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Wood Processing Residues

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Abstract Rising demand for and scarcity of wood – together with cost savings and resource efficiency requirements – have led to a constant increase in the use of wood processing residues, where appropriate, in the production of wood-based products. This chapter presents/reviews the available information and existing knowledge of residues at various regional levels. It describes the segment of wood processing residues as an important wood resource and the availability of data on a national and on a global level for the quantification and the projection of the resource. The chapter points out the importance of empirical data (collection). Furthermore, it provides a terminology concept for a harmonised use of the diverse assortments and production stages of wood processing residues.

Keywords Assortments of wood-based residues, Data availability, Forest industry branches, Terminology of wood-based residues, Wood resource assessment

Contents

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1 Introduction

Looking at the long-term trend, the demand for wood has constantly increased over the last few decades. On the one hand this is driven by a constantly increasing demand for wood-based products and, on the other, by increased demand for wood for energy purposes. Besides traditional users of wood resources, new competitors also influence the demand for wood. The chemical industry is likely to increase the use of woody biomass for biotechnological purposes and biorefinery of wood. Consequently, the demand for wood as a raw material is also rising in parallel with the demand for (its) related products.

Basically, the demand was largely fulfilled by a rising supply of roundwood, driven by increased fellings in forests. However, given the material structure of wood as a raw material, wood-based residues which accrue during the different steps of wood processing are also suitable for further material and energetic uses.

Rising demand and scarcity of wood – and also cost savings and resource efficiency – have led to a constant increase in the use of wood processing residues, where appropriate, in the production of wood-based products. For example, the development of particle board has its origin in technological investments for a more efficient use of the available quantities of wood processing residues. This resource originates from, for example, sawmills, planing mills or the furniture industry, and would otherwise have been disposed of as waste.

It should be noted that the increase of the material use of wood processing residues moved forwards in parallel with technological developments in the panel board industry and, to a certain extent, in the pulp industry. The material use of waste wood for particle board production is also strongly related to the scarcity of available fresh wood fibres and further possibilities to reduce costs of raw material.

In fact, in many countries the use of wood processing residues for different purposes is a necessity, given the limited availability of the raw material and the cost of fresh fibres/roundwood. In this regard, recent developments should also be noticed in the chemical industry which uses wood for biotechnological and biorefinery purposes.

However, knowledge of the market structure, concerning supply and demand of wood processing residues, is surprisingly low. It seems as if the official national statistical systems of data gathering throughout the world are only focusing on the main resource flow, as long as it can be called a product. However, if there is a supply of (wood) raw material that originally is a residue from the production of a specific (wood-based) product, there is nearly no statistical interest in the recording and surveying of these quantities. Anyhow, in any case, wood processing residues are valuable raw materials which achieve revenue if sold on the market.

So far, knowledge and information concerning available quantities of wood processing residues (i.e. available on the market) and the different kinds of

assortments of wood processing residues (available) in use are not easily at hand. It is therefore the objective of this analysis to unveil these questions: what are wood processing residues, what are the different assortments and sources and which quantities are supplied? It shows the importance of empirical research and field data to answer (the question and) the demand for detailed wood resource information.

Hence, the objective of this chapter is to review available information and existing knowledge regarding the resource of wood processing residues, its origins and available supply within the structure of forest industry. Existing research results and previous literature on biomass potentials on a European and on a global scale are compared. The chapter is intended to differentiate from common biomass potential studies. It is not our objective to show potentials of the resource but to give an overview of existing data and quantities based on modelling. Because modelling is used, based on empirical research results, the German wood resource monitoring project is presented as (so far unique) periodic empirical research on supply and use of wood resources, including wood processing residues.

The chapter is structured as follows. In Sect. 2 we present results of our review of the existing literature in this regard and provide an introduction to the terminology and a definition of wood processing residues. Section 3 focuses on the analysis of existing information and data on the supply of wood processing residues. This is done on three different regional levels: we first give insight to the research which has been conducted in this regard in Germany, we then present the available knowledge gathered on a European level and finally present our results on a global level. Section 4 concludes the chapter with a discussion.

