

Article

Cascade Use of Wood in the Czech Republic

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Abstract: Research Highlights: One of the priorities of the European Commission is to build up an effective circular economy based on recycling and multiple use of materials. Wood biomass is a renewable raw material and can be used several times in a cascading sequence. Each country has a unique situation regarding the availability and utilization of wood sources. **Background and Objectives:** The objective of this study was to analyze wood flow in the Czech Republic using the cascading principle of biomass use. The specific situation in the Czech Republic lies in a lack of valid and reliable input data from official statistics. Therefore, the reverse input method was applied. **Materials and Methods:** Input data analyses of roundwood sources and foreign trade were based on official statistical data. The calculation of raw wood volume consumption in primary processing was performed based on the data after our own correction and recalculation. It was then possible to build up a basic model of multi-stage cascade wood use. The input volume of roundwood was divided among all types of primary processing production using conversion factors. **Results:** Cascading use of wood (CUW) showed the level of efficiency of the resource. Official statistical input data and the reversed input data regarding raw wood volume entering wood processing revealed differences at a level of 27%. The overall CUW in the Czech Republic indicates a high rate of wood use in primary processing with low added value and in generating energy. **Conclusions:** The reverse input method reveals the real situation of wood consumption irrespective of the level of official statistical data. It is suitable to apply in an environment of incomplete or incorrect input data. CUW in Czechia showed an opportunity for increasing the efficiency of wood utilization. The structure of wood use needs to be optimized towards creating greater added value.

Keywords: wood flow; reverse input method; cascade use; forest-based sector

1. Introduction

Wood as a renewable natural resource can be a sustainable resource and can contribute to the development of the circular economy and bio-economy. The circular economy represents the principle of material flow management including many kinds of resources and their use in multiple contexts. The bio-economy approach is focused on bio-based products and innovative production processes [1,2].

According to many experts, raw materials such as wood biomass should be used several times in a cascading sequence of material use as efficiently as possible [3]. The availability of sufficient volume and appropriate wood raw material quality for primary processing is one of the basic conditions for the successful investment and operation of wood-processing capacities. Knowledge about total wood production and especially the structure of the produced wood enables the better assessment of operational, technological, and business risks. Material flow analysis is a well-established method that provides a useful tool to be used as the basis of a transition process towards improved wood flows and can contribute to sustainable forest management [3,4]. Material flow analysis supports the understanding of sustainable production and consumption by providing insight into material flows.

A method called streams for analyzing wood material flows was suggested by Hekkert et al. [5] and was tested in the Netherlands. The method is based on official statistical data available from so-called supply and use tables.

The approach to wood flow and its interpretation permits several ways of achieving a balanced outcome, and is best captured in the work of Mantau [6–8], who applied a cascading approach. This approach is simple, clear, and effective in the demonstration of the transformation of primary wood sources into products and of the co-production used for further types of processing or consumption. It is possible to identify the strengths and weaknesses of processing and carry out optimizations so that the wood flow can bring the greatest potential.

Different definitions of cascading use can be found in the existing literature [9–14]. The scientific pioneers of the concept, Sirkin and ten Heuten [9], describe cascading use as a complex interaction of material flows and utilization in different flows in different use phases and different cascade chains. Concepts describing the use of a resource in multiple phases over a specific time interval have been presented in many other theoretical and empirical studies [15–19]. The German federal environment agency’s glossary of key terms relating to resource conservation defines the cascading principle as a strategy for using raw materials or the products made from them in chronologically sequential steps as long, as often, and as efficiently as possible for materials and only to recover energy from them at the end of the product life cycle [12]. It is based on the use of so-called “cascades of use” that flow from higher levels of the value chain down to lower levels, increasing the productivity of the raw material [11]. Carus [10] defined a difference in the terms “single-stage” and “multi-stage” cascading: “Cascading use takes place when biomass is processed into a bio-based final product and this final product is used at least once more either as a material or for energy production. Cascading use of biomass is described as single-stage when the bio-based final product is used directly for energy production. Cascading use of biomass is described as multistage when biomass is processed into a bio-based final product and this final product is used at least once more as a material. It is only after at least two uses as a material that energy use is permitted.” Biomass should be used for energy only at the end of the material life cycle; a direct energy use of biomass without prior material use is not considered a cascading use [11]. An example of cascading wood use is presented in Figure 1.

