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ORIGINAL PAPER

The energy intensity of the production of energy chips from dendromass stands on long-term uncultivated agricultural land

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Abstract

The aim of this work was to investigate the energy intensity of the fuel wood chips production on unused agricultural land. The unused agricultural land, overgrown with forest trees, also called white areas, is the result of the end of the traditional intensive management of agricultural land by the natural succession of forest stands and pioneers' wood species on the borders of forest and non-forest land. These stands are advantageously localized due to previous method of the land utilization, accessible and therefore very interesting from the point of view of obtaining fuel dendromass. The logging and subsequent dendromass processing was carried out for the purpose of further land use as pasture land and also for the production of fuel wood chips and their subsequent sale to the end user. With the utilization of technology chain saw-forwarder-chipper, the energy intensity of each operation, expressed in terms of the amount of fuel consumed per unit of produced wood fuel, was determined. The share of energy consumed in the energy value of the harvested tree dendromass in the evaluated sites ranged from 0.43 to 0.62%, approximately 0.64 to 0.88% and the chipping 0.42 to 0.54%. The total amount of energy consumed after calculation the chipper transfers to an average distance of 180 km was within 1.46 to 2.11%. The average weight of the harvested trees caused the biggest impact on the energy intensity of the production process.

Key words: wood chips; biomass transportation; energy ratio; dendromass; unused agricultural land

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1. Introduction

Fuel wood biomass belongs to significant renewable energy sources (RES) in Slovakia. Currently, its largest consumers are energy sources in cities and used in the form of fuel chips (Oravec 2015). It is obtained, in particular, from raw wood of inferior quality logged on forest land, from raw wood logged on unused agricultural land with wood species, residues and waste after wood processing in the wood-processing industry and residues after mechanical treatment (debarking) of pulpwood in the pulp and paper industry (Oravec et al. 2016). The unused agricultural land, overgrown with wood species, called white areas, is the result of the end of the traditional intensive management of agricultural land by the natural succession of forest stands and pioneers'' on the borders of forest and non-forest land. The assortment structure of these stands is compared with the forest stands with a higher proportion of fiber and wood for energy use. These stands, whose area exceeded 270,000 ha in Slovakia in 2006 (Šmelko & Šebeň 2009) are advantageously localized, well accessible and therefore very interesting from the point of view of obtaining fuel dendromass. The production of fuel wood chips on this land consists of a number of working operations such as trees felling, wood skidding, dendromass drying, chipping and transportation. However, as is the case with most other RES, it is, to some extent, dependent on the use of non-renewable resources (fossil fuels) (Timmons & Mejía 2010).

Taking into the consideration the current increasing demand for fuel wood biomass, research of its production becomes increasingly important. One option to reduce the dependence of RES on fossil fuels is to introduce innovations and more modern, efficient technologies and technological processes into the practice. The low efficiency of work with the simultaneous abandonment of the largest ecological footprint is an accompanying phenomenon of obsolete technology and obsolete technological processes of wood production (Enache et al. 2016).

The aim of this research was to investigate the energy intensity of the production of fuel wood chips on unused agricultural land and the factors affecting it. With the utilization of chain saw-forwarder-chipper, the energy intensity of each operation, expressed in terms of the

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amount of fuel consumed per unit of produced wood fuel, was determined. The aim of the research was the impacts assessment of the above-ground tree biomass stock, tree species structure of the stands and the skidding distance on the energy intensity of the individual operations of the fuel chips production and on the overall energy intensity of the production process.

2. Material and methods

Tests of the technological process of the production of fuel wood biomass were carried out on unused agricultural land. Stands logging and subsequent processing of dendromass were carried out for the purpose of further land use as pasture land and also for the purpose of obtaining a fuel wood chip and its subsequent sale to an energy source. Measurements were carried out within three localities (Očová, Ľubietová, Liptovská Teplička) in Central Slovakia. The reason for selecting these sites is the diversity of terrain and climate conditions as well as the woody structure of the harvested stands affecting the production conditions of the logging, skidding and dendromass chipping. The production conditions of the evaluated sites are typical for most of the area of woody plantations on non-forested land in the conditions of Slovakia. The energy consumption of the entire production process was evaluated on the basis of the calculated energy value of the fuel consumed by the individual technologies. The following parameters have been evaluated for the need to meet the set objectives in the technological process of energy chip production:

- stock of above-ground wood biomass, wood species structure, slope of the terrain, skidding distance,
- wood felling – working time, fuel consumption, performance,
- wood skidding – fuel consumption, work (machine loading), working time (hours) – (particularly: drive to the stands, drive with load, load structure, stowage, downtime), performance,
- natural drying of dendromass – time (day), humidity, weight,
- wood chipping – working time, performance, fuel consumption,

The stock of above-ground tree biomass was measured at each of the three sites within an area of 1.5 hectares with dimensions of 100 × 150 m. The age of the trees in the evaluated stands ranged from 20 to 40 years. The volume of wood biomass was calculated on the basis of the thickness and height of the wood, including the main branches. The thickness of all the trees was measured on a stand of height 1.3 m. Trees height, stem thickness, and branches diameters were measured on logged samples selected on the basis of the observed thickness structure and the wood species composition of the stand. The stems and branches diameters were measured at 1 m interstice. Due to the number, thickness and height structure of the trees in the evaluated stands, 3% of the total number of trees as samplers were used on each area. The weight of the wood was measured by weighing the slices cut into pieces weighing less than 20 kg. The assimilation organs were not removed prior to the measurement of the mass of above-ground tree biomass samples. These were part of the mass and energy balances of the energy chips production process. The humidity of the fresh biomass was determined from the samples taken by hygrometer Testo 606 and the energy value was indicated by calorimetry.

The wood felling on the measured areas was carried out with STIHL MS 231 type saws. During the felling, the time of work was measured including woodcutting, transfers within the workplaces, chainsaws maintenance and necessary breaks. Fuel consumption was indicated by determining the volume and its weight in the bins before the start and finalization of the work. For the calculation of energy consumption, the low heating value of fuel consumption 43 535 KJ kg^{-1} was used. Felling performance and energy consumption were calculated using mass data of above-ground wood biomass on the measured areas

Skidding of wood biomass was carried out by the JD 810 D forwarder. The average skidding distance to the place of storage and subsequent chipping within particular stands was determined as the distance between the centre of the measured area and the stock. Time and distance of work activities, drive to the stand, raw material handling, transfers within the stand, drive with the load, unloading of raw materials and downtime were measured. Fuel consumption was measured with a fuel consumption flow meter. For calculation of energy consumption, the low fuel consumption of 41 868 KJ kg^{-1} was used. Skidding performance and measured power consumption were calculated using data on the mass of above-ground tree biomass on measured areas reduced by loss. Skidding losses were measured by measuring the weight of raw material left on the logging area and on the skidding path.

