

Szubska-Włodarczyk, Natalia

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An estimate of the energy production potential of agricultural biomass in the łódź Province

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An estimate of the energy production potential of agricultural biomass in the Łódź province

Introduction

Agriculture is a sector that has a significant impact on the environment and on quality of life of the population. Therefore, it is an area where it is necessary to initiate action for sustainable development. According to the 2009/28/EC Directive, Poland should achieve the level of 15% of energy being obtained from renewable resources in the total consumption in 2020. This goal will not be achieved without focusing activities on the development of dispersed energy production, including the activation of rural areas.

The aim of the study is:

- to estimate energy production potential of fallow soil and fallow land in the Łódź Province on the basis of selected energy crops,
- to calculate the minimum price of energy crops.

The following analysis verifies the main research hypothesis, i.e., that the Łódź Province has a theoretical and economical energy-production potential of biomass production in the areas of fallow soil and fallow land.

Key words: biomass, energy crops, the minimum price, energy and climate policy

JEL classification: Q1, Q4, Q5

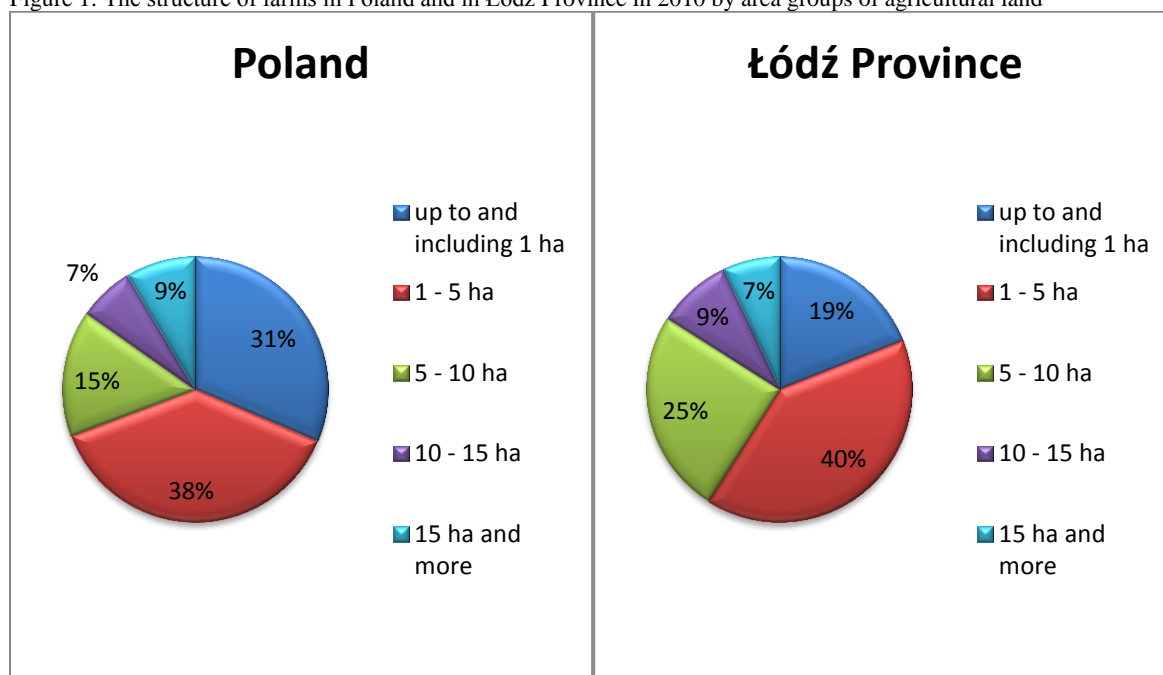
Methodology

Analysis of the area for sowing the energy crops

According to the Agricultural Census of 2010, the number of farms in Poland stands at 2,278 thousand. The number decreased by 656 thousand farms compared to 2002. The average size of agricultural land in a farm in the entire country is 6.82 hectares. The largest drop in the number of farms has been among the smallest ones, i.e., those up to 1 ha of arable land, and those between 1 and 5 hectares. A significant increase in the number of the largest farms (over 20 hectares) was also observed. The Łódź Province follows the national statistics. The largest part in the area structure are farms ranging from 1 to 5 hectares (40% of the total), followed by farms between 5 and 10 ha, as well as those under 1 ha. Figure 1 shows a

summary of the structure of farms, including the area groups of agricultural land in Poland and in Polish agricultural area and the Province of Łódź.

Figure 1: The structure of farms in Poland and in Łódź Province in 2010 by area groups of agricultural land



Source: own study based on the 2010 Agricultural Census, Central Statistical Office (GUS)

The total area of agricultural land in Poland in 2010 amounted to 15,534 thousand hectares. Compared to 2002, it decreased by 1365 thousand hectares. The area of agricultural land for sowing was 10,565 thousand hectares, the area of orchards - 363 thousand hectares, permanent grassland - 3,255 thousand ha. The share of sown area in the total of agricultural land is 68%. In addition, the structure of land used for sowing was as follows: 68% of agricultural land for cultivation were grain and cereals - 7,187 thousand ha, potatoes - 387 thousand ha, sugar beets - 206 thousand ha, rape (coarse seed) and agrimony - 946 thousand ha, ground vegetables - 139 thousand ha. According to the Central Statistical Office (GUS) data, the structure of agricultural crops changed, compared to 2002. The area of cereal crops was reduced by 5.8%, potatoes – by 3.8%, sugar beet by 0.85 and ground vegetables by 0.3%. However, there was a marked increase in rape (coarse seed) and agrimony by 4.9% and mangold by 3.3%¹. In the Łódź Province, grains predominate (79%) in the total sown area, followed by soilage (8.5%), potatoes (6.0%), industrial crops (3.3%), edible legumes (pod vegetables) (0.1%) and other crops (2.9%)².

¹ GUS (Central Statistical Office), [2011], *Rocznik statystyczny rolnictwa 2010* (Statistical yearbook of agriculture 2010), Zakład Wydawnictw Statystycznych, pp. 2-5.

² Urząd Statystyczny w Łodzi (Statistical Office in Łódź), [2012], *Rolnictwo w województwie łódzkim w 2011 r.* (Agriculture in the Łódź Province in 2011), Informacje i Opracowania Statystyczne.

The Łódź Province covers a total area of 18,219 km². In 2011 agricultural land accounted for 87.9% of the total area. Fallow land and other undeveloped agricultural land for sowing occupy 6.6% of the total. In the region, the largest percentage of fallow and waste land is in the Bełchatów (16%), Opoczno (12%), Radomsko (12%) and Pajęczno (11%) districts. These regions are located in the southern part of the Province of Łódź. It is related to the presence of the largest open lignite quarry in Poland in the Bełchatów district. The average farm size in the Łódź Province is 7.04 ha.