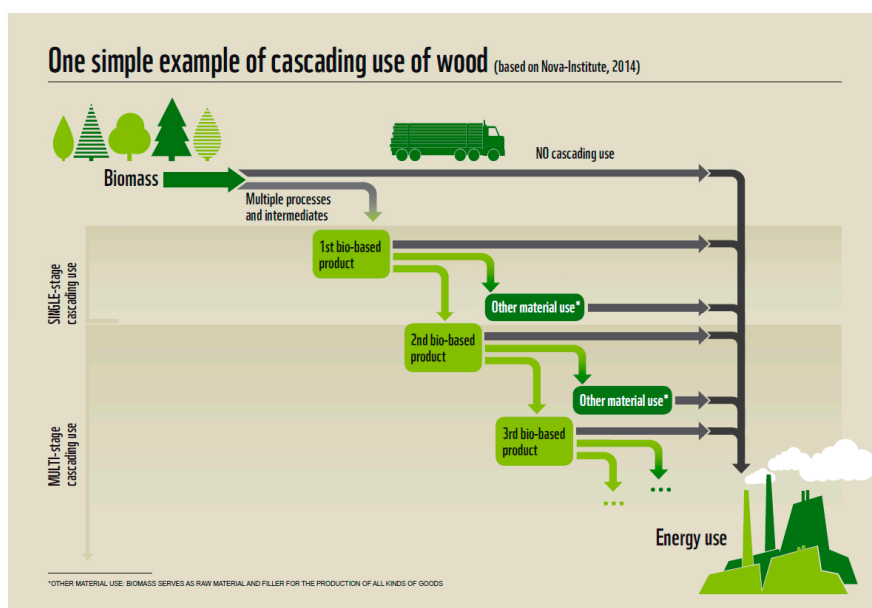


Figure 1. Cascading use of wood. Source: https://mobil.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Infographic_One_simple_example_of_cascading_use_of_wood.pdf.

According to Vis et al. [14], cascading use is defined as the efficient utilization of resources by using residue and recycled materials for material use to extend total biomass availability within a given system. Cascading at the market level can be evaluated through wood flow analysis.

The cascading principle was analyzed by presenting the utilization of wood resources in particular European countries: in Germany by Carus et al. [15] and Tashkiri [20], in Finland by Sokka et al. [21] and Salmi et al. [22], in France by Lenglet et al. [23] and Martire [24], in Switzerland by Binder [4], and in Austria by Höher et al. [25].

The cascade use of biomass has strong and complex links with existing methodology and policy strategies such as resource efficiency, bio-economy, the circular economy, and as an independent strategy in isolation is unlikely to be rewarding [2]. Several studies [13,16,19,26] have analyzed the policy framework promoting the cascading use of wood. The studies came to the conclusion that for the effective development of the cascading use concept, a harmonization of legislative measures by collecting input data regarding the availability and utility of resources is necessary. Further developing standardized methods for material classification, data acquisition, and processing is needed to provide complete and accurate input data.

Wood flow and its structure give basic information about the available raw materials for each type of processing; however, this is the case only if information is available about wood production structure. Otherwise, it is necessary to conduct an inverted procedure and reconstruct the wood flow based on the production of primary processing.

A different approach would need to be applied when there are no reliable or complete data on wood sources and their utilization. One example is the method applied by Latta et al. [27] that examines the models implemented and their mutual relation to express the balance between wood sources and their utilization. However, this approach can be used on an international level only with the modification and supplementation of the methods used for national or local levels. A chart of models and procedures demonstrating wood supply linkages is shown in Figure 2.

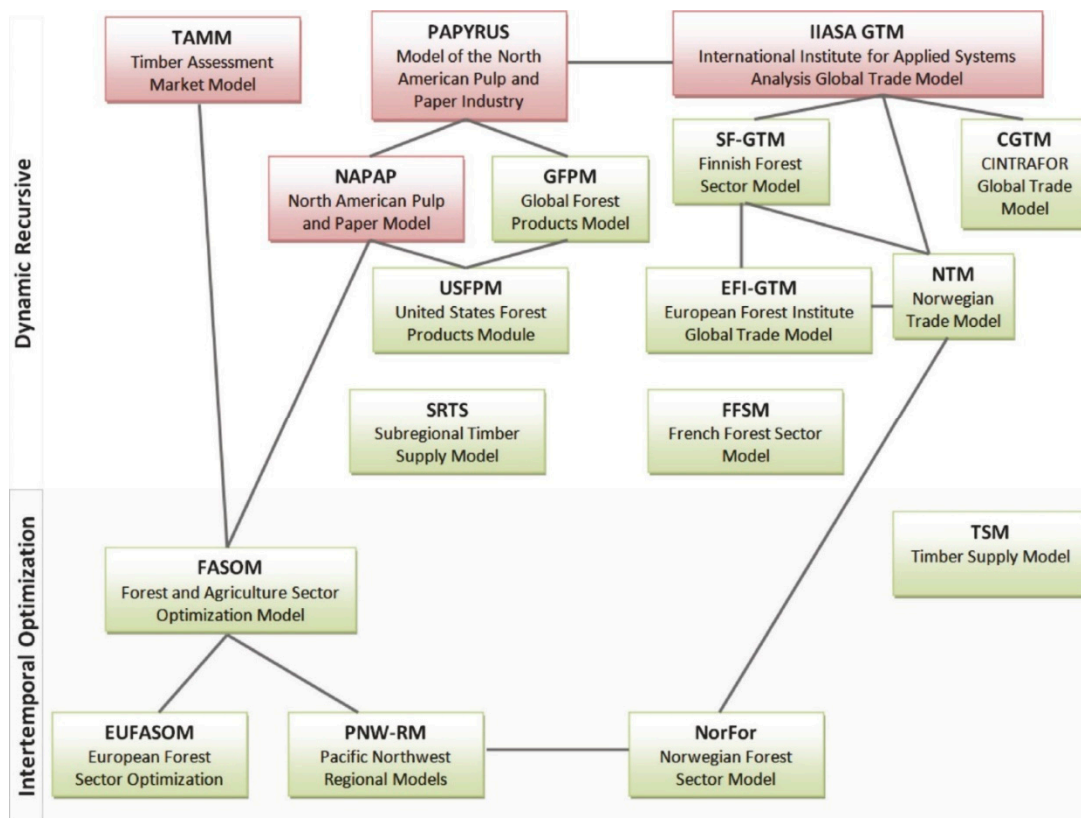


Figure 2. Timber supply models linkages [6].

