Influence of Diameter and Quality of Beech Logs on the Potential Energy of Sawmill Residues

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The influence of log diameter and log quality were studied relative to the potential heat energy produced from wood residue. Research was conducted on beech sawmill logs (30 cm to 49 cm in diameter and 4 m in length) of different qualities. Logs with greater diameters and of better quality increased the amount of products and decreased the amount of residue. A decrease in the diameter and quality of beech logs increased the total energy capacity, ranging between 840 kWh/m^3 (highest quality logs, 40 cm to 49 cm in diameter) and 1,350 kWh/m^3 (lower quality logs, 30 cm to 34 cm in diameter). Drying the lumber produced from logs of small diameters used less than 10% of the potential heating energy. However, logs of 40 cm to 49 cm in diameter increased this usage to 33%. When burner losses and drying energy losses were calculated, there was approximately 430 kWh/m^3 to 960 kWh/m^3 of leftover energy. This could be used for various purposes or it could be sold. The amount of obtained energy was influenced more by log diameter than by the log quality.

Keywords: Sawmill; Beech; Wood residues; Energy

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INTRODUCTION

Numerous studies on sawmill processing show different data concerning raw material yield and other effects of production. These studies' topics include the influences of diameter and log quality (Hapla and Ohnesorge 2005; Popadić 2014a), the types of technological processes (Shepley *et al*. 2004; Thomas and Buehlmann 2016), sawing methods (Popadić *et al*. 2014b), optimal opening face position (Chang *et al*. 2005; Todoroki *et al*. 2007; Lundahl and Grönlund 2010), and the precision of an operator's work on machines (Buehlmann and Thomas 2007; Wang *et al*. 2009).

Most of the studies focused on how the examined parameters influenced the main products. Wood residues were not usually the focus and sometimes not even calculated in the effects of processing. Residues are considered byproducts and are usually used to obtain heat energy. Residue quantity is rarely calculated with precision and is often given as an estimate. This is because although the main products have regular geometric shapes, which are easy to take into calculation, residues are made of irregular shapes that are difficult to quantify.

The first difficulty in measuring wood residues in sawmill processing is simply collecting it, especially sawdust. Consequently, its quantity is usually determined indirectly by calculating the difference between the quantities of the raw material and the main products. These results are influenced by the calculation errors of log volume. The precision of log volume calculation was researched by Nikolić (1990), Patterson and Doruska (2004), Ozcelik *et al*. (2006), and Patterson *et al*. (2007), among others. Most authors report that actual log volume is somewhat greater than the volume calculated using Huber's formula, as recommended by the standard EN 1309-2 (2006). Consequently, log processing yields more residues than are calculated, *i.e.*, some amount of wood is obtained for free. The situation is similar with bark. The European praxis calculates the log volume without bark, which makes the bark an overlooked energy resource.

The goals of this study were to determine the quantity and structure of sawmill residues in beech log processing and to determine how the log diameter and log quality influences the potential energy from wood residues. Beech wood was selected for this research because it is one of the most frequently processed commercial wood species in Europe. An additional goal was to assess what fraction of obtained energy could be used after the drying of lumber, considering that kiln drying is an energy intensive process that consumes up to 75% of the total energy in the wood industry process chain.

EXPERIMENTAL

Materials

The research was conducted on 90 European beech (*Fagus sylvatica* L.) sawmill logs (Scientific base of University of Belgrade - Faculty of Forestry, Serbia), 30 cm to 49 cm in diameter and 4 m in length. The logs were classified into three groups according to diameter: 30 cm to 34 cm, 35 cm to 39 cm, and 40 cm to 49 cm.

According to quality, they were organized into three classes according to the SRPS D.B4.028 (1979) standard. This standard was applied only to logs for sawmill processing. The 1st class includes the highest, and the 3rd the lowest quality logs. Measures (log diameter and length) as well as number and size of allowed wood defects within the quality classes are defined. Knots, fissures, cracks and shakes, false heartwood, as well as taper, spiral grain, and other wood defects are observed. There is no difference between sweep and crook; both are considered as sweep.

Each group had 10 logs. Groups were formed so that they contained equal amounts of butt logs and logs of irregular shapes. The average values of taper across the log groups ranged from 0.7 to 1.4 cm/m', and the average taper of all logs was 1.03 cm/m'. Somewhat higher values were observed in logs with larger diameter because of butt logs presence. This standard allows sweep up to 5%, but there were only three such logs in the sample.