Table 1: Area of districts of the Łódź Province including agricultural land use

Item	Area in km ²	Total area of farms in [ha]						
		land total	agricultural land total	agricultural land in good culture	sowed	fallow land, including green manure	remaining agricultural land in [ha]	Average total land area
Province total	18219	1152537.66	996978.35	954238.06	733211.30	21370.41	42740.30	7.04
District of Brzeziny	359	29145.42	22928.61	22370.34	19179.71	435.90	1230.54	6.36
District of Łódź - East	500	27992.55	25015.16	23784.63	19401.67	718.42	1285.85	6.08
District of Pabianice	492	27445.28	23700.06	22414.21	15883.96	651.83	1298.23	7.66
District of Zgierz	855	46949.39	41697.96	40399.73	30599.37	1242.85	558.27	7.78
District of Bełchatów	968	48799.04	35638.36	31535.17	19764.37	1600.89	4103.19	5.14
District of Opoczno	1040	57494.67	46042.11	41450.02	28320.20	1120.15	4592.09	5.32
District of Piotrków Trybunalski	1429	85339.94	74193.57	71461.57	59360.26	1383.83	2732.01	7.23
District of Radomsko	1443	77284.33	65669.86	59295.81	42774.91	1820.92	6374.06	6.07
District of Tomaszów Mazowiecki	1025	56445.07	49600.93	46280.75	37857.34	1289.81	3320.18	5.41
District of Łask	618	39650.76	32776.66	30746.44	22044.87	871.02	2030.22	6.89
District of Pajęczno	804	49015.54	40308.63	36964.33	28209.11	1260.48	3344.30	5.82
District of Poddębice	881	62388.27	55582.04	54619.72	39310.36	470.18	962.32	9.50
District of Sieradz	1491	103158.88	90020.85	88738.71	72670.08	702.58	1282.13	7.35
District of Wieluń	926	63241.82	52621.90	51048.30	43059.66	1035.09	1573.60	6.43
District of Wieruszów	577	37975.77	32453.94	30770.54	25215.83	1231.69	1683.40	6.73
District of Zduńska Wola	369	22526.01	19416.76	18254.49	14342.82	566.64	1162.28	5.59
District of Kutno	887	72011.25	68023.60	67650.09	59531.17	655.89	373.51	10.77
District of Łęczyca	773	64471.16	60096.01	59436.91	47180.55	442.94	659.09	9.07
District of Łowicz	988	81117.64	72543.87	71369.46	56524.76	826.61	1174.41	8.61
District of Rawa Mazowiecka	646	48139.42	43164.10	42099.08	19063.79	1574.37	1065.01	7.28
District of Skierniewice	755	51945.45	45483.37	43547.76	32916.51	1468.32	1935.61	6.74

Source: own study based on Central Statistical Office (GUS) data, Agricultural Census 2010.

It should be assumed that both in Poland and in the Łódź Province farming has a fragmented structure. Agricultural land of small area groups dominates. In the context of the use of the remnants of agricultural production for energy production, this feature has a negative effect on the development of local biomass markets. As a consequence, it is impossible to obtain potential agricultural raw materials for energy production due to the use of the remnants for own use. On the other hand, if there is surplus of production, the cost of collection and transportation of agricultural waste to decentralised centres is likely to be high. Moreover, high quality of the raw material seems unlikely to be assured due to the prolonged time of delivery to the target unit.

In order to select suitable energy crops, the agrochemical state of soil in the Łódź Province must be characterised. The study assumed that these values are the main determinant. It appears to be known that the more favourable these indices, the greater the probability of obtaining higher yield in crop production.

The main indicators of soil fertility include: the pH, the amount of assimilable forms of nitrogen, potassium, magnesium, phosphorus, mineral content, quality and abundance of groundwater. Soil fertility is formed naturally in the soil-forming processes. It is possible to increase fertility through the use of appropriate types and doses of fertilisers. Land productivity is defined as the quantity of plant biomass production³.

According to studies by IUNG (National Institute of Crop Science and Plant Cultivation in Puławy), nearly 70% of soils in the Łódź Province are highly acidic or acidic. This index is the highest, compared to other regions of Poland. The pH of the soil affects the plants' ability to absorb nutrients. More than 50% of soils require liming. Soils with pH<5 have the ability to collect heavy metals easier. The region's share of soil with low and very low average content of N_{min} (mineral nitrogen) in the spring is at a level of 20-30%. Nitrogen is an essential crop-producing component. On average, 20-40% of soils in the Łódź Province have low phosphorus content, and nearly 80% of soils have low and very low potassium contents. However, 50% of the soil is characterised by low and very low magnesium content⁴.

³ K. Filipiak, [2010], *Syntetyczny wskaźnik żyzności gleby (Synthetic index of soil fertility)*, [in:] M. Fotyma [ed.], *Nawozy i nawożenie (Fertilizers and fertilization)*, Polskie Towarzystwo Nawozowe, 41, IUNG, Puławy, pp. 7, 8.

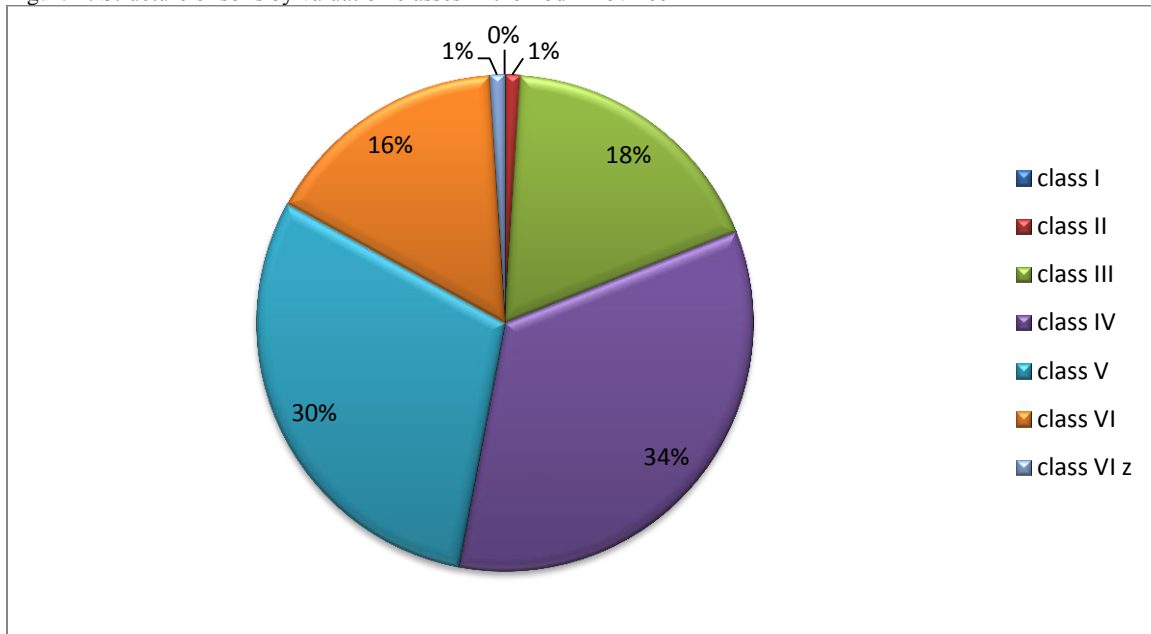
⁴ J. Igras, W. Lipiński, [2006], *Regionalne zróżnicowanie stanu agrochemicznego gleb w Polsce (Regional differentiation of the agrochemical condition of soil in Poland)*, [in:] Harasim A. [ed.], *Regionalne zróżnicowanie produkcji rolniczej w Polsce (Regional differentiation of agricultural production in Poland)*, Raporty PIB 3, Zeszyt 3, Instytut Upraw Nawożenia i Gleboznawstwa, Państwowy Instytut Badawczy, pp. 71 – 79.

About 16.4% of agricultural land in the Łódź Province is at risk of surface erosion⁵. This share is not the worst in the country, because the region is in eleventh place out of sixteen regions.

The research by Igras J. and W. Lipiński indicates that the Łódź province, together with the świętokrzyskie, mazowieckie, podlaskie and lubuskie provinces, is classified as a fourth region on a scale of 1 to 4. This region is characterised by the lowest intensity of crop production, the worst soils, low levels of fertilisation, particularly with calcium components, and the worst indicators of soil quality⁶.