2 Literature Review, Terminology and Definitions

2.1 Literature Review

Current research on biomass resources cannot be imagined without the assessment of wood processing residues. Various studies were published in the last few years, presenting global, European or regional biomass and bio-energy potentials, either for the current situation or for future scenarios. Agricultural and forest biomass are the specific focussed resources. Resource assessment of forest biomass often includes residues from the wood industry. However, this particular segment is not well-differentiated in the literature and overall energy potentials do not give respective resource information. Moreover, because of missing harmonised terminology and units, data are not comparable between regions and countries.

Volumes of wood processing residues represent a significant share of woody biomass. However, existing literature rather focuses on theoretical forest biomass quantities. Most of the studies on potential biomass supply present scenario-based results, such as, for example, [1, 2]. Available studies on wood biomass potential mostly summarise available volumes of wood biomass other than forest biomass without introducing further assessment approaches. In addition, information and

data on wood processing residue volumes are still rare. The segment of wood processing residues is not covered as comprehensively as required by official statistics and the empirical research is exceptional. So far, the available results from some countries are only based on modelling. A first approach to assessing and modelling volumes of wood processing on a broader level (e.g. EU27) was adopted by applying the wood resource balance for European countries [3–5].

The literature on wood biomass potentials differs considerably on methodological approaches, applied scenarios, references and data units. Particular results on volumes of wood processing residues are either subordinate or mixed with volumes of forest residues. Global estimates of global fuel resources, mainly related to forest resources, are available, for example, from Parikka [6]. Smeets and Faaij [2] provide results based on a literature review and general estimation of wood processing residues by using a share of 50% of the total forest industry production. Another study on a global level is presented by Thrän et al. [7] on spatial distribution of biomass potentials based on FAO data from 64 countries. Estimates of woody biomass potential, in particular shares of wood processing residue (with a 25% share of felled wood) potentials on European level are given by Ericsson and Nilsson [1] based on rough approximation.

A study by Alderman et al. [8] investigated the available volume of wood processing residues in Virginia (USA) on the basis of company surveys and product statistics nomenclature. A study by Szostak et al. [9] on the industrial wood residue market in Poland, based on a survey in the Polish forest industry, provides differentiated results on wood processing residues in combination with country statistics. In Germany, various studies based on mail surveys have been conducted within the wood resource monitoring. Results of the EUwood study [3] on the segment of wood processing residues are based on modelling and data of the above-mentioned empirical studies in the context of the German resource monitoring project (for detailed information see Sect. 3.1). Modelling volumes of wood processing residues (on a resource-based level) is based on data of material balance and specific conversion factors. The material balance of a wood product is described by the input of the initial raw material (roundwood, sawnwood, wood-based panels) and the output of the final product (compare [10]). However, reliable data on material balance and conversion factors can only be provided based on empirical research.

In contrast to this, the segment of sawmill residues is analysed in more detail [11–14]. Studies on material recovery within the sawmill industry were conducted mainly for North America. They provide information on sawmill residues as side information. The focus of most of these studies, however, lies on the increased lumber/sawnwood output and production efficiency.

The low number of available assessment studies compared to studies mainly focusing on biomass potential, which do not further differentiate into possible assortments, shows the importance of empirical research for comprehensive results given by primary data collection. National and international statistical databases are already quite well-set with data: Eurostat and FAO provide international statistics on the main sectors of the forest industry. However, encompassing wood resources supply and demand at a sufficient level of detail is not possible for reasons of imprecise terminology and, hence, definition of the resource.

2.2 Terminology and Definition

So far, terminology and definition for wood processing residues is neither definite nor well-harmonised. As results of volumes on wood processing residues differ in the literature [15], so do terms on residual woody biomass [16]. A broad variety of terms is used in the literature as regards the segment of residual woody biomass from industrial processes. Terminology describing the assortment of residues from roundwood production and further processing of wood products is inconsistent. For the most part, the resource of wood processing residues appears in the literature with similar features but it can also be confused with forest residues or waste wood. On the other hand, existing terminology summarises the whole resource of wood processing residues and does not clearly differentiate between its particular assortments such as sawmill residues and other wood processing residues or pulp production residues, which should be done because of the large differences in shares and the quantification of the different volumes.