Wood biomass skidded to the stock was freely stored for 91 days. At 7 day intervals, biomass samples were taken and their humidity measured using the same method as for fresh biomass. The number of samples taken at the same time was 50 – 60, depending on the thickness and wood structure of the biomass. The energy value of the samples was measured by the calorimetric method.

The wood biomass chipping at the stock was carried out by a Biber 92 drum chipper. Produced chips were filled by chipper into a 40 m^3 container removal set and then transported to the stock of end user. During the chipping, the total duration of the working time, including maintenance of the chipper, downtime, necessary breaks as well as the net time of the chipper, was measured. Fuel consumption was measured using a consumption flow meter. The measured values were compared to the total recorded fuel consumption. When calculating the energy consumption, the same fuel heat was used as for the skidding. In addition, fuel consumption of chipper transfer to the workplace was also included in the assessment of the energy intensity of the chipping. The total duration of transfers within the evaluated sites was 108 to 228 km. For an objective comparison of the results, the energy intensity was also calculated on an average distance of 180 km. The chipping power and the actual energy consumption were calculated using the energy value of the raw material, fuel consumption and the weight of the chips measured by the final customer as the difference in the weight of the loaded and emptied removal set. There was no loss of raw material mass during chipping due to its leaving in stock. The measured and calculated data were used to assess the impact of the logged stands structure and the production conditions on the time and energy intensity of the work activities as well as the influence of the storage duration of the wood biomass in the unchipped state on the overall energy balance of the production process.

3. Results

3.1. The tree species structure, stock and energy value of logged stands

The tree species structure, stock, moisture and energy value of woody biomass of the logged stand in Liptovská Teplička are presented in the Table 1. The total stock of above-ground wood biomass was 229.3 m^3, calculated per 1 ha 152.8 m^3. The largest stock was represented by spruce wood of 166.0 m^3 and its share within the total stock was 72.4%. The stock of other wood species, such as hazel, fir, beech and other wood species, ranged from 11.5 to 20.9 m^3.

The total mass of wood biomass in the fresh state was 185.0 t. The largest mass was spruce 128.3 t with 69.4% share of the total weight. The weight of raw materials of other wood was 12.3 to 18.7 t. The share of the weight of wood biomass of particular wood species is involved in Figure 1.

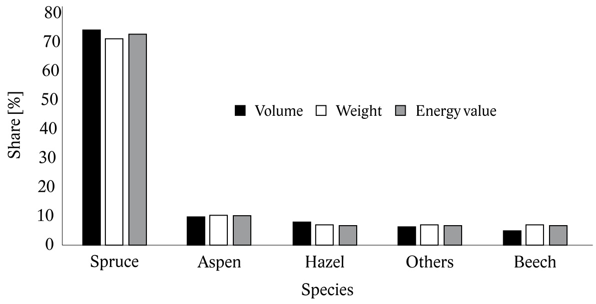

Fig. 1. Shares of volumes, weight and energy values of particular tree species, Liptovská Teplička.

Differences in the density of particular wood species have been revealed, which has increased the weight ratio of the hardwood compared to the volume structure of the tree species. The absolute humidity of the fresh-cut wood was 77.0 to 82.5% on average 79.75% and the energy value 8.41 to 8.91 MJ kg^{-1}, at an average of 8.66 MJ kg^{-1}. The highest energy value was measured for beech wood and the lowest one for the hazel. The total energy value of the stand was 1623.8 GJ. The share of the energy value of particular tree species is given in Figure 1. The total number of harvested trees was 2482, the highest number of hazels was 1214, and lowest the fir 84. The average volume of wood species was 0.092 m^3. The average weight of the wood was 0.075 t, most of the spruce and fir 0.157 resp. 0.147 t and the lowest one for hazel 0.015 t.

The tree species structure, stock, moisture and energy value of wood biomass of logged stand in Ľubietová are given in Table 2. The total stock of above-ground wood biomass was 217.8 m^3, with 145.0 m^3 per 1 ha. The largest stock was of the spruce wood of 105.7 m^3 and its share in the total stock was 48.5%. The stock of other tree species, including aspen, hazel, beech and other wood plants, ranged from 4.6 to 59.5 m^3. The share of wood biomass volumes of individual trees is shown in Figure 2.

The total mass of biomass in the fresh state was 184.7 t. The highest weight of the spruce was 82.3 t with

Table 1. Tree species structure, stock, moisture and energy value of the wood biomass of the logged stand in Liptovská Teplička.

Parameter	Thickness with bark, cm	Tree species					Total
		Spruce	Fir	Beech	Hazel	Other	
Wood biomass stock [m^3]	up to 8.0	53.9	5.3	4.4	18.0	7.7	89.4
	8.1 – 20.0	74.8	6.2	5.3	2.9	6.7	95.9
	20 and more	37.2	4.9	1.8	0.0	0.0	44.0
Total, [m^3]	—	166.0	16.5	11.5	20.9	14.4	229.3
Average stock per ha [m^3]	—	110.6	11.0	7.7	13.9	9.6	152.8
Wood biomass weight [t]	up to 8.0	42.3	4.1	5.1	16.2	6.7	74.4
	8.1 – 20.0	57.6	4.6	6.0	2.5	5.8	76.5
	20 and more	28.4	3.6	2.1	0.0	0.0	34.1
Total [t]	—	128.3	12.3	13.2	18.7	12.5	185.0
Wood biomass absolute humidity [%]	up to 8.0	82.6	85.7	79.4	82.9	81.1	n/a
	8.1 – 20.0	79.1	81.1	75.6	81.2	78.9	n/a
	20 and more	77.2	79.5	73.1	0.0	0.0	n/a
Biomass average humidity [%]	—	79.8	82.2	77.0	82.5	80.1	n/a
Energy value of wood biomass in fresh state [MJ kg^{-1}]	—	8.87	8.43	8.91	8.41	8.59	8,78
Total energy value of the wood biomass in fresh state [GJ]	—	1 138.2	104.0	117.6	156.9	107.1	1623.8
Number of harvested trees [pcs]	—	818	84	102	1214	265	2482
Average volume of harvested trees [m^3]	—	0.203	0.197	0.112	0.017	0.054	0.092
Average weight of harvested trees [t]	—	0.157	0.147	0.129	0.015	0.047	0.075

a share of the total weight of 44.6%. The weight of raw materials of other wood was 4.1 to 51.7 t. The share of the weight of the raw material of particular trees is shown in Figure 2.

