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Studying the heterogeneity of woody biomass: An experimental and statistical approach

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ABSTRACT

In this study the woody biomass was tested, possible using as energy material for alternative fuel producing as briquettes, pellets, or RDF (refuse-derived fuel) for example. The physical and energy properties of wood biomass were determined and statistical analysis methods were used to identify their heterogeneity. Significant differences were revealed when comparing the average calorific values for desired samples. This was correlated to the different moisture contents in the tested samples. The statistical analysis results showed a normal distribution of the calorific values for each sample of wood chips. Meanwile, a samples comparison showed the high moisture content in wood biomass taken from the location 2. We concluded that taking into account the results from the experiments of wood biomass together with their statistical analysis made it possible to producing of alternative fuel in higher quality.

Keywords: woody biomass, renewable energy, alternative fuel, statistical approach.

INTRODUCTION

Sustainable energy issues are coming to the forefront in all countries of the world today. This is due to the need for access to energy sources at home and in the workplace, in the production of goods and in the provision of various services, the need to ensure a sustainable economy of the country and prevent the depletion of natural resources. Due to the relevance of the above-mentioned acute energy problems, affordable and clean energy (SDG No. 7) ranks seventh among the SDG [Eurostat, 2025]. Since every fifth inhabitant of the planet does not have access to energy matarials (most of them live in Africa and Asia). SDG No. 7 is aimed at solving the problems of energy poverty, economic accessibility of energy resources, and ensuring sustainable energy development.

Meanwile, fossil fuels are exhaustible natural resources and are unevenly distributed across the planet, which does not contribute to equal access to energy resources. In this regard, the last decade has seen a particularly active search for alternative energy sources. Moreover, since any substances and materials to one degree or another have energy potential, then in striving to achieve SDG 7, some issues of Goal 12 and Goal 13 can be resolved in parallel. For example, Goal 12 seeks to achieve responsible consumption and production, which can be achieved by using any type of waste for energy purposes. While Goal 13 seeks to prevent or slow down climate change and this can be achieved by reducing the use of fossil fuels and eliminating waste landfills, which significantly provoke the release of greenhouse gases into the environment. Reducing CO_2 emissions is crucial to achieving climate neutrality, contributing to the achievement of Net Zero goals by 2050 [Sher et al. 2025].

The targets for the transition to renewable energy production in almost every country in the world can be achieved through the use of plant and woody biomass [Jezierska-Thöle, 2016]. The term "plant biomass" covers all renewable organic materials derived from plants, including special energy crops, agricultural crops used both as food and feed, agricultural residues, and aquatic plants [Prajapati et al., 2021; Annual Energy Outlook, 2025]. However, even taking into account the environmental and social benefits of crop residues, a significant part of forest (woody) biomass remains largely unused [Singh et al., 2021].

The commonly type of biomass that can be utilized is logging waste and by-products of forestry processes. Logging waste is a material that is formed during timber harvesting, as well as during the maintenance and cleaning of forest stands. In the literature, this material is defined as logging tailings/waste. A characteristic feature of this type of biomass is its heterogeneity. In addition to clean wood, it contains a large amount of bark, pine needles, cones and lignified young shoots [Prikhodko et al., 2021].

The usefulness of biomass as an energy raw material is confirmed, in particular, by its elemental composition. The content of C, H, N, S, oxygen and ash is relatively well known for wood of various species and wood waste, individual parts of trees [Bandurin et al., 2019], which can be found in wood chips, such as: wood, stumps, roots, bark, cones, seeds [Boria et al., 2018]. Opponents of the use of primary biomass as a renewable energy source argue that it is associated with deforestation. In practice, this means that the use of this type of biomass can lead to deforestation, that is, the mass cutting of trees. Deforestation, in turn, can negatively affect the environment, leading to loss of biodiversity, climate change and land degradation. However, if you look at the statistics, over the past 10 years, the total area of the world's forests has decreased by about 0.84%. Interestingly, in Poland, during this period, there was an increase in forest area by about 2.5% and an increase in forest cover from 28.8% in 2005 to 29.6% in 2020 (Figure 1) [https://globenergia.pl/drewno-modla-przeszlosci-czy-narzedzie-zielonej-transformacji/].

Wood and forest chips are perceived as a raw material of lower quality, not suitable for widespread use in unprocessed form. However, the low nitrogen and sulfur content (0.66% and 0.25%) and the high carbon content (over 50%) confirm the possibility of using pine logging waste as an energy raw material. Given the low nitrogen and sulfur content, low emissions of harmful substances such as nitrogen oxides, benzene and formaldehyde during combustion can be expected. The carbon content determines the calorific value of this biomass, which facilitates further research [Motghare et al., 2016].

