Chapter 18
Wood-Based Waste Management—Important Resources for Construction of the Built Environment

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Abstract The circular economy focuses on the utilisation of resources and the reutilisation of these resources and waste streams into value added products. Wood as a renewable resources represent one of the most important advantage of the forest based industry and all related industries. These sectors aim on the sustainable wood and different wood products production and utilisation, wood buildings including. Improved utilization of available industrial wood assortments and utilisation of wood waste to added value products generate profit for all actors in the supply chain. Analysis of wood flows take into account not only the uses of wood as a material, but also by-products and waste generated by the production to be used as inputs for further uses in construction, wood processing or energy sectors. This paper deals with the analysis of raw wood flows in Slovakia with a focus on wood-based waste management, utilisation of wood waste for long term wood products in the built environment. At the present time new approaches such as cascade use of woody biomass can be applied to ensure the sustainable utilisation of renewable resources. The material flow analysis (MFA)was used to identify relations between the resources and primary uses of wood. In particular the results show some particular examples of wood flows focused on possibilities of utilisation of wood waste from the wood processing industry (WPI) and recycled wood in the construction sector.

Keywords Construction · Wood-based Waste · Wood Flow Analysis · Cascading Factor · Environment · Slovakia

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18.1 Introduction

The path of raw wood material from its production to giving the final product to a consumer is relatively long, as it passes several stages of production and different types of markets until the final product fulfils the needs of the consumers. Before reaching the end-user, these stages include leaving the forest, primary wood processing, secondary wood processing, and subsequent wood-using industries. Within these stages, raw wood material is transformed into primary processed intermediate products (sawn wood, pulp), secondary processed products (furniture, construction, and joinery), and then has a role in the final production of different industries related to the use of wood (e.g., construction).

The economic growth of any national economy depends largely on the many different factors as, strength, competitiveness, effectiveness and investment attractiveness of the industry. In the last decades there are new challenges, such as transformation and adaptation to the new demands from the construction sector characterised by the process of globalisation, an extremely competitive business environment and new technologies and innovations. Therefore, wood consumption must be assumed and coordinated with the demand for traditional as well as innovative products. A lot of studies [1–3] assume increasing demand for wood in the European Union (EU) mainly due to an expected increase of energy consumption of the renewable resources. Thanks to new technologies and innovative products new opportunities of wood utilization are created in the building industry. It is necessary to take into account the fact that the wood processing industry (WPI) also produces significant amounts of wood residues (30–50% of the volume of processed wood), which can be used for industry purposes. Morover, the construction sector has been the primary consumer of sawn wood and other solid-wood products [4]. From this perspective, it is important to prefer outputs with higher added value, creating jobs and contributing to a better carbon balance (resource efficiency).

18.1.1 Wood in Construction

The construction industry is one of the most significant producers of waste in any given economy. In fact, construction is responsible for more waste globally than any other single area of economic activity. However, waste in construction has traditionally been considered as an inevitable by-product that is usually managed from a health and safety perspective rather than with recycling in mind [5]. According to a study in the United Kingdom, about 10 to 15 per cent of the wood used in new construction ends up in recycling. This statistic is a concern to policymakers, who observe that the recycling rate for construction and demolition (C&D) derived wood is considerably lower than for other C&D materials such as concrete (82 per cent) and structural steel (98 per cent) [6]. This suggests that there is considerable work to be done to make the construction sector more circular, including the use

of waste wood as a part of a broader system loop [7, 8]. To facilitate more post-construction wood re-entering the supply chain, systemic developments are needed to enhance sorting, separation and recovery options through, for example, more efficient recycling during demolition so that wood waste can be cycled back at the end-of-life stage to other industrial processes. Moving away from the business-as-usual approach would furthermore require cross-cutting and networked systems with stronger collaboration between business ecosystems (e.g., municipalities, architects, designers, builders and inhabitants.

Another approach to improve the circularity of the construction sector relates to the design and detailing of mass timber buildings for greater durability, including measures to hold materials in place for longer, prolong the lifespan of wood to reduce the demand for new materials and standardize modular wood construction elements that could be re-used and recycled more easily. This requires that the wood's entire life cycle (from primary to tertiary processing) is taken into account when constructing new buildings to allow for more efficient usage of side products (e.g., recovered wood).

18.1.2 Circularity Concepts in Forest-Based Industries

A circular economy refers to a wide range of materials and processes, both in the technical and biological cycle of the economy. As an example, wood may enter the technical cycle when it is combined with technical materials in the construction of buildings.

The term "value chain" entails a series of manufacturing steps that link raw materials to final products through different sub-sectors of an industrial or economic sector. A value chain can vary in scale from being local to global and the range of activities along the value chain may be implemented by different actors, such as resource extractors, processors, traders, retailers and service providers. Each sub-sector (e.g., furniture manufacturing or construction) could be described as a distinct value chain, however, processing steps in different product groups downstream often have common sources upstream [9].