The soils that predominate in the region are of the IV, V and VI valuation class (80% of the total). Figure 2 shows the structure of soil by valuation class.

Figure 2: Structure of soils by valuation classes in the Łódź Province



Source: own study based on CSO (GUS), Statistical Yearbook of Agriculture 2010, Zakład Wydawnictw Statystycznych, Warszawa 2011.

According to research by the European Regional Centre for Ecohydrology (Europejskie Regionalne Centrum Ekohydrologii) the problems associated with scarcity and poor quality of water are common in Poland in general, as well as in the Łódź Province. There is a noticeable reduction of water level in lakes, reservoirs and in the ground. Climate changes, the gradually increasing average air temperature affects the deterioration of retention capacity water

⁵ S. Krasowicz, W. Oleszek, J. Horabik, R. Dębicki, J. Jankowiak, T. Stuczyński, J. Jadczyzyn, [2011], *Racjonalne gospodarowanie środowiskiem glebowym Polski (Rational economic management of soil environment in Poland)*, [in:] Polish Journal of Agronomy, No. 7, pp. 43 – 58.

⁶ J. Igras, W. Lipiński, [2006], *Ocena wybranych elementów stanu żyzności gleby i jakości płytkich wód gruntowych na tle intensywności produkcji roślinnej w ujęciu regionalnym (Evaluation of selected elements of soil fertility condition and of quality of shallow groundwater on the background of intensity of crop production by the region)*, [in:] Pamięnik Puławski, Zeszyt 142, pp. 147 – 162.

resources and the drying of the outer layer of the soil⁷. As a consequence of that, agricultural productivity will reduce, the quality of agricultural products will deteriorate, the supply of agricultural products will reduce, prices will rise and the public health will deteriorate.

Selection of plants for energy production

It has been assumed that in the model, fallow land and waste land in the Łódź Province, as well as river basins, had been allocated for energy crops. The choice has been made from the following energy crops grown in Poland:

- Osier (*Salix viminalis*)
- Virginia mallow (*Sida hermaphrodita*)
- Multiflora rose/baby rose (*Rosa multiflora*)
- Giant miscanthus/elephant grass/chinese silver grass (*Miscanthus sinensis gigantea*)
- Sugar miscanthus (*Miscanthus sacchariflorus*)
- Switchgrass (*Panicum virgatum*)
- Prairie tallgrass/Big bluestem (*Andropogon gerardi*)⁸.

The agro-chemical conditions of the region, presented above (section 1.1), indicate that it is necessary to choose a little-demanding plant in terms of cultivation requirements. The choice should be made between osier, miscanthus and Virginia mallow. Other plants were eliminated from further consideration due to:

- susceptibility to weed - Prairie tallgrass⁹;
- energy-intensive production and inefficiency in the production of alcohol - switchgrass¹⁰;

⁷ Z. W. Kundzewicz, M. Zalewski, A. Kędziora, E. Pierzgałski, [2010], *Zagrożenia związane z wodą (Water-related threats)*, Nauka 4, pp. 87 – 96.

⁸ A. Zawadzka, M. Imbierowicz, [2010], *Rośliny energetyczne oraz technologie i urządzenia dla przetwórci biomasy (Energy crops and technologies and equipment for biomass-processing facilities)*, [in:] Kochańska E. [ed.], *Inwestowanie w energetykę odnawialną. Aspekty ekologiczne, technologie, finansowanie i benchmarking (Investing in renewable energy. Ecological aspects, technology, financing and benchmarking)*, Stowarzyszenie Doradców Gospodarczych Pro-Akademia, pp. 169, 170.

⁹ W. Budzyński, S. Bielski, [2004], *Surowce energetyczne pochodzenia rolniczego. Cz. II. Biomasa jako paliwo stałe (artykuł przeglądowy) (Fuels of agricultural origin. Part II. Biomass as solid fuel (review article))*, Acta Sci. Pol., Agricultura 3(2), pp. 19.

¹⁰ A. Zawadzka, M. Imbierowicz, [2010], *Rośliny energetyczne oraz technologie i urządzenia dla przetwórci biomasy (Energy crops and technologies and equipment for biomass-processing facilities)*, [in:] Kochańska E. [ed.], *Inwestowanie w energetykę odnawialną. Aspekty ekologiczne, technologie, finansowanie i benchmarking*

- high water content at the time of the final harvest – multiflora rose¹¹;

The reasons for the choice of other energy crops were the following.

Miscanthus has a C₄ photosynthetic pathway, which allows efficient use of water and minerals and efficient use of solar radiation. The negative feature of this plant is that the reproduction, in the Polish climatic conditions, can only be vegetative. In the conditions of the habitat it does not produce fertile seeds. Miscanthus is also susceptible to freezing¹². However, it seems that this plant has the potential for further development for energy purposes. Miscanthus prefers class IV and V soils. It has lower water and soil requirements than osier¹³.

Virginia mallow can give crop on arid lands. It is compared to osier. The problem is the low germination rate of seeds (often 30 - 50%)¹⁴.

Osier requires class III - IV soil with relatively high humidity. It has a large potential for biomass production and is suitable for energy-production and industrial use¹⁵. In practice, it is harvested manually on small plantations. In the case of large plantations, machine harvesting is used. The main disadvantage of this type of harvesting is the high cost of harvesting machines¹⁶. The amount of crop obtained depends on many factors such as: soil type and humidity, fertilizing, seedling quality, accuracy of soil preparation for planting, etc. In practice, osier is harvested every year, every two or every three years, the latter being the

(*Investing in renewable energy. Ecological aspects, technology, financing and benchmarking*), Stowarzyszenie Doradców Gospodarczych Pro-Akademia, pp. 174, 175.

¹¹ D. Chołuj, S. Podlaski, G. Wiśniewski, J. Szmalec, [2008], *Kompleksowa ocena biologicznej przydatności 7 gatunków roślin wykorzystywanych na cele energetyczne (Comprehensive evaluation of biological suitability of seven plant species used for energy-production purposes)*, [in:] A. Harasim [ed.], *Uprawa roślin energetycznych a wykorzystanie rolniczej przestrzeni produkcyjnej w Polsce (Growing energy crops and the use of agricultural production space in Poland)*, Studia i Raporty, Zeszyt 11, IUNG PIB, Puławy, pp. 81 – 99.

¹² M. Matyka, J. Kuś, [2011], *Plonowanie i cechy biometryczne wybranych genotypów miskanta (Yielding and biometric characteristics of selected genotypes of Miscanthus)*, Problemy Inżynierii Rolniczej, 2, pp. 157, 158.

¹³ J. Kolowca, M. Wróbel, [2010], *Wpływ wilgotności na właściwości reologiczne rozdrobnionej trawy energetycznej Miscanthus Giganteus (Influence of humidity on rheological properties of crumbled energy grass Miscanthus Giganteus)*, Inżynieria Rolnicza 4(122), pp. 115, 116.

¹⁴ M. Grzesik, R. Janas, Z. Romanowska – Duda, [2011], *Stymulacja wzrostu i procesów metabolicznych ślazuca pensylwańskiego (Sida hermaphrodita L. Rusby) za pomocą hydrokondycjonowania nasion (Stimulation of growth and metabolic processes of Virginia mallow (Sida hermaphrodita L. Rusby) by hydroconditioning of seeds)*, Problemy Inżynierii Rolniczej, 4, pp.81, 82.