The estimation of volumes of wood processing residues in particular needs prior common definition of the following relevant terms:

Residue: an inevitable remainder of any production process. The term does not imply any valuation or category of desired or undesired. It has to be differentiated from waste.

Waste: an unserviceable remainder of any production process. It is considered as useless and unsalable [17].

Moreover, the terminology and definition of wood processing residues should be differentiated according to their derivation. Residues are derived from production processes. In comparison to that, by-products receive a market value and product features from the markets' resource demands.

Wood processing residues accumulate during all mechanical and chemical production processes in the forest industry. The resource has to be differentiated from forest residues and waste wood. For a long time, wood processing residues were considered to be waste or remnant biomass without further use. After the demand for woody biomass for energy use started growing as well, wood processing residues, especially sawmill residues, became a by-product with competitive product features [18]. The resource comprises residues from sawmilling, residues from other wood processing activities and black liquor as the residue from the pulping process. In this context, bark is not considered as an assortment wood processing residue. Bark accumulates before the actual wood processing (debarking prior to, e.g. sawing or pulping process). As regards its characteristics, bark is not comparable to wood fibre and the use of residual woody biomass. However, in terms of wood resource supply, bark volume is considered as a forest resource [19] of, for example, 50.9 million m^3 in the EU27 [20].

Forest products definitions of the FAO cover data on the resource of wood processing residues by differentiating in two assortments: (1) wood chips and particles and (2) wood residues [21]. The application of the terms is difficult because of ambiguous meanings and application by third parties. The segments of

wood processing residues consist of different assortments (chips, slabs, dust, edgings, trims, cores). The two terms cannot be easily allocated to a corresponding segment with more than two different assortments. Forest industry production is very highly differentiated, and so are the assortments of residues (see Fig. 1). The volume of wood processing residues in this chapter is provided in cubic metre solid wood equivalent (m^3 swe). In general, assortments of wood and wood processing residues are dealt with and measured in different units (e.g. bulk volume, solid volume, tonnes). To assess total supply of, for example, wood processing residues and to comprise assortments of different units in the wood resource balance (see, e.g. [3]), all units are converted into cubic meter solid wood equivalents (m^3 swe) so that data can be compared with, for example, statistics on removals. Conversion factors depend on the wood specific gravity. Thus, the conversion factor for 1 m^3 solid wood into tonnes dry matter can vary between 0.48 tonnes/m^3 for and 0.55 tonnes/m^3 for the different assortments [19]. According to Mantau [19] the average of 0.5 tonnes/m^3 is a good approximation. The results of our analysis in Sect. 3 are provided in both units, cubic meter solid wood equivalent and in tonnes dry matter.

Figure 1 gives an overview of forest industry branches, forest product segments, the three considered segments of wood processing residues, the end-use sectors and