Not only sawmill and wood processing waste can be used for alternative fuel products used in thermal power engineering. For many countries, for example, in Southeast Asia, whose climate ensures the rapid growth of many types of wood, special cultivation of deciduous trees (they usually grow faster than conifers) for subsequent cutting and burning in boiler furnaces is promising. In this case, special sawing, splitting and crushing of wood is necessary [Sher et al., 2017].

Wood plays a key role in the natural carbon cycle. During photosynthesis, plants absorb carbon dioxide from the atmosphere, storing it as organic carbon – the main component of wood. The main elements that make up wood are: carbon (49.5%), oxygen (43.8%), hydrogen (6.0%), nitrogen (0.2%) and others. The main compounds that make up wood are: cellulose (about 45%), hemicelluloses (about 30%) and lignin (about 20%). In addition, wood also contains: sugar, protein, starch, tannins, essential oils, rubber and mineral substances that form ash when burned. The chemical composition of ash depends on the tree species, climate, soil, etc. (https://www.drewpol.pl/ciekawostki/).

Biomass is characterized by a zero balance of carbon dioxide emissions, which occurs as a result of closing the cycle, which can be written in terms of the following components (here, C is carbon): C (in biomass) a biomass combustion a CO_2 – a combustion product emitted into the atmosphere during photosynthesis – extraction of CO_2 from the atmosphere and restoration of C (into biomass).

As a result of burning biomass the amount of CO_2 absorbed during photosynthesis is released into the atmosphere. The source of energy contained in biomass is the absorbed energy of solar radiation. Carbon (as a chemical element) in wood contains on average 50%. The remaining composition of wood is approximately: 43% oxygen, 6% hydrogen and less than one percent nitrogen and traces of sulfur. One percent of mineral compounds contained in wood forms a solid residue – ash. An important practical advantage of the energy use of biomass is that the solid residue of the combustion process (ash) can be completely used by plants in the process of their development. The resulting ash can be returned to the soil, which cannot be done in the case of fossil fuels due to the content of various harmful components in the ash, including heavy metals [Pazalja et al., 2021].

The process of carbon dioxide circulation in nature can be compared with the closed water cycle in nature. However, although the water cycle between the various components of the environment is completely balanced, in practice the complete balancing of the carbon dioxide cycle is unfortunately disrupted by the sum of the processes associated with the preparation of biomass into a full-fledged fuel – this requires energy, which is associated with CO_2 emissions. To these losses in the complete balance of carbon dioxide emissions/absorption, we must also add the problems arising from the incomplete oxidation of flammable components contained in the biomass. To summarize the issue of the balance of CO_2 circulation in nature, it should be added that the main natural absorbers of this gas are soil, oceans and forests [Repo et al., 2015].

Wood biomass is considered a technologically more complex fuel compared to coal. A high degree of incomplete combustion of organic components of this fuel is also common. The energy density of wood is low compared to other types of fuel and depends on many factors. However, given the natural amount of wood and the environmental benefits obtained from the energy use of this fuel, the role of wood in energy (and various forms of its processing) will increase [García et al., 2015].

The aim of this article is to expand knowledge in the field of identifying the properties of wood biomass by verifying the experimental and statistical approach, taking into account the heterogeneity of wood biomass as an energy material, and forecasting the possibilities of increasing the quality of alternative fuel.

MATERIAL AND METHODS

Material

The research material was the woody biomass as raw material obtained from three different geographical locations (Figure 1) in the Subcarpathian region (Poland) during the summer period from June to August 2024. The share of agricultural crop species is dominated by Scots pine 34%, English oak 29%, European beech 12% and silver fir 9%, as well as Norway maple, sycamore maple, small-leaved linden, hornbeam, English elm, European spruce, European larch, black alder. Species such as single-stemmed hawthorn, common rowan, euonymus and sea buckthorn are also found. In this study, 14 wood chip samples were collected from each location (marked as Samples in Figure 1). The samples were freshly cut, i.e. they were not stored for a long time. The following was not taken into account:

- the type and age of wood;
- the purity of the collected sample, i.e. the presence of branches, needles, cones, leaves and other elements of natural forest biomass in the wood chips samples was not excluded;
- the comparison of the heterogeneity of wood chips as an energy raw material is based only on the thermal conductivity index, as the main criterion for the use of raw materials for energy purposes.