¹⁵ A. Zawadzka, M. Imbierowicz, [2010], *Rośliny energetyczne oraz technologie i urządzenia dla przetwórci biomasy (Energy crops and technologies and equipment for biomass-processing facilities)*, [in:] Kochańska E. [ed.], *Inwestowanie w energię odnawialną. Aspekty ekologiczne, technologie, finansowanie i benchmarking (Investing in renewable energy. Ecological aspects, technology, financing and benchmarking)*, Stowarzyszenie Doradców Gospodarczych Pro-Akademia, pp. pp. 169, 170.

¹⁶ D. Kwaśniewski, K. Mudryk, M. Wróbel, [2006], *Zbiór wierzby energetycznej z użyciem piły łańcuchowej (Harvesting osier with a chainsaw)*, Inżynieria Rolnicza 13, pp. 271, 272.

most efficient from the perspective of energy yield and energy-intensiveness. Large woody biomass growth is observed in that case. The useful life of the plantation is 25 - 30 years¹⁷.

Theoretical assumptions for the calculation of minimum prices of energy obtained from energy crops

The cost calculation (Table 2) was based on research by IUNG, with inflation rate taken into account. The calculation included the preparation of the field, the purchase cost of seedlings, the annual cost of care, fertiliser and remuneration for labour. In addition, the cost of machine harvesting¹⁸ was taken into account.

Table 2: Cost of setting up plantations of selected species of energy crops (prices as of the first quarter of 2009)

Species		Osier	Miscanthus	Virginia mallow	
reproduction material		cuttings	seedlings	seeds	seedlings
preparation of the field	soil testing	20			
	use of machines	941		871	941
	fertilisers, herbicides	832		729	832
	remuneration	97		54	97
cost of purchase (growing a seedling)	1800	16250	3000	3000	
cost of planting	use of machines	60	60	120	60
	remuneration	1156	1123	76	1728
Cost of care (first year of vegetation)	use of machines	340	200	340	
	fertilisers, pesticides	545	267	545	545
	remuneration	3564			
Total cost of setting up a plantation in PLN/ha/year	9355	2354	9319	11127	

Source: IUNG-PIB Puławy [in] Skrótnicki H. (ed.), *Skrócone normatywy produkcji rolnej, (Abridged standards for agricultural production)*, Wydawnictwo Ministerstwa Rolnictwa i Rozwoju Wsi, Radom 2010, Radom 2010, p 32;

The Net Present Value (NPV) method was used to calculate the minimum price. The following formula is used:

Formula 1:
$$NPV = \sum_{t=0} CF_t \times DF_t$$

where,

CF_t – Cash Flow

DF_t – discount factor ($DF = \frac{1}{(1+r)^n}$; where r – discount rate, n – the number of years)

It has been assumed that the minimum price¹⁹ for energy obtained from energy plantations was established for NPV = 0. Determining the appropriate discount rate was a

¹⁷ D. Baran, D. Kwaśniewski, K. Mudryk, [2007], *Wybrane właściwości fizyczne trzyletniej wierzby energetycznej (Selected physical properties of three-year old osier)*, Inżynieria Rolnicza 8(96), p. 7.

¹⁸ A. Lisowski [ed.], [2010], *Technologie zbioru roślin energetycznych (Harvesting techniques of energy crops)*, Wydawnictwo SGGW, pp. 126 – 132.

¹⁹ K. Havlíčková, J. Weger, J. Knápek, [2011], *Modeling of biomass prices for bio-energy market in the Czech Republic*, Stimulation Modelling Practice and Theory 19, pp. 1946 – 1956.

problematic issue. The project to adapt fallow land for growing energy crops does not have a clearly defined subject to real property ownership rights. Therefore, this paper presents the prices of biomass for the individual energy crops, taking into account the social discount rate (SDR) of 5.5% as recommended by the European Commission²⁰, the discount rate of 3% as recommended by the EPA²¹ and the discount rate of 7.796% as set by the President of the Energy Regulatory Office (URE) in 2012 as the weighted average cost of capital after tax²².

It should be noted that the calculated minimum price for each energy crop was determined from the perspective of the use of fallow and waste land in the Łódź Province. The analysis does not take into account the cost of transportation and processing of biomass. This is due to the fact that the research of the convenient location of distributed units is in progress.

Results

Analysis of energy potential of the selected energy plants

Considering the agrochemical conditions of the Łódź Region, the analysis assumed planting miscanthus and Virginia mallow (*Sida*) on fallow land, and planting osier along river beds. The model assumed the need to incorporate best practices as far as water management is concerned. Osier is grown perennially. There is a concern that in the long run, if osier is planted on fallow land, it will adversely affect the water balance of the area.

The values presented in Table 3 were used to estimate the energy-production potential of the crops.

Table 3: Dry matter yield and calorific value of selected energy crops

Feature	Virginia mallow (<i>Sida hermaphrodita</i>)	Miscanthus	Osier (<i>Salix viminalis</i>)		
			harvest each year	harvest every two years	harvest every three years
dry matter yield [t/ha]	10.7	17.7	14.8	16.1	21.5
calorific value GJ/ha	17.4	17.3	18.56	19.25	19.56

Source: own research, based on W. Budzyński, S. Bielski, *Surowce energetyczne pochodzenia rolniczego. Cz. II. Biomasa jako paliwo stałe (artykuł przeglądowy) (Fuels of agricultural origin. Part II. Biomass as solid fuel (review article))*, Acta Sci. Pol., Agricultura 3 (2) 2004; J. Kuś, A. Faber, M. Stasiak, A. Kawalec, *Plonowanie wybranych gatunków roślin uprawianych na cele energetyczne na różnych glebach (Yielding of selected plant species grown for energy purposes on different soils)*, Problemy Inżynierii Rolniczej, 1/2008; M. Matyka, J. Kuś, *Plonowanie i cechy biometryczne wybranych*

²⁰ Komisja Europejska, Dyrekcja Generalna ds. Polityki Regionalnej (European Commission, Directorate-General for Regional Policy), [2008], *Przewodnik do analizy kosztów i korzyści projektów inwestycyjnych. Fundusze strukturalne, Fundusz Spójności oraz Instrument Przedakcesyjny (Guide to cost-benefit analysis of investment projects. Structural Funds, the Cohesion Fund and the Instrument for Pre-Accession)*, Final Report, p. 62.

²¹ M. Ligus, [2012], *Efektywność inwestycji w odnawialne źródła energii. Analiza kosztów i korzyści (Efficiency of investment in renewable energy resources. Cost-benefit analysis)*, Wydawca CeDeWu Sp. z o.o., p. 59.

²² Urząd Regulacji Energetyki, Departament Taryf, *Taryfy OSD na rok 2012 (dotyczy OSD, którzy dokonali z dniem 1 lipca 2007 r., rozdzielenia działalności)*, Warszawa, Listopad 2011 (Energy Regulatory Office, Department of Tariffs, *DSO Tariffs for 2012 (applies to DSOs who separated business activities on 1 July 2007)*, Warsaw, November 2011, p. 11.

genotypów miskanta (*Yielding and biometric characteristics of selected genotypes of Miscanthus*), Problemy Inżynierii Rolniczej 2/2011; T. Piskier, *Potencjał energetyczny topinamburu (The energy potential of Jerusalem artichoke)*, Problemy Inżynierii Rolniczej, 1/2009.