The logs were sawn into commercial lumber. All of the products were measured according to the EN 975-1 (2009) standard, and their volumes (V_p) were calculated.

Methods

Ozcelik *et al*. (2006) compared the precisions of six well-known formulae for calculating log volume. They reported that the Newton, Center of Gravity, and Centroid methods were clearly superior to the other formulae. The accuracy of all methods, as indicated by Chi-square accuracy tests, ranged from the Newton > Center of Gravity > Centroid > Huber > Bruce > Smalian's formula, which performed the poorest. Therefore, Newton's formula was used (Eq. 1) to calculate the log volume (V_N) to determine the amount of sawmill residues,

$$V_N = (B + 4M + S) \times \frac{l}{6} \tag{1}$$

where B is the cross-sectional area of the butt end (m^2), M is the cross-sectional area at mid-length of the log (m^2), S is the cross-sectional area of the small end (m^2), and l is the log length (m).

Wood residues, as well as the energy obtained from them, were calculated using Newton's log volume formula. However, in European standards and praxis, log volume is usually calculated using Huber's formula, so Huber's log volume (V_H) was also used to calculate quantitative yield, as shown in Eq. 2:

$$V_H = M \times l \tag{2}$$

Differences in log volumes obtained using Newton's and Huber's formulae were calculated, and the quantitative yield (Q_y, %) was calculated by dividing the volume of products by the volume of the log without bark (Table 1.), as shown in Eq. 3:

$$Q_y = \frac{V_p}{V_H} \times 100 \tag{3}$$

The mass of the available wood (*e.g.*, coarse residues and sawdust) and the mass of the bark within the wood residues were used to calculate the energy effects of sawmill processing. Calculating wood mass and bark mass from their volume was done *via* density ($\rho = m / V$). The values used for this were the measured wood densities (ρ) from five samples from each log. Bark density was calculated by multiplying wood density by the coefficient 1.071 (Šoškić and Popović 1992). Coarse residues were collected after each log was processed, and their mass was measured. The mass of bark within the coarse residues was subtracted from this value to obtain the mass of wood in the coarse residues.

The sawdust volume was obtained by taking the real (Newton) log volume (without bark) and subtracting the lumber volume (real dimensions, with overmeasure) and wood volume in the coarse residues (obtained from known mass and wood density).

Debarking is rarely applied because beech bark is relatively thin and smooth. Therefore, some amount of bark stays on the unedged products and is delivered to the buyer without being included in the final processing calculation. The volume of the bark in the coarse residues was calculated by subtracting the volume of the bark on the final products from the total bark volume.

Assuming the oven-dry density (0.68 g/cm^3) and volume swelling (18%) of beech wood, the moisture content (MC) of the logs was calculated using Eq. 4:

$$MC = \frac{\rho \times 1.18}{0.68} - 1 \tag{4}$$

The gross calorific values of beech wood (5.5 kWh/kg) and of beech bark (4.98 kWh/kg) were assumed (Pavić 1965; CEN/TS 14961 2010; ECN 2019). The net calorific value is defined as the ratio between the released heat energy at full combustion and the unit of mass. Net calorific values were calculated according to the standard EN 14918 (2009), which prescribes the method of determining the calorific value of solid biofuels.

To estimate the potential energy of the wood residues and bark, it was assumed that during warehousing, their moisture content decreased and equalized. In addition, the coarse residues and bark were assumed to have an average moisture content of 50%, while the moisture content of sawdust was assumed to be 30%. Internal data of the authors (provided by the companies) indicate that these are typical values at combustion in companies that process beech logs. Additionally, moisture content equalization was conducted to enable comparisons between logs of different dimensions and quality classes.

The typical thermal efficiency of a biomass boiler is 70%, significantly less than that of most gas-, oil-, or coal-fired boilers. Reasons for reduced efficiency include moisture and ash in the fuel, incomplete combustion, flue gas temperature, entry of uncontrolled air, load factor, and a relatively small scale. In this study, the boiler efficiency was assumed to be 75.7% for wood with a MC of 50% and 78.5% for wood with a MC of 30% (Furtula 2014).