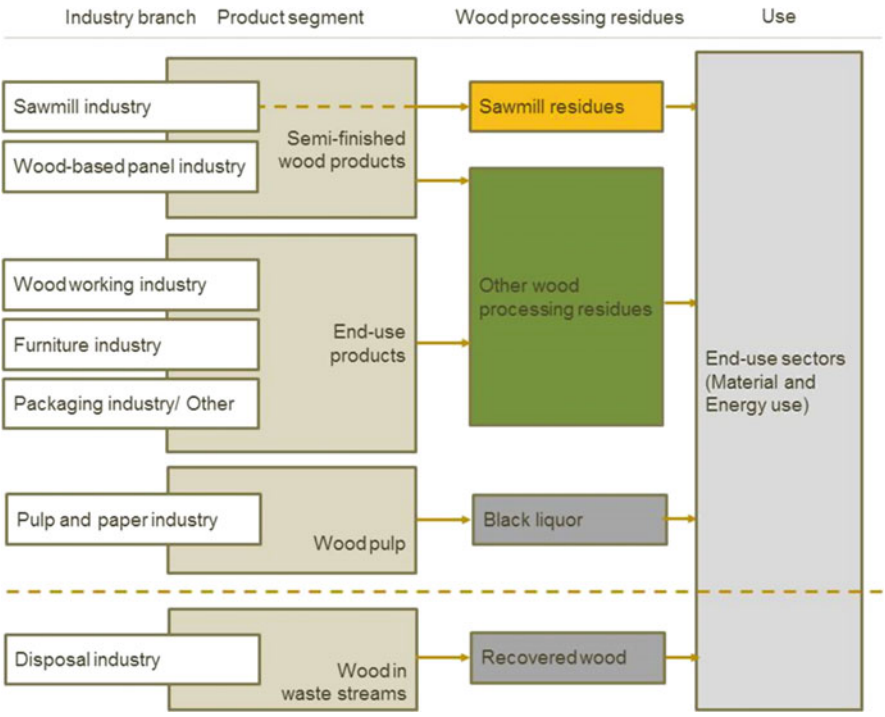

Fig. 1 Scheme of the forest industry sector and wood processing residues. Source: based on Saal [5]

the disposal industry as the sector which recovers wood from waste streams. It displays the context of the common forest industry production processes and production output (e.g. sawmill industry producer of semi-finished wood products and sawmill residues).

In the following, the particular segments of wood processing residues and their assortments are explained based on the origin of the resource.

Semi-finished wood products are produced within the sawmill industry and wood-based panel industry. They cover all sawnwood products and wood-based panels.

Sawmill residues inevitably accumulate as a side yield during production of sawnwood within the sawmill industry. The main assortments of sawmill residues are chips, sawdust and slabs. Cross-cut ends, edgings and trimmings are additional residues of sawnwood production. Sawmill residues consist of primary wood fibre. The assortments are a homogenous wood resource of constant dimensions and quality [22]. They are desirable for the production of pulp and wood-based panels and energy products, such as pellets.

Other wood processing residues (other than sawmill residues) accumulate during the production of wood-based panels, such as particle board, different fibreboard products, plywood and veneer. Residue assortments are shavings, veneer rejects and peeler cores, trimmings and edgings, wood dust and chips. Most of the residues are of fresh fibre, although wood processing residues of some fibre board products are an exception. Because of fillers and additives, these other wood processing residues do not consist exclusively of primary wood fibre.

Further amounts of other wood processing residues result from the manufacture of finished products. They cover all wooden products made of semi-finished wood products, such as furniture, packaging and applications in construction (e.g. engineered wood products). Wood processing residues which accumulate during the further processing of semi-finished wood products have to be clearly separated from sawmill residues and wood processing residues of primary fibre. Wood residues from further processing to finished products are residues such as dust and shavings from planning, milling and drilling as well as trims and clippings.

There is a huge variety of output shares of wood processing residues as it largely depends on the type of manufacturing process and the kind of wood product used as input to the respective production process. For example, sawmill residue shares range from 35% to 45% depending on wood species, log dimensions and technical processing parameters [10, 23–25]. Shares of wood processing residues from wood-based panel production also differ. Production of, for example, fibre boards or oriented strand board yields shares of 4–12% of wood processing residues. Production of, for example, plywood and veneer results in higher shares (45%) of wood processing residues because of lower material efficiency [26].

Black liquor is the residue of the pulping process within the pulp and paper industry. The residual mass mainly consists of lignin and hemicelluloses, cooking chemicals and water which are used to extract wood fibre. Approximately 40–50% of the input wood raw material is recovered as further usable fibre in the chemical pulping processes ([27], p. 38). So far, black liquor does not appear on resource

markets but is almost entirely used for industries' internal energy generation [28]. However, because of increasing demand for lignocellulosic resources, black liquor volumes are considered to be possible future chemical resources [19].

Recovered wood, also referred to as waste wood or post-consumer wood, is wood or wood products that have been disposed after a first use or after end use. It consists of wood from packaging materials, wood from construction or demolitions sites or wood which can be recovered from municipal waste (e.g. used furniture). Parts of recovered wood also originate from manufacturers of wood-based products which dispose of wood processing residues at waste management companies (e.g. [29–32]).

3 Supply of Wood-Based Residues: On Three Regional Levels

This section focuses on the analysis of existing information and data on the supply of wood processing residues. This is done on three different regional levels: first, results of wood resource monitoring research conducted in Germany is presented and compared with results of (modelling data EUwood) and available statistical data from FAO. Subsequently analysis of available data on a European and on a global level are undertaken.

