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## THE POSSIBILITIES OF MEETING ENERGY DEMANDS IN SYSTEM THERMAL POWER PLANTS BY USING LOCAL SOLID BIOMASS

Key words: energy demand in a thermal power plant, local biomass resources, meeting energy demands

**ABSTRACT.** What is of crucial importance in local conditions as concerns the heat power industry is the use of local biomass, especially waste biomass, as an energy raw material in the existing system of thermal power plants. The purpose of the present study is to assess the possibility of replacing hard coal as an energy raw material with solid biomass. Solid biomass is constituted by: surpluses of cereal straw and rape straw, as well as hay from unused meadows, from the upkeep of roadside trees and from energy crop plantations. The research was conducted on the example of thermal power plants associated in the “Together Warmer” Cluster. This cluster is formed by 10 thermal power plants in small towns in the Warmińsko-Mazurskie Province and the city of Biała Podlaska (Lubelskie Province). All of these are located in north-east Poland. Considering the high transport costs of biomass, a biomass technical potential was accepted within a radius of 30 km from the thermal power plant. The solid biomass potential for each of the ten thermal power plants demonstrates that most of the thermal power plants from the Cluster under examination are able to meet their energy needs with solid biomass from the nearest neighbourhood (replace hard coal). However, when taking a decision on replacing hard coal with local biomass, it is necessary to adequately handle logistics and replace boilers in thermal power plants with special boilers for the combustion of solid biomass.

### INTRODUCTION

System biomass thermal power plants in Poland are chiefly based on the use of hard coal. This may not be a long-lasting tool considering the deterioration of the natural environment, its negative impact on human health as well as the use of raw materials without any economic justification. There is strong and justifiable pressure on the part of international organizations on a radical limitation of the combustion of fossil materials, and particularly of coal, considering progressing climate changes, which are to a large extent dependent on CO<sub>2</sub> emissions. The system heating industry in Poland, which is relatively well developed, chiefly uses hard coal as material, most frequently in the form of fines. At the same time, there is a significant amount of agricultural waste and other waste in the form of solid biomass in rural areas in Poland. In the present study, the attempt was

taken to assess the possibility of replacing hard coal in selected thermal power plants in north-east Poland with local solid biomass, chiefly waste biomass. What also needs to be taken into account is that apart from the negative environmental impact of combusted coal and its negative impact on the health of local residents, the transport cost of coal to a specific region in Poland that is far away from coal mines is exceptionally high. Apart from this, the problem of unused biomass waste is also important, and requires solving. The diversification of agricultural production, and plant production in particular, through the cultivation of consumption and energy raw materials, serves to contribute to the improved income of the agricultural population as well as the economic activation of rural areas. This will also have an impact on the improved condition of the natural environment and the sustainable development of rural areas. The adequate utilization (with the use of the latest technologies in a combined system), in local thermal power plants, of any waste biomass from agriculture, industry, the municipal economy, forestry as well as from local energy crops of solid biomass, offers an opportunity for the most effective solution both for the suppliers of energy raw materials and thermal energy producers [Jasiulewicz 2007a,b, 2010b, Grzybek 2008, Janeiro, Resch 2017]. This article contains a part of the Author's study in the project implemented by the University of Warmia and Mazury in the year 2011 related to the possibility of replacing hard coal with biomass in the "Together Warmer" Cluster.