Even in this locality, the influence of lower measured spruce weights has been shown, as compared to hardwood, especially beech. The absolute humidity of fresh-cut wood was 76.9 to 111.9% in average 94.4% and the energy value was 5.84 to 8.98 MJ kg^{-1}, an average of 7.77 MJ kg^{-1}. Extremely high humidity in fresh state compared to other wood species has aspen, which causes a low energy value of the raw material. The total energy value of the stand was 1435.4 GJ. The share of the energy value of particular wood species is given in Figure 2.

The total number of harvested trees was 2959 pcs, the highest number of hazel, 1582 pieces and the least other species 86. The average volume of tree species was 0.074 m^3. The average weight of the tree species was 0.062 t, the highest for the spruce and aspen 0.183 resp. 0.124 t and the smallest one for hazel 0.022 t. Tree species structure, stock, moisture and energy value of wood biomass in harvested stand in Očová are given in Table 3.

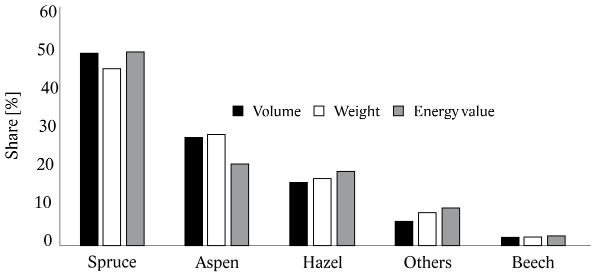

Fig. 2. Shares of volumes, weight and energy values of particular tree species, Ľubietová.

The total stock of above-ground wood biomass was 171.7 m^3, calculated per 1 ha 114.5 m^3. The largest stock had aspen wood 67.3 m^3 and its share in the total stock was 39.2%. The stock of other wood species, such as hazel, beech, oak and other wood species, ranged from 12.0 to 42.1 m^3. The share of wood biomass volumes of particular wood species is involved in Figure 3.

The total fresh biomass mass was 155.5 t. The largest weight was 58.3 t for aspen with a share of the total weight of 37.5%. The weight of raw materials of other tree species was 13.5 to 35.1 t. The share of the weight

Table 2. Tree species structure, stock, moisture and energy value of wood biomass of harvested stand in Ľubietová.

Parameter	Thickness with bark [cm]	Tree species: Spruce	Aspen	Hazel	Beech	Others	Total
	up to 8.0	33.8	17.9	28.7	4.7	2.9	88.0
Wood biomass stock [m^3]	8.1 – 20.0	45.7	36.7	6.1	5.2	1.7	95.4
	20 and more	26.2	4.9	0.0	3.4	0.0	34.4
Total, [m^3]	—	105.7	59.5	34.8	13.3	4.6	217.8
Average stock per ha [m^3]	—	70.4	39.6	23.2	8.8	3.0	145.0
	up to 8.0	26.8	16.1	25.9	5.5	2.6	76.8
Wood biomass weight [t]	8.1 – 20.0	35.5	31.6	5.4	6.0	1.5	80.0
	20 and more	20.1	4.0	0.0	3.8	0.0	27.9
Total [t]	—	82.3	51.7	31.3	15.2	4.1	184.7
	up to 8.0	84.1	119.5	84.1	80.6	85.2	n/a
Wood biomass absolute humidity [%]	8.1 – 20.0	80.9	109.8	82.7	76.1	81.7	n/a
	20 and more	78.1	101.3	0.0	74.0	0.0	n/a
Biomass average humidity [%]	—	81.2	111.9	83.7	76.9	84.1	n/a
Energy value of wood biomass in fresh state [MJ kg^{-1}]	—	8.51	5.84	8.26	8.98	8.31	7.77
Total energy value of the wood biomass in fresh state [GJ]	—	700.6	295.6	268.2	136.9	34.1	1435.4
Number of harvested trees [pcs]	—	852	325	1582	114	86	2959
Average volume of harvested trees [m^3]	—	0.124	0.183	0.022	0.116	0.053	0.074
Average weight of harvested trees [t]	—	0.097	0.159	0.019	0.133	0.048	0.062

Table 3. Tree species structure, stock, moisture and energy value of wood biomass of the harvested stand in Očová.

Parameter	Thickness with bark [cm]	Tree species: Aspen	Oak	Beech	Hazel	Others	Total
	up to 8.0	22.3	4.8	3.6	26.9	15.5	73.1
Wood biomass stock [m^3]	8.1 – 20.0	41.1	7.4	4.4	6.9	23.1	82.8
	20 and more	4.0	4.3	4.1	0.0	3.5	15.8
Total, [m^3]	—	67.3	16.5	12.0	33.8	42.1	171.7
Average stock per ha [m^3]	—	44.9	11.0	8.0	22.5	28.1	114.5
	up to 8.0	19.8	5.4	4.0	24.2	13.1	66.6
Wood biomass weight [t]	8.1 – 20.0	35.2	8.2	5.0	6.1	19.1	73.6
	20 and more	3.3	4.6	4.5	0.0	2.9	15.3
Total [t]	—	58.3	18.3	13.5	30.3	35.1	155.5
	up to 8.0	117.4	78.7	81.3	83.0	84.1	n/a
Wood biomass absolute humidity [%]	8.1 – 20.0	108.7	75.9	76.8	81.8	80.3	n/a
	20 and more	101.1	73.2	73.9	0.0	77.8	n/a
Biomass average humidity [%]	—	111.1	75.9	78.6	82.9	81.5	n/a
Energy value of wood biomass in fresh state [MJ kg^{-1}]	—	5.88	9.20	8.91	8.37	8.67	7.65
Total energy value of the wood biomass in fresh state [GJ]	—	342.6	168.1	120.5	253.7	304.5	1189.5
Number of harvested trees [pcs]	—	446	135	124	1208	1002	2914
Average volume of harvested trees [m^3]	—	0.151	0.122	0.097	0.028	0.042	0.085
Average weight of harvested trees [t]	—	0.131	0.135	0.109	0.025	0.035	0.053

of the raw material of particular wood species is given in Figure 3.