18.1.3 Analysis of Wood Flows—Theoretical Approach

Material flow analysis (MFA) was used to reveal and quantify relations between the resources and the primary uses of wood. EUROSTAT [10] distinguishes and explains the three basic dimensions of material flows: territorial dimension, product chain or life cycle dimension and the product dimension. Different approaches to material flow analysis and modelling have been used by e.g. [11–14]. The analysis of material flows can be also used as an analytical and modelling tool for different areas and sectors e.g., material balances of corporations and urban regions in industrialised countries [15],

regional wood management [16], and the generation of waste in regional systems [17].

The analysis of wood flows enables one to determine a balance between the production and the use of wood in the country. The analysis results reveal relationships between the production, quality, and availability of data, the balance of foreign trade, and the importance of wood in domestic consumption. Wood flow analysis is focused on all uses of wood and takes into account by-products and waste generated by processing the material input for further use. Both sides of the balance, the resources and the use side, are specific, as they incorporate different markets and products; therefore, it is necessary to examine each side individually. The overall structure of the balance is not constant and may vary depending on the uses of wood and wood products. In most cases, the balance includes such uses of wood for which there are no official statistics available, and the total consumption therefore cannot be simply calculated. Consequently, the consumption of wood may be much higher than indicated by official statistics [18].

18.1.4 Concept of Cascading Use of Wood Products

The utilization of wood for building industry represent optimal solution from an economic, as well as, an environmental point of view. A different way of potential wood and wood residues utilization in the value chain is described in the concept of cascading use of wood products. The final and optimal use of wood, both from an economic point of view and from the point of view of binding carbon dioxide (CO_2), is precisely in the construction industry. A cascade use can be defined as multiple use of the wood from trees by using residues, recycling (utilization in production) resources or recovered (collected after consumption) resources [19, 20]. The more often by products and recycling products are used the higher the cascade factor gets. Cascade principle means to use wood in an effort to increase added value of wood raw material from forests. It also means that wood should be primary used in the construction, furniture or other products with a long life cycle and energy should primarily be generated from waste or recycled products. In this sense we consider energy uses of wood as the least preferred way of utilization. The concept of cascading use of biomass can be defined as cascading in function. It is actually co-production, which can be achieved by using bio-refinery. Co-production is the production of different functional streams (e.g. protein, oil and energy) from one biomass stream, maximizing total functional use. Of course, after cascading in function, cascading in value or time follows. The cascading in time meaning that the life span of biomass use is increased (e.g. paper recycling). Another approach can also be defined as 'cascading in value' meaning that the maximum value of the whole life cycle of biomass is gained through optimizing the use of biomass for multiple services [21].

The main objective of the study is the identification of raw wood flows in Slovakia with a focus on utilisation of wood waste for long term wood products in the built environment. To follow above mention aim the re-search applied the concept of

cascading to optimise the use of wood in the chain of its processing. The approach was applied to identify relations between the re-sources and primary uses of wood focused on possibilities of utilisa-tion of wood waste from the WPI and recycled wood in the construction sector.

18.2 Methodological Approach

The domestic wood processing industry in the Slovak Republic is the major customer of the products of the forestry sector, and roundwood represents the main material input for this sector [22]. Similar links exist between the wood processing industry and other sectors that are dependent on wood products. MFA can be used for the quantification and modelling of wood flows. The analysis process includes the gathering of information and requires market experience and recognition of mutual relations in the "forest—wood—end-user" chain.

A single wood balance presents a global view of the resources and primary uses of roundwood in Slovakia. The main categories of resources are represented by the domestic roundwood production and imports, and the main uses by the domestic roundwood consumption and exports. The resource side is complemented by the recycled material and stock decrease, and the use side by the stocks increase. An increase in stocks causes a decrease in consumption, and vice-versa. The availability and consistency of data represent a limiting factor for the construction of the wood balance. Available data for 2021 from the FAOSTAT database [23] and the reports on forestry in Slovakia [24] were used. To achieve the state of wood balance, the resources should equal the uses. However, there were no data available on domestic consumption; therefore, it was deducted from the volumes of roundwood production and foreign trade.

Unlike the wood balance, which takes into account only uses of wood as a material, the wood resource balance is focused on different uses within the internal environment of the sector. The wood resource balance provides a detailed analysis of wood and wood products flows which has been done by survey. First of all, it takes into consideration by-products and waste generated by the production for use as inputs in wood processing or in the energy sector. The main categories of resources are (i) forest woody biomass, (ii) used material, (iii) other woody biomass, (iv) wood processing residues and (v) processed wood fuel. The main categories of uses consist of (i) wood processing industry (material stream) and (ii) energy use (waste stream). The analysis focuses on wood waste streams that can subsequently be used for the construction industry.

