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# Energy yield of logging residues of the south-eastern region of the Czech Republic

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**ABSTRACT**: The study analyses data obtained from the production of energy chips from logging residues. Geographically, the data come from the south-eastern portion of the Czech Republic. 6,671 t of energy chips were analysed by means of samples, their total energy content being 63.92 TJ. Based on the results of laboratory analyses of samples of wood chips with energy contents, ratio (reference) variables were derived and can be used as input (basic) data for the modelling of the energy potential of logging residues of the territory.

**Keywords**: wood chips; renewable sources; energy potential

In this country, the volume of logging residues generated as wood-harvesting waste is derived from the volume of harvested wood assortments produced, i.e. as a ratio variable that is very difficult to quantify. When designing biomass-utilising projects, it is very important to know the production limits of the attraction region to enable the effective planning of supplies of energy raw materials, as well as energy development projects. The variability of forest ecosystems, particularly in terms of growth and production conditions, limits the amount of woody biomass available in the region. The study aims at analysing data sourced within a specific territory; consequently, the results can be applied, to some extent, to other forest units provided that continuous validation and specification are ensured. In the Czech Republic, there is an absolute absence of such aggregated information, a fact that mostly affects researchers, operators of energy sources and minor forest owners. Businesses active in trading and manufacturing chiefly employ the "best judgement" in their decision-making processes and protect their experience as corporate know-how. Even so, very often there is under- or overestimation of production data and problematic planning of production and sales. On the other hand, large forest owners offer logging residues on the "cubic metre of harvested wood" basis, stemming from the fact that a unit marketed in this way is the most easy-to-grasp for them on the basis of their wood assortment production records. Any potential buyer of logging residues is required to agree to this business model. This creates a sort of a "black box" with volumes of logging residues per quantity of harvested wood being the input on the one hand, and bulk cubic metres of wood chips with energy content being the output on the other hand.

The present study thus aims at deriving proportional (reference) quantities that can be re-used in planning and optimising the energy use of waste woody mass in the region of interest as well as in the business and production model used in the Czech Republic.

## MATERIAL AND METHODS

The present study made use of data derived solely from the production of wood chips with energy content from logging residues, which can be de-

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fined as a woody mass remaining after tree felling, debranching and sorting, i.e. branches, treetops, splinters and handling shavings of characteristic diameter of < 7 cm (EN 14961-1:2010).

Data sourced from primary production and sales records of forest holdings and trading companies active in the production of wood chips with energy content were used for deriving the proportional values. The data were divided into nine production sites ("PS") of production of wood chips with energy content. To prevent disclosure of commercial confidentiality and anonymity of data contributors, the paper makes use of data aggregated into production sites ("PS") labelled with Latin letters A through I. This lack of spatial location accuracy of data sources is partly eliminated by detailed description of the raw material and extent of the analysed database.

The database was acquired in 2012 (January to December) and contained a total of 433 business cases representing 7,715 recorded numerical values. Of these, 258 business cases were used for the purpose of this study. The selection was made based on the completeness of the records; i.e. the business cases with incomplete data were not used for the purposes of the study. Data used for the analysis represented 44,971 $m^3$ of harvested wood inside bark (i.b.) (timber to the top of 7 cm o.b.) and 6,671 t of wood chips with energy content (LUTRO – air dried), the total energy content being 63.92 TJ (17.76 GWh, 1,531 toe, 605,996 thm).

The resources for the production of wood chips with energy content involved forest stands after planned major felling operations, or more specifically, logging residues resulting from such activities. The age of the forest stands ranged from 92 to 110 years, while the average felling log volume (mean stem) was 0.82 $m^3$ inside bark. The logging residues were collected on an area of 108.36 ha, which equals an average stand stock of 415 $m^3$ per hectare. Aggregated representation of woody species: spruce 62%, larch 10%, pine 9%, oak 6%, fir 5%; other coniferous and deciduous tree species amounted to 4%. The territorial unit belongs to CZ NUTS 064 – South Moravian Region (a south-eastern portion of the Czech Republic).