The influence of the higher density of hardwoods in comparison with other trees was revealed. The absolute humidity of the freshly grown tree species was 75.9 to 111.1% in average 93.5% and the energy value was 5.88 to 9.20 MJ kg^{-1}, in average 7.65 MJ kg^{-1}. There was high humidity and low energy value of aspen. The total energy value of wood biomass of the stand was 1189.5 GJ. The share of the energy value of particular tree species to its total value is given in Figure 3.

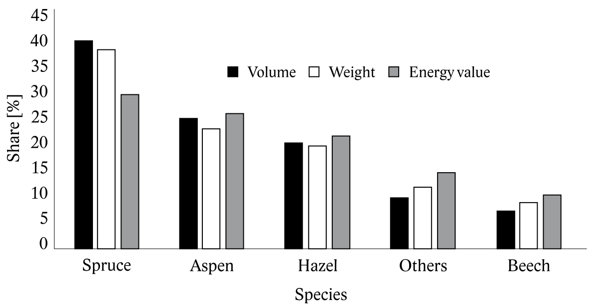

Fig. 3. Shares of volumes, weight and energy values of particular wood species, Očová.

The total number of harvested trees was 2914, the highest number of hazel 1208 pieces, and the smallest one the beech 124. The average volume of tree species was 0.085 m^3 and the average weight was 0.053 t. The largest average mass was oak 0.135 t and smallest hazel 0.025 t.

In order to compare the energy intensity of the chips production on the evaluated sites, the thickness structure of the biomass stocks is important in terms of the thickness levels share of 8 cm, 8.1 to 20 cm and over 20 cm and the number of trees with an average weight of 0.1 and above (Table 1 – 3). In harvested stands, the weight of wood biomass with a thickness of up to 8 cm ranged within a narrow range of 40.2 – 42.9%. The smallest share was measured in Liptovská Teplička and highest one in Očová. The share in the thickness of 8.1 to 20.0 cm was 41.4 to 47.3%. The smallest share was in Liptovská Teplička and highest in Očová. The largest differences were in the weight proportions of raw material with a thickness of over 20 cm. The largest share of 18.4% was measured in Liptovská Teplička and the smallest one in Očová. The structure of the weight proportions in the thickness steps at the individual sites is given in Figure 4.

The highest share of the number of wood species with a weight over 0.1 t was in Ľubietová 43.6%. In Liptovská Teplička, the share was 40.4% and in Očová only 24.2%.

In Liptovská Teplička, the biomass mass was up to 8 cm (36.9%) in Očová (39.7%). The share of raw material with a thickness of over 20 cm was 20.5% in Liptovská Teplička and only 11.4% in Očová. Differences in the thickness structure affected the increase of measured fuel consumption in comparison with Liptovská Teplička, in

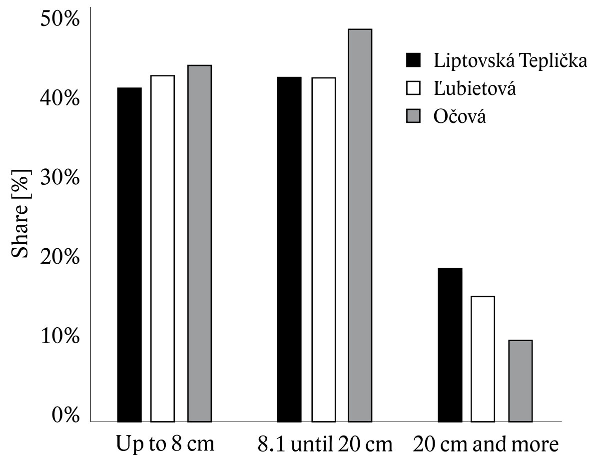

Fig. 4. Mass shares of wood biomass in thickness levels on particular sites.

Ľubietová by 5.2% and in Očová by 18.5%. As a result of the growth of the thin mass, the average hourly performance in Ľubietová decreased by 4.8% and Očová by 13.9%.

3.2. Loss of wood biomass during the skidding and weight decreasing during storage of wood

The size of wood biomass losses in skidding when loading the skidding vehicle and during drive to the stock and weight loss during storage in Liptovská Teplička are involved in Table 4, in Ľubietová in Table 5 and in Očová in Table 6.

Table 4. Loss of wood biomass during the skidding to the stock and loss of storage weight, Liptovská Teplička.

Parameter	Tree species					Total
	Spruce	Fir	Beech	Hazel	Others	
Skidding losses [t]	9.4	0.6	0.7	3.6	1.3	15.6
Drying weight losses [t]	16.5	1.6	1.2	2.5	1.9	23.8

Table 5. Loss of wood biomass during the skidding to the stock and weight loss during the storage, Ľubietová.

Parameter	Tree species					Total
	Spruce	Aspen	Hazel	Beech	Others	
Skidding losses [t]	5.7	3.5	6.5	0.7	0.4	16.9
Drying weight losses [t]	10.9	8.3	4.0	1.0	0.7	24.9

Table 6. Loss of wood biomass during the skidding to the stock and weight loss during the storage, Očová.

Parameter	Tree species					Total
	Aspen	Oak	Beech	Hazel	Others	
Skidding losses [t]	4.0	0.6	0.5	5.2	3.8	14.1
Drying weight losses [t]	9.6	1.6	1.1	4.1	5.3	21.7

Mass losses by skidding in Liptovská Teplička reached 15.6 t, which represented 8.4% of the mass logged in the stand. The largest losses were 9.4 t for the spruce with a share of 7.3%. The largest share of losses was found for the hazel 19.3% and the smallest one for the fir 4.9% and beech 5.3%. From the point of view of the thickness structure losses during the skidding, there were the largest for biomass with a thickness of up to 8 cm (11.1 t), which represented 15.2% of the logged mass of mentioned thickness. Zero losses were in the case of raw material with a thickness of over 20 cm.

During the storage, a total of 23.8 tonnes of water was evaporated from biomass, representing 14.1% of the raw material weight skidded to the stock. The greatest intensity of water loss was in biomass with a thickness of up to 8 cm with a share of 15.20% and the smallest one in the raw material with thickness over 20 cm (12.6%). For particular wood species, the largest share of water loss was for the hazel and other wood species (16.6% resp. 16.9%) and the smallest for beech (9.6%).

The total water loss due to the skidding and evaporation losses were 39.4 t, and their share of logged biomass in the stand reached 21.3%. Weights losses of up to 8 cm thickness were 20.7 i.e. 27.8%, biomass with a thickness of 8.1 to 20 cm 14.4 t (19.0%) and at a thickness above 20 cm 4.3 t (12.3%). The largest share of total losses was 33.2% for the hazel, 26.4% for other wood species and the smallest one 14.4% for beech.

