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Sustainable Energy Crop Production in Poland: Perspectives

Abstract

In the context of achieving the targets of the energy economy, Poland's demand for bioenergy is stimulated by several factors, including the biomass potential of agricultural cultivation. The objective of this article is to indicate perspectives for the sustainable production of energy crops in Poland through the production of total biomass as the main renewable source of energy utilized in the countries of Europe and supported by Directive 2009/28/EC of the European Parliament and of the Council of April 23, 2009 on the Promotion of the Use of Energy from Renewable Sources, currently in force. The most important reasons for promoting the production of plant biomass for energy purposes is the desire to work against climate change and reduce the emission of greenhouse gasses. This article indicates the significant role of Life Cycle Assessment (LCA) in biofuels and their production. Note is also taken of agro–climatic and soil conditions for the production of biomass in Poland as well as the economic aspects using the Agricultural Production Space Valuation Ratio (APSVR).

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1. Introduction

With the growth of an awareness of threats flowing from overexploitation and the ignoring of global climate change, governments, companies, and the public have started to work together to implement the concept of sustainable development. Scientific research institutes have gained access to funds for the development of new green technologies, while companies have started to use them happily, simultaneously creating their own innovative solutions. Green business is not limited exclusively to increasing the share of renewable energy in total production, which was set out centrally in the member states of the European Union, but also influences the types of activities undertaken by companies in just about all branches of the economy. Environmentally–friendly management allows countries and their citizens to draw benefits in the form of healthier, less energy–using cities, clean air, water, and soil, and better management of space and waste. Factors such as climate change, globalization, and urbanization put new challenges before Europe and the World. Responsible management of energy, water, and waste has become a necessity. In order to guarantee an appropriate living standard and generate profits in the face of ongoing climate changes, businesses must make changes in existing products and technologies as well as create and develop completely new technologies. Legal regulations and preferential treatment for green technologies as well as growing prices and shrinking stocks of conventional sources of energy and raw materials stimulate the development of environmentally–friendly markets, the generation and storage of energy, energy efficiency, raw material efficiency, waste management and recycling, sustainable water use and sustainable transportation. It is possible that energy generated using renewable sources may replace the energy potential produced using conventional raw materials and, in the long run, even atomic energy, assuming no new revolutionary changes occur in this field (such as cold fusion, for example). It is projected that the development of biofuels of the second (produced using lignocellulosic biomass) and third (produced using algae) generation as well as progress in photovoltaic and hydrogen technologies will completely transform the face of the automobile industry and, in a somewhat more distant future, the aviation industry. However, before this takes place, a lot of attention will continue to be concentrated on the improvement of technologies based on fossil fuels, especially in the realm of improved turbine and engine efficiency as well as reductions in GHGs other than CO_2 in the face of the present energy situation. In many countries, this process will most probably slow the dissemination of renewable energy above levels as required by legislation. It is for this reason that the development of energy using renewable sources will be influenced by policies on the state level as well as the involvement of international organizations. Creation of favorable conditions and rewarding entities investing in green technologies is stated first by companies from all sectors of the economy as a factor stimulating progress in this field (Henzelmann et al., 2011, pp. 7–25).

2. Biomass production

Biomass is the source of 10% of world energy consumption. The remaining 90% produced using fossil fuels (80%), hydropower (2%), atomic energy (6%), and solar energy (2%). The share of energy derived from biomass varies significantly depending on the part of the world. OECD nations account for a mere 3.9%. The figure for developing nations is 18.8%, while the sub–Saharan region of Africa accounts for 61.5% (Goldemberg 2011, p. 3).

Biomass encompasses an extremely broad scope of raw materials such as forest products (wood, logging residues, trees, shrubs and wood residues, sawdust, bark, etc.), biorenewable wastes (agricultural wastes, crop residues, mill wood wastes, urban wood wastes, urban organic wastes), energy crops (short rotation woody crops, herbaceous woody crops, grasses, starch crops, sugar crops, forage crops, oilseed crops), aquatic plants (algae, water weed, water hyacinth, reed and rushes), food crops (grains, oil crops), sugar crops (sugar cane, sugar beets, molasses sorghum), landfill, industrial organic wastes, algae, kelps, lichens, and mosses (Demirbas 2009, pp. 55–56).