3.1 Germany

The wood resource monitoring project in Germany has been continuously assessing the supply and demand of wood raw materials in the forest industry since 1999. This periodic research based on empirical surveys allows one to display the development of wood resource availability and wood flows within the forest industry. Additional information is achieved for balancing wood resources and information on conversion factors. This assessment requires comprehensive data sets. Some data are provided from national statistics. However, many parts are recorded insufficiently. Detailed information on particular wood consumers is not covered by official statistics or is only underestimated because of statistical cut off thresholds (e.g. [20, 33]). Volumes of wood processing residues are also not covered by official statistics. Based on detailed surveys on the wood resource input of the respective industry branches, the segments of sawmill residues and other wood processing residues from wood-based panel production and further processing are analysed. Thus, surveys are designed to gather information on internal and external distribution of wood processing residues. This allows one to describe the resource mix of wood biomass consumers and thus material flows. Figure 2 shows the

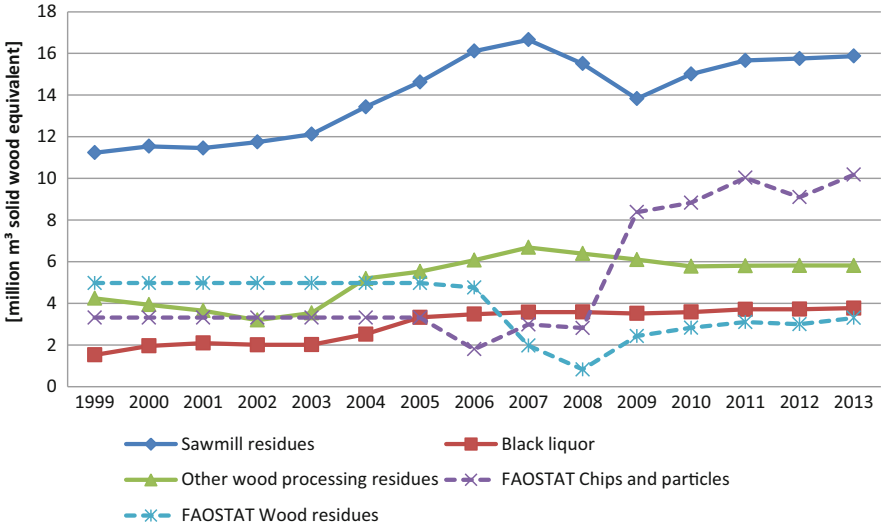

Fig. 2 Development of particular assortments of wood processing residues. Source: [19, 21]

development of the different assortments of wood processing residues in Germany. For comparison, data from FAO are also shown.

It can be seen from the graphs that, by volume, wood processing residues are an important source of wood supply in Germany. Data given by FAO differ considerably. On the other hand, because of different compositions of the assortments (1) chips and particles and (2) wood residues, the development of residue volumes can only be compared based on total volumes.

Table 1 presents current data on wood resources and wood use in Germany. Results of the latest resource monitoring of the German forest industry (2010) are shown in comparison to the resource potential calculated within the EUwood study [3] and available data by FAO for 2010.

As can be seen in Fig. 2 as well as in Table 1, data gathered by wood resource monitoring, based on empirical research, are significantly higher than data provided in international databases. A systematic underestimation of available volumes in FAO can be stated.

3.2 Europe

As described in Sect. 2.1, comparable assessment studies of wood processing residue volumes on national and European scale studies are rare. Thus, quantification of (potential) supply of wood processing residue volumes is based on modelling. Wood resource modelling depends on comprehensive datasets and feasible default values, such as material balance, industry consumption and size classes and

Table 1 Comparison of data on wood processing residues and post-consumer wood in Germany, 2010

Assortments	Resource monitoring 2010 Mantau [19] (million m^3)	EUwood, potential for 2010 Mantau et al. [3] (million m^3)	FAO, 2010 (FAO 2015) (million m^3)	
Sawmill residues	14.4	13.8		
of which chips	9.1[a]	8.9[b]	8.8	Wood chips and particles
Other wood processing residues	5.8	6.9	2.8	Wood residues
Black liquor	3.6	3.6		
Post-consumer wood	*14.0*	*8.7*		
Total (assessed)	23.8	24.3	11.6	Total
Total (incl. post-consumer wood)	37.8	33.0		
Total in tonnes dry matter [t_{dm}]	11.4	11.2	5.5	
Total (incl. post-consumer wood) [t_{dm}]	17.8	15.5		