Mass losses by skidding in Ľubietová reached 16.9 t, which represented 9.1% of the weight harvested in the stand. The biggest losses were for the hazel 6.5 t, where the largest share of losses of 20.8% of all harvested trees was recorded. The lowest share of losses was 4.6% for the beech, 6.8% for the aspen and 6.9% for the spruce. From the point of view of the thickness structure losses during the skidding, they were the largest for biomass with a thickness of up to 8 cm (11.6 t), which represented 15.1% of the harvested mass of mentioned thickness. Zero losses were in the case of raw material with a thickness of over 20 cm.

During the storage, a total of 24.9 tonnes of water was evaporated from the biomass, which was 15.0% of the raw material skidded to the stock. The greatest intensity of water loss was in biomass with a thickness of up to 8 cm with a share of 16.1% and the smallest one for the raw material with a thickness exceeding 20 cm (12.5%). The largest share of water loss was found for the hazel and other wood species (16.1% and 18.9% respectively) and the smallest one for the beech (9.0%).

Total losses by skidding and water evaporating were 42.1 t, and their share within the harvested biomass reached 22.8%. Mass losses with a thickness of up to 8 cm were 22.1 i.e. 28.8%, for the biomass with a thickness of 8.1–20 cm 16.4 t (20.5%) and for the biomass with a thickness of over 20 cm 3.5 t (12.9%). The largest share of total losses was hazel 33.5%, 26.8% in the other wood species and 13.2% for the beech trees.

Mass losses by skidding in Očová reached 14.1 t, which represented 9.1% of the weight harvested in the stand. The biggest losses were for the hazel 5.2 t, which had the largest share of losses of all harvested wood species 17.2%. The lowest share of losses was for the oak 3.3% and beech 3.7%. From the point of view of the thickness structure losses during skidding, they were the largest for biomass with a thickness of up to 8 cm (9.6 t), which represented 14.4% of the harvested mass of mentioned thickness. Zero losses were for raw material with a thickness of over 20 cm.

During the storage, a total of 21.7 tonnes of water was evaporated from the biomass, which was 15.6% of the raw material skidded to the stock. The largest intensity of water loss was for the biomass with a thickness up to 8 cm with a share of 16.5% and the smallest one for the raw material with a thickness exceeding 20 cm (11.1%). The largest weight share of water loss was for aspen (17.7%), other wood species (16.9%) and hazel (16.3%). The smallest one was for the beech (8.5%).

The total water loss due to the skidding and evaporation losses were 35.8 t and their share of harvested biomass reached 23.2%. Mass losses for a thickness of up to 8 cm were 19.0 i.e. 28.8%, for the biomass with a thickness of 8.1 to 20 cm 15.1 t (20.7%) and biomass with a thickness of over 20 cm 1.7 t (11.1%). The largest share of total losses was 31.0% for the hazel, 26.2% for other wood species and 23.3% for aspen. The smallest losses were for the oak and beech (12.1 resp. 12.6%). In spite of the different skidding distances, the losses due to the skidding were in a narrow range of 8.4 to 9.1%. Small overall differences were also found in weight and total losses and losses of wood biomass mass.

Differences in the size of loss shares due skidding were found, water evaporation, and the total sum of these values for individual trees at all sites. Losses by the skidding of hardwoods were in the range of 3.3 to 5.3%, for conifers 4.9 to 7.3% and for aspen 6.7 to 6.8%. For hazel and other harvested wood species these losses were 9.8 to 20.8%. The reason for this is a substantially higher proportion of biomass thinner than 8 cm, which makes difficult to fill the skidding vehicle hydraulically on the logging surface and also causes mass losses during the drive to the stock. The weight loss by water evaporation during storage was between 8.5 and 9.6% for hardwoods, 13.8% to 14.2% for conifers, 17.2% to 17.7% for aspen and for hazel and other logged wood species 16, 1 to 18.9%. The reason of differences is other physical properties of particular wood species (especially biomass density, moisture and water evaporation intensity are also affected by thickness).

3.3. Energy intensity of the biomass production

The tree species structure, weight, moisture and energy value of the chipped wood biomass in the Liptovská Teplička stock is given in Table 7.

The total weight of wood biomass was 145.6 t with an average humidity of 53.8% and an energy value of 1 805.0 GJ. During storage this value increased by 11.1%. The biomass energy value of particular wood species ranged from 11.27 to 13.1 MJ kg^{-1}. The average value

Table 7. The wood species structure, weight, moisture and energy value of the chipped wood biomass in the Liptovská Teplička stock.

Parameter	Thickness with bark [cm]	Tree species					Total
		Spruce	Fir	Beech	Hazel	Other	
Wood biomass weight [t]	up to 8.0	31.0	3.1	4.2	10.6	4.8	53.7
	8.1 – 20.0	46.6	3.8	5.2	1.9	4.5	62.0
	20 and more	24.8	3.2	1.9	0.0	0.0	20.7
Total [t]	—	102.4	10.0	11.3	12.5	9.2	145.6
Biomass absolute humidity [%]	up to 8.0	55.6	57.9	60.8	52.1	49.7	n/a
	8.1 – 20.0	54.3	55.8	59.9	52.8	48.9	n/a
	20 and more	54.2	55.5	58.7	0.0	0.0	n/a
Biomass average humidity [%]	—	54.8	56.3	60.2	52.3	49.3	53.8
Energy value of biomass in the dry state [MJ kg^{-1}]	—	12.31	11.98	11.27	12.63	13.1	12.1
Total energy value of the biomass [GJ]	—	1 261	120	127	159	100	1 805

Table 8. The tree species structure, weight, moisture and energy value of the chipped wood biomass in the Ľubietová stock.

Parameter	Thickness with bark [cm]	Tree species					Total
		Spruce	Aspen	Hazel	Beech	Other	
Wood biomass weight [t]	up to 8.0	20.1	11.7	16.6	4.5	1.8	54.7
	8.1 – 20.0	28.3	24.8	4.1	5.2	1.2	63.6
	20 and more	17.4	3.4	0.0	3.5	0.0	24.3
Total [t]	—	65.8	39.9	20,7	13.2	3.0	142.6
Biomass absolute humidity [%]	up to 8.0	56.9	77.2	53.8	61.7	52.1	n/a
	8.1 – 20.0	55.1	74.9	54.7	60.5	50.9	n/a
	20 and more	54.8	71.3	0.0	59.3	0.0	n/a
Biomass average humidity [%]	—	55.6	75.262	53.979	60.591	51.625	59.4
Energy value of biomass in the dry state [MJ kg^{-1}]	—	12.18	9.27	12.33	11.25	12.96	11.32
Total energy value of the biomass [GJ]	—	801	370	256	148	39	1614

was 12.1 MJ kg^{-1}. The tree species structure, weight, moisture and energy value of chipped wood biomass in Ľubietová stock are given in Table 8.