A practical starting point for eliminating the problems of uncertainty (validity and availability) of the data needed for each wood flow model is the application of the approach described by Džubur et al. [28]. Mathematical approaches are applied to fill in missing data based on a set of variables and their dependency functions when using roundwood at various levels of consumption with the help of fuzzy logic. A possibility framework for data reconciliation in material flow analysis was developed and applied to a case study on wood flows in Austria. This approach eliminates the need for the demanding, and often impossible, detection of accurate data. However, it requires a complete model description of wood sources as well as their consumption. It also demands the most accurate conversion factors for the material use of roundwood in different products and energy transformation.

Lenglet et al. [23] applied a similar approach to Mantau's for material flow in the context of climate change policy and energy transformation for the use of wood for energy purposes, and described wood flow in France. Even in this work, he criticized the need to systematize conversion units and consumption factors within the flow of material for each product and raw material in relation to the technology applied, because otherwise, it is necessary to allow certain limitations or use mathematical statistical methods. He proposed relying on the MFA—Material Flow Analysis framework depicted by Courtonne et al. [29], which uses wood fiber equivalent as a basic accounting unit. Wood fiber equivalent is the volume of wood fibers that are contained in the product at the fiber saturation point [30]. Data quality is assessed either by directly retrieving precision indicators from statistical sources, or, in most cases, by expert judgments based on the way that the data are built [23].

Cencic and Rechberger [31] solved the problem of lack of available input data by using the data reconciliation technique of a specific conversion factor calculated depending on the primary measurement unit for each wood-based product (e.g., fiber board, plywood, and pulp).

Martire [24], in his study conducted in the French region, developed a holistic assessment method to support the forest-based sector. His presented method is suitable for dealing with the competitive use of biomass, allowing the estimation of its positive impacts and the potential trade-offs for existing business.

To achieve a representability of wood flow in Austria, Höher et al. [25] used conversion factors for wood fuel assortments because the gained input data from the Timber Felling Report (TFR) and from imports do not include the share originating from further wood processing. To include uncertainties and interdependencies between stages of the wood supply chain and resource constraints, a simulation model of wood supply chains was developed and presented in the study of Mobini et al. [32]. The model showed the values of particular types of costs in the wood supply chain.

While the wood flow and cascade use issue has been examined in many countries, in the Czech Republic sufficient attention has not been paid to the analysis of cascade wood use. Few authors have dealt with wood sources and their determination. Kuřčák and Pek [33] in their work focused on wood source balance and pointed to its minimal level of use based on the available official data sources (the Ministry of Agriculture and the Ministry of Industry). However, the official data are not accurate and relying on them for analysis would not provide correct results. The methodology of statistical data collection has several limitations. Incomplete input data cause more complications than in countries with more precise data collection, for example the USA.

This paper deals with the determination of wood source availability and utilization in the Czech Republic. The objective of our research was to analyze wood flows based on the cascading use of wood. To meet this objective, the problem of incomplete input data had to be solved. The input data regarding raw wood volume entering primary wood processing had to be corrected and recalculated. Some limitations inhibiting a more accurate expression of wood flow were able to be mitigated in the application of the reverse input method. The reverse input method is based on data obtained from wood processing companies concerning raw wood consumption.

2. Materials and Methods

The proposal to examine the cascade use of wood sources required several input analyses. The framework for the methodology of input data processing for wood flow detection is defined as follows:

- Sources of roundwood (forest biomass): the analysis of available data sources and evaluation of the general processing potential of individual categories of available wood. The source of information is the Green Report of the Ministry of Agriculture (MA) [34] and statistical data from the Czech Statistical Office (CSO) for forestry [35]. During the analysis, limitations and additional values were identified to gain a comprehensive conception of wood supplies for domestic processing.
- Wood import and export (foreign trade balance): the analysis of roundwood export and import for determining the volume in the wood flow processing focused on the overall trend in identifiable products (at least on the level of roundwood products) according to the Ministry of Agriculture and the CSO. Foreign trade data published by the Ministry of Agriculture were based on the data issued by the CSO. Foreign trade data were obtained from two systems, Intrastat and Extrastat [36]. In the Intrastat report, the data were gained directly from companies (importing and exporting) in connection with data about value added tax (VAT) and trade with European Union (EU) countries. The remaining part of the foreign trade realized, mainly with non-European Union countries, is still subject to common customs procedures. Customs declarations (single administrative documents) were a source of statistical data for the Extrastat report. To analyze the wood flow of domestic processing, it was necessary to know how much wood was exported, what kind of species and qualities were exported, and what trends were developing regarding exports. The same questions apply to the roundwood import analysis.
- Determination of the wood volume entering primary industrial processing without further distinction in energy production and consumption: raw wood volume consumption was calculated as wood production minus export and plus import. This was reported in the statistical report of the Ministry of Agriculture elaborated by the Czech Statistical Office.
- Data corrections. This study worked with the limited official data sources concerning the input of roundwood. This is the main weakness of all known approaches for wood flow monitoring at the national and transregional levels because it is not possible to apply an active and deep method of wood consumption identification. Mathematical-statistical calculations were part of data processing and these compensated for loss of information as a consequence of non-response and the implementation of statistical thresholds. In the foreign trade section, the volume of wood export and import in the correction of non-conformities was identified.