The quality characteristics of the resulting energy raw material were taken from the results of ATRO (absolutely dry) acceptances at the customer (ČEZ Hodonín). The wood chips with energy content were sourced by the customer under the quantitative and qualitative acceptance (EN 14778:2011) on customer premises. The shipping weight was determined by direct measurement using a weighbridge as the difference between the weight of the load including the means of transport (gross weight) and that of the vehicle alone (tare). Before unloading each shipment, six random samples were collected to determine quality.

Quality parameters were evaluated as described above for samples with the time from extraction to laboratory analysis being not more than 4 weeks. The threshold was chosen on the basis of production and supply possibilities and customs of the data contributors.

## RESULTS

The summary values are compiled in Table 1, which makes it apparent that the greatest amount of data was obtained from the production sites (PS) G and H – about 66% of the total data. A significant amount of data was sourced from PS E and F – a total of about 20%. The remaining 14% of the data were shared by the remainder of the production sites which equalled five. Analysis of the data accumulated in the production database first derived aggregated data characterizing the wood chips with energy content sourced from individual production sites. The results are compiled in Table 1.

Deriving the ratio variables characterizing the wood chips with energy content produced from

Table. 1. Aggregated data of the input database characterizing the resulting product based on ATRO acceptances – wood chips with energy content

| | Production sites | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | Σ |
| Fuel energy content (GJ) | 2,015 | 1,484 | 2,084 | 3,203 | 8,180 | 5,327 | 24,441 | 15,060 | 2,119 | 63,919 |
| Actual weight (t) | 172 | 139 | 197 | 307 | 800 | 522 | 2,451 | 1,820 | 263 | 6,671 |
| ATRO weight (At) | 140 | 103 | 144 | 222 | 576 | 370 | 1,689 | 1,024 | 145 | 4,415 |
| $TM_{ib}$ ($m^3$) | 800 | 780 | 1,070 | 1,680 | 5,400 | 3,515 | 16,423 | 13,207 | 2,096 | 44,971 |
| Percentage | 1.78 | 1.73 | 2.38 | 3.74 | 12.01 | 7.82 | 36.52 | 29.37 | 4.66 | 100 |

$TM_{ib}$ – amount of extracted and recorded timber in cubic metres inside bark (measured with bark, the resulting amount excludes bark), it involves produced timber assortments, top diameter to 7 cm

Table 2. Statistical analysis of the ratio variables obtained – resulting data

| PS | $W_t^r$ (%) | $Q_i^r$ | $Q_i^d$ | $Q_i^r$ (brush wood) ($GJ \cdot TM_{ib}^{-1}$) | Ratio | | | $TM_{ib}$ shipment* | $\rho_v^r$ | $\rho_v^s$ | $A^r$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ($MJ \cdot kg^{-1}$) | | | $TM_{ib}$/GJ | $TM_{ib}$/t | $TM_{ib}$/At | | (kg per $m^3$ loose volume) | | |
| | | | | | ($m^3$) | | | | | | |
| A | 31.12 | 11.72 | 14.39 | 2.52 | 0.40 | 4.65 | 5.71 | 112 | 197 | 160 | 4.17 |
| B | 36.50 | 10.66 | 14.41 | 1.90 | 0.53 | 5.60 | 7.57 | 134 | 214 | 158 | 4.28 |
| C | 36.90 | 10.58 | 14.44 | 1.95 | 0.51 | 5.43 | 7.41 | 130 | 216 | 158 | 4.11 |
| D | 37.64 | 10.44 | 14.40 | 1.91 | 0.52 | 5.47 | 7.55 | 131 | 218 | 158 | 3.98 |
| E | 38.70 | 10.23 | 14.20 | 1.51 | 0.66 | 6.75 | 9.37 | 162 | 222 | 160 | 4.55 |
| F | 38.80 | 10.21 | 14.38 | 1.52 | 0.66 | 6.73 | 9.49 | 162 | 222 | 158 | 4.01 |
| G | 39.99 | 9.97 | 14.47 | 1.49 | 0.67 | 6.70 | 9.72 | 161 | 227 | 156 | 4.25 |
| H | 48.60 | 8.27 | 14.70 | 1.14 | 0.88 | 7.26 | 12.89 | 174 | 265 | 149 | 4.20 |
| I | 49.69 | 8.06 | 14.60 | 1.01 | 0.99 | 7.97 | 14.44 | 191 | 270 | 149 | 4.22 |
| **Statistical analysis results** ($\alpha$ = 0.05; $n$ = 9) | | | | | | | | | | | |
| S | 5.882 | 1.160615 | 0.1415 | 0.462019 | 0.187514 | 1.05 | 2.784291 | 25.302064 | 23.9971 | 4.2654 | 0.1677 |
| (d) ± actual | 4.5214 | 0.892127 | 0.1087 | 0.355139 | 0.144136 | 0.8113 | 2.140195 | 19.448888 | 18.4458 | 3.2787 | 0.1289 |
| $v_k$ | 14.790 | 11.58291 | 0.979 | 27.8324 | 29.0269 | 16.80 | 29.7785 | 16.75633 | 10.525 | 2.734 | 3.994 |
| $\sigma$ | 5.8821 | 1.160615 | 0.141 | 0.46201 | 0.18751 | 1.055 | 2.78429 | 25.30206 | 23.997 | 4.265 | 0.167 |
| $x'$ | 39.77 | 10.02 | 14.44 | 1.66 | 0.646 | 6.28 | 9.35 | 151 | 228 | 156 | 4.20 |
| $\bar{x}$ | 42.34 | 9.51 | 14.50 | 1.42 | 0.73 | 6.80 | 10.57 | 163.22 | 237.82 | 154.48 | 4.24 |