The amount of energy needed for kiln drying the beech lumber was calculated considering the usual drying process in Central and Southern Europe. It is the process in the conventional kiln (with vents) heated with water (*ca.* 90 °C), where the initial temperature in the drying schedule is usually *ca.* 35°C and at the end of drying it is about 60 °C, followed by 20 to 40 h of conditioning phase.

The total energy consumption depends on both the initial and final moisture content, lumber thickness, wood species, kiln schedule, *etc*. In addition, kiln-specific conditions (*e.g.*, the energy delivery system, operating efficiency, insulation levels, venting practices, and the fans' energy requirements) play an important role in the overall energy demands (Simpson 1991). The model for this study was drying of beech lumber – both 50-mm thick and 25-mm thick (1:1 ratio) – in an above-mentioned system (conventional kiln and a wood biomass boiler). An initial MC of 80% and final of 8%, as well as a kiln capacity of 100 m^3 were used for calculation. The calculation used the authors' internal data on energy consumption for the individual phases of drying. This included heat energy needed for evaporation of water (58% to 64%), heat loss by conduction, air leaking and venting (26 to 32%), and heating of lumber and kiln (10%). Then the calculation is done to determine which part of the available heat energy is needed for drying the lumber obtained from the logs.

RESULTS AND DISCUSSION

As expected, logs of higher quality class and greater diameter showed better quantitative yield (Table 1).

Table 1. Yield of Milled Beech Logs

Diameter (cm)	Class	Huber Volume (m^3)	Newton Volume (m^3)	Difference (%)	Volume of Products (m^3)	Quantitative Yield (%)	Moisture Content (%)
30 to 34	I	0.363	0.370	2.13	0.192	52.70	72.2
	II	0.333	0.340	2.08	0.166	49.57	74.7
	III	0.358	0.368	2.74	0.176	49.40	82.2
35 to 39	I	0.446	0.458	2.70	0.257	57.66	72.1
	II	0.455	0.463	1.94	0.249	54.70	75.1
	III	0.444	0.447	0.81	0.232	52.03	79.1
40 to 49	I	0.706	0.720	1.95	0.461	65.23	79.4
	II	0.660	0.688	4.22	0.428	64.51	74.1
	III	0.641	0.665	4.01	0.398	62.03	76.5

Newton's formula is more accurate, but gave a greater log volume than the standardized Huber's formula of approximately 1% to 4%. The quantitative yield in Table 1 is shown in the standard way (based on the Huber log volume), as it is calculated in the industry. This representation resulted in a greater yield and therefore indirectly decreased the amount of wood residue.

The average wood density for all logs was 1.013 g/cm^3, with a coefficient of variation of 5.96%. It ranged from 0.99 g/cm^3 (logs of the class I of diameters 30 to 34 and 35 to 39 cm) to 1.03 g/cm^3 (class I 40 to 49 cm, class III 30 to 34 and 35 to 39 cm). The outer parts of the felled logs had higher moisture than the inner ones and it might be assumed that thinner logs had a higher MC due to lower portion of heartwood. However, the MC is usually equalised in the log yard (Table 1), but that depends on the time that has passed from the tree fall to log processing.

Table 2 shows the average mass of the wood residues and bark, as well as the masses per m^3 of logs.

Table 2. Measured and Calculated Average Mass of Wood Residues and Bark

Diameter (cm)	Class	Coarse Residues (kg)	Sawdust (kg)	Bark (kg)	Coarse Residues (kg/m^3 of logs)	Sawdust (kg/m^3 of logs)	Bark (kg/m^3 of logs)
30 to 34	I	99.93	41.21	23.06	273.03	110.16	62.62
	II	105.82	37.90	22.57	312.71	112.43	66.66
	III	117.20	47.66	24.28	318.01	129.02	66.42
35 to 39	I	111.12	42.91	25.05	242.15	93.10	54.81
	II	118.91	50.86	25.55	256.33	110.71	55.27
	III	130.53	48.26	25.71	295.83	107.96	57.86
40 to 49	I	99.15	93.52	32.45	138.02	129.51	45.45
	II	108.79	80.49	30.81	159.83	118.44	45.13
	III	137.12	73.85	30.78	208.68	111.05	46.68

Table 2 shows a certain dependency of wood residue mass on log diameter and log quality, but conclusions can only be drawn after eliminating the influence of MC.

As shown in Fig. 1, the log diameter and log quality influenced the wood residue mass.