The total wood biomass weight was 142.6 t with an average humidity of 59.4% and an energy value of 1 613.7 GJ. During storage this value increased by 12.4%. The energy value of particular wood species biomass ranged from 9.27 to 12.96 MJ kg^{-1}. The average value was 11.32 MJ kg^{-1}.

Tree species structure, weight, humidity and energy value of chipped wood biomass in the stock Očová are given in Table 9.

The total weight of wood biomass was 119.4 t with an average humidity of 59.1% and an energy value of 1333 GJ. During storage this value increased by 12.1%. The biomass energy value of particular wood species ranged from 9.42 to 12.93 MJ kg^{-1}. The average value was 11.3 MJ kg^{-1}. There was no loss of raw material mass during chipping due to its leaving in the stock.

Table 9. The tree species structure, weight, moisture and energy value of the chipped wood biomass in the Očová stock.

Parameter	Thickness with bark [cm]	Tree species					Total
		Aspen	Oak	Beech	Hazel	Others	
Wood biomass weight [t]	up to 8.0	14.3	4.5	3.4	16.3	9.0	47.4
	8.1 – 20.0	27.6	7.3	4.4	4.7	14.5	58.4
	20 and more	2.8	4.2	4.1	0.0	2.5	13.6
Total [t]	—	44.7	16,0	11.8	20.9	25.9	119.4
Biomass absolute humidity [%]	up to 8.0	75.5	60.9	63.7	52.2	51.4	n/a
	8.1 – 20.0	72.6	60.1	61.0	53.6	50.7	n/a
	20 and more	70.1	57.9	58.6	0.0	49.9	n/a
Biomass average humidity [%]	—	73.4	59.6	60.8	52.4	50.8	59.1
Energy value of biomass in the dry state [MJ kg^{-1}]	—	9.42	11.39	11.12	12.56	12.93	11.3
Total energy value of the biomass [GJ]	—	421	182	132	263	335	1333

Table 10. Performance, Fuel Consumption and Energy Intensity of Wood Felling in Assessed Locations.

Parameter	Locality		
	Liptovská Teplička	Ľubietová	Očová
Number of harvested trees [pcs]	2 482	2 959	2 914
Volume of harvested dendromass [m^3]	229.3	217.8	171.7
Performance [m^3 h^{-1}]	10.71	8.68	7.31
The energy value of harvested mass [GJ]	1 623.8	1 435.4	1 189.5
The weight of the dendromass [t]	185	184.7	155.5
Average weight of wood [t]	0.075	0.062	0.053
Total fuel consumption [kg]	160.72	186.93	168.76
Measured energy consumption [MJ t^{-1}]	37.83	44.07	47.26
Measured fuel consumption [kg t^{-1}]	0.87	1.01	1.09
Overall performance [t h^{-1}]	8.64	7.35	6.62
Duration of work [h]	21.4	25.1	23.5
Number of motor saws [pcs]	4	4	4
Average hourly saw performance [t h^{-1}]	2.16	1.84	1.65
Total energy consumption [MJ]	6 998.6	8 139.9	7 348.7
Share of energy consumed on the energy value of the extracted dendromass [%]	0.43	0.57	0.62

3.4. Trees felling

Data on performance, fuel consumption and energy intensity of stands felling in the evaluated sites are involved in Table 10.

The total time of felling at assessed sites in areas with a size of 1.5 ha ranged from 21.4 to 23.5 hours. The average hourly performance in the conversion to the chainsaw was 1.65 to 2.16 t h^{-1}. Total fuel consumption reached 160.72 to 186.93 kg, with a consumption rate of 0.87 to 1.09 kg t^{-1}. The total energy consumption was 9 668.6 to 7348.7 MJ representing the share of energy consumption 0.43 to 0.62%.in the fresh biomass energy value of the harvested stand. The highest performance and the lowest measured fuel consumption and the share of the energy value of harvested biomass were achieved in Liptovská Teplička. The least favorable parameters were measured in Očová.

3.5. Wood skidding

The total skidding time on the assessed sites ranged between 19.5 and 20.97 hours and net skidding time of 17.52 to 8.33 hours. The total fuel consumption including the trailer transfers was 20.97 to 244.69 kg and the fuel consumption for the skidding was 168.24 to 179.55 kg. Fuel consumption for the transfers was 34.73 to 73.11 kg. The total actual energy consumption was 8498.0 to 10 244.7 MJ and, for the same transfer distance, it was 9 472.3 to 9 976.2 MJ. Measured fuel consumption for skidding was 1.01 to 1.19 kg t^{-1} and the total measured consumption calculated for the equal transfer distance of 1.35 to 1.60 kg t^{-1}. The share of total energy consumption for the skidding and transfers to the equal distance related to the energy value of the skidded wood biomass to the stock was 0.64 – 0.88%. After recalculation for the equal transfer distance, the highest was the performance, the lowest measured consumption and the share of the energy value of the skidded wood biomass reached in Liptovská Teplička were calculated. The least favorable skidding parameters were measured in Očová.

Based on the measurements, the factors influencing the performance and the energy process were analyzed. The overall performance of technology significantly affected the harvesting of wood biomass freely laid in the work area. Due to its character (thin, whole non-branched stems), it was problematic to use the load-carrying capacity of the vehicle set as much as possible. The dependence of performance during the skidding on the time required to stop cargo at the Ľubietová ($r^2 = 0.6361$, $P = 0.001$) site is shown in Figure 5.

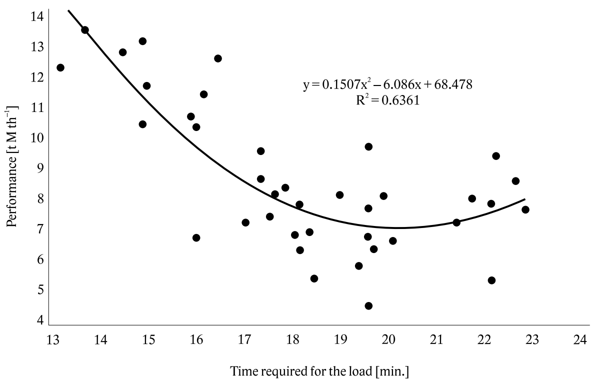

Fig. 5. Achieved technology performance, depending on time required for the load time in Ľubietová.