PS – production site; $W_t^r$ – water content in the original sample; $Q_i^r$ – heating value of the energy raw material (wood chips); $Q_i^d$ – dry matter heating value; $TM_{ib}$ – amount of extracted and recorded timber in cubic metres inside bark; t – actual weight (LUTRO); At – ATRO weight; *vehicle: a high-capacity walking floor trailer, cargo area capacity 90 stacked $m^3$ (unpacked), max. cargo weight 24 t; $\rho_v$ – bulk (volume) weight; $^{r, s}$ – real condition, initial; s – bulk density of chipped material; (d) ± act. – mean value of determination accuracy; $v_k$ – coefficient of variation; $\sigma$ – variance (variation); $x'$ – arithmetic average; $\bar{x}$ – weighted arithmetic average;

logging residues per PS in terms of quality was the next step in data analysis. The aggregate data were first split per PS and quality parameters (Table 2), then for each quality parameter, cumulatively for all the PS, with use of arithmetic ($x'$) and weighted arithmetic average ($\bar{x}$), where the volume of harvested wood of 7 cm ($TM_{ib}$) was determined as the weight of logged timber. The ratio variables were further tested statistically. The results are shown in Table 2.

## DISCUSSION

The data analysis found the following:

$W_t^r$ – water content in the original sample (%) – this variable is essential for the wood heating value to be useful (Kristensen et al. 2000; Paulrud 2004; Cutshall et al. 2013; Greene et al. 2014). This is the actual moisture content of the fuel (the index "t" denotes the raw status of the fuel – the actual weight that is referred to as LUTRO). The wood moisture content indicates the amount of water in the wood, expressed as a percentage. The field practice differentiates between "relative" and "absolute" moisture content of the wood. Using wood to generate energy employs relative moisture content; this was the case in the wood chip acceptances we analysed – the index "r" ($W_r$ – relative moisture content). The average final moisture of the data analysed: $x'$ = 39.77%, $\bar{x}$ = 42.34%. Cutshall et al. (2013) stated in their study that the initial moisture content of felled wood of 53% decreased during 4 weeks to a value of 43% due to transpiration drying, dropping further to 39% during the subsequent four weeks. The values we obtained for logging residues in the area of interest are correlated with the results of this research, and a decrease in moisture content in freshly produced logging residues can be considered to be about 10% during the initial 4 weeks, which is very important in terms of technological use of the resulting material and is crucial for the cost-effectiveness of utilising of logging residues to generate energy. It is necessary to mention a study published by Jirjis (1995), in which the author also points to the opposite tendency, i.e. that in the case of long-term storage of biomass (over 11 months) in piles, the initial drop of moisture is followed by the material regaining its moisture content and losing its quality.