Based on the information and corrected data regarding wood production, import, and export, as well as essential knowledge about primary wood processing, it was possible to build up a basic model of cascade wood use, which is composed of input roundwood volume calculated from wood production, deducting fuelwood and export and adding import. This volume is divided into all types of primary processing production and is gradually complemented with other sources such as woodchips, sawdust, particles, and bark. Generally, it is possible to express this procedure as a process where it is necessary:

1. to find out the types of primary wood processing;
2. to assign the individual types of processing to the average values of the disintegration of the material balance of the yield of 1 m³ of input wood (conversion factors);
3. to determine the production volumes of individual types of processing;
4. to determine the production structure and consumption of byproducts within one type of primary processing and between different types of processing (cascade).

The identified primary processing segments, according to the wood flow analysis, were wood impregnation, coniferous roundwood (SW), deciduous roundwood, veneer, coniferous plywood,

deciduous plywood, oriented strand boards (OSB), particleboards, medium-density fiberboard (MDF) (in joint production with particleboards and coniferous SW), pulp, and energy production. These primary processing segments are key segments of the forest industry where roundwood enters various products. In terms of total volume, primary processing segments of the furniture industry (apart from veneer) and wood construction from saw logs using roundwood directly were excluded, because it was very difficult to identify roundwood consumption and this presents only a small part of total wood consumption in these cases.

The conversion factors for assigning the material utilization of raw wood to individual types of processing were used as in Table 1 [37].

Table 1. Material utilization of raw wood for different manufacturing in the Czech Republic.

Product	Raw Wood Use/m ³ of Product
Softwood lumber	1.72 m ³
Hardwood lumber	1.88 m ³
Impregnation	1.07 m ³
Softwood plywood	1.81 m ³
Hardwood plywood	2.43 m ³
Veneer	2.04 m ³
OSB	1.61 m ³
MDF	1.63 m ³
Pulp	4.85 m ³
Particleboard	1.53 m ³

Source: [37]. Abbreviations: OSB, oriented strand boards; MDF, medium-density fiberboard.

Conversion factors were calculated as an average of values obtained on the basis of material decomposition in production. The material decomposition of raw wood depends on the technological procedures of individual processing types. It was calculated based on the sales of wood processing companies and their product structure, and verified by surveying companies.

The data on wood sources, corrected and recalculated, can be used as an input for modeling the flow of wood at the level of gross aggregates. This means that the separate flows of wood per product and tree species are unable to be identified. At this level, there is a missing link between the details of the wood supplies and foreign trade items, even if partial interconnection is possible. This principle requires creating a database of roundwood processors and the typological orientation of the prevailing production and applied technologies. All this information can be identified, sustained, and updated in the long term. As a simple basis, we can use existing statistics and work describing the status of primary processing in the Czech Republic. Such sources include the MPO and its Process Industry Panorama, in which it is possible to identify gross statistics on performance according to the NACE branch classification. It is also possible to use international statistics, in which the Czech Republic participates and passes on the statistics processed per branch according to its own methodology. To express real wood consumption through the application of the conversion factors of roundwood into products, a reverse method has to be applied. This method allows for the determination of the necessary wood volume input based on production data and the knowledge of the conversion of roundwood into products. When applying this method, it is possible to express the wood volume necessary for processing with a defined inaccuracy rate and determine the deviation from wood production data.

Similarly, wood production per product was defined using calculation by means of a statistical sample. These restrictions may be partially corrected by the application of the reverse calculation for wood sources from the data of the forest industry processors. This means that from the known data of the representative companies in primary processing, the necessary volume of wood that should be accounted for in processing was calculated. This method requires a detailed analysis of the economic values related to the transformation of the purchased material into the product. When applying this

method, it is possible to express the wood volume necessary for processing with a defined inaccuracy rate and determine the deviation from wood production data.

The study enhanced only primary wood processing and did not cover wood consumption in industrial processing, i.e., it did not analyze wood flow for energy consumption or household consumption, nor did it examine in detail wood consumption within the energy company production of primary processing. This requires additional and demanding research into energy capacities for the consumption of wood biomass. This segment of wood flow can be recorded but not accurately quantified.

