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RESEARCH OF THE WASTE BIOMASS TECHNICAL AND ECONOMIC VALUE AS ONE OF THE TECHNOLOGICAL AND ENERGY DEVELOPMENT CRITERIA OF WOOD PROCESSING PLANTS

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Preliminary notes

A precise establishing of quantity, share, structure and place where wood waste appears considerably influences the speed and direction of technological and energy development of wood processing plants. Technical and economic value of waste biomass projects energy usage and efficiency of a production plant. Lack of experimental studies and usage of general empirical relations are often reasons of inadequate practical compatibility and connection of waste biomass with total efficiency of the plant. Based on studies carried out in eight plants in the Republic of Croatia, it was possible to determine quantity, type, share, structure and place of wood residue/waste appearance in relation to annual raw material processing. Thermal and electrical energy consumption was measured during the thermal processing of sawn timber. Numerical values expressed the fuel and economic value, depending on the quantity and structure of waste biomass. The research suggests a new diagram for determination of existing efficiency and parameters for technical and economic values of waste biomass as one of the criteria for technological and energy development of wood processing plants.

Key words: *technical and economical value of biomass, technical and energy development criteria, wood processing plant*

Istraživanje tehničko-ekonomske vrijednosti otpadne biomase kao jednog od kriterija tehnološkog i energetskog razvoja drvoprerađivačkih pogona

Prethodno priopćenje

Precizno utvrđivanje količine, udjela, strukture i mjesta nastanka drvnog otpada značajno utječe na brzinu i smjer tehnološko-energetskog razvoja drvoprerađivačkih pogona. Tehničko – ekonomska vrijednost otpadne biomase projicira energetsku uporabu i učinkovitost proizvodnog pogona. Nedostatak eksperimentalnih istraživanja i korištenjem poopćenih empirijskih relacija često je razlog nedovoljne praktične usklađenosti i povezanosti otpadne biomase s ukupnom učinkovitosti pogona. Na temelju provedenih istraživanja u osam drvoprerađivačkih pogona u Republici Hrvatskoj kvantificirano su utvrđene količina, vrsta, udjel, struktura i mjesto nastanka drvnih otpadaka u odnosu na godišnju preradu sirovine. Izmjerena je potrošnja toplinske i električne energije pri toplinskoj obradi piljenog drva. Numeričkim vrijednostima iskazana je ogrjevna i ekonomska vrijednost ovisno o količini i strukturi otpadne biomase. Predložen je novi dijagram za utvrđivanje postojeće učinkovitosti i parametara tehničko-ekonomske vrijednosti otpadne biomase kao jednog od kriterija tehnološko-energetskog razvoja drvoprerađivačkih pogona.

Ključne riječi: *drvoprerađivački pogon, kriterij tehnološko-energetskog razvoja, tehničko-ekonomska vrijednost biomase*

1 Introduction
Uvod

Fast technology development and growing number of population on Earth and, at the same time, significant biosphere and atmosphere pollution accelerate scientific and expert discussions in order to reach applicable conclusions on equal treatment of all fuel and energy resources forms with an objective to sustain development. Energy technologies develop according to the criteria of lower environment pollution, higher degree of plant utilization, accessibility, lower or higher independence, economy, etc.

In a wider context, wood residue biomass is a result of a plant production in wood processing industry and/or a result of regular forestry operations and it is used more or less as power fuel in production of thermal (boiler rooms, power plants) and/or combined production of electrical and thermal energy (CHP plant). CHP plants are the most efficient and ecologically acceptable, where the price of produced energy in them can be from 35 % to 45 % lower than the price of energy produced in centralized energy systems. Although total degree of CHP plants performance amounts to over 70 %, the degree of produced electrical energy performance is generally lower, which is especially expressed in plants using biomass and it amounts to 20 – 30 % [1, 3, 4].

Discussions, data collections and analyses on biomass structure, i.e. on share and value of single forestry residue/wood waste form are frequent in the world and in our country and they are processed and presented in scientific and professional papers, studies, projects, guidelines and recommendations,… [1, 2, 3, 4]. According to the European Union recommendations, a constant increase in energy production from biomass is expected [5, 6].

Since there is no generally accepted methodology for evaluation of influential parameters (technical, technological, energy, social, economy,…) of biomass usage, models with a series of technical, technological and economy assumptions are developed through different European scientific projects, which are not possible to be implemented in all countries because of their different degrees of development and economy capabilities, especially in wood processing industry, in fluctuating business conditions and market demands [7, 8, 9, 10, 11, 12].