The collected wood chip samples were subjected to laboratory testing to determine the physical and energy parameters of wood

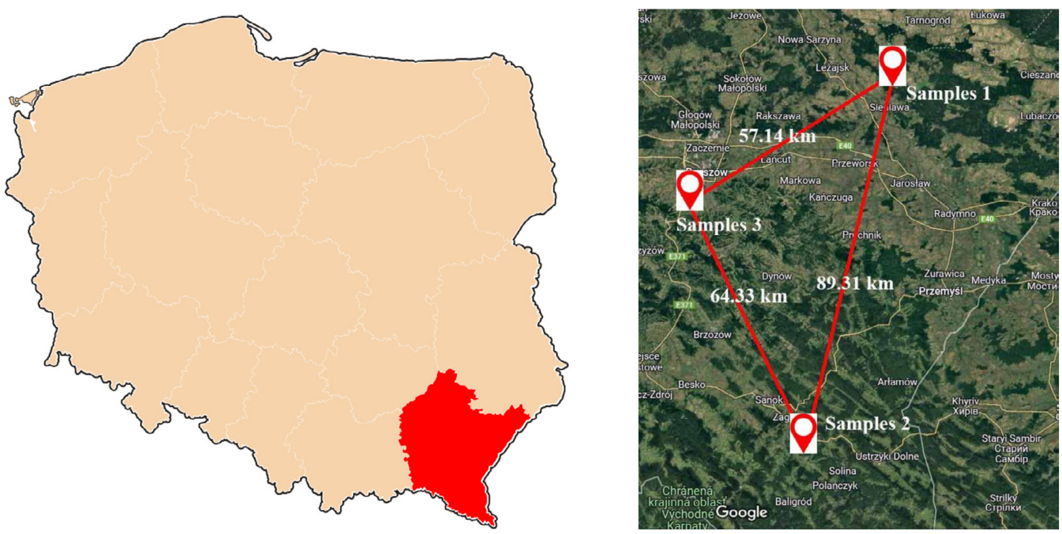

Figure 1. The Subcarpathian region (Poland) and sampling locations for testing: Samples 1 (50º 14’ 54.719” N, 22º 37’ 49.773” E); Samples 2 (49º 27’ 35.422” N, 22º 18’ 59.207” E); and Samples 3 (49º 58’ 49.91” N, 21º 57’ 3.097” E)

biomass. The study was conducted in accordance with the standards for this type of energy raw material in force in Poland. Such parameters as moisture, ash (underburnt) were determined, and finally the calorific value was determined as well.

A methods of statistical analysis was used, to identify significant differences in quantitative indicators of wood biomass quality are a sign for a more in-depth study of the characteristics of the biomass production region, such as soil quality, climate, etc., and the type of biomass for an effective approach to the procurement of energy raw materials. The results obtained are the basis for the development of sustainable green energy based on wood biomass.

Experimantal methods

External humidity

Samples were collected from three locations on the same day. In total, there were 14 sampling trips at approximately equal time intervals from June to August 2024. The average sample weight was 2.5–3 kg. Each sample was placed in a metal container in two repetitions (for one sample) and initially these containers were weighed on a laboratory scale (Figure 2a). To determine the external humidity (W_{ex}), the samples were kept in a room at a constant temperature of 21–22 °C until the weight of the sample became constant. After this, the indicator was calculated using the formula:

$$W_{ex} = \frac{m_{s+k} - m_{stable}}{m_{s+k} - m_k}, \tag{1}$$

where: m_k – empty container mass; m_{s+k} – the mass of a container filled with wood chips; m_{stable} – the mass of a container filled with wood chips after reaching a stable value.

The final value of was taken as the average of three repetitions for the same sample.

Hygroscopic humidity

After reaching a stable sample mass, the thermogravimetric method was used to determine the moisture content of the air-dried sample (W_h) and the mass loss on drying was calculated using the formula:

$$W_h = \frac{m_{stable} - m_{dry}}{m_{stable} - m_k}, \tag{2}$$

where: m_{dry} – mass of dried sample.

Analytical humidity content

The samples that reached a stable mass at a constant temperature were crushed and placed in a glass container in an amount of 1 g (Figure 2b). The container was placed in a drying oven for 1 hour, after which the analytical moisture content of the sample (W_a) was determined as the ratio of the difference between the initial mass and the mass after drying.

Total humidity

Total humidity (W_t) depends on external and hygroscopic humidity and is determined by calculation using the formula:

$$W_t = W_{ex} + W_h \frac{100 - W_{ex}}{100}. \tag{3}$$

Ash residue

The determination of the ash residue (A_a) was determined by ashing the sample in a muffle furnace and calcining the ash residue at a temperature of 800–830 °C (Figure 2c). After this, the samples were cooled at room temperature and weighed.