The quality of the final wood resource balance depends directly on the quality and availability of data on wood production and use in individual sectors. Generally, the availability of data on consumption is usually poor, and detailed data do not exist. Empirical research and expert estimations based on the available production data are commonly used to obtain the missing data. Under current conditions, wood resource balance data can be compiled as a mix of officially published and empirically

collected data. Official statistics are available for highly concentrated sectors such as the pulp and paper industry. However, certain sectors of the wood processing industry and building sector, such as the sawmill industry, are poorly concentrated; thus, access to data is complicated. Therefore, to estimate the material flows the main streams of primary wood processing and utilisation were only considered, in particular sawmilling industry, veneer and plywood production, particleboard and fibre board production, processed wood fuel, pulp and paper industry, energy. To quantify flows and balances in a single measurement unit meter cubic (m^3), the UNECE/FAO [6] official input/output ratios for Slovakia were used. The flow of wood as raw material and flow of wood residues as a waste from the process of wood products production was identified separately. The flow of wood residues was complemented by recycled wood and paper (post-consumer material). Wood as an elementary input comes from domestic sources (forest) and from the import. The production of roundwood was analysed in the structure corresponding to the main groups of assortments in terms of their use and quality (logs, pulpwood and energy wood). The concept of cascading is focused on the domestic utilization and therefore it was necessary to estimate the domestic consumption (apparent consumption). The presented paper describe of primary wood processing flows, which generates a key by-products (waste) for cascade utilization of wood. Based on wood balance of the available resources and the description of wood flows it was possible to describe and quantify the cascade use of wood. Cascade use is defined as multiple use of wood from the forest with wood residues from the forest industry. The more times the industrial residues and by-products are produced during processing of wood the higher factor cascade gain. The sectors of WPI in Slovakia are interconnected. For example, the waste from sawmills is used for industrial purpose (use in the production of wood base panels and pulp), as well as a source of energy (the production of end products such as pellets or briquettes). It can be also used outside the WPI for the production of energy in other sectors, heating plants and households. In case that the inputs to the process is only roundwood without additional other sources, the cascade factor takes the value 1.00 [3]. The cascading factor (CF) is calculated using the following Eqs. (18.1, 18.2) taken from Mantau [6, 25]:

$$Cascade = RW + IR \tag{18.1}$$

where: RW—recycled wood and paper, IR—industrial residues.

$$CF = 1 + {}^{Cascade}/_{WR_{forest}} \tag{18.2}$$

where: WRforest is wood resources from forest.

18.3 Quantification of Wood Flows for Construction Sector in Slovakia

The volume of domestic consumption (9.59 mil. m^3) was deducted from the volumes of roundwood production and foreign trade. Wood balance presents a global view on the resources and primary uses of roundwood in Slovakia and is illustrated in following Table 18.1. Due to unavailability of data it does not consider the stock changes.

Wood balance is mainly oriented to estimate domestic consumption regardless the further use of wood and, unlike wood resource balance, it considers foreign trade in wood products. Logs are mainly processed by sawmills and only a smaller proportion is consumed by plywood or veneer producers. As a paradox, in spite of a higher composition of broadleaved forests in Slovakia coniferous logs are the main raw material used by sawmills. Non-coniferous pulp wood and other industrial roundwood is mainly used by pulp and paper industry. Results of the wood resource analysis show that the total domestic resources were 7.23 mil. m^3 roundwood (Table 18.1.). However, except of roundwood the resource side is supplemented by wood processing residues consisting mainly of sawmill residues and black liquor. The majority of residues was produced by the pulp and paper industry (black liquor 0.99 mil. m^3) and the rest was produced by sawmill industry—sawdust, chips and particles (0.89 mil. m^3). Total domestic supply includeing wood waste and black liquor were 9.5 mil. m^3 roundwood equivalents. The following Table 18.2 gives a summary of all domestic supplies and utilization.

Indirect wood flows can be expressed by a cascade factor, which considers the repeated use of wood originating on the use side and returning back to the resource side and vice versa. Considering the actual total consumption of wood and wood based inputs 9.5 mil. m^3 and the volume of wood supply from forest wood biomass 7.2 mil. m^3 (domestic wood resources) the value of cascade factor was 1.32.

