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ANALYSIS OF THE POTENTIAL USE OF BIOMASS IN THE REGION OF WIELKOPOLSKA FOR EXISTING INDUSTRIAL APPLICATIONS

In recent years, the introduction of modern solutions to energy sector beyond energy efficiency places special emphasis on environmental issues. They concern efforts to achieve the lowest possible carbon dioxide emissions and toxic substances into the atmosphere. One of the main methods to reach this goal is using biomass as fuel. Because of its life cycle, biomass is considered as neutral to the atmosphere from the point of view of carbon dioxide emissions. Another advantage is the high availability, especially in agricultural, industrial and forestry areas as well as sludge from waste water treatment. Currently, there are many technologies that use biomass for the production of electrical energy such as co-combustion, biogas and gasification plants. This article provides a detailed analysis of the potential acquisition of biomass in the Wielkopolska region (western Poland) which indicates the possibility of a significant increase in electricity production from this source.

Keywords: biomass, energy potential of biomass, wood

1. INTRODUCTION

Biomass as a fuel was the first of your usage of human material for energy production. The industrial revolution led to a fall in its general meaning in the human economy. However, in many regions of the world, it is the basic material for the heating. As mentioned in the introduction to meet the challenges energy sector biomass became one of the sources that may have a significant part in reducing the share of fossil fuels in power generation.

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According to the Polish Energy Policy until 2030 [Polityka energetyczna... 2009] the share of renewable energy sources in total energy consumption of Poland is expected to rise to 15% to 2020 and 20% to 2030. It is also planned to achieve 10% share of biofuels in the fuel market by 2020.

Biomass as a renewable energy source seems to be the next to wind power and photovoltaic cells a promising solution that can have a big part in achieving the challenging climate targets. Due to many available technologies almost any organic waste can be used as a substrate for the production of electricity. This work focuses on assessing the energy potential of waste that can have the biggest share in the current and future production of electricity for the region of Wielkopolska.

Due to some disruption in global food markets and price fluctuations there is a tendency to use biomass in technologies not competing with food supply. A very big share in the production of energy carriers from renewable raw materials are fuels derived from oilseeds. However, for the reason mentioned above, i.e. competing oilseeds plantation with areas of food production, the new goal in biomass energy market is to reduce share of such kind of fuels in the total amount of energy obtained from biomass. Therefore this work is dedicated to the energy potential of waste biomass, which does not affect the food market.

2. CHARACTERISTIC OF WIELKOPOLSKA REGION

Wielkopolska voivodship is situated in the central-western part of Poland and covers an area of 29 826 km^2, which represents 9.54% of the whole country. It is the second largest region and plays significant role in the national economy (provides the biggest food production). Favorable results are obtained through historical tradition and good agricultural practices. Region is a national leader in the production of cereals and occupies leading positions in the production of oilseed rape, potatoes and sugar beet [GUS Rolnictwo 2014].

2.1. Advantages of Wielkopolska region on biomass production field

Total area of Wielkopolska is nearly 3 million hectares. Slightly more than one fourth of the surface is covered by forests. While 65% of region territory is developed by agriculture. Big share of plants growth area and high farming culture lead to large production of biomass. By simplified estimates typical crops allow to obtain between 10 and 15 tons of biomass per hectare [GUS Rolnictwo 2014]. It is equivalent to approximately 5–8 tons of coal [Grabowski 2013]. In case of Wielkopolska voivodship these values are in the upper limits (high productivity). It allows to specify biomass production in range between 18 to 27 million tons (culti-

vated area about 1,8 hectares) which means about 9 to 14 million tons of coal. Part of total produced biomass can be utilized for energy purposes.

Besides production of biomass derived from plants, Wielkopolska region has high potential to obtain big amount of animal origin biomass. According to the regional Data Base GUS 2015, the number of cattle, pigs and poultry in saturation of the animal population on 100 ha parameter significantly exceeds the average national production.

Therefore there is high possibility of animal origin biomass wastes utilization. In comparison with the rest of country the number of cattle, pigs and poultry particular population density of farm livestock at 100 ha Wielkopolska significantly exceeds the average national production [GUS Rolnictwo 2014]. On the one hand it increases impact on environment due to associated gas emission (mostly CO2 and CH4 greenhouse gases) and odorous which create necessity of facing animal and slaughterhouse wastes. From the other hand manure and slaughterhouse are suitable for biogas agricultural plant as a feedstock. Moreover utilization of these materials biogas plants results in producing very high quality natural fertilizers (fermented pulp) with extremely high fertilizing value, better than regular liquid manure.