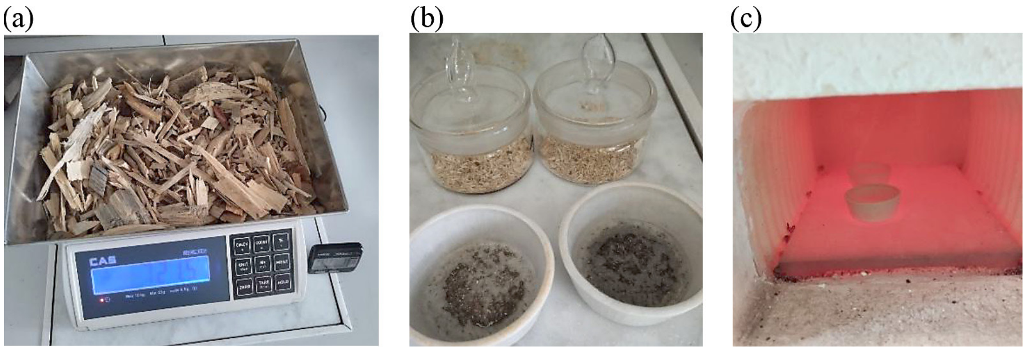

Figure 2. Sample preparation for analysis: (a) raw biomass, (b) crushed biomass in a glass containers, (c) heating in the oven

Calorific value

To determine the calorific value (analytical,), a calorimetric method was used (Figure 3), after which a special system recalculated the calorific value in working condition, taking into account the obtained analytical indicators of humidity and ash content of the samples.

Methods of statistical analysis

For the statistical analysis of the data experimentaly obtained, the Statistica 7 program was used, which is universal and freely available. The study was then conducted in five stages:
- Stage 1. Using the sampling coefficients of asymmetry and kurtosis, we checked the sample data for their normality.
- Stage 2. Box-plots and histograms analysis was made, with Kolmogorov-Smirnov test, Lilliefors test, Shapiro-Wilk test.
- Stage 3. The equality of variances was tested using the Cochran and Bartlett tests.
- Stage 4. The ANOVA test was used to check the equality of means.
- Stage 5. T-Student's test was applied for pairwise comparison of means between individual samples.

The statistical tests presented above were performed upon the calculations based on the following equations.
- Adjusted estimate of the Skewness coefficient:

$$Skewness = \frac{n^2}{(n-1)(n-2)} \cdot \frac{m_3}{s^3} = \frac{n^2}{(n-1)(n-2)} \cdot \frac{\frac{1}{n}\Sigma(x_i-\bar{x})^3}{\left(\frac{1}{n-1}\Sigma(x_i-\bar{x})^2\right)^{3/2}}, \quad (4)$$

where: $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$ – average value;

$s = \sqrt{\frac{\sum_{i=1}^{n}(x-\bar{x})^2}{n-1}}$ – the sample standard deviation;

m_3 – the third central moment, which is the average of the cubed differences from the mean; n – the total number of data points in the individual sample.

- Standard error (SE) Skewness:

$$SE_{Skewness} = \sqrt{\frac{6n(n-1)}{(n-2)(n+1)(n+3)}}, \quad (5)$$

- Adjusted estimate of the Kurtosis coefficient:

$$Kurtosis = \frac{n(n+1)}{(n-1)(n-2)(n-3)} \cdot \frac{\sum n_i(x_i-\bar{x})^4}{s^4} - \frac{3(n-1)^2}{(n-2)(n-3)}. \quad (6)$$

- Standard error Kurtosis:

$$SE_{Kurtosis} = SE_{Skewness} \cdot \sqrt{\frac{4(n^2-1)}{(n-3)(n+5)}}, \quad (7)$$

- Cochran test

$$C = \frac{S_{max}^2}{S_1^2+S_2^2+S_3^2} \quad (8)$$

- Bartlett's test

$$T = \frac{(N-l)\cdot ln\left(\frac{1}{N-l}\cdot\sum_{i=1}^{l} k_i S_i^2\right)-\left[\sum_{i=1}^{l} k_i\, ln(S_i^2)\right]}{1+\frac{1}{3(l-1)}\left[\sum_{i=1}^{l}\frac{1}{k_i}-\frac{1}{N-k}\right]} \quad (9)$$

$$N = \sum_{i=1}^{l} n_i;\ k_i = n_i - 1\ ;\ k = \sum_{i=1}^{l} k_i;,$$

$$S_i^2 = \frac{1}{n_i-1}\sum_{j=1}^{n_i}\left(x_j-\bar{x}\right)^2 ;\ j=\overline{1,n_i};\ i=\overline{1,l}.$$

where: N – total sample size; l – number of samples; k – number of groups, k_i – sample size of the i-th group; S_i^2 – variance of the i-th sample; n_i – number of observations in the i-th sample.