Performance data, data of fuel consumption and energy intensity of wood biomass skidding at assessed sites are given in Table 11.

3.6. Wood chipping

The total chipping time at assessed sites ranged from 21.1 to 2 hours and net chipping time was 18.4 to 19.9 hours. The average hourly performance in terms of networking time was 6.05 to 7.93 t h^{-1}. Total fuel consumption, including the transfers was 171.64 to 181.89 kg, fuel consumption for chipping 113.17 to 139.7 kg, fuel consumption for transfers was 31.94 to 68.32 kg. The total measured power consumption was 7186.2 to 7 615, and after the recalculation to the equal transfer distance due to the mutual comparability of results 713.3 to

Table 11. Performance, fuel consumption and energy intensity of skidding at assessed sites.

Parameter	Unit	Liptovská Teplička	Ľubietová	Očová
Total mass of skidded fresh biomass	t	169.40	167.80	141.40
Network time	h	18.08	18.81	17.52
Average hourly performance	t h^{-1}	8.33	8.00	7.24
Total duration of work	h	20.34	20.97	19.53
Average hourly performance in net time	t h^{-1}	9.37	8.92	8.07
Fuel consumption for skidding	kg	171.58	179.55	168.24
Measured fuel consumption for the skidding	kg t^{-1}	1.01	1.07	1.19
Transfers duration	km	228.00	156.00	108.00
Fuel consumption for transfers	kg	73.11	50.26	34.73
Measured fuel consumption for the transfers	kg t^{-1}	0.43	0.30	0.25
Total fuel consumption	kg	244.69	229.81	202.97
Total measured fuel consumption	kg t^{-1}	1.44	1.37	1.44
Total measured fuel consumption per average transfers travel distance of 180 km	kg t^{-1}	1.35	1.42	1.60
Energy value of skidded dendromass	GJ	1 486.80	1 302.40	1 079.20
The share of actual energy consumed in the energy value of the skidded biomass	%	0.69	0.74	0.79
Total actual energy consumption	MJ	10 244.70	9 621.70	8 498.00
Total energy consumption for an average transfers travel distance of 180 km	MJ	9 574.80	9 976.20	9 472.30
The share of energy consumption in the energy value of the skidded biomass	%	0.64	0.77	0.88

8 077.6 MJ. Measured fuel consumption for chipping was 0.78 to 1.17 kg t^{-1} and the total measured consumption was recalculated to the equal transfer distance of 1.15 to 1.62 kg. The share of total energy consumed for chipping and transfers to the equal distance to the energy value of the chipped wood biomass in the stock was 0.39 – 0.61%. After the recalculation to equal distance, the highest performance, the lowest specific consumption and the share of the energy value of the chipped biomass was reached in Liptovská Teplička. The least favorable chipping parameters were measured in Očová.

Performance data, data of fuel consumption and energy intensity of wood biomass chipping at assessed sites are given in the Table 12.

The energy consumption in the process of fuel chips production consisting of wood felling, wood biomass skidding to the stocks and its subsequent chipping was compared with the biomass energy values found in the logged stands and the biomass of these stands in the form of chips. The energy values of fuel chips made from stored raw material are higher due to moisture loss during storage on the assessed sites by 11.1 to 12.4%. For this reason, the share of the total energy consumed for the production of fuel chips is lower (1.05 to 1.52%) compared to the energy value of fresh biomass in logged stands (1.16 – 1.69%).

If we do not consider energy consumption for transfers of skidding vehicles and chippers between the workplaces, we found comparable energy values of the felling and skidding, whose shares of energy consumption on fresh biomass ranged between 0.43 and 0.61% and the value of fuel chips 0.39 up to 0.55%. After the transfers energy consumption calculation the energy intensity of the skidding has increased, and the share of energy on the value of fresh biomass has risen to 0.59 to 0.80% and the value of fuel chips 0.53 to 0.71%. Shares of energy consumption for chipping, including the transfers on fresh biomass value were 0.43 – 0.68% and fuel chips value 0.39 – 0.61%. Shares of energy consumption per chipping were 0.29 to 0.49%, respectively 0.26 to 0.44%.

The lowest energy intensity of the production process was achieved in Liptovská Teplička. Shares of energy consumption on energy biomass were higher in Ľubietová by 23.5% and 44.7% in Očová.

4. Discussion and conclusion

The energy intensity of the logging, skidding and chipping of above-ground tree dendromas has been investigated in the stands of wood species growing on long-term uncultivated agricultural land. These occur as a result of the end of the traditional intensive management of agricultural land through the natural succession of forest stands and pioneers'' wood species (Oravec & Slamka 2014). The experimental areas in terms of their wood species composition corresponded to the result of Šebeň (2008). The resulting product of the evaluated production process are fuel wood chips. These are currently the preferred form of biomass in terms of size and transport options (Manzone 2015). The energy intensity of the production was evaluated on the basis of fuel consumption using the technology chain saw – forwarder – chipper.

In spite of the attempt to replace gradually risk moto-manual felling of trees by machines (Moravčík et al. 2009), it is routine technology of the wood production combined with other mechanization means still used (Borz & Ciobanu 2013). We have found that the average weight of the wood is an important factor that affects the performance and energy intensity of the felling. With the decreasing average weight of the wood in Ľubietová by 17.3% and Očová 29.3%, compared to Liptovská Teplička, the energy intensity of the felling increased by 16.1, respectively 25.3%. Due to its decline, the average hourly performance in Ľubietová also decreased by 14.8% and Očová by 23.6%. In these stands on non-forest land, advantageously localized and well available with respect to the previous land use method (Oravec & Slamka 2014), consideration should be given to utilization of other available and more efficient technologies. The issue of dendromass processing on uncultivated agricultural land is actual also in the surrounding states on different levels. These are, in particular, countries where land ownership change and agricultural restructuralization (e.g. V4 countries) were implemented. Due to the terrain and climatic conditions and the tree structure of the harvested stands, the results can be used as follows:

– location Liptovská Teplička – mountain regions of Bohemia and southern Poland with a spruce prevalence,

Table 12. Performance, fuel consumption and energy intensity of chipping at assessed sites.