Summarizing Wielkopolska has very well conditions for the usage of energy captured in biomass and development of biomass origin technologies. Among many factors favoring such implementations following must be listed:

– a well developed agriculture and high biomass yields,

– high knowledge of farmers, presence of research institutions and consultancy (Poznan University of Technology, Poznan University of Life Sciences, Agricultural Advisory Centers etc.),

– a large share of forest areas and surrounding territories (especially western and northern regions),

– well developed agro-industry which generates large amount of biomass waste,

– proximity to Germany provide easier knowledge, technology and good solutions transfer, moreover huge market for processed biomass (briquettes, pellets).

The Table 1 and 2 show data of crop production and confide in the region. To show how important is the share of animal production in agriculture of Wielkopolska in Poland, the number of livestock referred to the national breeding [GUS Rolnictwo 2014].

Further, in terms of biomass source potential fuel for energy sector is wood from forestry. Forests in Wielkopolska cover an area of 767500 hectares, and the acquisition of wood in 2014 was equal to 3417900 cubic meters. Most of the harvested raw material is used in industry, but at every stage, from obtaining in the forest to disposal of used products, significant amounts of waste wood can be recovered.

Table 1

The structure of production in Wielkopolska region [GUS Rolnictwo 2014]

The type of crop	Area/ Cereal yields	Area/Cereal yields in Poland	The share of voivodship [%]/value related to the national average
Grain total area	729700 ha	7479000 ha	10,71
Grain yields	4,5 t/ha	3,6 t/ha	125,00
Sugar beets total area	31000 ha	158000 ha	19,62
Sugar beets yields	73,9 t/ha	58 t/ha	127,00
Rape and turnip rape total area	79100 ha	686000 ha	11,50
Rape and turnip rape yields	3,4 t/ha	2,7 t/ha	126,00
Wheat total area	197100 ha	2138000 ha	9,20
Wheat yields	4,7 t/ha	3,8 t/ha	123,00

Table 2

Number of livestock referred to national production [GUS Rolnictwo 2014]

Breeding	Total population		The share of voivodeship [%]
	Poland	Wielkopolska	
	Thousands		
Breeding total	133860	27477,0	20,5
Breeding cattle total	5920,4	889,3	15,0
Cows in this	2441,9	289,7	11,9
Pigs total	11724,1	4134,6	35,3
Poultry total	140691,0	45517,0	32,3
Laying hens in this	47430,0	12660,0	26,7

3. ESTIMATION OF THE ENERGY POTENTIAL

3.1. Assessing the potential of particular biomass types in Wielkopolska

During assessment particular source, which energetic material can be obtained it is necessary to evaluate following potentials:

– theoretical,
– technical,
– economical,
– accessible.

Theoretical potential is all the energy contained in a unit of raw material obtained on theoretical calculation base. By incorporating conversion method technical potential is assessed. Because of different technologies has certain own efficiencies, various results can be received for the same source of energy. Further the economic potential assessment is followed. This operation indicates, how much of the technical potential can be used in an economically viable way. Economic potential analysis is the most complicated part, because all the available technologies and the competitiveness must be considered. It requires taking into account the operating costs and the availability of another energy sources. The ultimate factor determining the profitability of the source potential is availability which shows how much of the primary energy can be meaningfully used. Generally it is several times smaller than the theoretical potential. Any investment should be preceded by such analysis taking into account energy consumed to produced usable energy [Duczkowska-Kądziel, Duda i Wasilewski 2013].

This paper focuses on estimating the technical potential of biomass in the region. As a basis for deliberations adopted biomass from agriculture, timber harvesting in forests and cleaning roads. In case of energy efficiency in the electricity production the most advantageous seem to be the combustion technology and even more promising gasification of biomass. The potential overall efficiency for these solutions are equal up to 40%for combustion in large plants [McKendry 2002], and about 40-50% for gasification [Roszkowski 2012]. However, not all organic material originating from the activities of agriculture and the food industry can be utilized in this way. Hence prevalence of building biogas plants. According to German Assessments [Basisdaten 2012] overall efficiency of biogas production is only approximately 1.5% (relative to the energy potential of the substrate) [Roszkowski 2013]. Despite so insignificant efficiency of electricity generation, the biogas plants are often the only viable technology for the use in certain categories of waste and present a number of another advantages such as production of high-quality fertilizers and heat supply for farm demands.