Studies conducted in relation to biomass potential, both at home and abroad, demonstrate [Weger et al. 2005] that the development of power industry based on biomass as a solid fuel needs to focus chiefly on the production of thermal and electric energy in a combined heat and power system. This necessitates a decentralization of the systems and the local use of the production of heat and power; at the same time, it contributes to increased economic and energy efficiency. Due to the specificity of biomass as a fuel and the related nature of the combustion process, it is not possible to use hard coal boilers in this system that are commonly used in the heat power industry. The simplest solution is to have hard coal boilers replaced with boilers that are adapted to biomass combustion with the use of heat energy for heating purposes. Nevertheless, it is a combined heat and power system that offers the most effective solution. It produces heat and power, e.g. in an Organic Rankine Cycle system. Considering its use based on biomass, this is a furnace and a biomass boiler set. Considering the possibility of the utilization of any biomass waste (RDF), in the project of the replacement of the basic energy material (coal), comprehensive preparation is required not only of the furnace but of the entire logistics system. In the case of smaller combined heat and power plants, taking into account energy and economic efficiency, it is recommended to use thermal oil in the heating medium internal cycle in the ORC system [Charun 2015]. It is new energy systems (combined heat and power plants) in particular that first need to be established in towns, where obsolete boilers are worn out. The district heating networks that exist in towns may continue their functioning, yet the existing obsolete sections of the networks need to be replaced with new generation systems (pre-insulated ones).

## MATERIAL AND METHODS

The purpose of the present study is to assess the potential of biomass, and that of agricultural waste (straw) in particular, in the closest neighbourhood of 10 municipal heat plants associated in the “Together Warmer” Cluster, which may replace hard coal that has so far been used as the energy fuel in all of the plants. The following research hypothesis was accepted for verification: in rural areas in this region, i.e. in the Warmińsko-Mazurskie Province, every year there is a large quantity of straw and other solid biomass waste that remains unused, while the local thermal plants use huge quantities of coal that is supplied from mines that are situated several hundred kilometres away. It is important to verify this issue, i.e. the possibility of replacing hard coal that is combusted in system thermal plants, with local biomass. This is also an important aspect from the perspective of the regional economy, as funds spent on the purchase of coal for other regions could remain in the region and offer the possibility of innovative development of the economy and improved living standards for local residents.

In accordance with the Polish energy law [Energy Law Act, 1997], the local authorities of communes are obliged to develop plans for the provision of electrical and thermal energy. Locally available renewable energy sources should be taken into consideration in these plans. In the conditions of Polish agriculture, straw constitutes the greatest waste potential of solid biomass [Jasiulewicz 2010a]. In order to assess the energy potential of straw, the following formula was used:

$$E_{se} = Zsł \times 14 \times 80\% \text{ (GJ per annum)}$$

$$Zsł = Pz \times Js/z \times Jn/s \text{ (t per annum)}$$

where:  $E_{se}$  – energy potential of straw,  $Zsł$  – mass of straw surplus (t),  $Pz$  – grain yield (t),  $Js/z$  – relation of straw yield to grain yield,  $Jn/s$  = index of straw surpluses in a given area, 80% – efficiency of equipment for the combustion of straw, 14 GJ/t – energy value of straw with the humidity of 18-22%.

To calculate the quantity of straw crop, a relationship is accepted in relation to the production of the wheat grain – 1:0,8, rye – 1:1,4, barley – 1:0,9, triticale – 1:0,8, oat – 1:1,05, corn – 1:1,50, cereal mixtures – 1:0,95 [Kuś et al. 2006].

In order to calculate the mass of wood waste from roadside trees, the following was accepted [Rogulska 2003]:

$$Zdr = 1.5 \times L \times 30\% \text{ (m}^3\text{)}$$

$$E = Zdr \times 8 \times 60\% \text{ (GJ)}$$

where:  $L$  – length of paved roads/km,  $Zdr$  – wood waste from roadside trees (m<sup>3</sup>),  $E$  – energy potential (GJ).

Research into the potential of straw for energy purposes was carried out using a survey method in communes located within a radius of 30 km from the registered offices of the existing district heating plants associated in the “Together Warmer Cluster” – in

the Warmińsko-Mazurskie Province, and of one heating plant (Biała Podlaska) – in the Lubelskie Province. Statistical data from the Central Statistical Office was used, as well.