The main rivers in the Province are the Bzura, Pilica and Warta²³. The length of rivers in the Łódź Province is estimated to be about 1300 km. It has been assumed that osier will be planted along the river beds on both sides of the river, in a 5-metre wide belt (the average length of an arm of harvesting equipment has been taken into account to minimize energy consumption in production). In addition, it has been taken into account that osier will be planted along 50% of the length of the rivers (areas protected by law must be concerned). The total area of the plantations is 650 ha. Assuming a short-cycle harvest, the dry matter yield is theoretically assumed at 9,620 tonnes, which gives 178,547.2 GJ of obtainable energy. However, if a harvest every two years is assumed, the dry matter yield is 10,465 tonnes, which can produce 201,451.25 GJ of energy. In the case of a harvest every three years, the dry matter yield is 13,975 tonnes, which gives 273,351 GJ of energy. The results of the estimate of energy potential for the other energy crops are presented in Table 4.

Table 4: Estimated energy-production potential of selected plants in the districts of the Łódź Province

Item	area for sowing in ha	theoretical potential			
		Virginia mallow (<i>Sida hermaphrodita</i>)		miscanthus	
		Dry matter yield t/year	Energy yield TJ/t of dry matter	Dry matter yield t/year	Energy yield TJ/t of dry matter
Łódź Province	64110.71	685984.6	11935.9	1134760	19630.9
District of Łódź – East *	1948.96	20853.87	362.8	34496.59	596.8
District of Pabianice	1937.68	20733.18	360.8	34296.94	593.3
District of Zgierz	2541.08	27189.56	473.1	44977.12	778.1
District of Brzeziny*	994.17	10637.62	185.1	17596.81	304.4
District of Bełchatów	5704.08	61033.66	1062.0	100962.2	1746.6
District of Opoczno	5712.24	61120.97	1063.5	101106.6	1749.1
District of Piotrków Trybunalski	4115.84	44039.49	766.3	72850.37	1260.3
District of Radomsko	8194.98	87686.29	1525.7	145051.1	2509.4
District of Tomaszów Mazowiecki	4609.99	49326.89	858.3	81596.82	1411.6
District of Łask	2901.24	31043.27	540.1	51351.95	888.4
District of Pajęczno	4604.78	49271.15	857.3	81504.61	1410.0
District of Poddębice	1432.50	15327.75	266.7	25355.25	438.6
District of Sieradz	1984.71	21236.4	369.5	35129.37	607.7
District of Wieluń	2608.69	27912.98	485.7	46173.81	798.8
District of Wieruszów	2915.09	31191.46	542.7	51597.09	892.6
District of Zduńska Wola	1728.92	18499.44	321.9	30601.88	529.4
District of Kutno	1029.40	11014.58	191.6	18220.38	315.2
District of Łęczyca	1102.03	11791.72	205.2	19505.93	337.4
District of Łowicz	2001.02	21410.91	372.5	35418.05	612.7

²³ Wojewódzki Program Małej Retencji dla województwa łódzkiego, Synteza [2005], (*Regional Small Retention Program for the Łódź Province, a synthesis*), M. Marszałek, S. Wiśniewski, at the order of the Wojewódzki Zarząd Melioracji i Urządzeń Wodnych.

District of Rawa Mazowiecka	2639.38	28241.37	491.4	46717.03	808.2
District of Skierniewice	3403.93	36422.05	633.7	60249.56	1042.3

Source: own study

Altogether, the development of fallow land in the Łódź Region can theoretically yield 11.9 PJ of energy from Virginia mallow (Sida) and 19.6 PJ of energy from miscanthus. The District of Radomsko is the area with the highest potential for energy yield from both the plants. However, the highest energy-production potential of Virginia mallow (Sida) is noted in the District of Opoczno.

Profitability analysis of energy production from selected energy crops

The cost of biomass production from energy crops was calculated in the short term and in the long term perspective. The short-term perspective took into account, in the case of Miscanthus and Virginia mallow, the costs until the first harvest, that is, in the second year since setting up of the plantation. In the case of osier, the costs were estimated for the first harvest after a year, after two and after three years.

The long-term perspective took into account the possibly shortest time of existence of perennial plantations. A period of 15 years was adopted for miscanthus and Virginia mallow (Sida), and a period of 20 years was adopted for osier.

The cost of preparation of land for agricultural biomass production, from the perspective of the entire Łódź Region, differed depending on the plant. It seems obvious that the development of river beds for growing osier is the least expensive, if only because of the area of the developed land. The cost of setting up an osier plantation was estimated at 6.11 million PLN. The total cost of harvest was 617 thousand PLN on the average. However, the annual cost of care in later years was assumed at 2.9 million PLN.

The cost of planting Virginia mallow (sida) was estimated separately for seeds and seedlings. The total cost of setting up plantations from the perspective of the entire Łódź Region was estimated at: for seeds - 600.5 million PLN and for the seedlings - 717 million PLN. The estimated cost of the harvest for seeds and seedlings amounted to 60.9 million PLN. The cost of care in the long term amounted to 286.6 million PLN.

The cost of setting up a miscanthus plantation is higher than for Virginia mallow (Sida) and amounts to 1.5 thousand million PLN. The total cost of harvest was assumed to be at the same level as in the case of Virginia mallow (Sida). However, the annual cost of care amounted to 259.7 million PLN. It is lower than in the case of Virginia mallow by 26.9 million PLN.

The analysis of the data indicates that in the short term perspective, i.e., when setting the price for NPV = 0 during the first harvest, the price levels are similar for miscanthus and Virginia mallow and osier with annual harvest. A substantial reduction of prices for osier harvested every two and three years is noticeable.

In the long term perspective the prices are the lowest for osier. The price is quite significantly different for Virginia mallow (sida). This is due to the fact that the seeds have a low germination rate. Despite the difficulties related to reproduction of miscanthus in the Polish climatic conditions, this plant seems to be competitive with osier.

Table 5: Summary of minimum prices for plantations of selected energy crops

Plantation duration	Minimum price [PLN/GJ]					
	miscanthus	Virginia mallow		osier		
		seeds	seedlings	harvest each year	harvest every two years	harvest every three years
Short-term perspective (7.796% discount)	54.49	52.57	57.63	53.96	31.63	19.35
Short-term perspective (5.5% discount)	57.53	52.32	57.33	53.96	31.49	19.20
Short-term perspective (3% discount)	53.65	52.05	57.00	53.96	31.32	19.03
Long-term perspective (discount 7.796%)	25.13	34.00	35.06	22.93	18.73	13.37
Long-term perspective (5.5% discount)	23.28	33.39	34.31	22.45	18.32	13.07
Long-term perspective (3% discount)	22.31	32.79	33.59	21.97	17.91	12.77

Source: own study

According to the Energy Regulatory Office (URE) there is one biogas plant in the Łódź Province, which produces energy from agricultural biomass, with a total installed capacity of 1.998 MW. Wind power systems dominate, with a total capacity of 216.365 MW.

The heat price in 2011 in Łódź Province determined by the weighted average method was 39.51 PLN/GJ (using the median of 44.60 PLN/GJ) and in 2012 – 39.93 PLN/GJ. The electricity price in 2012 was 227.68 PLN/MWh²⁴. The monthly reports²⁵ published by the Polish Power Exchange (TGE) indicate that in 2012, in the months from January to October,

²⁴ GUS (Central Statistical Office), [2012], *Gospodarka paliwowa – energetyczna w latach 2010, 2011 (Energy and fuel economics in the years 2010, 2011)*, pp. 234-237, GUS (Central Statistical Office), [2013], *Gospodarka paliwowo-energetyczna w latach 2011, 2012 (Energy and fuel economics in the years 2011, 2012)*, p. 235.