Wood residue/waste quantity, share and structure in domestic wood processing plants, resulting from different degrees and phases of processing up to the final product, are often superficially estimated and without their technical and economic evaluation. Studies of the place, quantity, structure and value of waste biomass from a single segment of a technological process are not performed completely and systematically, so the scientifically established data are missing, which could contribute to a more precise evaluation of a wood residue from the aspect of its energy and economic usage. Wood residue analyses are limited to the production process residue in forms of various residues, such as logging residues, offcuts/edges, bark, bark chips, sawdust, planer shavings etc., but they do not include wood residues resulting from thermal processing and its influence on raw material utilization, technological efficiency and value of the total waste biomass. This is the reason that the research of technical and economic waste biomass value at eight middle-sized and larger wood processing plants has been done in our country, taking into consideration their production capacities and technological possibilities with the objective to quantify values and scientific contributions in defining one of the applicable criteria of technological and energy development.

2
Object, material and method of the research
Objekt, materijal i metoda istraživanja

2.1
Object and material
Objekt i materijal

The research was carried out at eight wood processing plants, X1 to X8, during the period of two years, i.e. in three time intervals within the period from the second half of 2007 until the first half of 2009. Parquets, various furniture types and similar products were final products in six wood processing plants, X1 to X6, and in the plants X7 and X8, the production cycle ended with semi-products output, such as dried sawn boards and/or elements of various dimensions. The production processes used more or less different types of timber, where domestic oak and beech dominated, about 60 to 80 % of the annual raw material needs. In all of the plants the component part of the wood processing was a primary saw mill, and additional processing mill, thermal processing and final products lines were of different technology possibilities and technical equipment accessibility. Having the annual raw material processing higher than 10000 m^3, X1, X2, X3 and X6 were treated by larger plants, and with the annual raw material processing lower or equal to 10000 m^3, X4, X5, X7 and X8 were treated by medium plants. In the monitored plants the wood residue was used as fuel for heating and thermal wood processing, and all the excess, especially in summer time, was sold selectively according to the type and for different prices per unit of wood mass residue.

2.2
Method of research
Metoda istraživanja

The research was carried out for wood residue resulting after the primary processing (sawn boards and elements manufacturing) and after the thermal processing and final product manufacturing. The share of single residue types, which was treated by waste biomass from the primary processing, was determined partly by weighing and partly by monitoring and measuring, as well as multi-annual empirical data of experienced machine servers. Due to moisture oscillation and type of raw materials, as well as wood residues from the primary processing, and in smaller part due to timber preparations from the final production during the study, the share was calculated by mean density and average moisture in order to establish the volume and lower waste biomass fuel value, where bark and bark chips: $u_b = 50$ %, $\rho_b = 450$ kg/m^3; offcuts/edges: $u_o = 55$ %, $\rho_o = 520$ kg/m^3; saw dust and planer shavings (saw mill and in smaller part final processing): $u_{sp} = 20$ %, $\rho_{sp} = 220$ kg/m^3. Numerical registering and establishing of wood residue quantity was performed after a weekly working cycle in monitored time periods (t_1 – 2/2 2007; t_2 – 2008; t_3 – ½ 2009).

Duration of convective drying (heating, active drying, equalizing and conditioning) was measured for sawn timber (sawn boards, elements) of 27 to 80 mm thickness from its mean starting moisture content of 35 – 40 % and 70 – 80 % to its final mean moisture content of 8 – 10 %. In X1, X2, X3, X5 and X6 plants drying was performed automatically, and in X4, X7 and X8 plants it was performed semi-automatically according to previously determined general drying regimes for individual timber types and thickness.