- The Student's t-test:

$$T_{1,2} = \frac{|\bar{x}_1-\bar{x}_2|}{\sqrt{S_1^2+S_2^2}}\sqrt{n} \quad (10)$$

Figure 3. A calorimetric method for calorific value determination

RESULTS AND DISCUSSION

Experimental results

The results of moisture content, humidity, and calorific value of samples tested were presented in Table 1. In the Subcarpathian forests the proportions of coniferous (50.2%) and deciduous (49.8%) species in the stands are almost equal (https://strzyzow.krosno.lasy.gov.pl/zasoby-lesne/-/asset_publisher/x9eK/content/ porownaj-las-na-fotografiach). The predominant species are Scots pine 34%, English oak 29%, European beech 12% and silver fir 9%, as well as other species. It is possible that there are regional differences in the predominance of one or another tree type, but this was not investigated in the current work.

Previous studies have found that the calorific value of forest biomass primarily depends on the type of tree and the moisture content of the wood (Piętka et al., 2019). Humidity has a significant impact on the efficiency of energy devices using this fuel. The lowest level of dust and carbon monoxide emissions is provided by wood with a humidity of about 15%. High wood humidity can reduce the efficiency of the furnace to 30–50%(https://www.eko-palnik.com/aktualno%C5%9Bci/drewno-jako-odnawialne-%C5%BAr%C3%B3d%C5%82o-energii).

The moisture of biomass, which is stored in the spaces inside dead cells and cell walls (Demirbas, 2007; Montes et al., 2011), usually reduces the calorific value of the material. Freshly cut wood usually has a moisture content of about 45–55% by weight. It should be noted that Samples 2 had an average moisture content of 48.14%, unlike the other two samples, Samples 1 – 34.68% and Samples 3 – 35.46%. As can be seen, the mathematical analysis showed that the average comparison of the average thermal conductivity values for Samples 1 and Samples 3 samples gives no significant differences; at the same time, significant differences were found in Samples 2 in relation to Samples 1 and Samples 3.

Important factor affecting the amount of energy per unit volume is the density of wood (Piętka et al., 2019). The gross calorific value of wood does not vary much among tree species (18.7–21.9 MJ kg^{-1}), but is slightly higher in conifers than in deciduous trees (Huhtinen, 2005). The variation in this parameter is directly related to structural differences at the molecular, cellular and tissue levels.

Table 1. Results of an experimental study of the phisical parameters of wood biomass samples

Parameter (unit)	Sample collection number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Samples 1														
W_{ex} (%)	36.47	28.95	29.32	29.59	29.79	27.91	32.97	27.24	28.40	31.10	25.37	22.15	21.04	24.39
W_h (%)	8.37	7.54	6.64	8.0	7.44	8.78	7.99	10.06	7.30	8.10	9.23	8.49	9.86	8.12
W_a (%)	9.10	7.78	8.58	9.630	8.59	9.30	9.25	9.37	9.53	9.14	9.77	10.83	11.41	9.54
W_t (%)	41.79	34.31	34.01	35.24	35.01	34.24	38.37	34.56	33.67	38.03	32.26	28.76	28.83	30.53
A_a (%)	0.88	0.80	1.02	0.87	0.82	0.75	1.28	0.79	0.80	0.73	0.90	0.40	1.88	0.78
Q_a (J/g)	9880	10120	10450	10653	10797	10884	11102	11017	11031	11108	11408	11567	11811	12320
Samples 2														
W_{ex} (%)	50.17	46.40	46.90	48.25	42.65	44.69	51.03	45.00	46.30	47.00	46.29	49.53	45.07	46.29
W_h (%)	10.27	7.64	7.58	8.17	8.82	10.04	8.28	9.15	8.90	7.44	9.01	8.16	12.34	8.39
W_a (%)	10.90	7.84	8.99	9.10	7.42	10.98	9.55	10.27	9.18	9.72	8.82	9.25	13.77	9.79
W_t (%)	55.29	50.46	50.96	52.48	47.71	50.24	55.06	50.03	52.08	50.94	51.29	56.00	51.85	50.80
A_a (%)	0.65	0.40	0.44	0.50	0.23	0.55	0.39	0.76	0.42	0.57	0.30	0.42	0.32	0.45
Q_a (J/g)	6869	7011	7035	7422	7509	7612	7682	7794	7957	8096	8328	8511	8445	8832
Samples 3														
W_{ex} (%)	29.87	30.82	38.08	32.29	24.53	28.13	26.85	25.97	29.51	26.00	32.30	27.13	27.52	33.51
W_h (%)	9.69	8.27	10.04	8.79	8.08	7.83	7.81	8.65	9.71	7.17	7.40	7.94	10.20	7.55
W_a (%)	10.72	10.06	9.67	10.20	9.89	10.66	9.45	9.63	9.49	9.14	8.85	10.88	9.78	9.38
W_t (%)	36.67	36.54	44.30	38.24	30.63	33.76	32.56	32.37	36.36	31.36	37.31	32.92	34.91	38.53
A_a (%)	0.63	0.58	0.64	0.42	0.30	1.57	1.27	0.77	0.65	1.67	0.72	1.46	1.07	0.98
Q_a (J/g)	9452	9787	9889	9947	10013	10141	10235	10486	10745	10840	10995	11219	11402	11855

Note: W_{ex} – external humidity, W_h – hygroscopic humidity, W_a – analytical humidity, W_t – total humidity, A_a – ash residue, Q_a – calorific value.