$Q_i^r$ – heating value of the energy raw material (wood chips) (MJ per kg). $Q_i$ (heating value) represents the heat released by the combustion of 1 kg of fuel to produce $CO_2$, $SO_2$, $N_2$ and steam (instead of water). The heating value is determined by dividing the heat that is released when the fuel has completely burned by the weight of the fuel when flue gases cool down to the initial temperature of the fuel. Heating value $Q_i$ (Lower heating value) refers to the heat released under the same conditions as the heat of combustion, but the resulting water is in the form of steam. Heating value is significantly influenced by fuel moisture content (Kristensen et al. 2000; Bedane et al. 2011). Average heating value $Q_i^r$ obtained from the analysed data: $x'$ = 10.02 MJ·kg$^{-1}$, $\bar{x}$ = 9.51 MJ·kg$^{-1}$.

$Q_i^r$ of brushwood (GJ·m$^{-3}{}_{VHir}$) refers to the quantity derived by the author from the heating value of wood chips with energy content related to the amount of harvested wood inside bark (produced wood with a top diameter ≥ 7 cm). The relationship can be taken in writing using equation (1):

$$Q^r_{i\ \text{logging residues}} = \frac{Q_i^r\ \text{wood chips (GJ)}}{m^3{}_{VHib}} \quad (\text{GJ·m}^{-3}_{VHib}) \qquad (1)$$

The resulting average heating values of brushwood: $x'$ = 1.66 GJ·m$^{-3}_{VHib}$, $\bar{x}$ = 1.42 GJ·m$^{-3}_{VHib}$. It can therefore be stated that the analysed region can be expected to possess an energetic potential of the logging residues generated of 1.66 GJ·m$^{-3}{}_{VHib}$ per every cubic metre of wood (timber) inside bark.

$Q_i^d$ – dry matter heating value (MJ·kg$^{-1}$). The heating value of dry matter (the index "d" refers to dry matter, the index "daf" refers to the combustible matter, i.e. dry matter without ash) of wood chips with energy content produced from logging residues ranged from 14.38 to 14.70 MJ per kg. The average dry matter heating value for the analysed data: $x'$ = 14.44 MJ·kg$^{-1}$, $\bar{x}$ = 14.50 MJ·kg$^{-1}$.

$A^r$ – ash (%) is another important quality parameter of fuel (Narodoslawsky et al. 1996) and is classified as a ballast material, along with water. Since ballast materials reduce fuel efficiency, the heating value of fuel needs to be distinguished from that of the combustible matter, the latter not being affected by the content of ballast matter. In the combustion process, a certain amount of the reaction heat is consumed to heat the ballast matter and evaporate water, which slows down the combustion process and causes the combustion stability to decrease in extreme cases. An increased content of ballast matter, particularly water and ash, increases transportation costs and production of problematic solid combustion residues, which need to be managed as waste (Röser et al. 2011; Greene et al. 2014). The average ash content within the analysed data (6.671 t of wood energy chips) was $x'$ = 4.2%, $\bar{x}$ = 4.24% (max. of 4.55%, min. of 3.98%). The resulting ash content in our case is influenced by the type of woody mass, i.e. logging residues. The example of logging residues indicates that the proportion of ballast ash is higher than that of pure wood, probably due to the higher content of bark (bark is higher in ash). Assumed can also be a greater share of impurities (litter) mixed into the brushwood during brushwood picking and handling. The statement mentioned above can be supported by the research of Picchio et al. (2012) involving wood chips with energy content obtained from plantations of fast-growing tree species (FTS). Picchino et al. (2012) found that the proportion of ash in wood chips sourced from 2-year FTS reached the average level of 3.8%, which was 2.8% for three-year trees. Erol et al. (2010) found that the ash content in woody species was 5.75% for common ash and 3.47% for poplar. Dzurenda et al. (2012) analysed the green wood chips from poplar branches to find that the ash content per sample averaged 0.52% for wood, 6.86% for bark and 3.36% for wood mixed with bark. It indicates that an increased share of bark and a lesser proportion of wood have a negative effect on the resulting value of ash in wood chips with energy content (Sarenbo 2009). Liaquat (2011) and Gruduls (2013) revealed in their studies an increase in ash content due to melting snow, i.e. increased amount of impurities. $\rho_v$ – bulk (volume) weight (kg per m$^3$ loose volume) of chipped material is defined as the mean density of bulk, discontinuously distributed substance, i.e. it involves the bulk density of an unpacked material (Eq. 2).

$$s = m_s/V_s \quad (\text{kg·m}^{-3}, \text{kg·prms}^{-1}) \qquad (2)$$

where:

$s$ – bulk density of chipped material,

$m_s$ – weight of a given volume of chips (kg),

$V_s$ – geometric volume of the filled space (m$^3$).