According to the number and power, as well as possibility of regulating the rotor number of revolutions in installed fans, the electrical energy consumption was calculated for each drying cycle per m^3 of dried wood mass. The regulation of number of revolutions n of a fan rotor was carried out only in plants X1, X2 and X4 in intervals of the decrease in wood mean moisture u_{mm} according to the conditions: $n_1 = 100$ % for $u_{mm} \geq 50$ %, $n_2 = 90$ % for $u_{mm} = 49 – 25$ %, $n_3 = 80$ % for $u_{mm} = 24 – 12$ % and $n_4 = 70$ % for $u_{mm} \leq 12$ % . In other plants the circulation was carried out under constant air flow speed and under the maximal number of revolutions the fan rotor during the total cycle of wood drying. The total consumed energy was expressed by adding of the consumed electrical energy in all intervals from the start to the finish of the drying process and by using the functional dependence of the electro-motor power N and the number of revolutions of the fan rotor n in the form: $N/N_x = (n/n_x)^3$. The installed electrical energy of other consumers (pumps, regulation parts…) for drying of 1 m^3 of sawn timber amounts to 0,01 – 0,015 kW. Consumption of thermal energy was established by adjusting technical conditions in X1 plant during several drying cycles of different timber types and thickness. Warm water was used with working temperature regime ≤ 90/70° as a primary fuel medium of laminated air heaters. Thermal energy consumption was measured by an electronic device connected to the flow measuring device installed in the return duct and the temperature sensors of fuel medium in the return duct and the supply duct.

The quantity of wood waste resulting from the thermal processing (drying) was established by a calculation, i.e. the difference of the timber volume before drying and the timber volume used in further processing until the final product. Small changes due to shrinkage and water loss during the drying process were ignored. Due to a very complex way of monitoring and measuring of total saw dust quantity and planer shavings from the final production, the quantity of wood waste was established by collecting of evaluated data and the total quantity of waste biomass (without wood residue after the timber thermal processing) was increased by approximately 4 %.

The mean value of individual timber types share from the primary processing and a smaller part from the final processing was established as an arithmetic mean value of the measured or empirical data in three time periods.

$$Wb_{\mathrm{w(b)}}, Wb_{\mathrm{w(o)}}, Wb_{\mathrm{w(sp)}} = \overline{X} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i$$
$$x_i = f \begin{cases} Wb_{\mathrm{w(b)}} i \\ Wb_{\mathrm{w(o)}} i \\ Wb_{\mathrm{w(sp)}} i \end{cases} \tag{1}$$

where:
$Wb_{\mathrm{w(b)}}$ – waste biomass (bark and bark chips)
$Wb_{\mathrm{w(o)}}$ – waste biomass (offcuts/edges)

$Wb_{w(sp)}$ – waste biomass (saw dust and planer shavings)
n – time of period
x_i – number of periods.

According to [1, 2], bark and bark chips lower fuel value having the mean moisture content of 50 % is $H_{i,b}$ = 8 400 kJ/kg, according to [1, 2] offcuts/edges lower fuel value having the mean moisture content of 55 % is $H_{l,o}$ = 12500 kJ/kg, while saw dust with a lower share of planer shavings having the moisture content of 20 % is $H_{l,sp}$ = 8 800 kJ/kg.

Lower fuel value of waste biomass from the primary processing and a smaller part from the final processing, $H_{l,pp}$, was established by calculating, according to the following formula (2), while quantified values for monitored periods and plants from X1 to X8 are shown in Table 1

$$H_{1,\mathrm{pp}} = a \cdot H_{1,\mathrm{b}} + b \cdot H_{1,\mathrm{o}} + c \cdot H_{1,\mathrm{sp}} \qquad (2)$$

where:
$H_{l,pp}$ – lower fuel value (primary processing)
$H_{l,bb}$ – lower fuel value (bark and bark chips)
$H_{l,o}$ – lower fuel value (offcuts/edges)
$H_{l,sp}$ – lower fuel value (saw dust and planer shavings)
$a = V_b/V_{pp}$; $b = V_o/V_{pp}$; $c = V_{sp}/V_{pp}$ are coefficients of certain wood waste type incidence in total waste quantity.
After the thermal treatment (drying), lower fuel value of wood waste is expressed by the following equation (3) [4] and is $H_{l,tp}$ = 17400 kJ/kg.

$$H_{1,\mathrm{tp}} = y \cdot \left[2500 \cdot \left(6{,}883 - \frac{u}{1+u} \right) \right] + + y_1 \cdot \left[2500 \cdot \left(7{,}333 - \frac{u}{1+u} \right) \right] \qquad (3)$$

where:
$H_{l,tp}$ – lower fuel value (waste timber after thermal processing)
y – is a coefficient of raw material incidence; oak and beech, ash = 0,7
y_1 – is a coefficient of raw material incidence; fir, spruce = 0,3
u = 9 % – final mean moisture of dried wood