It varies among tree species, age groups, tree parts and tree heights, and is also affected by environmental determinants. Beech wood is characterized by a relatively high density, ranging from 653 to 807 kg m^{-3}. Generally, the density increases with moisture content, reaching 711 kg m^{-3} at 11.9% by weight (Piętka et al., 2019). Previous studies (Montes et al., 2011) found significant variations in calorific value and physical properties among 45 tree species in India, as well as differences between tissue types within the trees. In contrast, no significant differences in calorific value were found among the three eucalyptus species grown in Ethiopia and assessed at the same age; and the calorific value did not differ significantly. It is obvious that more research is needed on the thermal conductivity of different wood species for sustainable forest management to ensure efficient and sustainable green energy. Since this factor was not studied in the current study, it may be a target for future studies.

In energy production, the most important parameter of wood biomass is its chemical composition (Montes et al., 2011). Wood consists of a variable mixture of cellulose, hemicellulose, lignin and other compounds. Its energy properties differ not only between species, but also depend on the forest site and atmospheric conditions, harvest time, degree of decay and many other factors (Montes et al., 2011). However, this factor was not studied in this study, although it is important for ensuring storage conditions for wood raw materials if harvesting is carried out in the summer and long-term storage is required during the heating season. It should also be noted that obtaining biomass in the form of wood chips is three times less energy-intensive than obtaining bales. When burning energy chips in a CHP unit, more than 10 times more energy is generated than is required to obtain and transport biomass in the form of bales, and more than 30 times more than is required to obtain and transport biomass in the form of wood chips (Golos & Kaliszewski, 2015).

Results of statistical analysis

Results from the descriptive statistics of three samples site were obtained and showed in Table 2. Using the coefficients of asymmetry and kurtosis, we presented the hypotheses for normality of sample data:

- Null hypothesis H_0: The sample comes from a normally distributed population (the skewness coefficient equals zero).
- Alternative hypothesis H_1: The sample does not come from a normally distributed population (the skewness coefficient differs from zero).

The results of analysis were presented in Table 3. Results of standard error Skewness shows that for all three samples, the |Z| value is significantly less than 1.96, so there is no reason to reject the null hypothesis

Table 2. Descriptive statistics

Indicator	Samples 1	Samples 2	Samples 3
Valid N	14	14	14
Sample mean ($\bar{x}$)	11010.57	7793.07	10500.43
Sample median	11024	7738	10360.5
Minimum	9880	6869	9452
Maximum	12320	8832	11855
Sample variance (S^2)	416630.88	363717.15	485347.03
Sample standard deviation (S)	645.47	603.09	696.67
Standard error of mean	172.51	161.18	186.19
Lower quartile	10653	7422	9947
Upper quartile	11408	8328	10995

Table 3. Testing the asymmetry coefficient

Indicator	Samples 1	Samples 2	Samples 3
Adjusted skewness	0.2035	0.0693	0.4431
Standard error (SE) skewness	0.5974	0.5974	0.5974
$\lvert z_{Skewness}\rvert = \lvert Skewness / SE_{Skewness}\rvert$	$\lvert z\rvert = 0.3406$ <1.96	$\lvert z\rvert = 0.0549$ <1.96	$\lvert z\rvert = 0.7384$ <1.96

for all three samples. So we conluded, that the sample skewness coefficientes for three samples all are not statistically significant, and all three samples may be normally distributed (Table 4).

To estimate of the Kurtosis coefficient the next two hypothesis were stated:

- Null hypothesis H_0: The sample comes from a normally distributed population (the kurtosis coefficient equals zero).
- Alternative hypothesis H_1: The sample does not come from a normally distributed population (the kurtosis coefficient differs from zero).

Analysis shows, that the Z-tests for all three samples are significantly less than 1.96, so there is no reason to reject the null hypothesis for all three samples. Based on the provided data, the Kurtosis coefficient for all three samples was not

Table 4. Testing the Kurtosis coefficient

Indicator	Samples 1	Samples 2	Samples 3
Adjusted Skewness	0.2845	-0.9153	-0.6460
Standard error Skewness	1.1540	1.1540	1.1540
$\lvert z_{Skewness}\rvert = \lvert Skewness / SE_{Skewness}\rvert$	$\lvert z\rvert = 0.2465$ <1.96	$\lvert z\rvert = 0.7931$ <1.96	$\lvert z\rvert = 0.5598$ <1.96