²⁵ Towarowa Gielda Energii S.A. (Polish Power Exchange S.A.), [2012], *Raport Miesięczny (Monthly Report)*, p.1.

the weekly average-weighted price oscillated around 180 PLN/MWh. According to the economic analysis of energy crops, the price per MWh for Sida (Virginia mallow) is at the level of PLN 126.21 to 120.91 depending on the assumed discount rate in the long term. In comparison, this price range for miscanthus is from 90.46 to 80.33 PLN, while the price for the osier is from 82 PLN/MWh to 46 PLN/MWh.

The total electricity consumption in the Łódź Province in 2011 was 11,751 GWh, which is nearly 8% of energy consumed in the country. Moreover, the total consumption in the Łódź Province in 2012 was 11,035 GWh which is 7.5% of energy consumed in the country. The theoretical potential of energy crops (taking into account the average energy value for osier harvested every year, every two or every three years) stands at: osier and miscanthus - 19,848.68 TJ and osier and sida - 12,153.68 TJ. These values are, respectively, for a mix with miscanthus - 47%, and for a mix with sida - 29% of the total electricity consumed in the Łódź Province.

Discussion

The term biomass include a lot of energy carrier. This is what the final product will become the processed biomass depends on: available substrate, technology and investment capacity. According to the European Parliament and Council 2009/28/EC Directive of 23 April 2009, biomass is the part of products, waste and biological residues from agriculture (including vegetal and animal substances), forestry, industry including the fisheries and aquaculture as well as the biodegradable fraction of industrial and municipal waste²⁶.

Distinguished biomass from energy crops and by-products, i.e. the forestry industry and agriculture, nurturing of parks and gardens, food waste and the paper industry²⁷. The chemical energy of biomass by different conversion methods is transformation into heat, electricity and transport fuel. The carbon dioxide is byproduct of the chemical energy conversion. It is assumed that the carbon dioxide balance is zero because of the closed circuit - the amount of carbon dioxide in the transforming process to the final energy is equal the amount absorbed by the plant as a result of photosynthesis²⁸. Biomass is the raw material for the production of

²⁶ Dyrektywa Parlamentu europejskiego i Rady 2009/28/WE z dnia 23 kwietnia 2009 r. w sprawie promowania stosowania energii ze źródeł odnawialnych zmieniająca i w następstwie uchylająca dyrektywy 2001/77WE oraz 2003/30/WE (Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC), p. 27.

²⁷ S. van Dyken, B. H. Bakken, H. I. Skjelbred, [2010], *Linear mixed – integer models for biomass supply chains with transport, storage and processing*, Energy 35, p. 1338 – 1350.

²⁸ G. Jastrzębska, *Odnawialne źródła energii i pojazdy proekologiczne (Renewable energy sources and green vehicles)* Wydawnictwo Naukowo – Techniczne, Warszawa 2007, pp. 57, 58.

solid energy carriers (chips, pellets, briquettes), liquid energy carriers (ethanol, methanol) as well as gas energy carriers (woodgas, methane).

In Europe, notes the increased interest in biogas plants. Germany is a leading country where there are about 5,000 active biogas plant. The main energy raw material is corn. While livestock manure are supplement to energy production. They facilitate the decomposition of substrates. The European Union encourages to use of waste agricultural to energy production. In addition, the biogas plants can play a significant role in the sustainable rural development due to the decentralized nature, as well as enable the development of non-agricultural employment in rural areas and stimulating economic development in the region²⁹. In the literature is many studies on the use of energy crops. Intentional cultivation, i.e. to intend for the energy production, are the risks connected with the possibility of crowding out the food production. There is concern that with the using appropriate support agricultural policy instruments may adversely affect food security.

Biomass can be an important source of energy production to take into consideration the limited resources of coal and other conventional energy carriers (oil and gas). In addition, increased demand for renewable energy sources is conditioned by the need to reduce greenhouse gas emissions. Moreover, world population increase that generates GDP growth, it is expected to increase demand for food, including highly processed products, which require more energy to production. A various possibilities for the use of biomass enable transformation traditional agricultural production (food production) to obtain the real energy resources³⁰. The possibility of generate energy from renewable sources increases the competition between the agricultural and the energy sectors, which is result from a similar demand for natural resources. Growing legal requirements for the technical and biological food production is a huge problem for some developing countries³¹. It is necessary to integrated approach to the use and management of agricultural space.

The use of agricultural space for energy production incline to speculation on the food market. Observed the increase food prices in the world. In March 2011, food prices increased on average by 2.2% compared with February - the price of sugar increased by 39.4%, flour by 4.9%, bread by 2.6%, dairy products by 0.6%, vegetable fats and butter by 1.7%. Analyzing

²⁹ A. Kupczyk, A. Wójcik, M. Majkowska, [2010], *Wybrane problemy rozwoju sektora biogazu rolniczego w Polsce (Selected problems of agricultural biogas development in Poland)*, [in:] F. Krawiec [ed.], *Odnawialne źródła energii w świetle globalnego kryzysu energetycznego. Wybrane problemy (Renewable energy sources in the global energy crisis. Selected problems)* Diffin, pp. 77-87.

³⁰ A. Roszkowski, [2009], *Bioenergia – pola i lasy zastąpią węgiel, ropę i gaz?(Bioenergy – will fields and forests replace coal and oil)*, *Inżynieria Rolnicza* 1(110), pp. 243, 244.

³¹ BEFS, [2010], *Bioenergy and Food Security. The BEFS Analytical Framework*, *FAO*, pp. 3-10.

the interval from April 2010 to March 2011, food prices in Poland rose by 7.3%, in the United States by about 2.8%, in the European Union average of 3.3%. The highest increase food prices was recorded in Poland, Slovakia, Hungary, Romania, Bulgaria, Lithuania, Latvia, Estonia. The lowest increase this ratio has been shown in Norway, Sweden, Spain, France, Belgium and Switzerland³². The harvest all types of grain in the world gradually increased to 2008 and amounted to 2 520 700 thousand tons while fertilizer consumed per 1 ha of agricultural land. In contrast, the total harvest of grain in the world in 2009 declined by 31 398 thousand tons compared to 2008. Taking into consideration external shocks (i.e. natural disasters such as tornadoes in the United States, the tsunami in Japan) can be estimated that the grain harvest may further decline with further increase food prices. Crop production for energy purposes requires action for achieving energy efficiency, while in the crop production for food purposes – achievement high quality food. There is a fear soil over-exploitation in the case of use conventional methods for energy purposes. On the other hand, according to the concept of sustainable agriculture is required use the agriculture space to crop production for energy purposes without interference in the crop production for food purposes, taking the fallow land into consideration. In recent years there has been an increase the prices of all cereals in Poland - the price of decitonne wheat grain increased by nearly 50 % in February 2011 compared with 2009, and the price of rye approximately 40 %, barley about 53%, oats and mix cereal by 41%, triticale by 46%, maize by 50 %. In 2012, agricultural product prices increased on average 4.2% compared with the previous year. In 2013 there was a further increase prices of the agricultural products.

Topicality issues result from the need to implement EU energy and climate policy by the member states, and that take into consideration of the increasing role of renewable energy sources. In April 2013 the European Parliament in the project "Resolution on microgeneration - small-scale electricity and heat generation" stated i.e., the need to support action to enable the development of local renewable energy cooperatives/association and to engage of community. The guidelines aim to support the internal energy market, to enable the member states to implementation the energy package and climate protection package in 2030 and to ensure energy security in the long run.