Total lower fuel value of waste biomass resulting from wood processing plants, X1 to X8, is expressed by a relation

$$H_{1,\mathrm{bm}} = z \cdot H_{1,\boldsymbol{pp}} + z_1 \cdot H_{1,\mathrm{tp}} \qquad (4)$$

where:
$H_{l,bm}$ - lower value biomass
z - waste biomass volume of primary processing / total waste biomass volume
z_1 - waste biomass volume after thermal processing / total waste biomass volume

Excess of different residues/waste types from the primary processing (bark and bark chips, saw dust and planer shavings), and partly from the final processing, as well as wood waste after the thermal processing in X1, X2, X3 and X6 plants, were sold without an organized sale, i.e. according to the customers' needs. In the total quantity of sold biomass, the waste share from the primary processing was within the range from 45 to 65 %, while the share of wood waste after the thermal processing was around 35 to 55 %. The average share of bark and bark chips was around 30 %, offcuts/edges around 40 % and sawdust and planer shavings around 30 % in the total quantity of sold waste from the primary processing and partly from the final wood processing. Single item prices for some types of waste are outgoing values from the monitored wood processing plants within the monitored period. The mean value of prices for the sold biomass was established for the mean value of wood waste share from the primary processing, 55%, and the mean value of wood waste share after the thermal processing, 45 %, according to the equation (5)

$$P_{\mathrm{bm}} = \left[0{,}55 \cdot \left(0{,}3 \cdot P_{\mathrm{b}} + 0{,}4 \cdot P_{\mathrm{o}} + 0{,}3 \cdot P_{\mathrm{sp}} \right) + 0{,}45 \cdot P_{\mathrm{tp}} \right] \qquad (5)$$

where:
P_{bm} - prices biomass
P_b - prices (bark and bark chips)
P_o - prices (offcuts/edges)
P_{sp} - prices (saw dust and planer shavings)
P_{tp} - prices (waste timber after thermal processing).

The average price of convective drying of sawn wood mass single volume was established by adding costs of electrical and thermal energy, preparation and manipulation, labour and other fixed expenses, without other commercial values, that could result from current market circumstances, for the drying cycle up to a low final moisture share of a 50 mm thick timber. The calculation included average waste biomass density of 400 kg/m^3, with the price of electrical energy for industry purposes = 0,85 HRK/kWh (Croatia kuna/kWh, 1€ = 7,35 HRK).

3 Measuring results and data systematization
Rezultati mjerenja i sistematizacija podataka

Annual raw material processing and mean percentage value of the share for single wood waste types from the primary processing and a smaller part from the final processing in wood processing plants X1 to X8, within the monitored periods, are shown in Table 1.

An average drying time for sawn boards and elements in plants X1 to X8, from the middle starting moisture content up to the middle low final moisture content for the dominant timber types, beech and oak, are shown in Figure 1, and for ash, fir and spruce the data are given in Figure 2.

The inclinations of the curve on the graphs indicating an average drying interval for a specific timber type and for different thicknesses of sawn boards and elements describe the drying regimes applied in plants X1 to X8. Generally, the inclinations of the curve in Figure 1 and Figure 2 are determined by the strictness of the drying regime for specific types and thicknesses of sawn timber.

Oak sawn boards and elements drying, having thickness of 32 to 60 mm, average moisture content u_s = 70 – 80 % up to u_f = 8 – 10 %, density around ρ_{timber} = 700 – 750 kg/m^3 (10 % moisture content), needed around 820 kW/m^3 of timber, while beech sawn boards and elements drying, having the same thickness and moisture content range and density of ρ_{timber} = 580 – 620 kg/m^3 (10 % moisture content) needed around 610 kW/m^3 of thermal energy wood.

Considerably less, i.e. around 390 – 400 kW/m^3 of thermal energy wood was used for drying fir and spruce, up to the middle low moisture content (8 – 10 %). The electrical energy consumption at variable and constant number of revolutions of the fan rotor is shown in Table 2. As a product of an exact research of quantities and shares, total lower fuel value of waste biomass was established for plants X1 to X8 within the monitored period – Table 3.