In the following paragraphs methods for estimating the potential of individual types of waste biomass are described. Assessments include woody biomass wastes derived from forest, waste from timber industry, biomass for the production of

biogas, hay and woodlots potential calculations. The described methods for calculating the potentials and coefficients of obtaining various sources of biomass for energy purposes has been adapted to the circumstances in Wielkopolska region.

3.2. Woody biomass wastes derived from forest

The estimations of available wood resources for energy from forests were performed based on area of forest land and annual growth of wood. The input data were taken from Regional Directorate of State Forest (RDLP Regionalna Dyrekcja Lasów Państwowych). For the calculations of wood resources for energy purposes, methods resulting from growth and obtaining of wood from forests were used. Because of the diversity of biomass occurring in forests, some simplification [European... 2007] were assumed**.** The energy potential calculating formula is given below [Kowalczyk-Juśko 2009]:

$$P_{edl} = Z_{dl} \cdot F_{edl} \cdot \rho_{wit} \cdot W_{ddl} \quad (1)$$

where:
P_{edl} – energy potential of forest waste wood,
Z_{dl} – annual wood harvesting,
ρ_{wit} – average density of wood,
F_{edl} –factor of potential of wood waste from woods in Wielkopolska region,
W_{ddl} – average low heating value of wood.

According the national action plan for energy from renewable source [Ministerstwo Gospodarki 2010] data the amount of forest biomass for power sector realizable and economically reasoned in Poland is equal to about 18% of the total volume of harvested material and this value was taken as the base rate for the calculation of the potential in the Wielkopolska region. However, some of the material, is used for heating. Moreover it is necessary to leave part of the wood on site to protect the ecosystem. With introducing some legal solutions this cavity may be supplemented by the utilization of wood coming from natural disasters.

3.3. Woody biomass wastes derived from the timber industry

In Poland, wood waste (industrial and postconsumer) represents significant potential base for further usage in power generation. The supply is estimated at 46% in relation to the acquisition of raw wood. In practice they are fully utilized in production processes, while large reserves are in the field of recovery and use of wood contained in worn wood products. Their usage is crucial because they are heavy burden to the environment. It is estimated that for Poland (the same value is con-

sidered for Wielkopolska region) in relation to the input timber industry wood, these wastes represents about 16% [Roszkowski 2013].

The following equation presents the calculation method of industry wood wastes estimation.

$$P_{edt} = Z_{dl} \cdot \rho_{wit} \cdot F_{edt} \cdot F_{udt} \cdot W_{d\,wit} \quad (2)$$

where:
P_{edt} – Energy potential of waste wood,
Z_{dl} – annual wood harvesting,
ρ_{wit} – average density of wood,
F_{edt} – base of wood utilized in industry factor,
F_{udt} –waste wood after industrial treatment factor,
W_{dwi} – average low heating value of wood.

3.4. Wood resources from woodlots

Woodlots are productive and protective clusters of trees and shrubs outside the forests. It consists of trees along roads and waterways, among agricultural crops, houses and farm buildings and within industrial plants. This kind of biomass is difficult to obtain because woodlots cover small areas with diverse ownership structure. Taking into account the foregoing, estimation of the energy potential can be reduced to utilization of wood from roadside formula [Buczek, Kryńska 2007]

$$Z_{dz} = 1{,}5 \cdot L \cdot 0{,}3[\frac{t}{year}] \quad (3)$$

where:
Z_{dz} – resources of wood from woodlots,
1,5 – quantity of wood possible to obtain from 1km of woodlots,
L – length of roads in Wielkopolska region,
0,3 – roads woodlots factor.

The amount of energy which can be derived from woodlots is further calculated according to the principles described for the use of forest biomass**.** The information about the length of roads in Wielkopolska were provided by Central Statistical Office [GUS Transport drogowy... 2014]

3.5. Biomass for the production of biogas

The raw material for biogas production should be divided into three separate categories:

– waste from the agro-food industry agricultural,
– sludge from the sewage treatment plant.