In the “Together Warmer” Cluster, 10 municipal thermal power plants with the following thermal powers are associated: Działdowo (13.8 MW), Nidzica (7.76 MW), Olsztyn (179.8 MW), Morąg (13.0 MW), Iława (39.0 MW), Ostróda (44.1 MW), Bartoszyce (36.20 MW), Kętrzyn (33.8), Mrągowo (26.5 MW) and Biała Podlaska (68.0 MW). Within a radius of 30 km from the thermal power plants, an estimation of biomass potential was performed: from agricultural cultivations, especially cereals (straw), grasses from unused meadows, wood from the upkeep of roadside trees as well as from the existing plantations of willow (Table 1). The total calculated size of the technical potential of biomass was matched with the capacity of the thermal power plant and the energy value used of the material utilized in the form of hard coal (in GJ). In the calculation of the energy potential of straw as a surplus that may be used in the thermal plant, the need to use straw on the farm and to supplement humus in soil was taken into account (according to the Institute of Soil Science and Plant Cultivation in Puławy).

## RESEARCH RESULTS

Energy contained in cereal straw constitutes the largest unused energy potential of solid biomass in agriculture and in rural areas in the area under examination (cf. Table 1). Cereal crops in the Warmińsko-Mazurskie Province constitute ca. 70% [GUS 2010] of the overall area of agricultural cultivation. This large share of cereals in crops contributes to the large volumes of straw produced: on the level of ca. 1.5 million tons, out of which over 400 thousand tons constitute a surplus, upon taking into account the needs to use straw for litter, fodder and ploughing [Kuś et al. 2006].

The straw surplus (which accounts for ca. 30% of the total straw production) may be used in the power industry. The share of cereals in crops in the subsequent years maintains a similar high level; the share of rape is high as well (9.8% in 2012) [GUS 2013, 2016]. In the “Together Warmer” Cluster, the thermal plants were divided into three groups: the North Group (3 heating plants), the South Group (6) and Biała Podlaska (cf. Table 1). It is evident, based on the research conducted, that in three communes in the North Group (heating plants in Bartoszyce, Kętrzyn and Mrągowo), there is sufficient potential of solid biomass, which may meet the needs of the thermal plants while replacing hard coal. If we take into consideration the existing surplus of the biomass potential in the region of the Kętrzyn Thermal Plant, the value of the biomass energy potential should be sufficient (taking the Olsztyn Thermal Plant into account).

The Biała Podlaska Thermal Plant (68 MW) is located in the Lubelskie Province, yet it functions in the “Together Warmer” Cluster. The total biomass potential in the communes that surround this plant is 503.94 TJ, and it can safely be presumed that it is able to satisfy the energy needs of the Biała Podlaska Thermal Plant.

The following thermal plants are included in the South Group of the Cluster: Nidzica, Morąg, Olsztyn, Ostróda, Działdowo and Iława. The total straw biomass potential in the South Group of the Cluster is 2,096.9 TJ per annum, in the North Group: 1,985.31 TJ per annum and in the region of Biała Podlaska: 490.60 TJ (cf. Table 1).

Table 1. Potential of agricultural and non-agricultural biomass in the regions of the thermal plants in the “Together Warmer” Cluster