Bulk density for the analysed data ranged from 197 to 270 kg per kg·prms$^{-1}$, with average values being $x'$ = 228, $\bar{x}$ = 237.82. Bulk density of dry matter: $x'$= 156, $\bar{x}$ = 154.48. Bulk density is an important parameter in terms of logistics (Angus-Hankin et al. 1995; Hamelinck 2005; Ranta et al. 2006). Further, quantities were derived from the aggregate data in relation to the basic record-keeping unit, i.e. m$^3$ of harvested wood. It was found: obtaining a unit of energy (GJ) required an average of

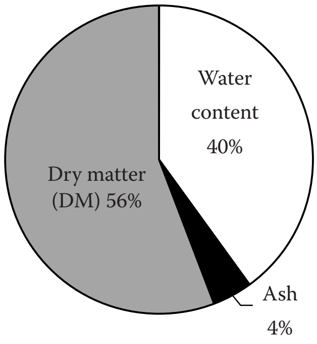


Fig. 1. Percentage of individual components per average sample of wood chips produced

$x'$ = 0.64 $TM_{ib}$, $\bar{x}$ = 0.73 $TM_{ib}$ (min. 0.40, max. 0.99) of harvested wood (timber), while producing a tonne (t) of wood chips necessitated the treatment of logging residues that equalled $x'$; $\bar{x}$ = 6.28; 6.8 $TM_{ib}$ (min. 5.71, max. 14.44). A truck = a shipment (V = 90 stacked $m^3$, about 24 t) was fully filled with logging residues that equalled the logging volume of $x'$; $\bar{x}$ = 151; 163 (min. 112; max. 191) $TM_{ib.}$ The production of an atro tonne (At) of wood chips needed the processing of logging residues that equalled the harvested wood quantity of $x'$; $\bar{x}$ = 9.35; 10.57 (min. 5.71; max. 14.44) $TM_{ib.}$

Fig. 1 shows the average percentage of individual components represented in the fuel – produced and delivered wood chips. The water content was 40%, dry (combustible matter) matter was 55.80% and ash content was 4.20%.

## CONCLUSIONS

Analysing the production data of the area of interest identified average quality characteristics of wood chips with energy content made exclusively from logging residues as follows: average moisture content $W_t^r$ = 42.34%, heating value $Q_i^r$ = 9.51 MJ per kg, ash content $A^r$ of 4.24%. Obtaining a unit of energy (GJ) required an average of $x'$ = 0.64 $TM_{ib}$, $\bar{x}$ = 0.73 $TM_{ib}$ (min. 0.40, max. 0.99) of harvested wood (timber), while producing a tonne of wood chips necessitated the treatment of logging residues that equalled $x'$; $\bar{x}$ = 6.28; 6.8 $TM_{ib}$ (min. 5.71, max. 14.44). A truck = a shipment (V = 90 stacked $m^3$, about 24 t) was fully filled with logging residues that equalled the logging volume of $x'$; $\bar{x}$ = 151; 163 (min. 112; max. 191) $TM_{ib}$. The production of an ATRO tonne (At) of wood chips needed the processing of logging residues that equalled the harvested wood quantity of $x'$; $\bar{x}$ = 9.35; 10.57 (min. 5.71; max. 14.44) $TM_{ib}$. The data sourced from the research can be used as an input for optimising models of seeking alternatives of efficient use of logging residues as a renewable energy raw material (Freppaz et al. 2004; Rentizelas et al. 2009; Schmidt et al. 2010; Rauch et al. 2011). The optimising models based on the collected data are to provide information on the available energy balance (Röser et al. 2011) of the region through which they will provide the best possible support for the energy utilisation of logging residues and the diversification of the energy mix of the region (Naik et al. 2010), while contributing to the reduction of greenhouse gas emissions (Kobayashi 2011; Cocchi et al. 2013). Last but not least, the data will promote the motivation of small forest owners to market this source of energy (Conrad et al. 2011; Joshi et al. 2011).

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