Volumes in million m^3 solid wood equivalent
Total volume given in tonnes dry matter [t_{dm}] are based on the conversion factor of 0.47 t_{dm}/m^3 solid wood equivalent
Source: [3, 5, 19, 21, 23]
[a]Döring and Mantau [23]
[b]Calculations based on Saal [5]

particular coefficients. This information is not covered by official statistics and only partly available for some countries. As shown in Sect. 2.2, data by FAO on wood chips and particles and wood residues are not fully applicable. However, data that can be generally applied to the production of forest products, consumption and trade data for Europe (EU28/EFTA), are available from FAO.

Within the EUwood study, the modelling of wood processing residue volumes on a European scale was carried out [5] for the purpose of a European Wood Resource Balance. This included detailed quantification of the segment wood processing residues. Similar modelling based on EUwood results was used for the European Forest Sector Outlook Study 2012 [34]. The modelling approach followed the general forest industry structure (see Fig. 1) which follows a resource-based assessment structure. German data served as default data for modelling wood processing residue volumes in Europe [3, 34]. Datasets of comparable extent for other European countries are not known so far. Results of the periodic resource monitoring of the German forest industry sectors were applied as default values on FAO production and wood products consumption data (see [5]).

The comprehensive size class structure and further parameters of the German sawmill industry were applied to sawnwood production data (by FAO) to model volumes of *sawmill residue assortments* of the EU27 countries and to consider national differences in industry size and material conversion efficiency.

Volumes of *other wood processing residues* from the production of wood-based panels were estimated based on generalised parameters and material conversion factors. It is generally assumed that production processes throughout the producing countries are of similar quality and technological development. Thus, conversion factors are applied for all countries. Data on wood-based panel production volumes are given by FAO.

Residue volumes of *other wood processing residues* from production processes of finished products are estimated based on the wood consumption within the particular end-use processing sectors: construction, furniture and packaging industry and others. Country specific coefficients were applied to sawnwood and wood-based panel consumption (including import and export volumes) (FAO) to model particular wood consumption of the sectors. Again, German default values were applied to estimate respective shares of wood processing residues within the different end-use sectors.

Shares of black liquor as a residual product of the pulp industry were calculated based on pulp production data by FAO and available country specific conversion factors [10]. Further influencing parameters such as the share of coniferous roundwood input were modelled.

Table 2 shows the results of the EUwood study on the different segments of wood processing residues in comparison to available data by FAO.

As already seen in Table 1, data on wood processing residues based on the differentiated assessment [3] mainly based on German default values are significantly higher compared to statistical data provided by FAO.

3.3 Global Data

As presented in Sect. 2.1, studies on the supply of wood processing residues on a global scale are rare. Moreover, results of considered global estimates (compare Sect. 2.1) are not comparable because of different methodological approaches.

To provide the possible range of global volumes of wood processing residues, we applied the presented methodologies and compared the results with data from FAO. The following Table 3 shows the available data by FAO in comparison to calculated wood processing residue volumes based on Parikka [6]; FAOSTAT [21] and Saal [5].

FAO provides data on wood chips and particles and wood residues for 80 producing countries. The other countries do not report the respective volumes. For this study the global supply of sawmill residues and wood chips in particular, other wood processing residues from wood-based panel production and black liquor were roughly estimated based on FAO/UNECE [10]. Other wood processing residues

Table 2 Comparison of data on wood processing residues and post-consumer wood in the EU27, 2010

Assortments	EUwood, potential for 2010 Mantau et al. [3] (million m^3)	FAO, 2010 (FAO 2015) (million m^3)	
Sawmill residues	86.6		
of which chips	46.7[a]	61.2	Wood chips and particles
Other wood processing residues	29.7	47.0	Wood residues
Black liquor	60.4		
Post-consumer wood	*52.0*		
Total (assessed)	176.7	108.2	Total
Total (incl. post-consumer wood)	228.7		
Total in tonnes dry matter	83.1	50.8	
Total (incl. post-consumer wood) [tdm]	107.5		