Dis- trict	Region of thermal plant	Power of thermal plant MW	Straw for energy use		Grasses		Plantations of energy plants		Roadsides covered with shrubs		Energy value of straw for energy use	Energy potential of non- used meadows	Energy potential from the plantation of energy plants	Potential of wood from the upkeep of roads	Total existing potential of biomass
			thous. t	ha	ha	t	ha	t	km	t					
	Bartoszyce	36.2	124.1			120	120	694.0	347.0	1,737.35		2.16	2.78	1,742.29	
	Kętrzyn	33.8													
	Mragowo	26.5	17.7	100	400	80	80	1,302.0	652.5	247.96	5.60	1.44	5.21	260.21	
I	Total		141.8	100	400	200	200	1,996.0	999.5	1,985.31	5.60	3.60	7.99	2,002.50	
	Nidzica	7.76	18.4			60	60	1,044.0	522.0	257.17		1.08	4.18	262.43	
	Morąg	13.0	76.3	44	176	990	990	1,140.0	570.0	1,076.39	2.46	17.82	4.56	1,101.23	
	Olsztyn	179.8	17.3			120	120	5,577.1	2,788.6	241.59		2.16	22.31	266.06	
	Ostróda	44.1	6.2			47	47	147.0	73.5	87.26		0.85	0.59	88.70	
	Działdowo	13.8	26.5			100	100	309.0	154.5	370.61		1.80	1.23	373.64	
	Łąwa	39.0	4.6							63.88				63.88	
II	Total		149.3	44	176	1,317	1,317	8,217.1	4,108.6	2,096.90	2.46	23.71	32.87	2,155.94	
	Biała Podl.	68.0	35.0	180	720	50	50	591.0	295.5	490.60	10.08	0.90	2.36	503.94	
III	Total		35.0	180	720	50	50	591.0	295.5	490.60	10.08	0.90	2.36	503.94	
	I + II + III in total		326.1	324	1,296	1,567	1,567	10,804.1	5,403.6	4,572.81	18.14	28.21	43.22	4,662.38	

Source: own calculation based on surveys carried out by the Warmińsko-Mazurski University in Olsztyn in the year 2011 as part of the project

Taking into account the potential of the following biomass: straw from cereal crops, grasses from unused meadows, biomass from the upkeep of roadside trees and energy plant plantations, the overall biomass potential in the communes (those that responded to the surveys) is as follows (Table 1):

- South Group – 2,155.94 TJ/per annum,
- North Group – 2,002.50 TJ/ per annum,
- Biała Podlaska – 503.94 TJ/ per annum.

The straw biomass potential was determined based on the data from the Central Statistical Office from the year 2010 in districts situated near the thermal plants. Based on the data from the Central Statistical Office, taking into account the area of cereal crops and the harvest volumes of four primary cereals, it was possible to determine the overall harvest of straw; out of its total value, only 30% was accepted for energy purposes [Kuś, Matyka 2010, Rogulska 2003]. From the overall amount of straw, similarly as in the analysis of the communes, the amount of straw that is required for ploughing in soil to maintain an adequate level of humus was accepted. In addition, the amount of straw required to be used as litter for animal breeding was taken into account (according to the Institute of Soil Science and Plant Cultivation in Puławy). The straw potential related to districts that constitutes a surplus (for energy purposes) was calculated by accepting 14 GJ/t of straw. The straw energy potential in relation to districts in the South Group of the “Together Warmer” Cluster constitutes 6,008.47 TJ per annum, in the North Group: 4,290.94 TJ per annum, and in the region of Biała Podlaska –1,972.20 TJ per annum. The total straw biomass potential for energy purposes related to districts in the region of the thermal plants from the South Group and North Group is 10,298 TJ per annum. This offers the possibility to almost completely satisfy the energy needs of the local thermal plants [Jasiulewicz 2011].

As assessed by the users of the thermal plants, the full capacity of the thermal plants is only used very rarely; most frequently, this is 50 to 70%. Hence, the use of energy raw materials is substantially lower than peak values, and the quantity of biomass that is available locally should satisfy the needs. What also needs to be noted is the substantial improvement in the area of the thermal insulation of buildings and an improved condition of heat distribution networks, which has substantially limited heat demand on the part of users.

