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Research Article

Management of Waste Wood in the Energy and Fertilizer Industries. Case Study of Poland

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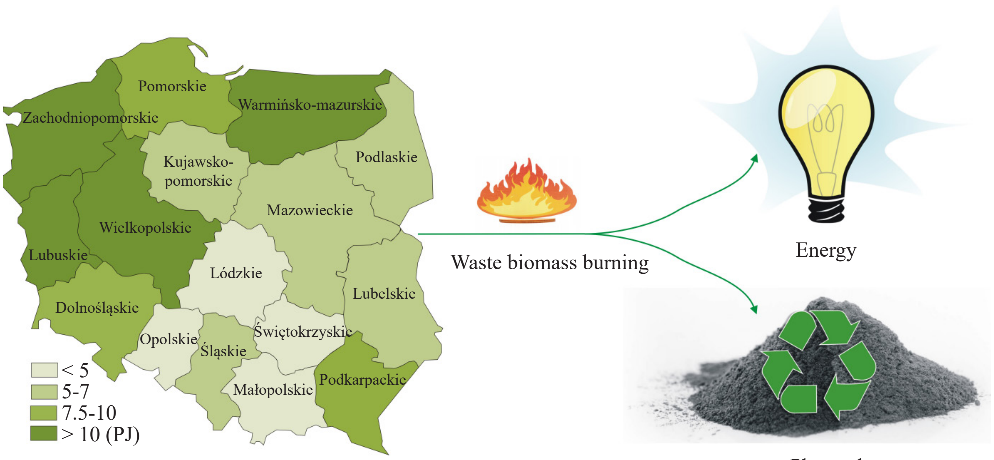
Abstract: The energy transition requires the provision of stable energy production, which can be ensured by the production of energy from waste biomass. Physicochemical analysis was carried out and the heat of combustion was determined for 11 different tree species. The moisture content of the biomass was within wide limits: from 9.41% for elderberry to 43.92% for sweet cherries. In turn, the ash content ranged from 0.77% for pine to 3.58% for elderberry. The lowest heat of combustion was found for oak biomass: 18.82 MJ/kg, and the highest for pine: 21.23 MJ/kg. A fertilizer called phytoash obtained from biomass combustion contains large amounts of fertilizing calcium and magnesium and has an alkaline reaction. Phytoash can be used as fertilizer in the fertilizer industry on acidic soils in Poland. The largest amounts of calcium and magnesium for fertilizer purposes can be used in the Zachodniopomorskie Voivodeship (2,023 Mg/year and 2.86 Mg/year), the Warmińsko-Mazurskie Voivodeship (1,625 Mg/year and 2.30 Mg/year), and the Wielkopolskie Voivodeship (1,612 Mg/year and 2.29 Mg/year) and Lubuskie Voivodeship (1,609 Mg/year and 2.28 Mg/year). Calculations indicate a fairly large energy potential from waste biomass, which allows its use in the energy mix or industry, e.g. food, in Poland. The calculated amount of electricity from waste biomass would cover Poland's needs by 6% and heat by 20%.

Graphical abstract:



DOI:

Keywords**:** biomass, phytoash, fertilizer industry, food industry, renewable energy, Poland

1. Introduction

We are currently facing an energy crisis and excessive population growth, which leads to the need to use renewable energy sources (RES) instead of conventional methods using limited raw materials such as natural gas, hard coal or crude oil (Grataloup et al., 2024; Igliński et al., 2022). RES include solar, wind and tidal energy, but this category also includes energy from burning plant biomass, which has an almost zero carbon footprint due to the fact that it produces organic substances using carbon dioxide from the air and emits it as a result of combustion (Grataloup et al., 2024).

One o type of RES is biomass-it is the third largest natural source of energy in the world (Paraschiv & Paraschiv, 2023). According to the definition specified in European Union regulations, biomass includes fractions of products susceptible to biological decomposition, waste and residues of the agricultural industry (including plant and animal substances), forestry and related industries, as well as fractions of industrial and municipal waste susceptible to biological decomposition (European Commission, 2014). Biomass means the biodegradable fraction of products, waste and residues of biological origin from agriculture (including plant and animal matter), forestry and related industries, including fishing and aquaculture, as well as the biodegradable fraction of industrial and municipal waste (Bays et al., 2024; Nguea & Fotio, 2024).

Progressing climate change means that Poland is increasingly hit by strong winds, which not only cause material losses and threats to health and life, but also contribute to the creation of large amounts of waste biomass, especially in the case of trees (Igliński et al., 2011; Smaliychuk et al., 2023). The uprooted tree, commonly called a windfall, cannot be used for construction purposes due to numerous structural damages, although it can still be used in the energy industry (Igliński et al., 2014). Significant amounts of waste biomass are also produced during tree felling and maintenance work. Biomass has long been used to some extent in Poland for energy purposes, primarily for heating. For example, Janowicz (2006) determined the potential of forest and agrarian biomass on approximately 755 PJ/year. In the study Igliński (2018) calculated that in Poland the potential of waste wood is 101.7 PJ/year, and straw-92.1 PJ/year.

Ash from biomass combustion contains large amounts of calcium and magnesium and trace amounts of heavy metals, which is why it is called biofertilizer (phytofertilizer) and used in the fertilizer industry (Capela et al., 2022). The management of phytoashes is part of the sustainable production of energy and natural fertilizers, which has a positive impact on the environment (Zhai et al., 2021). The results of research on the impact of biomass ashes on the physicochemical properties of soils indicate that their effect is comparable to that of mineral fertilizers (Meller & Bilenda, 2012). Moreover, the ingredients in phytoash are present in proportions appropriate to the soil. Therefore, they are safe, easily digestible and non-toxic. The porous structure of biofertilizer absorbs various (harmful substances, hence it is a strong detoxifying agent (Augusto et al., 2022).