Because the bark on beech logs is of the same thickness, its share of volume decreased as the log diameter increased, as did its mass per m^3 of logs (Fig. 1). The higher percentage of coarse residues in small logs is the consequence of the fact that a thicker slab should be made on small-diameter logs to set the width of the first board. Also, in the case of board edging, the percentage of edgings in narrow boards is greater than in wide boards. Thus, due to the generally wider boards the larger logs have less coarse residues.

The amount of sawdust was correlated with the total length of cuts made during the timber processing. This length depended mostly on the product structure. In this study, the mass of sawdust was 70 kg/m^3 of logs to 94 kg/m^3 of logs. Due to the high variation of data, there was no clear correlation between sawdust mass and log diameter and quality.

Logs with larger diameters and a higher quality yielded more products and therefore less wood residues. They had no influence on the amount of sawdust but on the mass of coarse residues, as shown in Fig. 1.

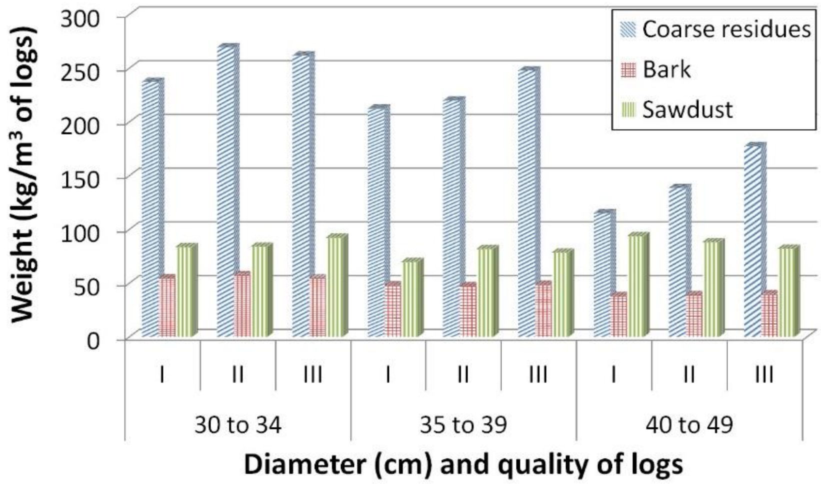

Fig. 1. Weight of wood residues per m^3 of logs with assumed MC (50% for coarse residues and bark, 30% for sawdust)

Table 3 shows the values of potential energy by unit of volume (m^3) of logs according to the assumed MC of wood residues and the calorific values of wood and its bark at that MC. Considering that it was assumed that MC of coarse residues, bark and sawdust was equal, it can be concluded that the differences in the amount of energy between the groups of logs are primarily a consequence of the difference in the mass of the residue.

Table 3. Calorific Value of Wood Residues and Bark per m^3 of Logs

Diameter (cm)	Class	Coarse Residues (kWh/m^3 of logs)	Sawdust (kWh/m^3 of logs)	Bark (kWh/m^3 of logs)	Total (kWh/m^3 of logs)
30 to 34	I	762.99	318.10	158.95	1240.05
	II	866.73	319.71	166.81	1353.25
	III	841.99	351.58	159.15	1352.72
35 to 39	I	683.06	265.42	139.44	1087.92
	II	707.11	311.38	137.79	1156.27
	III	796.92	298.75	141.11	1236.78
40 to 49	I	369.82	357.22	110.72	837.76
	II	446.03	335.62	113.28	894.93
	III	570.55	312.13	115.33	998.02

Table 3 indicates that the amount of energy from coarse residues increased due to decreasing log diameter and log quality (maximal ratio between average values was approximately 1:2.3). In contrast, the amount of energy from sawdust did not show a clear correlation with either the log diameter or quality. The amount of energy from the bark increased with smaller log diameters, but the fraction of bark energy among the total energy was constant (approximately 12% to 13%). The total energy value increased with smaller diameter and lower quality beech logs, according to the shown amounts and the structure of the wood residues after processing.