Inappropriate use the economic instruments force to support the EU climate and energy policy have negative influence to use biomass as an energy source. Increase imports of biomass from developing countries in order to realize the objectives of climate package often

³² <http://epp.eurostat.ec.europa.eu>

is destabilized, not balanced on the EU world economy. In the report, "The Social Dimension of EU Biofuel Policy. Ecologic Briefs" (2012) identified many negative social factors as a consequence of biofuel policies. The main are: rising food prices, non-compliance with labor law, child labor on the energy plantations in low-developed countries, the sale of lands transnational companies, increase water consumption to production.

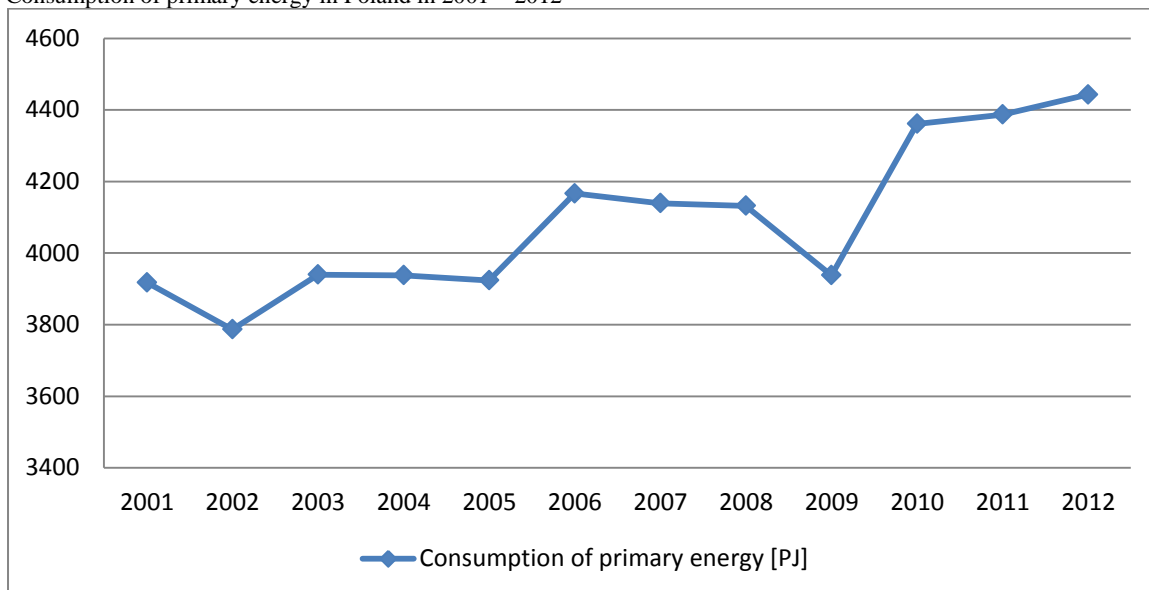
According to the forecasts of the Ministry of Economy, the economic potential of energy crops will reach 250.3 PJ in 2020. While the demand for biomass will be 299 PJ in 2020. According to forecasts energy prices could rise twice³³. In 2012 was used 467.4 PJ of heat and 525.1 PJ of electricity³⁴. The share of renewables in primary energy production was only 11.7% in 2012. Poland is obliged to achieve 15% of energy from renewable sources in final energy consumption in 2020. The difference between the primary and final energy is that the primary energy is included in the original carriers obtained directly from the environment. Whereas, the final energy is converted primary energy taking into consideration the efficiency of the processes of its processing. Therefore, it seems that the realization of Polish commitments will be difficult to achieve. One of the instruments to support the development of renewable energy are certificate of origin, the so-called green certificates. The problem is that the market is unstable. This is confirmed by a large drop price of green certificates in December 2012. The result was moved back power plants from co-firing of biomass with coal.

There is an observable trend to increase primary energy consumption in Poland. In 2012, the total stood at 4,443 PJ. The average energy consumption per capita was 114.4 GJ.

³³ Ministerstwo Gospodarki, [2009], *Prognoza zapotrzebowania na paliwa i energię do 2030 roku (Forecast demand for fuel and energy by 2030)*.

³⁴ GUS (Central Statistical Office), [2012], *Gospodarka paliwowo – energetyczna w latach 2010, 2011 (Energy and fuel economics in the years 2010, 2011)*.

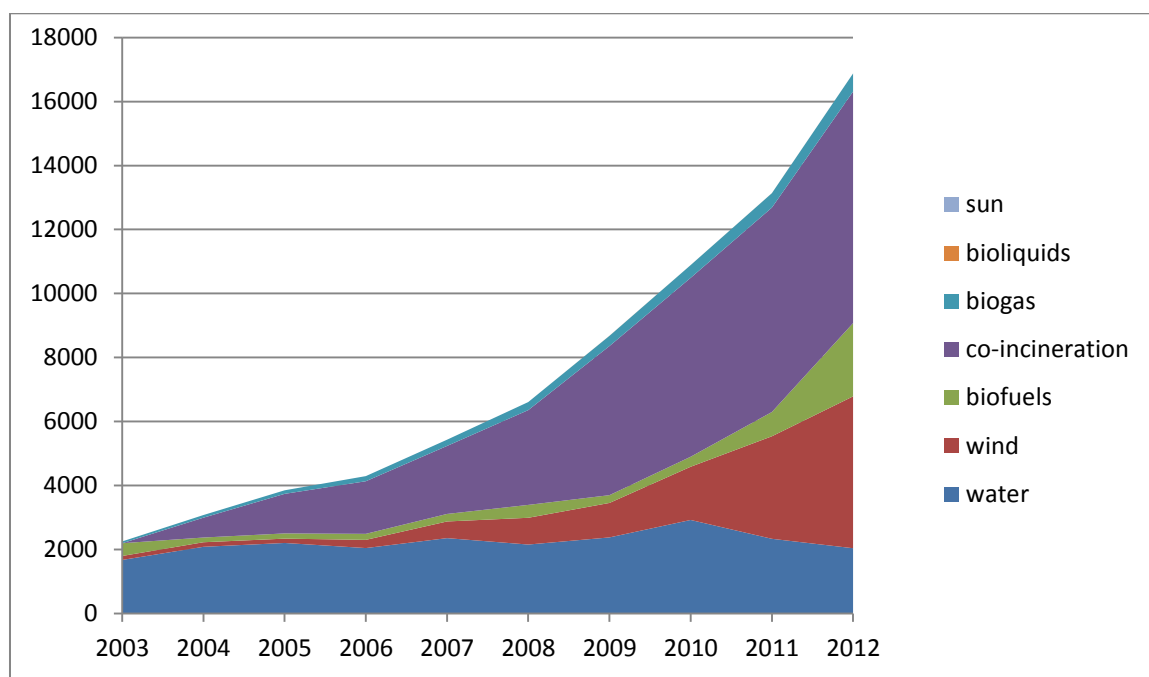
Figure 3: Consumption of primary energy in Poland in 2001 – 2012



Source: own study based on CSO (GUS), *Gospodarka paliwowo – energetyczna w latach 2010, 2011 (Energy and fuel economics in 2010, 2011)*, Warsaw 2012, p. 52 GUS, *Gospodarka paliwowo – energetyczna w latach 2011, 2012*, Warszawa 2013, p. 52.

About 13% of the energy produced in the world comes from renewable resources. In Poland, the share of renewable energy in the total energy production in the years 2007 - 2010 increased from 6.69% to 10.16%. Electricity production from renewable resources in Poland in 2012 was 16,879 GWh. The structure of electricity production from renewable energy resources is presented in Figure 4. Co-incineration of biomass and coal has the largest share. This method is controversial as to its reasonability its positive effect on reducing the emissions. However, the factors justifying the use of this method are: the lack of continuous supply of good quality biomass, lack of properly functioning local biomass markets, and the lack of implementation of appropriate technology in large power plants and co-generating power plants.