Additionally, phytoashes have a high neutralization potential, so they can be treated as a substitute for fertilizer lime in the fertilizer industry, especially in recultivation applications (Nunes et al., 2016). This line of research is not yet well documented. The standard dose of wood bio-ash used as calcium fertilizer is 30-50 g per 1 m^2. This treatment contributes to improving plant yields and enriching the soil with humus (Lundström et al., 2003). In gardens and allotments, you can use phytoash mixed with powdered tree bark. It then provides very good protection for plants against frost. You can cover plants or their more sensitive parts with this mixture for the winter (Olatoyan et al., 2023).

The aim of the research was to determine the chemical composition, heat of combustion and fertilizing properties of waste biomass, which allowed for:

1) determining the suitability of biomass in terms of its use for energy purposes,
2) comparative analysis of biofertilizer and biomass of various plant species,
3) calculation of the available mass of Ca and Mg from phytoash in Poland,
4) calculation of the energy potential obtained from waste biomass in Poland.

In the available literature, the approach to waste biomass and phytoash in Poland is laconic. The authors decided to fill this literature gap. Contrary to appearances, the potential of waste biomass and phytoash is large and worth using in the energy, heating and fertilizer industries. Therefore, the authors selected the most common trees in Poland for the study, and for the analysis of phytoash they chose instrumental analysis methods: Scanning Electron Microscopy/Energy

Dispersive X-ray (SEM/EDX) and X-Ray Fluorescence (XRF).

2. Characterization and preparation of waste biomass for analysis

For each study, waste tree biomass provided by the heating plant in Pisz and the Lębork CHP plant (Poland) was used in the autumn and winter, without leaves or needles (Table 1).

Table 1. Biological characteristics of the tested biomass

No.	Species	Comments
1.	European ash (*Fraxinus excelsior*) (Urbanowski et al., 2022).	A fast-growing species and often planted along roadsides.
2.	Sweet cherry (*Prunus avium var. Kordia*) (Blanco et al., 2021).	It grows naturally in Poland on the Oder River, in the entire southern part and in the Pomeranian Voivodeship.
3.	Northern white-cedar (*Thuja occidentalis*) (Arteau et al., 2020).	A plant growing mainly in gardens, parks or cemeteries.
4.	Silver birch (*Betula pendula*) (Färkkilä et al., 2023).	Often used in Poland for fuel and for the production of charcoal.
5.	Elder (*Sambucus nigra*) (Ferreira et al., 2022).	It occurs in Poland in lowlands and up to an altitude of 1,100 m above sea level in mountain areas.
6.	Baltic pine (*Pinus sylvestris*) (Erdem & Bayrak, 2023).	The most common tree in Poland.
7.	Purple plum (*Prunus domestica subsp. oeconomica*) (Szymajda et al., 2023).	In Poland, the best areas for growing plums are in the Podkarpackie region and in the valleys of larger rivers.
8.	Black poplar (*Populus nigra*) (Tebbi et al., 2022) or White poplar (*Populus alba*) (Hematabadi et al., 2020).	The tree has not yet reached the age where the bark could change from light gray and smooth to blackish and longitudinally furrowed.
9.	English oak (*Quercus robur*) (Vospernik et al., 2024).	Due to the sampling from a younger tree, the bark was smooth and grey-brown.
10.	Common pear (*Pyrus communis*) (Bhagat et al., 2024).	The most popular variety in amateur cultivation, as well as the most common variety ripening in summer in commercial cultivation.
11.	Apple tree (*Transparente de Croncels*) (Ladon et al., 2024).	The tree is characterized by strong growth and large, spherical and highly dense crowns.

For each analysis, the samples were chopped with pruners into 1-2.5 mm pieces (depending on the thickness of the branch). The biomass was dried at 105 °C for 2 hours. After initial roasting in crucibles, the biomass samples were transferred to an oven at 1,000 °C for 2 hours.

Before determining the heat of combustion, the biomass was ground into dust in a ball mill. The calorific value test was carried out in a KL-12 calorimeter with an isothermal jacket (Trombley et al., 2023).

In order to examine the percentage of elements contained in the ash samples remaining after roasting, two different methods were used: scanning electron microscopy using an X-ray spectrometer (SEM-EDX) (Wang et al., 2008) LEO Electron Microscopy Ltd., model 1430 VP and a Quantax 200 X-ray fluorescence (XRF) spectrometer with an XFlash detector 4010 by Bruker AXS (Tavares et al., 2023). An example SEM photo of a plum ash sample is shown in Figure 1 (the rest of the photos were very similar).

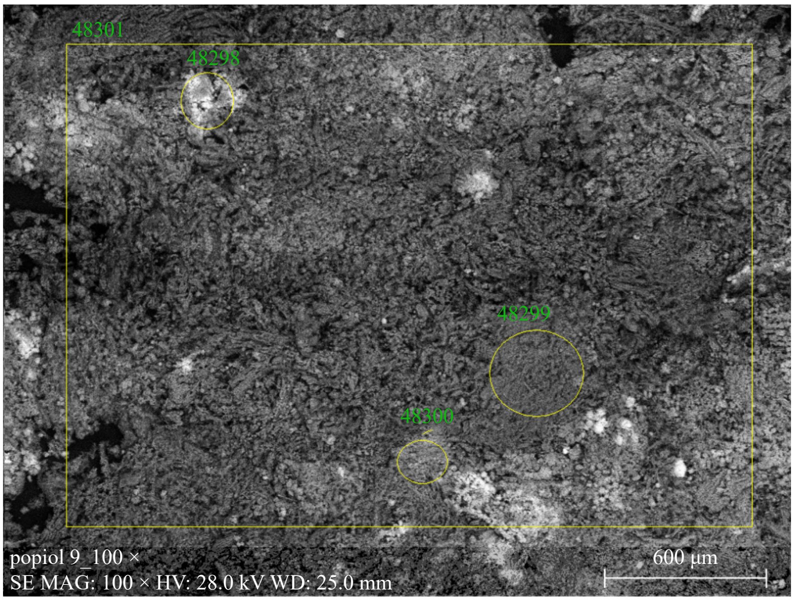


Figure 1. SEM image of a plum ash sample as an example

3. Results

The moisture content (%) of the analyzed biomass is shown in Figure 2. It is within quite wide limits: from 9.41% for elderberry to 43.92% for sweet cherries. Different moisture values depend on the type of biomass, the date of its collection and the place and time of storage. Biomass cut long ago dries slowly in a well-ventilated place. The conclusion is that before burning/co-incineration of waste biomass, its moisture content should be checked.