Growth in the share of energy derived from biomass is relatively slow because there are still a large number of unknowns. Firstly, there is the problem of stability of supplies and levels of biomass reserves are insufficient to satisfy energy and heat production needs. Secondly, it is not known if the utilization of biomass is economically viable at current and future fossil fuel prices, especially assuming no system of subsidies. The present rate of growth of biomass share is insufficient to satisfy requirements set for the year 2020. Achieving a level of energy and heat utilization using biomass of 1,650 TWh annum^{-1} as established by the European Commission necessitates the delivery of biomass with a primary energy of between 1,850 and 3,400 TWh, depending on method of use. Such a level may prove very difficult at this time due to an insufficiently attractive biomass value chain in the case of most countries and methods of utilization. Uncertainty on the part of companies, forest owners, and farmers with respect to the energy use of biomass in the future is hampering long–term investments. Without intensified action a paradoxical situation may emerge in which in spite of a lowering of biomass production costs, its price will go up as a result of growing demand caused by the costs of CO_2 emissions and green certificates as well as insufficient supply. This may have a negative impact on the paper industry. Thus, what is necessary is decided and quick action if the European Union wants to take advantage of its internal biomass production potential. In spite of the fact that biomass is the main renewable energy source utilized in Europe (Table No. 1) and the countries of the European Union consume 41.5% of the world's energy from renewable sources (Table No. 2), there is still a significant shortfall to achieving set targets and especially the whole of its bioenergy potential.

The most significant reason for promoting the production of biomass for energy purposes is the desire to work against climate change. A popular argument for absolutely vital action provides a slogan that says that production and energy utilizing biomass is neutral in terms of carbon dioxide emissions. This supposition is not completely true as the production of energy plants is tied with the direct and indirect emission of greenhouse gasses. This involves the burning of fuels during cultivation and transportation as well as in the production of fertilizer and plant protection chemicals. Additionally, the use of nitrogen fertilizer and post–harvest remnants release certain amounts of nitrous oxide whose role in creating a global warming potential (GWP) is 298 time greater than that of carbon dioxide. According to Crutzen et al. (2008), the production of first generation liquid fuels using cereals and rape may result in climate warming. It is only bioethanol made of sugar cane that may bring about a decrease in the greenhouse effect.

The basic assumptions behind the certification system for sustainability of the first generation biomass production chain are tied with the transposition of the guidelines of the European Commission as contained in the directives of the European Parliament and Council. Of significance is the fact that Directive 2009/28/EC encumbers fuel suppliers with an obligation to reduce the emission of greenhouse gasses derived from the fuel over its entire life cycle. This means including its production in the refinery, during transportation, and subsequently during combustion in engines. In its turn, Directive 2009/30/EC of April 23, 2009 (modifying Directive 98/70/EC) applies to gasoline and Diesel fuel specifications and also introduces mechanism for monitoring and limiting the emission of greenhouse gasses. Application of life cycle assessment (LCA) for biofuels and their production allows for a fuller assessment of their environmental impact. Analysis of their life cycle (LCA) is an evaluation method encompassing the complete production and product use chain. In the case of biofuels it encompasses the production of reproductive material, the establishing of plantations, cultivation, harvesting, transportation, the building and use of systems for processing biomass, all the way to the management of wastes generated in the production of energy. Pursuant to the PN–EN ISO 14040 standard, life cycle assessment may be used to:

- Identify environmental threats occurring in the technological line of the given products, during various stages of its life cycle,
- Select significant indicators for assessing the effects of activities on the environment, including measurement techniques,
- Undertake decisions in industry, government organizations, and nongovernmental organizations (strategies, priorities, and process design, inclusive of proposed changes in this regard), and
- Undertake marketing actions in the area of environmental assessment, product environmental declarations, descriptions of the processes that are the subject of licenses, etc., where due to the complexity of questions of environmental management, their solutions usually requires the collaboration of interdisciplinary teams, where all system components—economic, legal, technical, and related to the natural environment—must be taken into account in order to develop the proper action strategy.

Zah et al. (2007) applied a modified LCA method in their wide–ranging research into biofuel. They state that most biofuels are characterized by a more negative impact on the environment than gasoline. Only ethanol made of sugar cane and sugar beets, biodiesel made using spent oil, and biofuels made of wood had a more favorable impact on the environment than gasoline. The results of that analysis stress the importance of the development of second generation biofuels made of lignocellulosic biomass (Faber 2008).