As the greatest heat energy consumers in the whole wood products chain, conventional kilns are dominant in the world and consume approximately 50% more energy than is required to evaporate water (Elustondo and Oliveira 2009). Guzenda and Olek (2000) report specific energy consumption values of approximately 1.4 kWh/kg above fiber saturation point (FSP) and more than 2.8 kWh/kg below FSP. Dzurenda and Deliiski (2012) report that drying 60-mm-thick beech lumber has a specific energy consumption between 400 kWh/m^3 and 560 kWh/m^3. In the current study, the average specific heat consumption (calculated against assumed conditions) was 435 kWh/m^3 for beech lumber 25-mm-thick and approximately 480 kWh/m^3 for 50 mm.

When this specific heat consumption was recalculated as the heat needed for drying the lumber obtained from 1 m^3 of logs (Table 4), it was clear that drying lumber made from logs with small diameters used less than 10% of the potential obtained heat energy. Conversely, for logs of 40 cm to 49 cm in diameter, that share was several times larger, at approximately 30%. In addition, the log quality had an influence, but it was much smaller; the shared heat energy used for drying was greater with higher quality logs. This was less pronounced with logs of smaller diameters due to having more variation. The calculated energy consumption for drying ranged between 3.68% (class II log, 30 cm) and 46.01% (class I log, 49 cm). It was clear that log diameter and log quality were crucial to the amount of energy that remained after drying for the manufacturer to use for other purposes (*e.g.*, steaming of lumber, heating of workspaces during cold seasons, and sale on the market).

Table 4. Energy per m^3 of Product

Diameter (cm)	Class	Energy Needed for Drying Lumber Obtained from 1 m^3 of Logs (kWh/m^3)	Biomass Energy Needed for Drying (kWh/m^3)	Surplus Energy from Biomass (kWh/m^3)	Share of Energy Needed for Drying (%)
30 to 34	I	87.78	114.85	1125.20	9.26
	II	75.92	99.46	1253.79	7.48
	III	80.39	105.18	1247.54	7.99
35 to 39	I	117.74	154.16	933.77	14.08
	II	113.88	148.96	1007.31	12.89
	III	106.23	139.05	1097.73	11.41
40 to 49	I	210.92	274.24	563.52	32.74
	II	195.85	255.15	639.78	28.71
	III	182.07	237.71	760.31	23.86

With older and/or smaller kilns, heat consumption can be an additional 20% larger than stated in this study. In older kilns, the main causes for this result are much greater air leakage, and in small kilns, in relation to the volume of lumber, greater energy consumption for heating and humidification (Milić *et al*. 2014).

Figure 2 shows the average structure of wood residues in sawmill processing of beech logs and potential energy that could be obtained from them. It also shows the average energy consumption for the drying of wood products.

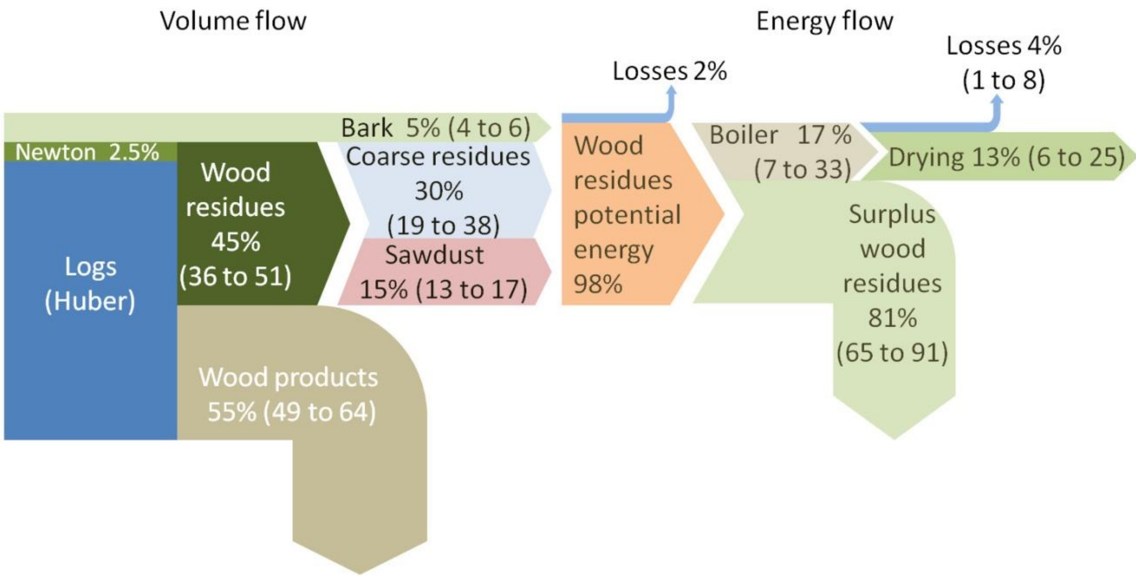

Fig. 2. Diagram of volume and energy flow of beech sawmill production (ranges of average data per group of logs are given in parentheses)