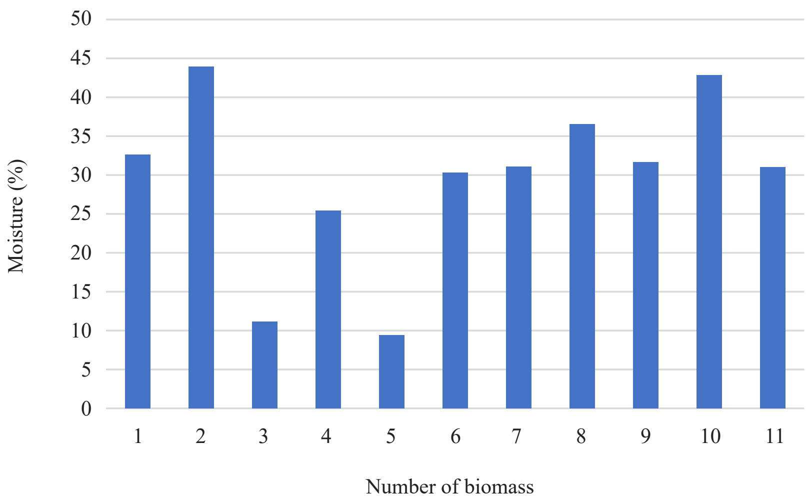


Figure 2. Moisture content (%) in biomass

The ash content (%) of the analyzed biomass is shown in Figure 3. On average it is 1.5%, with the lowest in the case of pine: 0.77% and the highest in the case of elderberry: 3.58%. The ash content depends on the type of biomass, the soil on which it grows, and the place where the biomass is stored after cutting. Pine grows on poor, sandy soils, low in minerals. In turn, elderberry grows on more organic soils, richer in minerals. In general, the ash content in the tested samples is higher than in wood samples taken directly from the tree (Zhao et al., 2022). Ash content was determined in biomass without drying, so sample no. 5 with the lowest moisture content has the highest ash content. The tested biomass was lying on the ground, so it could have become dirty, which resulted in an increase in the ash content. Therefore, it is concluded that the place of storage/drying of biomass is important-concrete surfaces are better than soil/sand, which may cause the biomass to get dirty.

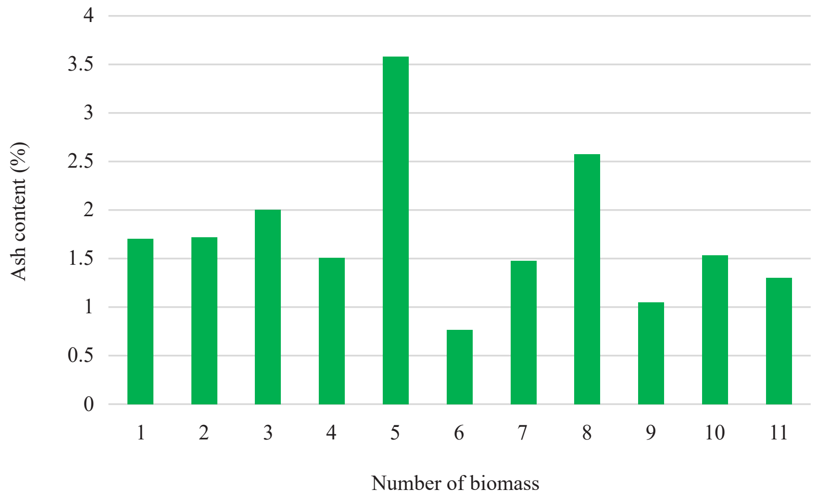


Figure 3. Ash content (%) in biomass

The heat of combustion (MJ/kg) of the analyzed biomass is shown in Figure 4. The lowest heat of combustion was found for oak biomass: 18.82 MJ/kg, and the highest for pine: 21.23 MJ/kg. The calorific value is influenced by the type of biomass and, above all, the chemical composition of wood. Pine contains relatively much resin and essential oils, which increase the heat of combustion.

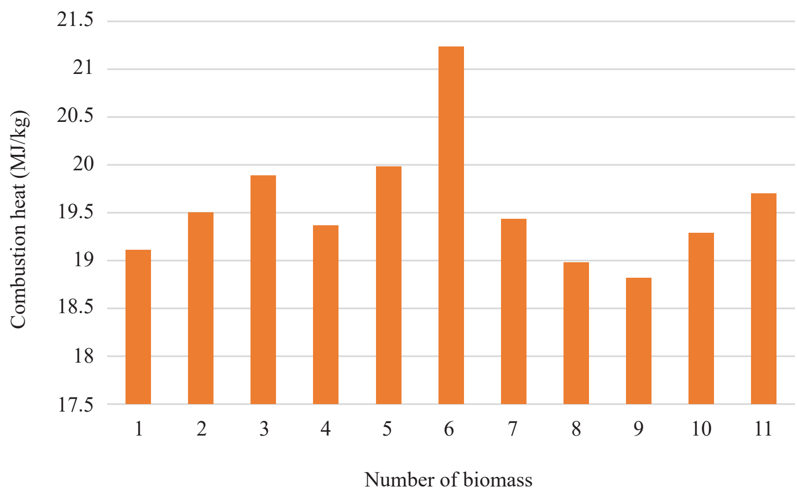


Figure 4. Heat of combustion (MJ/kg) of biomass

Fertilizer obtained from biomass combustion contains large amounts of calcium and magnesium (Table 2). The least calcium is found in pine, and the most in thuja. XRF analysis indicates higher calcium contents in the ash than EDX analysis. The least magnesium was found for birch, and the most for plum. XRF analysis indicates lower magnesium contents than EDX analysis.