Table 1 *Annual raw material processing, waste biomass from the primary processing and its lower fuel value*
Tablica 1. *Godišnja prerada sirovine, otpadna biomasa iz primarne prerade i njena donja ogrjevna vrijednost*

Wood proces. plant X1 - X8	Annula raw material processing, V_{rm}/m^3		Residues type and quantity-primary proc., V_{pp}						Lower fuel value, $H_{l,pp}$ kJ/kg
			Bark and bark chips, V_b		Offcuts/edgs, V_o		Saw dust + pl. shav., V_{sp}		
			m^3	%	m^3	%	m^3	%	
X1	½ 07	8000	1040	13	950	12	1110	14	9815
	2008	17000	2380	14	1860	13	2390	14	9692
	½ 09	6000	1020	17	720	12	600	10	9771
X2	½ 07	9000	900	10	1170	13	1710	19	9851
	2008	22300	3345	15	2453	11	3568	16	9618
	½ 09	8100	729	9	1458	18	1215	15	10307
X3	½ 07	8300	1328	16	1245	15	996	12	9947
	2008	14200	2272	16	1704	12	2130	15	9688
	½ 09	6450	838,5	13	1161	18	774	12	10234
X4	½ 07	5200	728	14	468	9	520	10	9668
	2008	9650	1061	11	1254	13	869	9	10111
	½ 09	4350	522	12	478	11	435	10	9873
X5	½ 07	5370	483	9	537	10	1020	19	9666
	2008	8850	708	8	1150	13	1505	17	9974
	½ 09	4250	467	11	510	12	638	15	9868
X6	½ 07	6950	1112	16	626	9	1320	19	9396
	2008	12830	1796	14	1540	12	2309	18	9671
	½ 09	5150	670	13	721	14	875	17	9868
X7	½ 07	4170	792	19	334	8	751	18	9298
	2008	7450	1341	18	820	11	1192	16	9528
	½ 09	3500	560	16	315	9	700	20	9396
X8	½ 07	4600	690	15	828	18	736	16	10008
	2008	8200	1066	13	1312	16	1640	20	9917
	½ 09	4050	688	17	567	14	729	18	9700

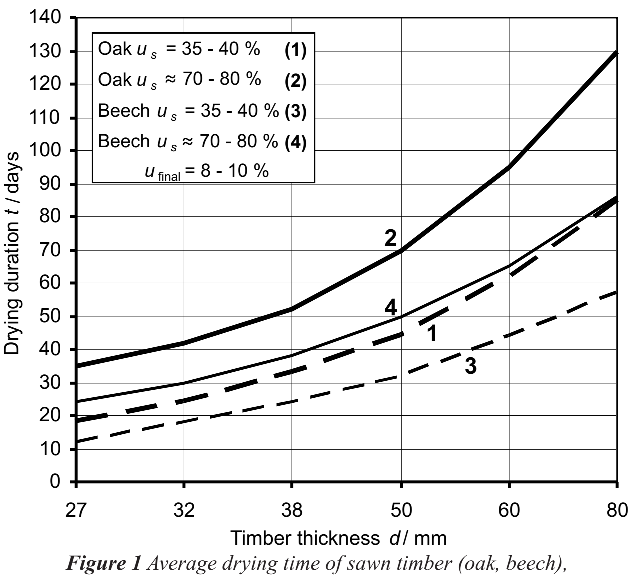

Figure 1 *Average drying time of sawn timber (oak, beech), plants X1to X8*
Slika 1. *Prosječno trajanje sušenja piljenog drva (hrast, bukva) pogoni X1 do X8*

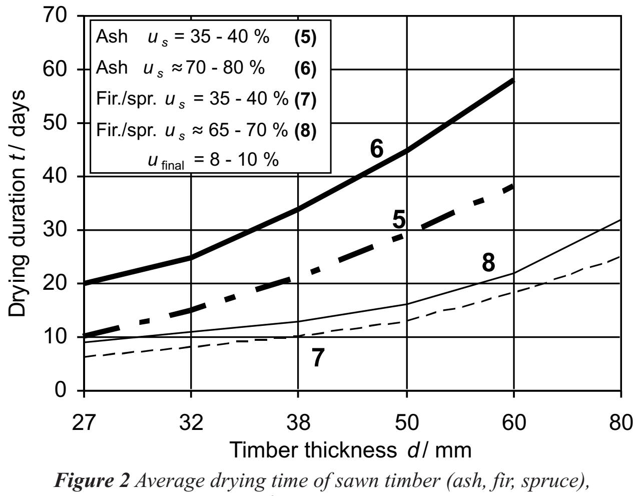

Figure 2 *Average drying time of sawn timber (ash, fir, spruce), plants X1 to X8*
Slika 2. *Prosječno trajanje sušenja piljenog drva (jasen, jela, smreka), pogoni X1 do X8*

The unused waste biomass excess from the primary processing and after the thermal processing from X1 and X4 plants was sold to customers for their personal needs and for different purposes. The prices per 1 m^3 of waste biomass are shown in Table 4. The average price of waste biomass after the thermal processing was four times higher in comparison to the rest from the primary processing. The average raw material price is expressed mainly for second class logs.