Volumes in million m^3 solid wood equivalent
Total volume given in tonnes dry matter [t_{dm}] are based on the conversion factor of 0.47 t_{dm}/m^3 solid wood equivalent
Source: [3, 21]
[a]Calculations based on Saal [5]

Table 3 Comparison of different calculations on global data on wood processing residues, worldwide 2010

Basis	Parikka [6] (million m^3)		FAO/ UNECE [10] (million m^3)		Saal [5] (million m^3)		FAO, 2010[a] (million m^3)	
Range	From	To	From	To	From	To		
Assortments								
Sawmill residues	339.4	414.8	223.7	394.8	229.5	404.9		
of which chips	83.1	101.6	118.4	243.5	108.2	190.8	260.4	Wood chips and particles
Other wood processing residues					104.7[b]		46.7	Wood residues
Black liquor			277.8	333.3	278.5	296.2		
Total (assessed)	422.5	516.4	619.9	971.5	720.7	996.6	307.1	Total
Total (t_{dm})	198.6	242.7	291.4	456.6	338.7	468.4	144.3	

Volumes in million m^3 solid wood equivalent
Total volume given in tonnes dry matter [t_{dm}] are based on the conversion factor of 0.47 t_{dm}/m^3 solid wood equivalent
Source: [5, 6, 10, 21]
[a]Data are based on FAO country data, available/provided for 80 countries
[b]Data based on coefficients of wood processing residue shares of wood-based panel production – only one value calculated

from further processing, such as from the furniture industry, were not estimated as the modelling approach developed for the EUwood study [5] was/is not applicable on a global scale. The estimation of sawmill residues and chips is based on general assumptions on material recovery [6] and country data [10]. The estimations of black liquor volumes are rough shares based on conversion factors [10] and more specific estimations which consider shares of wood species input in global pulp production given by, for example, Goetzl [35]. Minimum and maximum ranges are presented.

As Tables 1–3 show, the statistical data provided by FAO also underestimates the volume of wood processing residues in total on the global level. This is partly because of the low coverage of only 80 reporting countries. Moreover, the given values for wood chips and particles are not clearly defined. They may also include reported residue assortments of different origin. However, underestimation is also through lack of statistical coverage of the volumes of wood processing residues, even if the quantities imply significant global volumes of wood assortments.

4 Discussion

Wood processing residues contribute to wood supply by around one-fifth of the total wood biomass. In general, supply and available volumes of wood processing residues are dependent on the processing of roundwood. The efficiency of roundwood utilisation influences the supply of wood processing residues. It is assumed that the production of semi-finished and finished wood products increases [3, 34, 36]. Thus, an increasing supply of residues is expected in connection with increased roundwood processing and the increasing demand for wood and wood products. Further, an increase in demand and scarcity of wood resources probably leads to a more efficient use of wood processing residues.

However, as the results show, there is a huge discrepancy between officially reported data on wood processing residues and empirical (or modelled) data. Discrepancy may be because of terminology deficits and little reported data. Wood processing residues have a significant impact on sustainable wood supply. Their occurrence depends completely on the wood processing industry. The variety of assortments and sources is as poorly addressed in the literature as is the calculation of the quantity. In some cases the quantities may be calculated fairly well because of the unique technical relationship. Residues are an inevitable remainder of any production process. If conversion factors are well-known, the quantities can be calculated based on the underlying production statistics. This applies mainly to the semi-finished sector (e.g. sawmill and pulp industry). However, the further processing of wood (e.g. construction, furniture) is very diverse and research has not paid much attention to this issue so far. Aside from unknown available quantities, the question of utilisation should be analysed because it is not known to what extent residues are consumed internally or are available on the market. Most likely, most of the material is used for power and heat but only a few

empirical studies on residue utilisation are available. This chapter clarifies the terminology of wood residues and summarises existing data on quantities. However, as official statistics focus on products, analyses in this area probably always rely on empirical studies. It is strongly recommended to intensify such studies and possibly apply the results on international statistics in order to provide more realistic data. These data are needed for a better estimation of sustainable use of wood as well as, for example, for the quantification of cascades in circular economy because residues are the main source of cascading use of wood.

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