When it comes to the analysis of heavy metals, the XRF method is more accurate than the EDX method. Very small contents of Hg and Pb were found: below the limit of detection (LOD).

Table 2. Content (%) of selected metals in biomass ash

No.	Species	Ca (%)		Mg (%)		Hg (%)		Pb (%)	
		EDX	XRF	EDX	XRF	EDX	XRF	EDX	XRF
1.	European ash	61.11	61.46	3.82	2.78	1.57	LOD	1.71	LOD
2.	Sweet cherry	50.94	80.76	5.41	1.82	1.29	LOD	1.64	LOD
3.	Northern white-cedar	64.03	89.32	4.19	1.00	1.51	LOD	2.02	LOD
4.	Silver birch	71.61	78.48	2.43	1.10	1.56	LOD	1.84	LOD
5.	Elder	72.44	76.29	7.75	3.29	1.52	LOD	2.00	LOD
6.	Baltic pine	43.58	80.80	4.08	1.30	1.26	LOD	1.65	LOD
7.	Purple plum	59.80	80.93	10.16	3.07	1.39	LOD	1.74	LOD
8.	Poplar	78.60	86.85	3.84	1.20	1.64	LOD	2.01	LOD
9.	English oak	59.90	70.82	4.05	1.77	1.39	LOD	1.72	LOD
10.	Common pear	49.50	81.19	5.04	2.32	1.33	LOD	1.66	LOD
11.	Apple tree	66.28	79.89	3.92	1.16	1.49	LOD	1.57	LOD

LOD: limit of detection

4. Technical potential of waste biomass in Poland

The purpose of the calculations was to estimate the amount of waste biomass that can be obtained for energy purposes in Poland. In this study, renewable waste biomass resources are treated as the amount of energy that can be obtained from biomass per year. The efficiency (S) of energy acquisition was assumed to be 80%. The most important source of data on forestry and agricultural production was the Central Statistical Office.

4.1 *Technical potential of energy from waste wood in Poland*

Forests in Poland consist mainly of coniferous trees (pine dominates)-87% and deciduous trees: 13%. Waste wood is produced during maintenance work, logging, in sawmills, in furniture factories, etc., and as post-consumer wood. It was assumed that total waste constitutes 50% of the amount of harvested wood in the forest (Central Statistical Office, 2023d). For the calculation of the energy potential, the heat of combustion of pine was assumed: 21.23 MJ/Mg (87% of biomass) and the average heat of combustion of ash, thuja, birch, poplar and oak: 19.36 MJ/Mg (13% of biomass); on average, forest biomass has a heat of combustion of 20.99 MJ/Mg. Wood will be burned in high-efficiency cogeneration: electricity will be produced with an efficiency of 30% and heat with an efficiency of 50%, which gives a total efficiency of E = 80%.

Figure 5 shows the amount of energy that can be obtained annually from waste wood generated during forest clearing and wood processing in the wood industry in Poland, divided into individual voivodeships.

Figure 5. Distribution of the amount of energy that can be obtained annually from waste forest wood in Poland (PJ)

The calculated amount of energy that can be obtained annually from waste wood from forests in Poland is 117.1 PJ/year, with the greatest potential in the voivodeships with the highest forest cover: Zachodniopomorskie Voivodeship (13.2 PJ/year), Warmińsko-Mazurskie Voivodeship (10.6 PJ/year), Lubuskie Voivodeship (10.5 PJ/year) and Wielkopolskie Voivodeship (10.4 PJ/year).

In the study (Igliński et al., 2018) the calculated potential is lower, which results from a different calculation methodology, as well as from other data from the Central Statistical Office (earlier years).

4.2 *Technical potential of energy from waste wood from orchards in Poland*

According to the Central Statistical Office (2023b), 72.5% of the orchard area in Poland is covered by apple trees, 6.8% by plum trees, 4.8% by sweet cherries, 2.4% by pear trees, 13.6% by other fruit trees. The average calorific value of fruit tree biomass was calculated, assuming that the remaining fruit trees have the heat of combustion of pear trees (i.e. the lowest). The average heat of combustion of waste biomass from orchards in Poland is 19.61 MJ/kg.

As a result of grubbing up orchards, it is possible to obtain about 80 Mg/ha of biomass in the case of older plantations (age about 30 years) and about 60 Mg/ha in the case of modern low-growth plantations (age about 15 years); annually, this gives approximately (assuming grubbing up once every 30 or 15 years, respectively) an average of 3.5 Mg/(ha·year). However, the amount of biomass generated annually during maintenance works varies, depending on the age and species of trees, from 4 to 10 Mg/(ha·year), i.e. approximately on average 7 Mg/(ha·year) (Igliński et al., 2018).

It was assumed that 50% of waste wood would be used for energy purposes. Biomass will be burned in high-efficiency cogeneration: electricity will be produced with an efficiency of 30% and heat with an efficiency of 50%, which gives a total efficiency of $E = 80\%$.

Figure 6 shows the amount of energy that can be obtained annually from waste wood generated during forest clearing and maintenance work in orchards in Poland, divided into individual voivodeships.