The limitation of the proposed cascade wood use model is the application of average production prices, which are necessary for determining the physical volume of production in main and secondary production so that the total sales are in relation to the structure of sales of products, materials and own consumption.

3. Results

In this section, the results of the input analyses and overall wood flow in cascade use in the Czech Republic are presented. The wood flow is based on data from the year 2016.

3.1. Results of Input Analyses

In terms of statistical monitoring, wood production presents a wood volume without bark gained from a statistically restricted group of information providers. In the Czech Republic, forests up to 200 ha are excluded from this monitoring. According to the statistical data, the total production volume of roundwood was 17,616,553 m³. Coniferous wood noticeably prevailed and approximately 9.8 million m³ of logs had wide industrial utilization. There was a high proportion of fuelwood among both deciduous and coniferous wood. The question is whether it this was idle wood for industrial processing. For deciduous wood, fuelwood constituted up to 47% of the total volume delivered. However, a volume of felling residue and forest chips of approximately 1.9 million m³ was not included in the total deliveries of roundwood.

The first part of the wood source analysis for wood flow in industrial processing identified the following factors:

- roundwood production is reported only as a subset, and does not include all forest owners and wood harvesting in a specified group of respondents;
- it provides no information on the supply of forest biomass and wood or forest residue and wood chips produced in the forest;
- there is no statistical monitoring of bark volume from forest production;
- there is a considerable difference between the statistical monitoring of wood production of the Ministry of Agriculture and that of the National Forest Inventory (NFI; identifies average annual production at the level of 21.83 million m³ of wood).

The current official data about forest statistics do not allow the creation of an accurate impression of wood flow in primary processing and do not give the necessary data for an energy consumption assessment. The classification of wood products and their utilization in industrial processing is not interconnected with the consumption of the primary processing sector. The estimated volume of woodchips is 1.9 million m³, the volume of fuelwood reaches more than 2 million m³, and the addition of wood from non-forest areas may give a total volume of up to 3.5 million m³ of wood used in the industrial or energy sector.

The analysis of roundwood export and import for the purpose of determining its volume in wood flow processing focused on overall trends in the identifiable products, at least on the level of roundwood products, according to the Ministry of Agriculture and the CSO. The data published in the Forest Status Report for 2016 [34] represented a gross statistical expression. One of the most common and frequently communicated problems of CSO data is their unreliability in values expressing technical

units. Because the financial statement is related to VAT, it often happens that respondents do not pay much attention to the accuracy of the values expressing the volume in the technical units. There is no way forward other than to proceed with several corrections based on mathematical statistical methods. This is why the Ministry of Agriculture has to use some methods to correct the basic data provided by the CSO. However, these recalculations are made over the aggregation of the primary data.

3.2. Input Data Correction and Calculation

The corrected CSO database contains foreign trade statistical data corrected according to the largest variation in the number of technical units. The CSO data correction algorithm is based on the long-term average development of individual items and identifies the extremes of the reported values; according to the weight and price values, it corrects the real values of the technical units. Subsequently, the value of exports and imports is used according to the data corrected by its own methodology (reverse-verifiable and readily corrected for more correct values). To monitor and evaluate foreign trade properly, it is necessary to also use the authors' own procedure to remove apparent mistakes (export cannot be higher than total production plus import). The application of limits or elimination of the extremes in the primary data allows the capture of the greatest deviations and the recalculation of the correct values based on the historical development of the products. Thus, more realistic values for the detailed items can be obtained, providing better conclusions. The corrections for the year 2016 of roundwood export ranged from 1,732,059 m³ to 140,199 m³.

The wood deliveries for domestic processing are presented in Table 2, based on the corrected database from the CSO. Raw wood consumption was calculated as wood production minus wood volume exported plus wood volume imported. If the consumption of direct fuelwood not entering primary processing is excluded (2,344,415 m³), the volume of input raw wood for primary processing can be calculated as 11,781,197 m³.

Table 2. Raw wood consumption based on CSO corrected data in 2016.

	in m ³ Without Bark	Wood Production (incl., Self-Production)	Export	Import	Consumption
Coniferous and Deciduous	Total	17,616,553	5,177,709	1,686,768	14,125,612
	Saw logs	10,340,681			
Of which	Pulp	4,931,627			
	Fuelwood	2,344,245	195	25	
Coniferous	Total	15,923,807	5,034,094	1,486,316	12,376,029
	Saw logs	9,868,837			
Of which	Pulp	4,504,892			
	Fuelwood	1,550,078			
Deciduous	Total	1,692,746	143,615	200,452	1,749,583
	Saw logs	471,844			
Of which	Pulp	426,735			
	Fuelwood	794,167			

Source: [35] and own calculations. Abbreviations: CSO, Czech Statistical Office.

In the official data of the CSO, only around 93.17% of wood production was reported, according to published data by Matejiček [38]. It was therefore necessary to supplement the volume of wood harvested from forests of under 200 ha. This is so far the only available data about the share of forest owners. After applying a relative recalculation for the remaining 6.83% of area (1,291,414 m³), the total wood production was 18,907,697 m³, which was a proportional increase considering the same average harvesting per hectare, meaning wood consumption in the Czech Republic would then be 15,417,026 m³. This was divided by into even shares of deciduous and coniferous wood as with the land above 200 ha. This meant that the total coniferous wood harvested would be 17.1 million m³, and for deciduous wood 1.82 million m³.