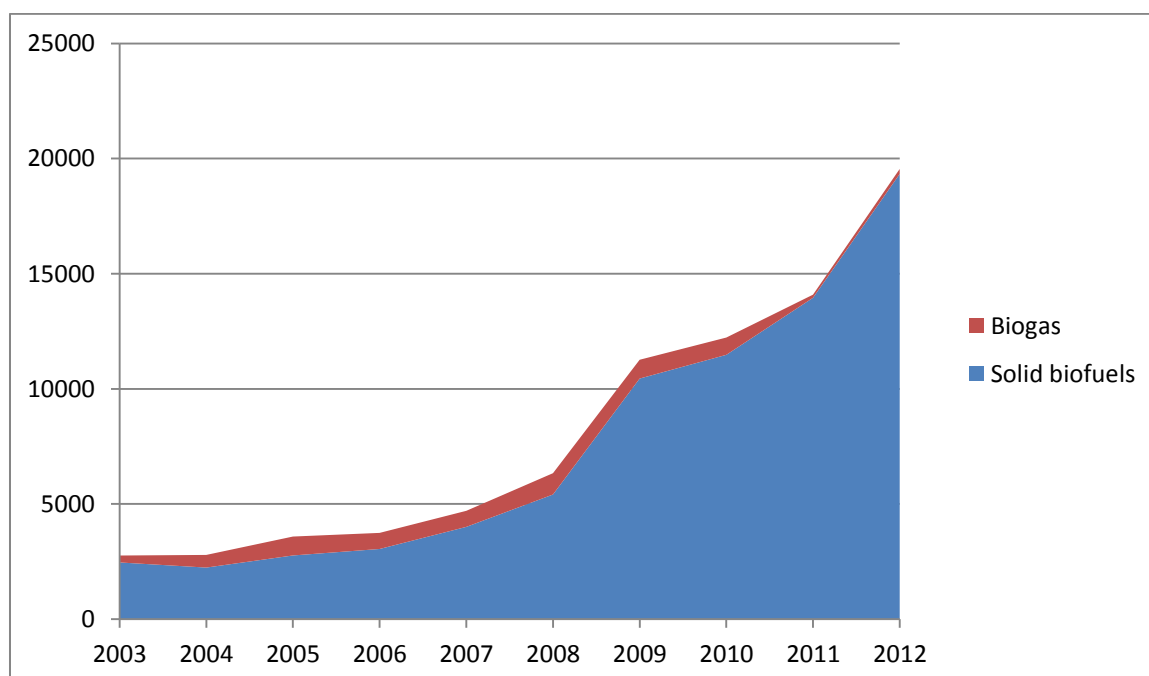
Figure 4: Production of electric power from renewable resources in the years 2003 - 2012 [GWh]



Source: Energy Regulatory Office (Urząd Regulacji Energetyki), data from the Polish Power Exchange (Towarowa Giełda Energii) for 2010, GUS, Energia ze źródeł odnawialnych w 2012 r., Warszawa 2013, s.57.

Heat production from renewable resources in Poland in 2012 was 19,548 TJ. The structure of heat production from renewable energy resources is presented in Figure 6.

Figure 5: Production of heat from renewable resources in the years 2003 - 2012 [TJ]



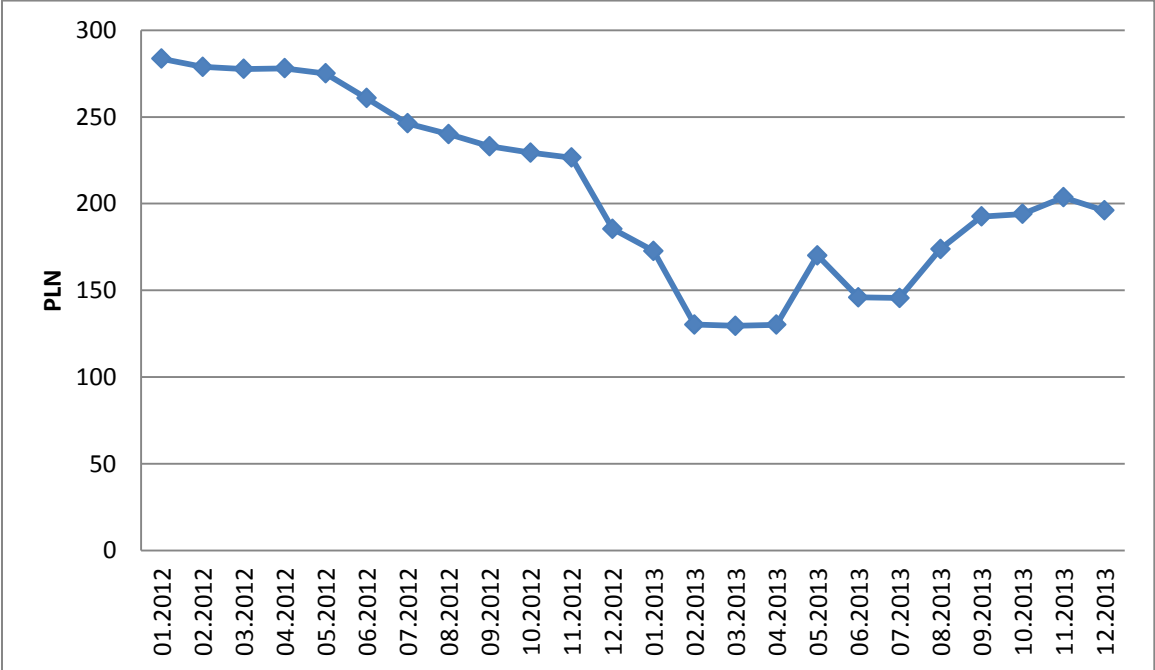
Source: own study based on CSO (GUS), Energia ze źródeł odnawialnych w 2012 r., Warszawa 2013, p. 63.

We can make the following thesis: implementation of Polish commitments regarding to energy - climate package ("3x20%") is dependent on the further development of co-firing.

The last two years have shown a peculiar instability of the energy sector and the high risk of achieving the indicative targets by Poland. It seems that there is a need for a green revolution in the energy sector. One of the conditions for the development of renewable energy is achieved the following aim: energy from renewable sources to be cheaper than energy from coal. To this end, the EU has introduced economic instruments such as: the emissions trading system and green certificates.

In Poland, support for development of energy market from renewable sources is not very effective. The RES Act was adopted April 8, 2014 - after a long waiting period. There are concerns that hopes support for prosumers disappeared.

Figure 6: Average price of green certificates



Source: own study based on data from the Polish Power Exchange (Towarowa Gielda Energii), www.tge.pl (date of access 23.05.2014)

Green certificates market crisis has had a negative impact on biomass producers. After the experience of the end of 2012, a further development of the agricultural biomass seems to be difficult. This paper is a kind of attempt to stimulate discussion on the economic aspects of the development of the agricultural biomass. It should be emphasized that estimates presented in the paper does not include the additional cost i.e. transport of biomass to the processing location, the energy production, commissions. Reflections on economic potential are strictly theoretical. The energy price from biomass is dependent on many factors, i.e. the energy price from conventional carriers, the certificates of origin prices, the emission allowances prices, cost of agricultural production, agricultural policy instruments. These issues require extensive research and analysis. In the literature, one of the barriers to growth in the use of agricultural

biomass for energy purposes is the lack of well-functioning local biomass markets. It is absurd to import the biomass from abroad, while have a high potential in the country.

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