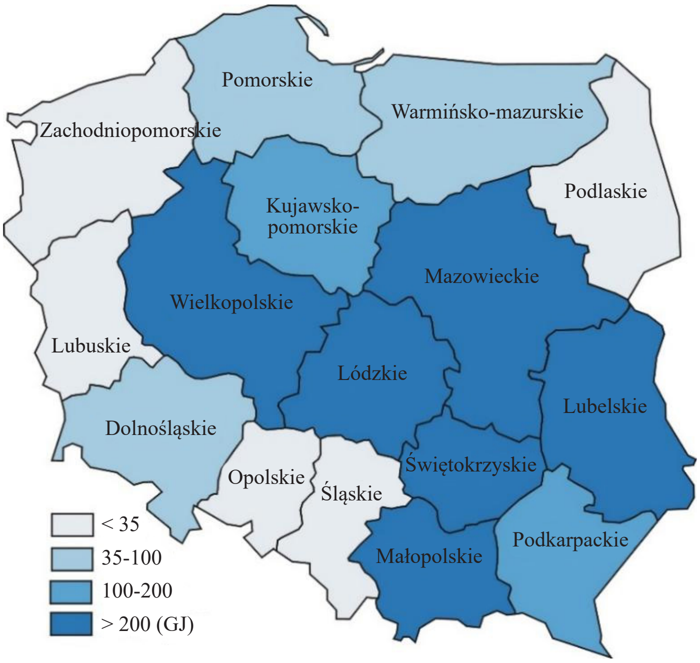


Figure 6. Distribution of the amount of energy that can be obtained annually from waste wood from orchards in Poland (GJ)

Figure 7. Distribution of the amount of energy that can be obtained annually from waste wood from roads in Poland

The calculated amount of energy that can be obtained annually from waste wood from orchards in Poland is 7.0 PJ/year, with the highest potential in the Mazowieckie Voivodeship (2.8 PJ/year), Świętokrzyskie Voivodeship (1.1 PJ/year), and Łódzkie Voivodeship (0.9 PJ/year) and Lubelskie Voivodeship (0.9 PJ/year).

In the study (Igliński et al., 2018) the calculated potential is lower, which results from a different calculation methodology, as well as from other data from the Central Statistical Office (earlier years).

4.3 *Technical potential of energy from waste wood from roads in Poland*

In Poland, it is common to plant trees along roads. According to data from the Central Statistical Office, the length of roads in Poland is 315,000 km (Central Statistical Office, 2023b).

In order to estimate the energy that can be obtained annually from waste wood, it was assumed that the volume of wood that can be obtained annually per kilometer of road for energy purposes is 1.5 m^3/(km·year), and the dominant species is poplar (18.982 MJ/kg).

It was assumed that 50% of waste wood would be used for energy purposes. Biomass will be burned in high-efficiency cogeneration: electricity will be produced with an efficiency of 30% and heat with an efficiency of 50%, which gives a total efficiency *E* of 80%.

Figure 7 shows the amount of energy that can be obtained annually from waste wood from roads in Poland, divided into individual voivodeships.

The calculated amount of energy that can be obtained annually from waste wood from orchards in Poland is 586 GJ/year, with the greatest potential in the Mazowieckie Voivodeship (75 GJ/year), Wielkopolskie Voivodeship (58 GJ/year), Małopolskie Voivodeship (49 GJ/year), Lubelskie (45 GJ/year), Śląskie (41 GJ/year), Dolnośląskie (40 GJ/year) and Łódzkie (40 GJ/year).

In the study (Igliński et al., 2018) the calculated potential is higher, which results from a different calculation methodology, as well as from other data from the Central Statistical Office (earlier years).

4.4 *Total amount of energy from waste biomass for energy and industry in Poland*

Electricity and heat obtained from waste biomass can be used in energy, heating and industry. For example, the food industry requires significant amounts of electricity and heat in the production cycle. Investing in a heat and power plant using waste biomass then makes perfect sense.

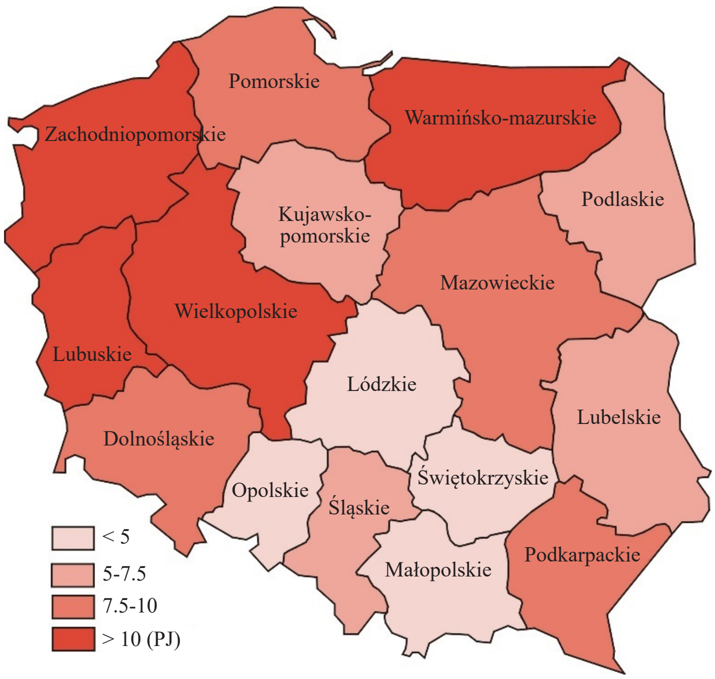


Figure 8. The amount of energy that can be obtained annually from waste wood generated during forest clearing, wood processing in the timber industry, orchards and biomass from roads in Poland

Figure 8 shows the amount of energy that can be obtained annually from waste wood generated during forest clearing, wood processing in the timber industry, orchards and biomass from roads in Poland, divided into individual voivodeships.