The amount of biogas from agricultural production can be estimated on the basis of a formula taking into account the amount of livestock (in LU) and the factor of the amount of biomethane for particular groups of animals:

$$V_{br} = \sum_{i=1}^{n} L \cdot F_{bsdi} \cdot 365 \quad (4)$$

where:
V_{br} – volumetric potential of agriculture biogas (related to one year period),
L – Amount of animals in DJP,
F_{bsdi} – biogas production indicator calculated for DJP [m^3/DJP/day].

Based on the information obtained on farms, dominant medium structure cattle and pigs and the main trend of breeding poultry (chickens and broilers hens) for the conversion of physical units to the large animal equivalent. The following, secondary indicators: cattle – 0,8 DJP, pigs – 0,2 DJP, poultry – 0,004 DJP were assumed. DJP is large conversion unit, equivalent to 500 kg animal.

Table 3

DJP conversion unit for livestock [Kowalczyk-Juśko, Biogazownie]

Cattle		**Pigs**	**Poultry**
Liquid manure 1,5–2,9	Manure 0,56–1,5	0,6–1,25	3,5–4,0
Average 1,5		Average 1,0	Average 3,75

Waste from sewage treatment plants are dependent on the volume flow of waste water and its type, but for simplicity averaged values were taken. Obtaining 0.3 kg dry weight from 1 kg of material entering the plants and bio-methane production from 1 kg of dry weight equal to 0.3 m^3. Then the volume potential of this biomass is calculated from the formula:

$$V_{bo} = V \cdot S \cdot W_{CH_4} [\frac{m^3}{year}] \quad (5)$$

where:
V_{bo} – volumetric potential of biogas from sewage treatment plants,
V – wastewater stream,
S – factor of formation of dry matter from wastewater,
W_{CH4} – low heating value of biogas.

3.6. Straw potential

A very large share of the energy potential from the areas could be a surplus of straw as a waste from the production of cereals. As it was described before, Wielkopolska region has big production of cereals what is connected with creating very large quantities of straw. However, due to high number of the livestock-above average on the background of the country, regional agriculture requires significant amount of straw and even shortages of it occur [Ludwicka Grzybek 2010]. For this reason, its energy potential is not considered in this work. Moreover, because of the properties of the biomass affecting their technical use (high content of nitrogen, sulfur, chlorine) estimations of its potential would require a more detailed analysis that goes beyond the scope of this article**.**

3.7. Hay energy potential

Hay is mainly used as feed for ruminants. In recent years a decline in livestock hay consumption causes pasture land exceeds the demand of agriculture, which involves the extensive use of them or even hay omission and degradation of grasslands. In the case of unused production potential meadows and pastures for fodder purposes, part of the biomass from these areas can be earmarked for energy purposes. Hay potential can be defined as the product of the area, their use for energy purposes factor, and the size of the crop.

$$Z_{si} = A_1 \cdot F_{ws} \cdot Y_{si}[\frac{t}{year}] \quad (6)$$

$$P_{esi} = Z_{si} \cdot W_{dsi} \quad (7)$$

where:
Z_{si}– hay potential,
A_1– area of grassland,
F_{ws}–energy purposes utilization of hay factor,
Y_{si}– hay yield from area unit,
P_{esi}– hay energetic potential.

For purpose of calculations the Central Stastical Office [GUS Rolnictwo 2014] data were taken. Total hay yield in Wielkopolska voivodship was equal to 1314900 t. Precise determination of the utilization factor of hay for energy purposes requires the knowledge about the use pasture on studied area with a special focus on areas of meadows and pastures uncut. An average in the country this ratio stands at 5–10%. Because of high livestock breeding in Wielkopolska 5% was assumed. While hay yield is dependent on habitat conditions. In Poland average yield is approx. 4 t/ha [Kowalczyk-Juśko, 2009]. The low heating value of the first cut of hay is equal to 14 MJ/kg, and this value was taken for the purpose of this calculation.

4. STATEMENT OF RESULTS

During the production of electricity from combustion of biomass efficiency for power range of 2–10 MW is 15–20% and for the capacity above 30 MW is equal to 40% [McKendry 2002]. The efficiency of biogas plants generating electricity is approximately10–15% [Roszkowski 2012]. Because of huge mass of potential feed material, ultimately electricity produced using this technology can constitute a big part in the overall biomass energy mix of the region.

The most common method of disposing of these gases is the combustion in gas engines or in small gas turbines. For this reason, the potential base for the calculation is not represented in the calorific value of the fermentation mass but produced gas. In modern cogeneration systems for biogas utilization combustion efficiency of entire systems can exceed 40% [Motyl, Lisocki 2008].