The diagram indicates that appreciable amounts of energy come from wood residues that are virtually obtained for free (bark and log volume calculation error). However, there are additional losses when converting the residues into energy. One part of the losses was due to the inability to collect and burn some of the residues, while another part was caused by losses due to transporting energy to and from the boiler. Total energy losses depended on an array of factors, including the amount of bark on the delivered logs, the efficiency of residue transport, the level of technical equipment, the proper functioning of the energy production, and the energy transport systems. As shown in Fig. 2, on average there was more than 80% of the surplus energy at the end of the process. This energy could be used to steam beech wood products, to heat workspaces, to sell on the market, *etc.*

CONCLUSIONS

1. Larger diameter and higher quality class beech logs increased the volume of products and decreased the volume of wood residues produced. The log diameter and log quality showed a correlation with the mass of the coarse residues and bark, but no correlation with the amount of sawdust was established. According to the structure and quantities of the wood residues after processing, beech logs with smaller diameters and of lower quality yielded more total energy. The maximum difference ratio between the average energy values of the coarse residues was 1:2.3, and the shared energy from the bark among the total obtained energy was approximately 12% to 13%.
2. The total energy from residues after the sawmill processing of the beech logs was between 840 kWh/m^3 (logs of highest quality, 40 cm to 49 cm in diameter) to approximately 1,350 kWh/m^3 (logs of lower quality, 30 cm to 34 cm in diameter). The amount of energy was affected more by the log diameter than by log quality. After burner losses and the needed drying energy were considered, there was 430 kWh/m^3 to 960 kWh/m^3 of energy that could be sold or used for other purposes.

3. The drying of lumber made from logs of small diameters used less than 10% of the total heat energy, but with logs 40 cm to 49 cm in diameter, usage increased to 30%. In addition, the log quality had lower influence, but it can be expected that the share of heat energy used for drying would be greater in logs of higher quality.

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REFERENCES CITED

Buehlmann, U., and Thomas, R. E. (2007). "Relationship between lumber yield and board marker accuracy in rip-first rough mills," *Holz als Roh- und Werkstoff* 65(1), 43-48. DOI: 10.1007/s00107-006-0099-7

CEN/TS 14961 (2010). "Solid biofuels. Fuel specification and classes," European Committee for Standardization, Brussels, Belgium.

Chang, S. J., Cooper, C., and Guddanti, S. (2005). "Effects of the log's rotational orientation and the depth of the opening cut on the value of lumber produced in sawing hardwood logs," *Forest Products Journal* 55(10), 49-55.

Dzurenda, L., and Deliiski, N. (2012). "Convective drying of beech lumber without color changes of wood," *Drvna Industrija* 63(2), 95-103. DOI: 10.5552/drind.2012.1135

Elustondo, D. M., and Oliveira, L. (2009). "Model to assess energy consumption in industrial lumber kilns," *Maderas. Ciencia y Tecnología* 11(1), 33-46. DOI: 10.4067/S0718-221X2009000100003

EN 1309-2 (2006). "Round and sawn timber – Method of measurement of dimensions – Part 2: Round timber – Requirements for measurement and volume calculation rules," European Committee for Standardization, Brussels, Belgium.

EN 14918 (2009). "Solid biofuels – Determination of caloric value," European Committee for Standardization, Brussels, Belgium.

EN 975-1 (2009). "Sawn timber - Appearance grading of hardwoods - Part 1: Oak and beech," European Committee for Standardization, Brussels, Belgium.

Energy Research Centre of the Netherlands (ECN) (2019). "ECN Phyllis2 database for biomass and waste," Phyllis2, (https://phyllis.nl/), Accessed 20 Jan 2019.

Furtula, M. (2014). *Uticaj Ekoloških i Energetskih Faktora na Korišćenje Čvrstih Drvnih Goriva u Srbiji* [*The Impact of Ecological and Energy Factors on More Efficient Use of Solid Wood Fuels in Serbia*], Ph.D. Dissertation, University of Belgrade - Faculty of Forestry, Belgrade, Serbia.