The quantified mean values of the wood drying expenses per 1 m^3 of wood mass are shown in Table 5. Approximately 44 % of the expenses belong to thermal energy, and 32 % to electrical energy, while preparation of wood mass for drying, labour costs, energy losses and similar factors make up 24 % of total expenses for convective drying of sawn timber.

***Table 2** Electrical energy consumption in convective drying of different types and thickness of sawn timber*
***Tablica 2.** Potrošnja električne energije pri konvektivnom sušenju različitih vrsta i debljina piljenog drva*

Timber type	Tim. thic. d/mm	Drying duration t/days	Consumed electrical energy kWh/m^3 of wood mass				
			Plants - fans		Other co.el.en.	Total kWh/m^3	
			$n \neq$ const.	$n =$ const.		$n \neq$ const.	$n =$ const.
Oak	27	18 – 35	122	180	6	128	186
	32	24 – 42	146	216	7,5	153,5	223,5
	38	33 – 52	221	281	9,5	230,5	290,5
	50	44 – 70	263	390	13	276	403
	60	62 – 95	351	520	18	369	538
	80	85 – 130	468	695	23	491	718
Beech	27	12 – 24	66	87	3	69	90
	32	18 – 30	87	116	4	91	120
	38	24 – 38	160	210	7	107	217
	50	32 – 50	190	252	8,5	198,5	260,5
	60	44 – 65	232	310	10,5	243	321
	80	57 – 86	326	432	15	341	447
Ash	27	10 – 20	78	101	4	82	105
	32	16 – 25	98	130	4,5	103	134.5
	38	20 – 35	136	180	6	142	186
	50	30 – 48	180	240	8	188	248
	60	38 – 55	218	290	10	228	300
Fir, spruce	27	6 – 9	52	60	2	54	62
	32	8 – 11	65	72	2,5	68	81
	50	13 – 17	97	110	4	101	114
	60	15 – 19	110	125	4,5	114,5	129,5
	80	25 – 30	179	202	7	186	209

***Table 3** Total quantity of waste biomass and its lower fuel value within the investigation period*
***Tablica 3.** Ukupna količina otpadne biomase i njena donja ogrjevna vrijednost za ispitivano vremensko razdoblje*

Wood proces. plant X1– X8	Waste biomass								Total lower fuel value $H_{\mathrm{l,bm}}$
	Primary processing, V_{pp}		Thermal proc. – drying, V_{tp}		Total – waste. biomass, $V_{\mathrm{t.bm}}$		z	z_1	
	m^3	%	m^3	%	m^3	%	---	---	kJ/kg
X1	12070	39	5296	17	17366	56	0,695	0,305	12090
X2	16548	42	8906	23	25454	65	0,65	0,35	12542
X3	12448	43	6943	24	19391	67	0,642	0,358	12622
X4	6335	33	4893	25	11228	59	0,564	0,436	13161
X5	7018	38	4916	27	11934	65	0,588	0,412	12743
X6	10969	44	5584	22	16553	66	0,663	0,337	12258
X7	6805	45	3824	25	10629	70	0,64	0,36	12284
X8	8256	42	4381	26	12637	75	0,634	0,347	12486

***Table 4** Waste biomass prices from wood processing plants*
***Tablica 4.** Cijene otpadne biomase iz drvoprerađivačkih pogona*

Wood proceessing plant	Bark HRK/m^3	Offcuts/ edges HRK/m^3	Saw dust + pl. sha. HRK/m^3	Timber after thermal processing, HRK/m^3		Average price HRK/m^3
				Waste	Raw mater.	
X1	35	100	65	300	600	443,5
X2	25	95	70	280	600	432,5
X3	40	110	80	340	600	467
X4	15	80	60	220	600	399
Mean value	28,75	96,25	68,75	285	600	-------