Table 1. Primary production of renewable energy: 1999 and 2009

	Primary production (1,000 toe[1])		Share of total, 2009 (%)				
	1999	2009	Solar energy	Biomass and waste	Geothermal energy	Hydropower energy	Wind energy
EU—27	92,674	148,435	1.7	67.7	3.9	19.0	7.7
Euro area	62,261	104,794	2.2	64.4	5.4	18.7	9.2
Belgium	498	1,661	1.5	91.4	0.2	1.7	5.2
Bulgaria	665	1,129	—	68.9	2.9	26.4	1.8
Czech Republic	1,409	2,593	0.5	90.5	—	8.1	1.0
Denmark	1,619	2,754	0.5	78.0	0.4	0.1	21.0
Germany	8,069	27,692	3.5	77.0	1.7	5.8	12.0
Estonia	526	864	—	97.7	—	0.3	2.0

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[1] Tons of oil equivalent

Ireland	222	614	0.7	45.3	—	12.7	41.4
Greece	1,419	1,804	10.4	51.2	1.2	25.1	12.1
Spain	6,031	11,905	5.7	47.9	0.1	19.0	27.3
France	16,528	19,567	0.3	70.2	0.6	25.1	3.5
Italy	9,401	14,746	1.0	34.0	32.6	28.7	3.8
Cyprus	44	75	77.3	21.3	—	—	—
Latvia	1,571	2,089	—	85.6	—	14.2	0.2
Lithuania	656	992	—	94.5	0.5	3.6	1.4
Luxembourg	35	80	2.5	80.0	—	11.3	6.3
Hungary	843	1,851	0.3	92.0	5.2	1.1	1.5
Malta	0	0	:	:	:	—	—
Netherlands	1,210	2,768	0.9	84.4	0.1	0.3	14.2
Austria	6,675	8,352	1.5	54.6	0.4	41.5	2.0
Poland	3,757	6,031	0.0	94.8	0.2	3.4	1.5
Portugal	3,342	4,747	1.1	66.4	3.7	15.0	13.7
Romania	4,400	5,275	—	74.2	0.5	25.3	0.0
Slovenia	551	863	—	53.1	—	46.9	—
Slovakia	458	1,223	—	68.5	0.7	30.7	0.1
Finland	7,256	7,833	0.0	85.8	—	13.9	0.3
Sweden	13,359	15,819	0.1	62.8	—	35.8	1.4
United Kingdom	2,133	5,107	1.4	74.1	0.0	8.9	15.7
Norway	11,872	12,116	—	9.7	—	89.6	0.7
Switzerland	4,693	4,760	0.9	30.1	4.4	64.5	0.0
Croatia	900	1,030	0.5	42.6	0.3	56.2	0.5
Turkey	10,701	9,909	4.3	46.8	16.4	31.2	1.3

Source: Eurostat.

Table 2. Consumption of renewable energy[2] in member states of the European Union and the United States (2001–2011)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Change 2011 over 2010 %	2011 share of total world production %
	million tonnes of oil equivalent[3]												
Austria	0,4	0,4	0,5	0,7	0,9	1,2	1,4	1,4	1,4	1,5	1,6	8,20	0,80
Belgium	0,4	0,4	0,4	0,5	0,6	0,8	0,9	1,1	1,5	1,6	2,1	27	1,10
Bulgaria	-	-	-	*	*	*	*	*	0,1	0,2	0,3	61,8	0,10
Czech Republic	0,1	0,1	0,1	0,2	0,2	0,2	0,3	0,4	0,5	0,7	1,1	60,90	0,60
Denmark	1,3	1,6	1,8	2,2	2,2	2,1	2,4	2,3	2,3	2,8	3,4	21,40	1,80
Finland	1,9	2	2,1	2,4	2,2	2,5	2,3	2,4	2	2,5	2,6	1,70	1,30
France	0,7	0,8	0,9	1	1,1	1,4	1,9	2,3	2,8	3 ,4	4,3	26,90	2,20
Germany	3,6	5	6,2	8,2	9,6	11,7	15,2	16,4	16,9	18,9	23,2	22,90	11,90
Greece	0,2	0,2	0,3	0,3	0,3	0,4	0,5	0,6	0,6	0,7	0,9	29,70	0,50
Hungary	*	*	*	0,2	0,4	0,3	0,3	0,5	0,6	0,6	0,7	3,40	0,30
Ireland	0,1	0,1	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,7	1,1	51,30	0,50
Italy	1,9	2,2	2,6	2,9	3,1	3,5	3,8	4,1	4,6	5,8	7,7	32,10	4,00
Lithuania	*	*	*	*	*	*	*	*	0,1	0,1	0,1	67,10	0,10
Netherlands	0,7	0,9	0,9	1,2	1,7	1,8	1,7	2,1	2,4	2,5	2,7	8,40	1,40
Poland	0,1	0,1	0,1	0,2	0,4	0,5	0,7	1	1,4	1,8	2,2	26,90	1,20
Portugal	0,4	0,5	0,5	0,6	0,8	1,1	1,4	1,8	2,3	2,8	2,8	2,10	1,50
Romania	-	*	*	*	*	*	*	*	*	0,1	0,2	226,50	0,10
Slovakia	*	*	*	*	*	*	0,1	0,1	0,1	0,1	0,1	1,80	0,10
Spain	2	2,9	3,6	4,4	5,6	6,2	7,2	8,7	10,7	12,5	12,7	1,50	6,50
Sweden	1	1,1	1,3	2	2,1	2,3	2,7	3	3,1	3,5	4,1	16,80	2,10
UK	1,2	1,4	1,7	2,1	2,7	3,1	3,3	3,7	4,5	5	6,6	32,30	3,40
EU	16,2	19,8	23,2	29,2	34,3	39,5	46,7	52,7	58,8	68,1	80,9	18,90	41,50
USA	16,8	18,7	18,8	19,6	20,6	22,7	24,7	29,5	33,6	38,9	45,3	16,40	23,20