Table 18.1 Domestic wood resources in Slovakia (m^3)

Wood resources		Use of wood	
Roundwood production	7 448 000		
Roundwood import	2 000 000	Roundwood export	2 290 000
Recycled paper	141 113		
		Domestic consumption	7 299 113
Total sources	**9 589 113**	**Total uses**	**9 589 113**

Sources Authors' own research, FAOSTAT 2023 [22] and Green Report 2022[23]

Table 18.2 Utilization of by-products derived from industrial wood processing in 2021

Wood based resources		m^3	Use	Use m^3	Production	
Forest woody biomass	Coniferous Logs	2 722 420	Coniferous Sawnwood	2 289 096	1 067 517 m^3	Wood processing Industry
			Non Coniferous Sawnwood	947 839	266 879 m^3	
	Non Coniferous Logs	951 839	Veneer, Plywood and other Large Boards Production	437 325	437 325 m^3	
	Pulp Wood and Other Industrial Wood	2 923 388	Particleboard and Fibre Board Production	1 138 644	882 487 m^3	
	Wood Fuel	560 352			3 299 t	
	Energy Wood and Logging Residues	47 125				
Recycled material	Post-Consumer Paper	141 113	Pulp and paper industry	2 310 188	1 238 430 t	
Industrial residues	Sawdust	254 585	Other Energy Wood	2 382 392	722 TJ	Energy Users
	Chips	472 543				
	Particles	166 950	Energy Use of Wood in Industry		12 536 TJ	
	Black liquor	988 467				
Processed wood fuel	Pellets, briquettes and others	276 702	Private Households		24 359 TJ	
Total		9 505 484	9 505 484			

* m^3-cubic meters, t-tons, TJ-Terajoule
Sources Authors' own research, FAOSTAT 2023 [22]

18.4 Discussion

Wood residues and by-products are produced during industrial processing of wood. The waste stream is represented by different types of waste generated during the logging operations (e.g., logging residues) as well as the waste generated during primary mechanical and chemical processing of wood (sawdust, chips, black liquor), which can be used either industrially or for the production of energy. The primary source of wood residues used for production of agglomerated wood-based panels, processed fuel wood, and energy generation is the sawmilling industry. Wood balance is primarily used to estimate domestic consumption, regardless of the further use of wood; unlike the wood resource balance, it considers foreign trade in wood

products. Taking into account roundwood classification, the wood resource balance distinguishes wood flows for individual sectors according to the intended use of assortments. Logs are primarily processed by sawmills, and only a small portion is consumed by plywood or veneer producers. As a paradox, in spite of the large proportion of broadleaved forests in Slovakia, coniferous logs are the primary raw material used by sawmills. Non-coniferous pulp wood and other industrial roundwood is used by the pulp and paper industry for the production of pulp, or alternatively for the production of particleboard and fibre board. The importance of wood for energy production has been increasing recently. Wood fuel is used for energy production in either internal or external facilities. At the same time, it represents a significant source for heat energy in households. Wood, which was traditionally utilised as material for the production of wood products, is presently in demand for energy production. The increasing direct or derived demand for energy wood causes an increase in energy wood prices. Wood cascading considers complete wood using cycle and recognizing the differences in wood flows. The concept of cascading can help to optimize the use of wood in the whole chain of its processing and utilization in Slovakia. Results of the analysis can help in many innovations to increase the efficiency of the cascade of wood processing for construction industry.

18.5 Conclusion

The utilisation of wood is continually changing, and the demand for roundwood is changing depending on the technologies and on the demand of final wood products. On one side, wood and wood products production is subject to available resources and has been recently influenced by the high proportion of accidental felling. On the other side, wood production tries to adapt to rapidly changing on the market. The applied concept of cascading can describe the actual consumption of wood in various forms. The outcome of the analysis of wood material flows and cascading concept in Slovakia go out the balance between the resources and the primary uses of wood and wood residues. The analysis describes in detail the relationships between resources (wood and waste), basic production indicators, foreign trade relations, and the use of raw wood material and waste in the domestic conditions. Main conclusions can be considered as follow:

- The wood market in Slovakia is permanently developing and the demand for roundwood is changing depending on the possibilities of its use. There are many specifics influencing production and consumption patterns at the domestic market. On one hand, timber production is subject to available resources, which are the result of long-term forest management and long-term planning.
- Timber production has been recently influenced by the high proportion of accidental felling. However, it tries to adapt to rapidly changing market conditions and requirements of wood processing sector that vary over a relatively short period of time.

- The applied material flow analysis can transparently reveal the actual consumption of wood in its various forms. Such an approach also allowed pointing out the vulnerability of revealed relationships occurring due to the limited wood resources and exiting regulative as well as supporting measures.

This analysis is a key base for improving the use of circular economy principles in the above wood base sectors and construction. Better use and knowledge of wood material flows may ensure production of higher added value products as well as to lead to cost reduction. Despite the fact that the research is given as a model for Slovakia at a certain point in time, the methodology and approach is applicable to different types of industries, as well as, countries at different times for comparison possibilities. Concurrently, it may scale up the innovation process and increase investments to the wood processing sector, which may ensure the production of the long-life wood products such as wood buildings and consequently increase the volume of carbon stored in wood-based products and applications.

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