7,35 HRK = 1€

4 Analysis of results
Analiza rezultata

A new diagram in Figure 3 illustrates the systematization results of the exact research of parameters for technical and economic values of waste biomass, carried out in eight wood processing plants in the Republic of Croatia. Equation (6) defines the relation between the waste from the primary processing and raw material. Different values of this relation are shown by raw material utilization straight line *I1* in Figure 3. Relation (7) establishes wood mass utilization lines *I2*, including the share of wood waste, in percentage terms, after the primary and thermal processing. The waste share ranging from 25 % to 50 %, i.e. the share of unused wood after the thermal processing (the highest frequency), is illustrated by six straight lines $I_{2,25}$ to $I_{2,50}$ at the pace of 5 %. Line $H_{\mathrm{lbm,x}}$ establishes the relationship between the existing thermal value of the total quantity of waste biomass and the thermal value of waste after the thermal processing of sawn wood (equation 8). The relation of waste biomass prices is presented by straight line $P_{\mathrm{bm,x}}$ (equation 9), which divides indications areas A and B from C and C$_1$. The inclination of the straight line $P_{\mathrm{bm,x}}$ is affected by waste biomass prices within the region.

Table 5 *Expenses of sawn timber convective drying (sawn boards and elements)*
Tablica 5. *Troškovi konvektivnog sušenja piljenog drva (piljenice i elementi)*

Wood processig plant	Mean value of timber convective drying expenses, HRK/m^3				
	Electric energy	Thermal energy	Preparat., manipul., labour costs	Other expenses + energy losses	Total
X1	175	279	110	80	684
X2	175	272	90	60	597
X3	175	294	80	30	579
X4	243	251	100	95	689
X5	175	274	110	60	619
X6	175	274	70	40	559
X7	243	274	75	60	652
X8	243	274	90	25	632
Mean v.	200,5	274	90,6	56,25	626,4

7,35 HRK = 1 €

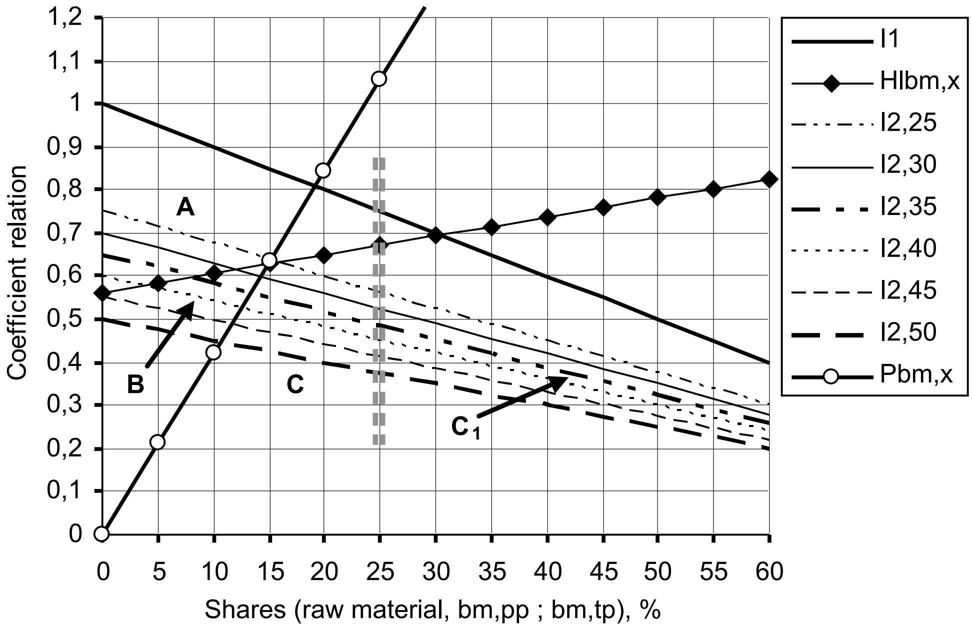

Figure 3 *Diagrams of efficiency and parameters for technical and economical waste biomass value; criteria for establishing technology and energy development of wood processing plants*
Slika 3. *Dijagrami učinkovitosti i parametara tehničko-ekonomske vrijednosti otpadne biomase; kriterij za utvrđivanje tehnološko-energetskog razvoja drvnoprerađivačkih pogona*

A numerical establishing of a set of values ($I1, I2, H_{\mathrm{lbm,x}}$) and their grouping to the left or to the right from straight line $P_{\mathrm{bm,x}}$ into the nearest indication area (A, B, C, C$_1$) enable rapid evaluation of conditions and the determination of one of the criteria for technology and energy development of wood processing plants. The costs for the study have been reduced.