Source: based on BP Statistical Review of World Energy, June 2012, bp.com/statisticalreview, p. 38.

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[2] Based on gross generation from renewable sources, including wind, geothermal, solar, biomass, and waste, and not accounting for cross–border electricity supply.

[3] Converted on the basis of thermal equivalence assuming 38% conversion efficiency in a modern thermal power station.

* Less than 0,05.

3. Biomass production climate and soil conditions in Poland

A breakthrough took place over recent years in the development of information technology and its application in analyzing phenomena of spatial character. Methods and instruments created or adapted in Poland as a result of work on the Integrated Spatial Information System for Agricultural Production (ISISAP) may be operationally used to assess regional differentiation in agricultural production conditions, simultaneously replacing the traditional descriptive expert reports with more accurate quantitative analysis based on continuous monitoring as well as analysis of updated databases and continuously improved methods for modeling and making projections (Krasowicz and Kopiński 2009).

Each year, only a small part of devastated and degraded areas of Poland are subject to efforts aimed at their recultivation and redevelopment for agricultural functions. For all practical purposes, such actions are not undertaken in the Voivodeship of Łódź. Areas requiring recultivation are forested. Bearing in mind the fact that a total of 2,935 ha of agricultural land (192 ha in the Voivodeship of Łódź) as well as 551 ha of forests (215 ha in the Voivodeship of Łódź) were released for mining operations and housing estate sites in Poland in the year 2010, the intensification of actions aimed at returning degraded areas to agriculture is justified. Analysis of the soil growing quality grade structure of land withdrawn in 2010 shows that most is classified Grade IV (789 ha), which is appropriate for energy crops, and Grades I–III (922 ha), which is for food production. Only 111 ha were classified as Grades V and VI, where agricultural use is very limited. Also worth noting is the systematic decrease of fallow and set–aside land in Poland from approximately 11.9% of total arable land in 2000 to 3.8% in 2008. The year 2009 saw a slight increase in these areas to 4.1%. The largest percentage share of fallow and set–aside land belongs to the public sector. In the year 2009 it amounted to 65,500 ha (CSO, 2011a). According to the Central Statistical Office (GUS), Poland has seen a continuous tendency of a decrease in arable land area and an increase in forest areas since 1938. Over the years 1990–2009 this was -7% and +1.7%, respectively, of Poland’s surface area. In 2011 the area of arable land decreased by 48,000 ha as compared with the year 2010, while the forest use area increased by 29,000 ha.

The Agricultural Production Space Valuation Ratio may be used as a measure of the production potential of a habitat. Weights assigned in assessing individual factors are mirrored in their rank in shaping harvest levels. Soil conditions are of greatest importance in valuating agricultural production space (approximately 70% of observable harvest variability – 18–95 points). The influence of the remaining factors is significantly lower and accounts for approximately 30% (Igras and Lipiński 2006). The share of the climate factor (agro–climate) is in the 1–15 point range. The influence of water conditions rates 1–5 points, while landform can receive 0.1–5 points. Variations in the natural production potential on a national scale stems from spatial soil differentiation, landform, precipitation, and temperature. The value of the valuation indicator is contained in the range from 31 points for habitants least useful for agriculture to 120 points for the best habitats with optimum conditions for plant growth. The average Agricultural Production Space Valuation Ratio for Poland amounts to 66.6 points (Table No. 3). The greatest restrictions in the development of plant production occur in areas with an indicator value of less than 52 points. The largest concentrations of land of little usefulness for agriculture are found in the Podlaskie (the lowest value for Poland at 55.0 points), Mazowieckie, and Pomorskie voivodeships (Igras and Lipiński 2006).