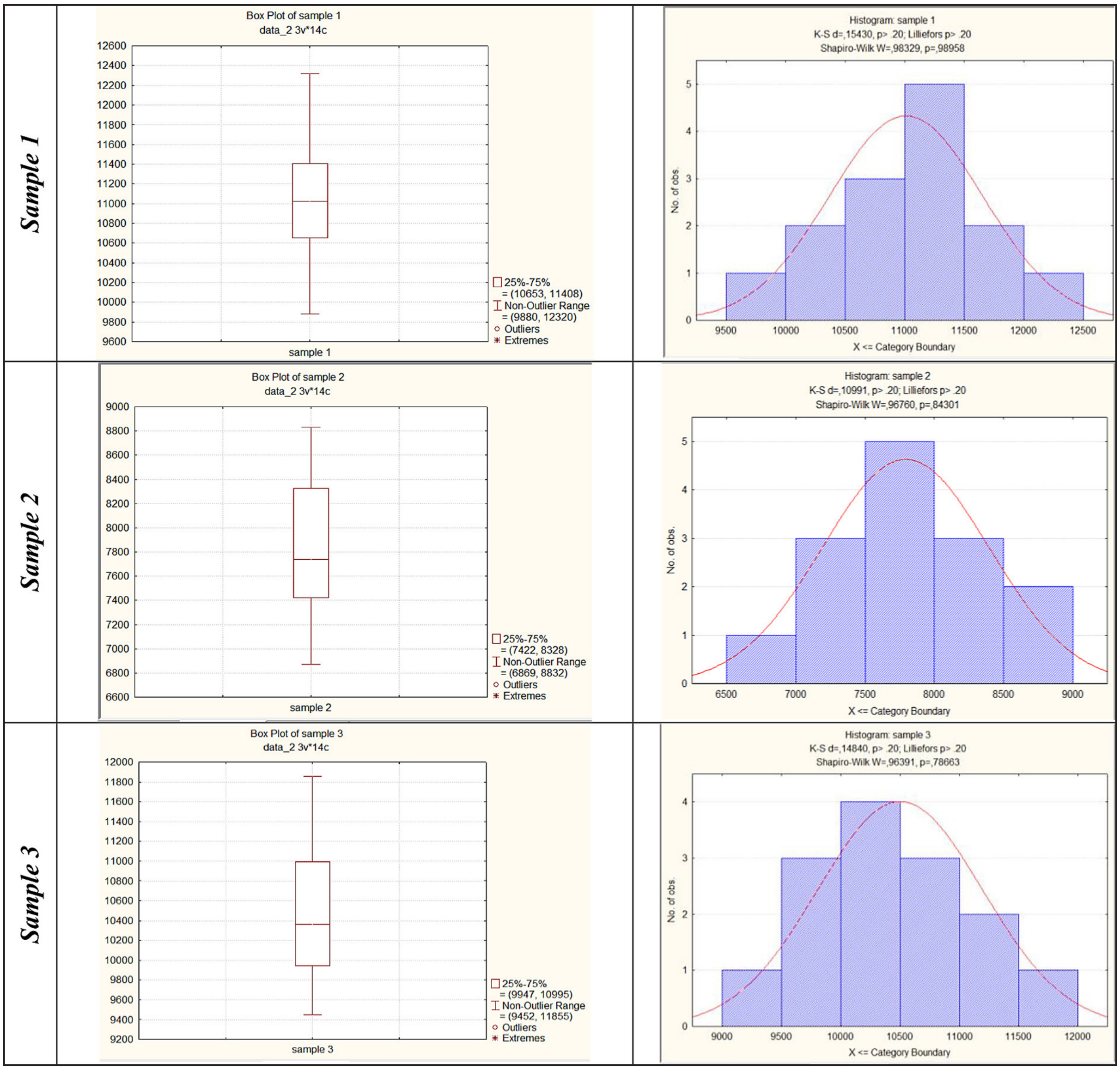

Figure 4. Box plots and histograms for the three study samples

statistically significant, and therefore the all three samples can be considered normally distributed.

Results of box-plots and histograms analysis with Kolmogorov-Smirnov test, Lilliefors test, Shapiro-Wilk test were shown in Figure 4. Based on these results the fairly good symmetry about the median, consistent with a normal distribution shown. The type of histogram also indicates a normal distribution.

For analysis of Kolmogorov-Smirnov test, Lilliefors test, and Shapiro-Wilk test two hypothesis formulated, as following:
- Null hypothesis H_0: The sample data are drawn from a normally distributed population.
- Alternative hypothesis H_1: The sample data are not drawn from a normally distributed population.

For all trials, there was no reason to reject the null hypothesis of normal distribution, as results shows in Table 5. The next hypotheses were formulated for analyzing the equality of variances using the Cochran and Bartlett tests:
- Null hypothesis H_0: The variances are equal.
- Alternative hypothesis H_1: The variances are not equal.