In the Fig. 2a summary of estimated potential energy of individual types of biomass is presented. To show how the process of waste biomass and how their participation can provide the basis for the production of electricity, the obtained results are presented in the form of energy flow chart. Figures in parentheses indicate percentage of total production. To visualize the realizable amount of electricity production final value is given in GWh per year. In this case, the assumed value of the power generation systems efficiency is equal to 30% [Roszkowski 2013].

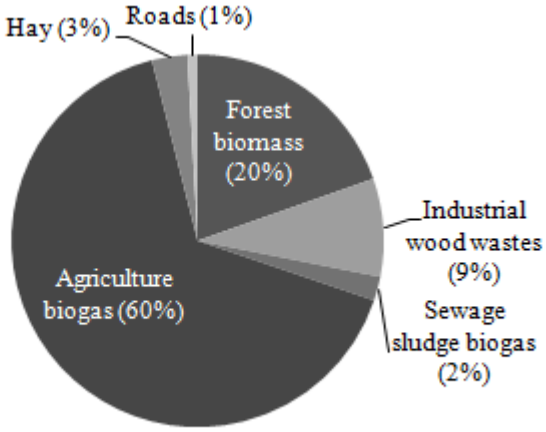

Fig. 1. Share of particular fuels in total biomass regional potential (own work)

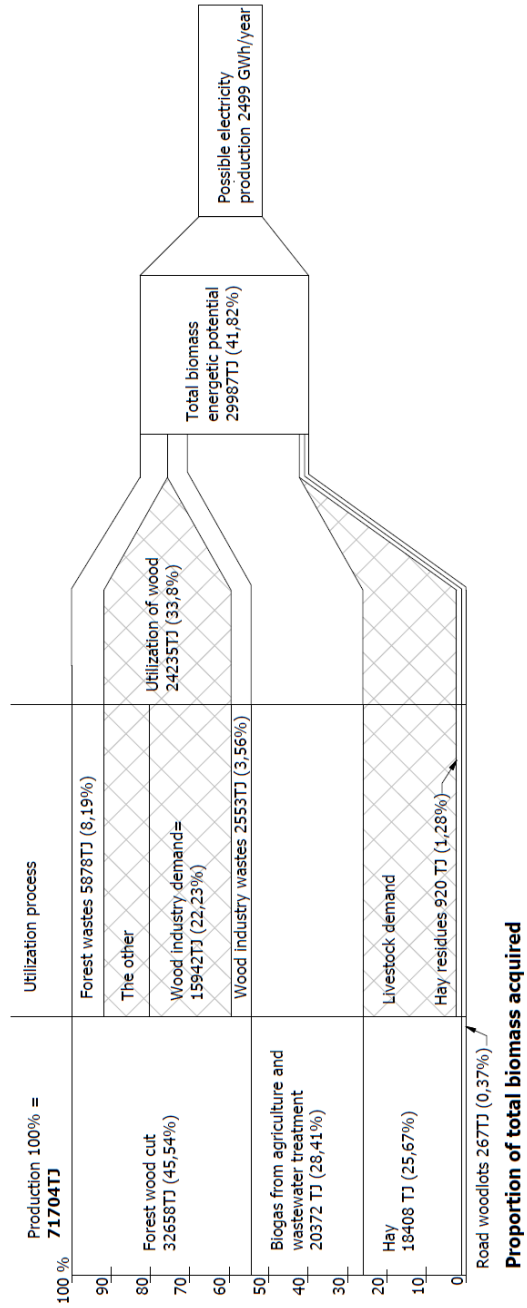

Fig. 2 Energy flow chart of biomass energetic potential in Wielkopolska region (own work)

Presented energy flow chart presents clearly formation of prospective energy which can be obtained from biomass wastes. However to introduce share of particular energy sources pie chart was created (Fig. 1).

As it can be seen in the graph the largest share of obtaining electricity is in the biogas production from agriculture and forest as well as industry wood wastes.