Guzenda, R., and Olek, W. (2000). "Computer aided analysis of costs and energy consumption of kiln drying of hardwoods," in: *2nd COST E15 Workshop: Quality Drying of Hardwood*, Sopron, Hungary, pp.16

Hapla, F., and Ohnesorge, D. (2005). "Modelling of the sawn timber yield of beech logs with regard to their dimension and red heart proportion," in: *Broad Spectrum Utilisation of Wood: Proc. COST Action E44 Conference,* Vienna, Austria, pp. 16.

Lundahl, C. G., and Grönlund, A. (2010). "Increased yield in sawmills by applying alternate rotation and lateral positioning," *Forest Products Journal* 60(4), 331-338. DOI: 10.13073/0015-7473-60.4.331

Milić, G., Kolin, B., Todorović, N., and Gorišek, Ž. (2014). "Energy consumption of beech timber drying in oscillation climates," *Drvna Industrija* 65(4), 309-314. DOI: 10.5552/drind.2014.1367

Nikolić, M. (1990). "*Određivanje količine drveta merenjem po masi* [Determination of wood quantity by mass measuring]," *Šumarstvo* 1, 3-10.

Ozcelik, R., Wiant, Jr., H. V., and Brooks, J. (2006). "Estimating log volumes of three tree species in Turkey by six formulae," *Forest Products Journal* 56(11-12), 84-86.

Patterson, D. W., and Doruska, P. F. (2004). "A new and improved modification to Smalian's equation for butt logs," *Forest Products Journal* 54(4), 69-72.

Patterson, D. W., Doruska, P. F., Hartley, J., and Hurd, M. (2007). "Validating the Patterson and Doruska equation for estimating the volume of hardwood butt logs," *Forest Products Journal* 57(1), 67-70.

Pavić, J. (1965). *Uticaj Zapreminske Težine i Grešaka Drveta na Toplotnu Moć Bukovine* [*The Influence of Wood Density and Wood Defects on Calorific Value of Beech Wood*], Ph.D. Dissertation, Univ. Belgrade - Faculty of Forestry, Belgrade, Serbia.

Popadić, R. (2014a). *Istraživanje Uticaja Prečnika i Kvaliteta Bukove Oblovine na Količinu Glavnih i Sporednih Proizvoda u Pilanskoj Preradi Drveta* [*The Influence of the Beech Log Diameter and Quality on the Sawmill Production Yield*], Ph.D. Dissertation, University of Belgrade, Belgrade, Serbia.

Popadić, R., Šoškić, B., Milić, G., Todorović, N., and Furtula, M. (2014b). "Influence of the sawing method on yield of beech logs with red heartwood," *Drvna Industrija* 65(1), 35-42. DOI: 10.5552/drind.2014.1312

Shepley, B. P., Wiedenbeck, J., and Smith, R. L. (2004). "Opportunities for expanded and higher value utilization of No. 3A Common hardwood lumber," *Forest Products Journal* 54(9), 77-85.

Simpson, W. T. (1991). *Dry Kiln Operator's Manual*, U.S. Department of Agriculture Forest Products Laboratory, Madison, WI, USA.

Šoškić, B., and Popović, Z. (1992). "*Varijacija učešća i svojstava kore nekih domaćih vrsta drveća* [Variations of barks share and properties of autochthonous tree species," *Drvarski Glasnik* 1, 3-9.

SRPS D.B4.028 (1979). "Products of forest utilization – Broadleaved saw logs," Institute for Standardization of Serbia, Belgrade, Serbia.

Thomas, R. E., and Buehlmann, U. (2016). "Potential for yield improvement in combined rip-first and crosscut-first rough mill processing," *BioResources* 11(1), 1477-1493. DOI: 10.15376/biores.11.1.1477-1493

Todoroki, C. L., Monserud, R. A., and Parry, D. L. (2007). "Lumber volume and value from elliptical western hemlock logs," *Forest Products Journal* 57(7-8), 76-82.

Wang, J., Goff, W. A., Osborn, L. E., and Cook, G. W. (2009). "Assessments of hardwood lumber edging, trimming, and grading practices of small sawmills in West Virginia," *Forest Products Journal* 59(5), 69-75.

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