The calculated amount of energy that can be obtained annually, including waste wood from forests, during wood processing in the timber industry, orchards and biomass from roads in Poland, is 124.6 PJ/year, with the greatest potential in the voivodeships with the highest forest cover: Zachodniopomorskie Voivodeship (13.3 PJ/year), Wielkopolskie Voivodeship (10.8 PJ/year), Warmińsko-Mazurskie Voivodeship (10.6 PJ/year) and Lubuskie Voivodeship (10.5 PJ/year). For example, the food industry is very well developed in the Wielkopolskie Poland Voivodeship. And waste biomass should be sent to on-site heat and power plants.

5. Phytoash management in the fertilizer industry

After burning the biomass, phytoash remains, which is a valuable agricultural fertilizer, primarily due to its high calcium and magnesium content.

Using data from the Central Statistical Office (2023c), the phytoash content in biomass (Figure 3) and the calcium and magnesium content in ash (Table 2, XRF marking), the available mass of calcium and magnesium in individual voivodeships was calculated (Table 3).

Table 3. Mass of calcium and magnesium available in individual voivodeships

Voivodeship	Calcium mass (Mg)	Magnesium mass (Mg)
Dolnośląskie	1,532	2.17
Kujawsko-Pomorskie	962	1.36
Lubelskie	929	1.33
Lubuskie	1,609	2.28
Łódzkie	646	0.93
Małopolskie	605	0.86
Masovian	1,155	1.70
Opolskie	668	0.94
Podkarpackie	1,184	1.68
Podlaskie	857	1.21
Pomorskie	1,343	1.90
Śląskie	821	1.16
Świętokrzyskie	619	0.90
Warmińsko-Mazurskie	1,625	2.30
Wielkopolskie	1,612	2.29
Zachodniopomorskie	2,023	2.86
Poland	18,099	25.58

Most of the calcium can be used for fertilizer purposes in the Zachodniopomorskie Voivodeship (2,023 Mg/year), the Warmińsko-Mazurskie Voivodeship (1,625 Mg/year), the Wielkopolskie Voivodeship (1,612 Mg/year) and the Lubuskie Voivodeship (1,609 Mg/year). In the same voivodeships there is also the largest amount of available magnesium, respectively in the Zachodniopomorskie Voivodeship-2.86 Mg/year, in the Warmińsko-Mazurskie Voivodeship-2.30 Mg/year, in the Wielkopolskie Voivodeship-2.29 Mg/year and in the Lubuskie Voivodeship-2.28 Mg/year.

6. Discussion

The moisture content of the tested biomass samples ranged from 9% to approximately 44% of the wood mass, and the ash content ranged from 0.76% to 3.58% of the total mass. Fruit trees had a higher water content, which may be due to the fact that the trees from which the biomass was collected were younger (with the exception of pear trees, fruit trees had been growing in a given area for about a decade or less) compared to the biomass from the forest.

The heat of combustion of dried wood ranged from 18.82 MJ/kg for poplar to 21.23 MJ/kg for pine. The reason for such a high result for Scots pine, which was the only one to exceed the value of 20 MJ/kg, maybe the high resin content in the biomass, which was noticeable even after grinding in a vibratory grinder, because the resulting dust adhered more to the walls of the ground vessel and the string bag in which was stored than shredded biomass from other types of wood.

Due to the fact that biofertilizer from biomass combustion contains large amounts of elements that create alkaline compounds (calcium, potassium, sodium and magnesium usually constitute at least 65% of the total mass of ash for both types of tests), this confirmed the thesis about the positive effect of ash on the increase in pH value soil. This is beneficial because most soils in Poland are acidic. You should only remember to use an additive containing nitrogen compounds (e.g. sewage sludge), preferably with the addition of a few missing micronutrients (boron, cobalt and molybdenum). The largest amounts of calcium and magnesium in the fertilizer industry can be used in the Zachodniopomorskie Voivodeship (2,023 Mg/year and 2.86 Mg/year), the Warmińsko-Mazurskie Voivodeship (1,625 Mg/year and 2.30 Mg/year), and the Wielkopolskie Voivodeship (1,612 Mg/year and 2.29 Mg/year), and Lubuskie (1,609 Mg/year and 2.28 Mg/year).

This study assumes that electricity from solid biomass will be obtained with an efficiency of 30%, and heat with an efficiency of 50%. The total amount of electricity that could be obtained was estimated at 10.50 TWh, and heat-62.34 PJ (Table 4).

Table 4. Amounts of electricity and heat from biomass that can be obtained annually in Poland

Type of biomass	The amount of electricity (TWh/rok)	The amount of heat (PJ/rok)
Biomass from forests	9.76	58.55
Biomass from orchards	0.58	3.50
Biomass from roads	0.16	0.29
Sum	10.50	62.34

The calculated amount of electricity from waste biomass would cover Poland's needs in 5.9%, and heat in 19.8%. In 2022, 178.8 TWh of electricity and 315.1 PJ of heat were consumed in Poland (Central Statistical Office, 2023a). The use of waste biomass in cogeneration installations would increase the share of RES in the country's energy balance.

Heat and power plants using waste biomass should be operated by large food producers-they consume large amounts of electricity and heat all year round. Having your own electricity and heat would make you independent from unreliable external supplies and would be economically attractive.

Ash management is part of sustainable energy production, which has a huge impact on the environment, while storing phytoashes from biomass is a waste of valuable nutrients. Results of research on the influence of phytopashes from biomass on the physicochemical properties of soils indicate that their effect is comparable to that of mineral fertilizers. The ingredients are present in phytoash in proportion proper to nature. Therefore, they are safe, easily digestible and non-toxic. Its porous structure absorbs various harmful substances hence it is a powerful detoxifying agent.