Parameter	Unit	Liptovská Teplička	Ľubietová	Očová
Energy value of the harvested stand biomass	GJ	1 623.8	1 435.4	1 189.5
Energy value of the fuel chips	GJ	1 804.9	1 613.7	1 332.8
Energy consumption in wood felling	MJ	6 998.6	8 139.9	7 348.7
Share of felling energy consumption in energy value of harvested stand	%	0.43	0.56	0.61
Share of felling energy consumption in energy value of chips	%	0.39	0.5	0.55
Energy consumption in wood biomass skidding calculated for the equal transfers distance	MJ	9 574.8 (7 183.7)	9 976.2 (7 517.4)	9 472.3 (7 043.9)
Share of skidding energy in energy value of harvested stand biomass	%	0.59 (0.44)	0.70 (0.52)	0.80 (0.59)
Share of skidding energy in energy value of chips	%	0.53 (0.40)	0.62 (0.47)	0.71 (0.53)
Energy consumption in wood biomass chipping calculated for equal machine transfers distances	MJ	7 013.3 (4 755.0)	7 631.3 (5 373.3)	8 077.6 (5 849.0)
Share of chipping energy consumption in energy value of harvested stand biomass	%	0.43 (0.29)	0.53 (0.37)	0.68 (0.49)
Share of chipping energy consumption in energy value of the chips	%	0.39 (0.26)	0.47 (0.33)	0.61 (0.44)
Total energy consumption	MJ	23 586.7 (18 937.3)	25 747.4 (21 030.6)	24 898.6 (20 241.6)
Share of total energy consumption in energy value of harvested stand biomass	%	1.45 (1.16)	1.79 (1.45)	2 009 (1.69)
Share of total energy consumption in energy value of the chips	%	1.31 (1.05)	1.59 (1.30)	1.87 (1.52)

Note: The figures in brackets indicate energy consumption and their shares in the case of no calculation of energy consumption for transfers.

– locality Ľubietová – mountain regions of Bohemia, Poland and northern Hungary, with mixed hardwood and softwood stands,
– locality Očová – the territory of Hungary and South-East Bohemia with mixed areas of soft and hard broadleafs.

Wood was skidded by JD 810 D forwarder with a load of 9 t and a reach of 8.7 m. Although these machines are designed for the export of logs, in practice they are used for the export of logging residues and energy wood in spite of the insufficiently utilized capacity (Hakkila 2004; Slotta & Spevár 2010; Klvač 2011). The JD 810 D belongs to the class of small forwarders and the producer recommends it to be used especially for shorter skidding distances, but the effect of their utilization is influenced by several factors (Macrì et al. 2016). Since the production of energy wood was only the added value of the intention and the main reason for the logging was the need for the restoration of the original pastures, the whole trees were harvested. This method is increasingly being used on forest land due to the increase in demand for wood chips, however there are fears of excessive loss and withdrawal of nutrients (Hytönen & Moilanen 2014). The results of particular time-demanding work operations of the skidding by the forwarder in these natural-production conditions are comparable with the results of Dvorak (2000), Slamka (2009) and Slamka & Radocha (2010) which evaluated the harvesting residues of forest stands. In the case of freely scattered and thin wood mass, the load structure is a time-consuming operation that can affect the performance of the machine and hence the energy intensity of the whole process. However, the opposite effect may also occur. The dependence presented in Figure 5 is not of a linear path, and over the 20-minute limit for the load there was rising trend for the performance in comparison with so far decreasing performance. This situation arises in cases where, at the expense of the time of loading, a better utilization of the loading area and load-bearing capacity of the technology is used. Another influencing factor of the skidding is the thickness structure of the extracted biomass. The impact of the skidding distance on energy intensity was insignificant, due to a small share of transfers between stands and biomass stocks. The share of driving times in Liptovská Teplička on the networking time was 18.1% at the skidding distance of 370 m and in Očová 15.0% at the skidding distance of 160 m.

Concentrated mass was in heaps stored and dried 95 to 128 days at particular locations. This is the split technological process in which the continuity and interlink of the chips production operations interrupted for a certain period in order to reduce the moisture content of the wood by its natural drying in the stand either in the heaps or at the place of removal (Simanov 1995). The moisture content of a tree depends on the type of wood species, the part of the tree and the seasons, the highest being in the spring and the lowest one at the end of the vegetation in the winter period (Dzurenda & Banski 2016). Together with the dimensions, it is one of the most important factors affecting the efficiency of the energy conversion of the chips (Pari et al. 2013). Another important factor is the degree of their biodegradation, while all factors influence to a large extent the storage method (Pettersson & Nordfjeld 2007; Oravec et al. 2012). From the point of view of the inclination to microbial degradation, especially relatively young plant material derived from fast-growing wood species is particularly demanding (Jirjis 2005).

The natural dendromass drying method, which was also used in the tests performed, is in terms of increasing the energy efficiency of Röser et al. (2011) sufficiently effective. Although Brand et al. (2011) as well as Afzal et al. (2010) point to the need to select a suitable annual period for mining and subsequent storage, Filbakk et al. (2011) have also achieved satisfactory results in the wetlands of Norway, where most of the small heating plants are designed to burn wood chips with a moisture content of 35%. In the Mediterranean climate of Italy, the moisture content of the poplars for energy purposes was reduced from 59% below 30% after 100 days of natural drying, and the analyzes confirmed that air temperature is the main driving force (Pari et al. 2013). Simanov (1995) states that the time required to reduce the relative humidity is three or more months. On the other hand, if the storage time of dendromass is too long before chipping, it may have a negative impact on the quality of the chips, as Pochi et al. (2015) discovered for the poplars. Drying in the combustion process is according to Gebreegziabhera et al. (2013) a costly process whose economy affects the dimensions of the produced wood chips. From the point of view of the final quality, the biggest demands on the producers are given by the small heat plant operators, due to the more demanding provision of efficient operation and minimization of maintenance costs (Röser et al. 2011).

In terms of the energy intensity of wood chips production, most of the studies published as input energy refer to the energy value of diesel directly used in their production and transport. According to the results of Timmons & Mejía (2010), the dependence on it is not extreme and the share of input energy does not exceed 2% of the total potential energy of wood chips. The share of input power to 5% was published by Börjesson in 1996. Using the same comparison criterion, i.e. fuel consumption, the input energy needed to produce wood chips from experimental areas did not exceed 2% of their energy value. We have found that with decreasing weight and thickness of wood species, the energy and time demand of work operations is increasing. An important influence factor is also the duration of the mechanisms transfers between the workplaces. In order to achieve the energy efficiency of the logging and production activities it is necessary to optimize the choice of workplaces with an emphasis on works concentration.

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