According of the Cochran test for a statistical significance level of $\alpha = 0.05$ for three samples of 14 observations each, we have got the value $C_{critical} = 0.5698$. Because $C < C_{critical}$ then was no reason to reject the null hypothesis of the variances are equal.

The result of Bartlett's test was obtained value of 0.262. For a significance level of $\alpha = 0.05$ with 2 degrees of freedom result obtained ≈ 5.991. Bacause the test statistic value of 0.262 was less than the critical value of 5.991, there is no reason to reject the null hypothesis. This indicates that the variances of the three samples can be considered equal. Then, the ANOVA test used for the distributions analysing with equal variances (Table 6, 7), and the hypotheses stated:
- Null hypothesis H_0: The means of all groups are equal.
- Alternative hypothesis H_1: At least one group mean is different from the others.

Results from the Table 7 showed that the F-statistic is approximately 99.231, which is significantly greater than the F-critical value of 3.238, and the p-value is $5.03 \cdot 10^{-16}$, which is much smaller than the typical significance level of 0.05, so we reject the null hypothesis. This indicates that there are significant differences between the groups.

At the last, the Student's t-test for pairwise comparison of means between samples permormed withresults showed in Table 8. The results of Student's t-test for Samples 1 and Samples 2 ≈ 13.63, for Samples 1 and Samples 3 ≈ 2.01, and for Samples 2 and Samples 3 ≈ 10.99. The critical value for a two-tailed test at a significance level of 0.05 with 26 degrees of freedom obtained ≈ 2.06. Comparison was made of the

Table 5. Testing the hypothesis of normal distribution

Test	Samples 1	Samples 2	Samples 3
Kolmogorov-Smirnov test	d = 0.154, p > 0.20	d = 0.110, p > 0.20	d = 0.148, p > 0.20
Lilliefors test	p > 0.20	p > 0.20	p > 0.20
Shapiro-Wilk test	W = 0.983, p = 0.987	W = 0.968, p = 0.843	W = 0.964, p = 0.787
Conclusion for sample	all p-value more then 0.05	all p-value more then 0.05	all p-value more then 0.05

Table 6. Data for the ANOVA test

Groups	Count	Sum	Average	Variance
Samples 1	14	154148	11010.57	416630.88
Samples 2	14	109103	7793.07	363717.15
Samples 3	14	147006	10500.43	485347.03

Table 7. ANOVA test results

Source of variance	SS	df	MS	F	P-value	Fcrit
Between groups	83730895.19	2	41865448	99.2311	5.0311E-16	3.2381
Within groups	16454035.79	39	421898.40			
Total	100184931	41				

Table 8. The data for Student's t-test

Indicator	Samples 1	Samples 2	Samples 3
Valid N	14	14	14
Sample mean ($\bar{x}$)	11010.57	7793.07	10500.43
Sample variance (S^2)	416630.88	363717.15	485347.03

observed value of the Student's t-test with the critical value, and obtained:

- Samples 1 and Samples 2: $T_{1,2} > T_{critical}$ – since the calculated t-statistic (13.63) is greater than the critical value (2.06) the null hypothesis of equality of means should be rejected. Therefore there is a significant difference between the means of the two Samples.
- Samples 1 and Samples 3: $T_{1,3} < T_{critical}$ – since the calculated t-statistic (2.01) is less than the critical value (2.06) then no reason to reject the null hypothesis of equality of means. Therefore there is no significant difference between the means of the two Samples.
- Samples 2 and Samples 3: $T_{2,3} < T_{critical}$ – since the calculated t-statistic (10.99) is greater than the critical value (2.06) the null hypothesis of equality of means should be rejected. Therefore here is a significant difference between the means of the two Samples.

CONCLUSIONS

The study revealed that all items of Samples 2 of woody biomass had total humidity significantly higher than samples taken from the other two locations, although sampling was carried out on the same day and under the same climatic conditions. The moisture content noted in the range of 47.708–65.002%, as opposed to 28.759–41.787% (for Samples 1) and 31.360–44.297% (for Samples 3). Woody biomass humidity was stated as a significant influencing factor that reduces the calorific value. Thus, Samples 2 had the lowest calorific value of 6869–5709 J/g as opposed to 9880–11811 J/g (for Samples 1) and 9889–10840 J/g (for Samples 3), which makes this material less efficient used for alternatively fuel production.

From the statistical analysis, the results revealed a normal distribution of the calorific values for each sample of wood chips. A pairwise comparison of the means between all samples using the Student's t-test revealed significant differences for Samples 2, in opposite to Samples 1 and Samples 3. It would be worthwhile to study, what factors influenced the high moisture content in wood biomass from the Samples 2.

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