7. Conclusions

-The heat of combustion of dried wood ranged from 18.82 MJ/kg for poplar to 21.23 MJ/kg for pine.

-Due to the fact that biofertilizer from biomass combustion contains large amounts of elements that create alkaline compounds, this confirmed the thesis about the positive effect of ash on the increase in pH value soil.

-The largest amounts of calcium and magnesium in the fertilizer industry can be used in the Zachodniopomorskie Voivodeship (2,023 Mg/year and 2.86 Mg/year), the Warmińsko-Mazurskie Voivodeship (1,625 Mg/year and 2.30 Mg/year), and the Wielkopolskie Voivodeship (1,612 Mg/year and 2.29 Mg/year) and Lubuskie (1,609 Mg/year and 2.28 Mg/year).

-The calculated amount of electricity from waste biomass would cover Poland’s needs in 5.9%, and heat in 19.8%.

Conflict of interest

There is no conflict of interest.

References

Arteau, J., Boucher, É., Poirier, A., & Widory, D. (2020). Historical smelting activitiees in Eastern Canada revealed by Pb concentrations and isotope rations in tree rings of long-lived white cedars (*Thuja occidentalis* L.). *Science of the Total Environment, 740*, 139992. https://doi.org/10.1016/j.scitotenv.2020.139992

Augusto, L., Beaumont, F., Nguyen, C., Fraysse, J.-Y., Trichet, P., Meredieu, C., Vidal, D., & Sappin-Didier, V. (2020). Response of soil and vegetation in a warm-temperature Pine forest to intensive biomass harvests, phosphorus fertilisation, and wood ash application. *Science of The Total Environment, 850*, 157907. https://doi.org/10.1016/j.scitotenv.2022.157907

Bays, H. C. M., Bolding, M. C., Conrad, J. L., Munro, H. L., Barrett, S. M., & Peduzzi, A. (2024). Assessing the sustainability of forest biomass harvesting practices in the southeastern US to meet European renewable energy goals. *Biomass and Bioenergy, 186*, 107267. https://doi.org/10.1016/j.biombioe.2024.107267

Bhagat, R., Walia, S. S., Dheri, G. S., Singh, G., & Sharma, K. (2024). Pear (*Pyrus communis*)-based agroecosystem improves soil nutrient dynamics, microbial biomass, enzymatic activity, farm productivity and profitability. *Scientia Horticulturae, 336*, 113398. https://doi.org/10.1016/j.scienta.2024.113398

Blanco, V., Zoffoli, J. P., & Ayala, M. (2021). Eco-physiological response, water productivity and fruit quality of sweet cherry trees under high tunnels. *Scienta Horticulturae, 286*, 11018. https://doi.org/10.1016/j.scienta.2021.110180

Capela, M. N., Tobaldi, D. M., Seabra, M. P., Tarelha, L. A. C., & Labrincha, J. A. (2022). Characterization of ashes produced from different biomass fuels used in combustion systems in a pulp and paper industry towards its recycling. *Biomass & Bioenergy, 166*, 106598. https://doi.org/10.1016/j.biombioe.2022.106598

Central Statistical Office. (2023a). *Energy 2023*. Warsaw.

Central Statistical Office. (2023b). *Statistical Yearbook of Agriculture 2023*. Warsaw.

Central Statistical Office. (2023c). *Statistical Yearbook of Voivodeships*. Warsaw.

Central Statistical Office. (2023d). *Yearbook of Forest Statistics 2023*. Warsaw.

Erdem, F., & Bayrak, O. C. (2023). Evaluating the effects of texture features on Pinus sylvestris classification using high-resolution aerial imagery. *Ecological Informaics, 78*, 102389. https://doi.org/10.1016/j.ecoinf.2023.102389

European Commission. (2014). *Cohesion Policy 2014-2020.* Investments in economic development and employment growth. https://ec.europa.eu/regional_policy/information-sources/legislation-and-guidance/regulations/2014-2020_en

Färkkilä, S. M. A., Valtonen, A., Saravesi, K., Anslan, S., Markkola, A., & Kontunen-Soppela, S. (2023). The effects of geographic orgin and genotype of fungal diversity of silver birch (*Betula pendula*). *Fungal Ecology, 63*, 101241. https://doi.org/10.1016/j.funeco.2023.101241

Ferreira, S. S., Martins-Gomes, C., Nuns, F. M., & Solva, A. M. (2022). Elderberry (*Sambucus nigra* L.) extracts promote anti-inflammatory and celluar antioxidant activity. *Food Chemistry: X, 15*, 100437. https://doi.org/10.1016/j.fochx.2022.100437

Grataloup, A., Jonas, S., & Meyer, A. (2024). A review of federated learning in renewable energy applications: Potential, challenges, and future directions. *Energy and AI, 17*, 100375. https://doi.org/10.1016/j.egyai.2024.100375

Hematabadi, H., Madhoushi, M., Khazaeyan, A., Ebrahimi, G., Hindman, D., & Loferski, J. (2020). Bending and shear properties of cross-laminated timber panels made of poplar (*Populus alba*). *Construction and Building Material, 265*, 120326. https://doi.org/10.1016/j.conbuildmat.2020.120326

Igliński, B., Cichosz, M., Skrzatek, M., & Buczkowski, R. (2018). Technical potential of waste solid biomass for energy purposes in Poland. *Inżynieria i Ochrona Środowiska, 22*(1), 109-118. https://doi.org/10.17512/ios.2019.2.1

Igliński, B., Iglińska, A., Kujawski, W., Buczkowski, R., & Cichosz, M. (2011). Bioenergy in Poland. *Renewable and Sustainable Energy Reviews, 6*(15), 2999-3007. https://doi.org/10.1016/j.rser.2011.02.037

