Trochu, J., Chaabane, A., & Ouhimmou, M. (2018). Reverse logistics network redesign under uncertainty for wood waste in the CRD industry. Resources, Conservation and Recycling, 128, 32-47. https://doi.org/10.1016/j.resconrec.2017.09.011

Verkerk, P. J., Fitzgerald, J. B., Datta, P., Dees, M., Hengeveld, G. M., Lindner, M., & Zudin, S. (2019). Spatial distribution of the potential forest biomass availability in Europe. Forest Ecosystems, 6(1), 1-11. https://doi.org/10.1186/s40663-019-0163-5

Arkadiusz Kawa ORCID ID: https://orcid.org/0000-0003-0697-8838
Łukasiewicz Research Network,
Poznań Institute of Technology, Poznan, **Poland**
e-mail: arkadiusza.kawa@pit.lukasiewicz.gov.pl