5. CONCLUSIONS AND DISCUSSION

In connection with the conducted analysis the following conclusions can be stated:

1. The analysis shows the huge potential of biomass waste resulting from harvesting of wood process, wood processing and agriculture in the region of Wielkopolska. The calculated amount of energy technically possible to obtain amounts to 2499 GWh in year. According to the information of the city of Poznan portal the total energy demand in the city is amounted to 2 219 GWha year. This means that the energy potential of waste biomass, resulting in the entire region is enough to cover the total consumption of electricity in the region. The total amount of energy produced in Wielkopolska in 2010 was amounted to 13,168 GWh, which indicates that the technical potential of biomass would cover almost 20% of regional demands.

In practice, the use of the full potential of biomass energy waste in region is impossible. Not all of this waste biomass can be utilized for economic reasons. Before any investment an economic analysis of available solutions must be carried out. For waste from forests almost all the available mass can be co-fired directly or after briquetting. Currently, there is a large market of pellets for heating households. In dealing with forest biomass as feedstock for the production of electricity, it is always important to take into account competition with applications for heating. In the case of waste from the timber industry, it is not advisable to burn it in home furnaces for central heating demands. Because of a large share of chemicals impregnates, which are subjected to wood to improve its properties, their combustion is very dangerous due to emission of toxic substances. In the power industry, in contrast to the small boilers, the exhaust gas can be cleaned. Moreover large boilers can be designed to improve quality of combustion.

2. The analysis indicates a very high potential for production of electrical energy from biogas resulting from fermentation of agricultural waste. Despite the low efficiency of the entire process, because of large amounts of animal waste, energy potential value amounts to almost 30% of the total realizable waste biomass electricity. Moreover, the use of waste for the production of biogas is connected with number of other benefits. Digestate material has very good fertilizing properties. Nitrogen compounds contained are much better absorbed by plants compared to the batch material. In addition, waste heat processing of biogas can be used on-farm for heating buildings or drying grain. Ultimately it allows for large savings in agri-

cultural production. However, further development of agricultural biogas plants requires the introduction of additional benefits for investors, because the current price of green electricity does not allow for the expected return on investments.

3. The industrial practice shows that it is possible to use nearly all the theoretical potential agricultural waste for energy purposes. With the introduction of appropriate legislation and the promotion of biogas plants among the society, more than 8,000 biogas plants were built in Germany. Due to similar surface and climate conditions the region of Brandenburg (east Germany) can be given as a reference for Wielkopolska voivodship. Total power of biogas installations operating there was equal to 432 MWe (as of 2015) which is more than 3,000 GWh of energy produced per year. This value is near to whole calculated waste biomass energetic potential presented in this paper. It means that besides agriculture wastes, there are many other sources of feed for biogas plant. These include waste from the food industry, biodegradable waste from the municipal sector and mainly plant breeding directly for the production of biogas (competition with food supply market).It can be concluded that installation of biogas plants seems to be the most promising solution for waste biomass utilization in case of amount of realizable electric energy. Consequently it could help to increase the share of renewable energy in the energy sector and to fulfill climate targets stated by EU Commission.

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ANALIZA POTENCJAŁU WYKORZYSTANIA BIOMASY ODPADOWEJ W WOJEWÓDZTWIE WIELKOPOLSKIM DO ZASTOSOWAŃ PRZEMYSŁOWYCH

Streszczenie

Współcześnie, rozwój energetyki skupia się nie tylko na wprowadzaniu nowoczesnych rozwiązań w kierunku zwiększenia sprawności poszczególnych jej procesów, ale również na zmniejszeniu negatywnego wpływu wytwarzania energii elektrycznej i ciepła na środowisko naturalne. Szczególny nacisk kładzie się na redukcję emisji gazów cieplarniany oraz substancji toksycznych do atmosfery. Wykorzystanie biomasy jako substratu dla potrzeb energetyki wydaje się być jedną z najbardziej obiecujących możliwości. W myśl obowiązujących przepisów jest ona uważana za neutralną dla emisji dwutlenku węgla. Kolejną zaletą biomasy jest jej powszechne występowanie, zwłaszcza na terenach z dużym udziałem obszarów leśnych, przemysłu drewna oraz rolnictwa. Obecnie dostępnych jest wiele technologii pozwalających na jej efektywne wykorzystanie, takich jak współspalanie z surowcami kopalnymi, produkcja biogazu oraz zgazowanie. Niniejszy artykuł prezentuje analizę technicznego potencjału pozyskania energii elektrycznej z biomasy produkowanej na terenie województwa Wielkopolskiego.

Słowa kluczowe: biomasa, potencjał biomasy, gospodarka drzewna