Igliński, B., Piechota, G., & Buczkowski, R. (2014). Development of biomass in Polish energy sector: an overview. *Clean Technologies and Environmental Policy, 6*(17), 1-15. http://dx.doi.org/10.1007/s10098-014-0820-x

Igliński, B., Pietrzak, M. B., Kiełkowska, U., Skrzatek, M., Kumar, G., & Piechota, G. (2022). The assessment of renewable energy in Poland on the background of the world renewable energy sector. *Energy, 261*, 125319. https://doi.org/10.1016/j.energy.2022.125319

Janowicz, L. (2006). Biomass in Poland. *Energetyka i Ekologia*, 601-604. https://elektroenergetyka.pl/upload/file/2006/8/elektroenergetyka_nr_06_08_e2.pdf

Ladon, T., Chandel, J. S., Sharma, N. C., & Verma, P. (2024). Optimizing apple orchad management: Investigating the impact of planting density, training systems and fertigation levels on tree growth, yield and fruit quality. *Scientia Horticulturae, 334*, 113329. https://doi.org/10.1016/j.scienta.2024.113329

Lundström, U. S., Bain, D. C., Taylor, A. F., & van Hees, P. A. W. (2003). Effects of acidification and its mitigation with lime and wood ash on forest soil processes: a review. *Water, Air and Soil Pollution, Focus, 3*, 5-28. https://doi.org/10.1023/A:1024131615011

Meller, E., & Bilenda, E. (2012). The influence of ashes from biomass combustion on the physicochemical properties of light soil. *Polityka Energetyczna, 3*(15), 287-292.

Nguea, S. M., & Fotio, H. K. (2024). Synthesizing the role of biomass energy consumption and human development in achieving environmental sustainability. *Energy, 293*, 130500. https://doi.org/10.1016/j.energy.2024.130500

Nunes, L. J. R., Matias, J. C. O., & Catalão, J. P. S. (2016). Biomass combustion systems: A review on physical and chemical properties of the ashes. *Renewable and Sustainable Energy Reviews, 53*, 235-242. https://doi.org/10.1016/j.rser.2015.08.053

Olatoyan, O. J., Kareem, M. A., Adebanjo, A. U., Olawale, S. O. A., & Kehinde, T. A. (2023). Potential use of biomass ash as a sustainable alternative for fly ash in concentrate production: A review. *Hybrid Advances, 4*, 100076. https://doi.org/10.1016/j.hybadv.2023.100076

Paraschiv, L. S., & Paraschiv, S. (2023). Contribution of renewable energy (hydro, wind, solar and biomass) to decarbonisation and transformation of the electricity generation sector for sustainable development. *Energy Reports, 9*, 535-544. https://doi.org/10.1016/j.egyr.2023.07.024

Smaliychuk, A., & Latocha-Wites, A. (2023). Climate change adaptation policy and practice: Case study of the major cities in Poland. *Cities, 141*, 104474. https://doi.org/10.1016/j.cities.2023.104474

Szymajda, M., Maciorowski, R., Rabcewicz, J., Białkowski, P., & Buler, Z. (2023). Suitability of plum (*Prunus domestica* L.) cultivats for combine harvesting of the fruit. *Scientia Horticulture, 313*, 111895. https://doi.org/10.1016/j.scienta.2023.111895

Tavares, T. R., Molin, J. P., Alves, E. E. N., Melquiades, F. L., Carvalo, H. W. P., & Mouazen, A. M. (2023). Towards rapid analysis with XRF sensor for assessing soil fertility attributes: Effects of dwell time reduction. *Soil and Tillage Research, 232*, 105768. http://dx.doi.org/10.1016/j.still.2023.105768

Tebbi, S. O., & Debbache-Benaida, N. (2022). Phytochemistry, chemical composition and therapeutic uses of *Populus nigra* L. aerial parts from 1991-2021 onwards: An overview. *Sustainable Chemistry and Pharmacy, 30*, 100880. https://doi.org/10.1016/j.scp.2022.100880

Trombley, J. B., Wang, C., & Thennadil, S. N. (2023). Model-free measurements of calorific content and ash content of mixed garden wastes using a bomb calorimeter. *Fuel, 352*, 129105. https://doi.org/10.1016/j.fuel.2023.129105

Urbanowski, C. K., Turczański, K., Andrzejewska, A., Kamczyc, J., & Jagodziński, A. M. (2022). Which soil properties affect soil mite (Acari, Mesostigmata) communities in stands with varoipus of European ash (*Fraxinus excelsior* L.)? *Applied Soil Ecology, 180*, 104633. http://dx.doi.org/10.1016/j.apsoil.2022.104633

Vospernik, S., Vigres, C., Morin, X., Toïgo, M., Bielak, K., Brazaitis, G., Bravo, F., Heym, M., Río, M., Jansons, A., Löf, M., Nothdurft, A., Pardos, M., Pach, M., Ponette, Q., & Pretzsch, H. (2024). Can mixing Quercus robur and Quercus petraea with Pinus sylvestris compensate for productivity losses due to climate change? *Science of the Total Environment, 942*, 173342. https://doi.org/10.1016/j.scitotenv.2024.173342

Wang, S., Baxter, L., & Fonseca, F. (2008). Biomass fly ash in concentrate: SEM, EDX and ESEM analysis. *Fuel, 3*(87), 372-379. http://dx.doi.org/10.1016/j.fuel.2007.05.024

Zhai, J., Burke, I. T., & Stewart, D. I. (2021). Beneficial management of biomass combustion ashes. *Renewable and Sustainable Energy Reviews, 151*, 111555. https://doi.org/10.1016/j.rser.2021.111555

Zhao, X., Oyedeji, O., & Webb, E. (2022). Impact of biomass ash content on biocomposite properties. *Composites Part C: Open Access, 9*, 100319. https://doi.org/10.1016/j.jcomc.2022.100319