Bark volume should be added to this figure as the basic potential of material utilization. According to Decree 84 on Forestry Planning in the Czech Republic, paragraph 7, part L [39], for coniferous trees the coefficient for bark calculation was 0.90909 and for deciduous trees 0.86956. Therefore, 1,981,670 m³ of

bark production was obtained (where 1,709,132 m³ was coniferous and 272,538 m³ was deciduous). This volume needed to be corrected further on in the flow of processing; additional bark is obtained from debarking saw logs as well as from pulpwood. The values of consumption and bark volume are adjusted according to foreign trade balance as follows: the volume of the bark exported had to be deducted and the volume of the bark of imported wood had to be added (adding the balance). The net export of bark in the foreign trade wood balance was in the amount of 346,256 m³. This means that, in total, 1,635,414 m³ of bark entered the wood flow (bark consumption). The volume of fuelwood bark still had to be deducted; this was in the amount of 294,236 m³, calculated as the difference of wood harvested by all owners (18,907,967 m³) and the volume of wood of all owners without fuelwood (16,391,873 m³). Thus, the volume of fuelwood was obtained and the volume of bark using the bark coefficient 0.88306 was calculated. Accordingly, this did not enter the wood flow as a raw material. Finally, the volume of bark in the raw material flow was calculated as 1,341,178 m³.

Fuelwood is not debarked. It was necessary to exclude from the wood balance the amount of direct fuelwood that was immediately consumed and did not enter the total flow of industrial processing. The fuelwood volume for 2016 was 2,344,245 m³. After recalculation for all forest owners, the fuelwood volume would be 2,516,094 m³. By subtracting fuelwood from harvesting by all owners (18,907,967 m³–2,516,094 m³), 16,391,873 m³ of wood was obtained, and after the deduction of exports and the addition of imports (–3,490,946 m³), the basic volume of delivered wood for processing in the Czech Republic was obtained, which was 12,900,932 m³ without bark.

Therefore, 12,900,932 m³ of wood without bark and 1,341,178 m³ of bark entered consumption, excluding fuelwood. However, it was also necessary to exclude or adopt a statement on the area utilization of fuelwood outside industrial processing. Residue and woodchips in the amount of 1.9 million m³ (CSO) were additional input items.

To summarize, the final inputs were 12.9 million m³ of wood, 1.3 million m³ of bark, and 1.9 million m³ of biomass. There were 16.1 million m³ raw materials in total entering wood processing (see Table 3).

Table 3. Wood production and consumption in 2016 after recalculation.

Raw Wood in m ³	Total	Coniferous	Deciduous
Wood production (incl. self-production) [32]	17,616,553	15,923,807	1,692,746
Wood production by all owners	18,907,967	17,091,131	1,816,836
Bark	1,981,670	1,709,132	272,538
All owners with bark	20,889,637	18,800,263	2,089,374
Production by all without fuelwood with bark	16,391,873	15,427,422	964,451
Export	5,177,709	5,034,094	143,615
Import	1,686,763	1,486,315	200,452
Raw wood consumption without fuelwood and bark	12,900,932	11,879,644	1,021,288
Bark consumption without fuel bark	1,341,178		
Residue and woodchips consumption	1,900,000		
Total raw wood consumption	16,142,110		

Source: own calculation based on data [35,39].

The second source of roundwood production entering wood processing comes from non-forest areas. The only currently relevant data about wood production outside the forest can be taken from the results of National Forest Inventory (NFI) II [40]. For forests there is a point estimation of 0.49 million m³/year (lower limit 0.40 million m³/year, upper limit 0.57 million m³/year). This volume is mainly processed outside the industry. It must be distinguished between how much bark and residue make it into the wood flow for material processing and how much into the wood flow for energy processing. However, this requires separate analysis and data collection that are not directly tracked at the moment.

3.3. Cascade Use of Wood

A basic model of cascade wood use is composed of the basic roundwood volume calculated from wood consumption, deducting fuelwood. This volume is divided into all types of primary processing production and is gradually complemented with other sources such as woodchips, sawdust, particles, and bark.

It is rather easy to find out the volume of wood sources for the individual segments in terms of the market situation, where only a few companies are dominant and they are the only representatives of the segment. The primary processing segments in the Czech Republic where it is possible to identify all companies participating in roundwood consumption are veneer, plywood, OSB, particleboards, MDF, and pulp. Due to the high concentration of sawn wood production, it is possible to identify more than 50% of wood entering sawn wood processing and, in the case of other sawn wood processing capacities, to carry out complementary identification to enable the creation of the converse coefficients typical for the sector or apply the converse coefficients already created and applied in other studies [37]. The reverse approach can be applied to create a wood flow model for primary processing in the Czech Republic. Production values from the company data were calculated for wood consumption in the mutual cascade: see the chart in Figure 3.