$$I_1 = 1 - \frac{V_{\mathrm{pp}}}{V_{\mathrm{rm}}} \tag{6}$$

$$I_{2,25} \ldots I_{2,50} \ldots I_{2,x} = \left(1 - \frac{V_{\mathrm{pp}}}{V_{\mathrm{rm}}}\right) \cdot \left(1 - \frac{V_{\mathrm{bm,tp}}}{V_{\mathrm{ttp}}}\right) \tag{7}$$

$$H_{\mathrm{lbm},x} \frac{\varphi \cdot H_{1,\mathrm{pp}} + \varsigma \cdot H_{1,\mathrm{tp}}}{H_{1,\mathrm{tp}}} \tag{8}$$

$$P_{\mathrm{bm},x} = \frac{p \cdot P_{\mathrm{tp,av}}}{P_{\mathrm{pp,av}}} \tag{9}$$

where:
I - average exploitation of wood mass (raw material)
$I_{2,..}$ - average exploitation of wood mass (raw material + thermal processing)
$H_{\mathrm{lbm},x}$ - lower value biomass, x
$H_{\mathrm{l,pp}}$ - lower fuel value (primary processing)
$H_{\mathrm{l,tp}}$ - lower fuel value (waste timber after thermal processing)
$P_{\mathrm{bm},x}$ - prices biomass, x
$P_{\mathrm{tp,av}}$ - average prices (waste timber after thermal processing)
$P_{\mathrm{pp,av}}$ - average prices (after primary processing)
$V_{\mathrm{bm,tp}}$ - waste timber after thermal processing
V_{pp} - waste biomass, primary processing
V_{rm} - annual raw material processing
V_{ttp} - timber for thermal processing
p - procent/100, (0 – 1)
φ - share, (0 – 1)
ς - share, (0 – 1)

A ($H_{\mathrm{lbm,x}}$; I_1 ; $P_{\mathrm{bm,x}}$; axis y) – high average raw material usage, optimal waste biomass quantity, possible CHP plant building.

B ($H_{lbm,x}$; $I_{2,50}$; $P_{bm,x}$; axis y) - lower raw material usage, a bit higher waste biomass quantity, partial technology improvement necessary, CHP plant building is possible.

C ($H_{lbm,x}$; $I_{2,50}$; $P_{bm,x}$; axis $y \leq 25$ % of x value) - lower raw material usage, higher waste biomass quantity even after wood thermal processing, technology improvement of wood thermal processing is necessary, CHP plant or warm water power plant building is possible.

C_1 ($H_{lbm,x}$; I_1 ; $I_{2,50}$; axis $y \leq 25$ % of x value) - lower and low raw material usage, higher waste biomass quantity, especially after wood thermal processing, technology improvement is extremely necessary, especially of wood thermal processing, CHP plant building is not recommended, irrational consumption of biomass for energy purposes.

Providing the efficient thermal processing of sawn wood and minor waste quantity, a diagram shown (Figure 3) can only be used for accurate determination of waste biomass quantity from the primary processing.

5 Conclusion
Zaključak

The research includes and shows quantities, types and structures of waste biomass in eight wood processing plants, resulting from different phases in wood processing up to the finished product or semi-finished product. Quantification diagrams were used to illustrate the exact duration of convective drying of different types (oak, beech, ash, fir and spruce) and thicknesses, from high, medium and starting moisture content to the low and final moisture content of sawn timber. Measuring determined the usage of thermal and electrical energy during the drying cycle of sawn wood. Numerical values expressed drying expenses per volume unit of sawn wood mass. Based on the studies that were carried out, a new diagram (Figure 3) was suggested for determination of existing efficiency and parameters of technical and economic waste biomass value as one of the criteria for technical and energy development of wood processing plants. Depending on the numerical values, bordered by various characteristic lines inclinations, there are four indication areas (A, B, C, C_1) for evaluation of conditions and expressing suggestions for technology and energy development of wood processing plants.

Due to economical reasons, it is necessary to establish the quantity and structure of waste biomass of each wood processing plant, and the diagram suggested earlier enables us to test one of the justification criteria when deciding on building a CHP plant.

Numerical development and software adjustment of new practical and ready-to-use results could contribute to application of the suggested model for variously organized wood processing systems with final and semi-final output.

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