## SUMMARY AND CONCLUSIONS

Taking into consideration the energy provision for system thermal plants with biomass raw materials over a long period of time, changes need to be taken into account in the structure of production directions, especially in the reduction of the share in cereal crops, which will cause a reduction in the harvest both of cereals and straw. Therefore, when opting for a replacement of energy fuel with biomass, one needs to be secured by creating one’s own plantations of perennial energy plants such as wicker or poplar. This is all the more justifiable that the majority of the communes in the Warmińsko-Mazurskie Province possess good conditions for the cultivation of energy plants [Jasiulewicz 2007a,b, Faber et al. 2009]. The area of the Warmińsko-Mazurskie Province is, to a large extent, covered with forests (34%), which is an additional chief asset as regards the use of biomass as an

energy fuel. The establishment of the plantations of perennial energy plants also involves the necessity to purchase specialist equipment in logistics centres: for planting, harvesting (including chipping), transport and the possibly of processing to produce pellets. Such a logistics centre, one that is well equipped, should provide services to several thermal plants by providing these with biomass fuel characterised by adequate parameters. The processing of raw biomass into pellets is also recommended considering the favourable parameters of pellets, which include:

- a considerably greater energy value (t);
- a significantly greater bulk density ( $t/m^3$ ),
- safety and easy storage (low humidity < 10%),
- easy use of transport,
- the possibility to simultaneously use various biomass types: agricultural, forest biomass and biomass from industrial production.

To conclude, it needs to be stated that the use of local waste (agricultural) biomass is fully justifiable, in place of hard coal used thus far. The use of modern technologies in the CHP system in a dispersed arrangement: in the existing municipal thermal plants is recommended.

The analysis conducted, related to the possibility of replacing hard coal with agricultural waste biomass in a local system, demonstrates that it is completely feasible. The decision related to the replacement of fuel involves the need to replace the boiler with one that is adapted to biomass combustion as well as the need for logistics preparation.

Coal and biomass co-combustion is absolutely not justifiable: there is no energy, economic or environmental justification.

The use of renewable sources in the form of local biomass counteracts the global warming phenomenon, which has an impact on the improved condition of the natural environment, sustainable development and the improved state of the residents' health. Furthermore, this contributes to meeting the RES targets in the European Union [Janeiro, Resch 2017].

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## MOŻLIWOŚĆ ZASPOKOJENIA POTRZEB ENERGETYCZNYCH W CIEPŁOWNIACH SYSTEMOWYCH PRZEZ WYKORZYSTANIE LOKALNEJ BIOMASY STAŁEJ

Słowa kluczowe: potrzeby energetyczne ciepłowni, zasoby lokalnej biomasy stałej, zaspokojenie potrzeb energetycznych

### ABSTRAKT

W warunkach lokalnych w zakresie energetyki ciepłej istotną sprawą jest wykorzystanie lokalnej biomasy, zwłaszcza odpadowej, jako surowca energetycznego w istniejących ciepłowniach systemowych. Celem opracowania jest oszacowanie możliwości zastąpienia węgla kamiennego, jako surowca energetycznego biomasą stałą. Biomasę stałą tworzą nadwyżki słomy zbóż oraz rzepaku, a także siano z niewykorzystanych łąk, pielęgnacji drzew przydrożnych oraz z plantacji upraw energetycznych. Badania przeprowadzono na przykładzie zrzeszonych ciepłowni w Kłastrze „Razem Ciepłej”. Klaster ten tworzy 10 ciepłowni w niedużych miastach województwa warmińsko-mazurskiego oraz w mieście Biała Podlaska (w województwie lubelskim). Całość zlokalizowana jest w północno-wschodniej Polsce. Ze względu na wysokie koszty transportu biomasy uwzględniono potencjał techniczny biomasy z obszaru w promieniu 30 km od ciepłowni. Oszacowany potencjał biomasy stałej dla każdej z 10 ciepłowni wskazuje, że większość ciepłowni lokalnych badanego klastra jest w stanie zaspokoić swoje potrzeby energetyczne (zastąpić węgiel kamienny) biomasą stałą z najbliższej okolicy. Przy podjęciu decyzji o zastąpieniu węgla lokalną biomasą – konieczne jest odpowiednie przygotowanie logistyki, a także wymiana kotłów w ciepłowniach na specjalne kotły do spalania biomasy stałej.

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