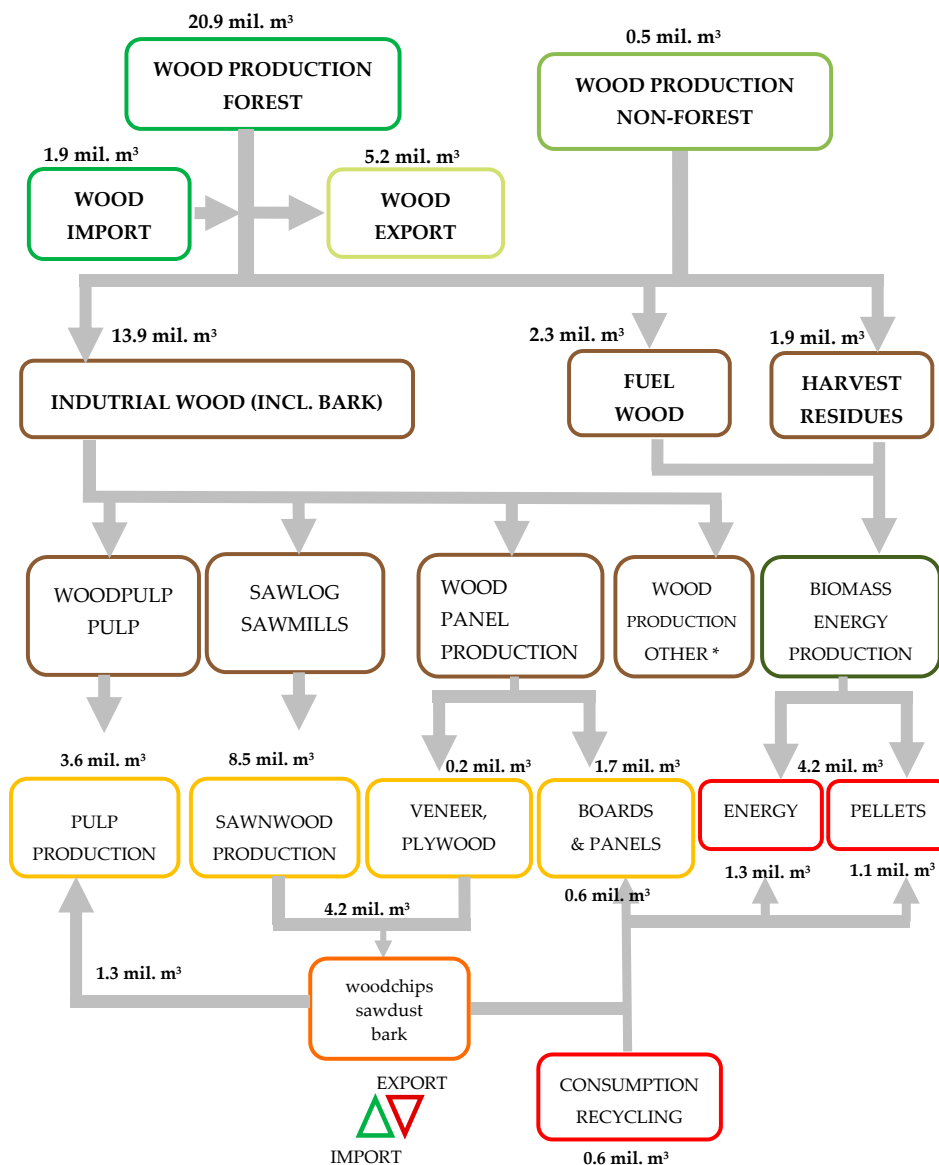


Figure 3. Chart of cascade wood use in the Czech Republic. * wood products for construction and art.

The input data in the model of cascade wood use consist of a basic volume of raw wood calculated from harvested wood separated from fuel wood and export, and with the import of wood added. This volume is divided into all types of primary wood processing production and then it is gradually supplemented with other sources such as woodchips, sawdust, and bark. The production segments of primary wood processing are pulp production, sawn wood (saw log and sawmills), wood panel production with segments (veneers, plywood, wooden boards, and panels), and biomass energy production (energy, pellets).

The raw wood in the Czech Republic for primary industrial processing presented 75.5% of wood consumption; the rest of the wood was fuel wood and harvest residue used in energy production. Harvest residue made up 10.5% of the material from wood production according to the official statistical data. However, the monitoring and data collection of harvest residue was not complete, and the real amount could have been higher. The prevailing manufacturing type was sawn wood (47%), then fuel production (23%), followed by pulp production (20%). The mentioned wood segments produce products with low added value. This means that 90% of primary processed wood created low added value. Only 10% of raw wood was transferred into products with higher added value in wood panel production. Wood panel products are input materials in the further production of furniture or construction products and the value of the wood can increase more.

It can be stated that the valorization of wood in the Czech Republic is not as high as possible due to the prevailing processing focusing on products with low added value. Higher wood panel production could increase the level of added value within the wood chain. In the monitored year, the total value of primary wood processing other than in energy production was CZK 60,000,000,000, equivalent to EUR 2,220,000,000 (by average conversion rate in 2016: 27 CZK/EUR). The value corresponds to 13.9 mil. m³ of industrial wood at EUR 158 per m³.

4. Discussion

Based on the analyses of input data for the wood flow chart in the Czech Republic it can be stated that the official data on wood sources in the Czech Republic are incomplete and inaccurate. Therefore, they do not allow their application for the wood flow without additional calculations and further investigation of wood consumption in the energy segment. The consumption of wood biomass produced in the forest, outside the forest, and at the processors is not directly monitored. Indirectly, these data are collected in the Agenda of the Ministry of Industry and Trade or the Ministry of the Environment for the purpose of identifying the consumption of renewable raw sources. In this situation, mathematical approaches and a fuzzy logic method can be applied as described in works of Latta et al. [27] and Džubur et al. [28]. In this paper, the methodology of Lenglet et al. [23] was followed and the cascading approach to wood flow analysis introduced by Mantau [8] was applied. When comparing the official statistical data to the corrected and recalculated data, a difference in the amount of roundwood entering industrial processing was discovered. The official data provided information suggesting around 4.3 million m³ less than the recalculated data, which is a deviation of 27%. This means that the real consumption of roundwood in primary wood processing was around 4.361 million m³ more. This fact was proved by the application of the reverse method for determining input roundwood consumption. The previous work of the authors [37,41,42] have pointed to the importance of accurate data regarding input wood sources in wood processing. Otherwise, wood flow and its cascade use cannot be calculated correctly.

The findings of the paper show the possibilities for solving the problem of incomplete and inaccurate official input data in the Czech Republic:

- to extend collecting data on wood sources to all forest owners regardless of their size;
- to improve accuracy in the values expressing volume of wood;
- to provide statistical monitoring of bark volume from the forest production;
- to harmonize the databases and techniques for monitoring wood production created by official state entities;

- to improve (introduce) the interconnection of data between wood production and its consumption in the primary processing sector.

The analysis of cascade wood use has significant potential in solving the imbalance between material and energy uses of industrial wood residue as presented in several studies [2,8,14,26]. To have a real image of how the wood is processed and valorized, complete and correct data are needed. The reverse input method based on data from wood processors can also serve as a control mechanism for the official reported data. Monitoring wood flows in cascade use enables the detection of reserves and allows higher wood valorization that contributes to higher economic performance, as measured by GDP.

Further research will therefore focus on suggestions for policy makers and the proposal of sufficient and accurate input databases created at the national level by means of official institutions. The results of current scientific studies [2,8,15,16,19,24,26] regarding wood flows in cascade use are an inspiration for the directions of future research:

- the proposal of methods and procedures by collecting data regarding raw wood supply;
- the investigation of methods for monitoring wood use in material and energy use and household consumption directly by state institutions;
- harmonization between data collection regarding raw wood supply from national (domestic) and foreign wood sources;
- possibilities for the integration of the hierarchy principle of wood biomass cascading use into the bioeconomy strategy.

5. Conclusions

To satisfy the current and future needs of the population, a more efficient and sustainable use of wood biomass is essential. The integration of cascading use as a key instrument for resource use efficiency optimization is very important.

The contribution of the study presented in the paper can be seen in its application of the cascading wood use model in situations of incomplete input data using the reverse input method. It enables the recording of the real situation of wood consumption irrespective of the level of statistics in the Czech Republic and thus it may be applied to all countries with sales data for individual segments of primary processing. However, there is a need to change the monitoring of wood production and roundwood foreign trade, because the current approach to data collection is unreliable and does not provide confidence in the correct use of information. A difference between the official data and the corrected data concerning the volume of raw wood entering primary processing at a level of 27% was identified.

It is possible to draft an image of wood flow and its cascade use in the Czech Republic that represents the real situation as long as complete and accurate official data on wood sources and foreign trade are available. At present, it is therefore a weakness that additional calculations and corrections of the input data are needed for the consumption of wood biomass produced in the forest, outside the forest, and at processors. This is why any model of wood cascade use is limited due to the application of mathematical and statistical methods in order to correct input data on raw wood consumption and average production prices by determining the physical volume of production of the main and secondary production methods so that the total sales are identified in relation to the structure of sales of the products, materials, and consumption.

The overall cascade use of wood in the Czech Republic indicates a high rate of wood use in primary processing with low added value and in the production of energy. It can be stated that there is room to increase the efficiency of wood utilization. The structure of wood use needs to be optimized towards the creation of higher added value.

To evaluate cascade wood use for raw wood efficiency optimization in the Czech Republic, further research and analysis is needed. Sawn wood production and energy production are the most

complicated segments because it is necessary to carry out the collection of relevant data in these cases. Wood flow for energy or household consumption and for energy production requires additional research for energy capacities. Cascade wood use contributes to the development of an efficient circular economy based on green renewable materials. It leads us to the conclusion that this issue is worthy of investigation in more varied of contexts and that it should be extended by using recycled wood flow in the aim of finding the most optimal model for individual countries where the efficiency of raw wood utilization can be maximized.

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