Table 3. Partial and overall agricultural production space valuation ratio by voivodeship

Voivoidships	Valuation indicator				Total Agricultural Production Space Valuation Ratio
	Quality and usefulness of agricultural soils	Agricultural climate	Landform	Water conditions	
Dolnośląskie	56.9	10.4	3.8	3.8	74.9
Kujawsko–pomorskie	54.4	9.2	4.0	3.4	71.0
Lubelskie	55.8	10.6	4.0	3.8	74.1
Lubuskie	43.6	11.6	4.3	2.7	62.3
Łódzkie	43.2	11.5	4.4	2.8	61.9
Małopolskie	53.6	9.3	2.4	4.0	69.3
Mazowieckie	43.1	9.7	4.1	3.0	59.9
Opolskie	60.5	13.4	4.1	3.6	81.6
Podkarpackie	52.7	10.7	3.0	4.0	70.4
Podlaskie	41.0	7.5	3.7	2.8	55.0
Pomorskie	50.6	8.5	3.7	3.4	66.2
Śląskie	46.8	11.2	3.6	2.6	64.2
Świętokrzyskie	52.2	10.6	3.1	3.5	69.3
Warmińsko–mazurskie	51.1	8.1	3.4	3.4	66.0
Wielkopolskie	46.4	11.2	4.4	2.8	64.8
Zachodniopomorskie	50.0	9.8	4.0	3.6	67.5
Poland	49.5	9.9	3.9	3.3	66.6

Source: based on Igras and Lipiński, 2006.

4. Plant Cultivation Conditions in Poland

Natural conditions for plant production in Poland are worse in comparison with other European countries (Kukula and Igras 2004). The reason for this is the dominance of light soils of low natural fertility, insufficient precipitation, and a relatively short growing season.

4.1.Soil

The share of very light and light soils in Poland is approximately 60%. Most of the soils are strongly or moderately acidic and demonstrate a low content of basic nutrient components. Changes in plant production structure have a significant impact on soil fertility, which determines both the volume and intensity of agricultural production in a direct way. Among aspects defining the fertility of the soil, the most important are acidity, organic matter content, nitrogen mineral form, and abundance of macro– and micro–elements (Igras and Lipiński 2006).

4.2. Soil Acidity (pH)

From an agricultural point of view, it is the negative effects of the acidifying of the soil that are extremely important. A low pH lowers the assimilability of nutrient components, especially phosphorus, magnesium, and molybdenum. At the same time, it increases the mobility of components such as aluminum and heavy metals. The accumulation of heavy metals in the soil, especially cadmium and lead, may lead to their excessive concentration in plants. A high content of these metals disqualifies plants for consumption. The acidity structure of soils in Poland is presented in Table No. 4. The worsening of the acidity of the soil is a phenomenon that is progressing as a result of the insufficient application of CaO in cultivation (Igras and Lipiński 2006). The use of lime fertilizers in Poland fell from approximately 1,693,900 tons (95.1 kg ha^{-1} UR) in the year 1999 to 591,400 tons (38.1 kg.1 kg ha^{-1} UR) in the year 2010. The lowest use per hectare of agricultural land occurs in the Świętokrzyskie, Małopolskie, Podkarpackie, and Podlaskie voivodeships. The highest use of 102.8 kg ha^{-1} is found in the Voivodeship of Opole (CSO, 2011b). The solving of the problem of soil acidification and the improvement of its acidity should be a priority of state policy in the area of agriculture.

Table 4. Structure of soil acidity in Poland in 2006–2010

Voivoidships	Soil acidity (%)				
	Very acidic pH < 4.5	Acidic pH 4.6 – 5.5	Slightly acidic pH 5.6 – 6.5	Neutral pH 6.6 – 7.2	Alkaline pH > 7.2
Poland	18	29	30	15	8
Dolnośląskie	12	28	38	15	7
Kujawsko-pomorskie	8	20	30	25	17
Lubelskie	22	28	23	15	12
Lubuskie	13	35	36	11	5
Łódzkie	33	34	21	9	3
Małopolskie	26	28	22	15	9
Mazowieckie	30	32	22	12	4
Opolskie	5	19	50	21	5
Podkarpackie	33	32	21	11	3
Podlaskie	26	34	23	13	4
Pomorskie	15	37	30	14	4
Śląskie	11	25	40	18	6
Świętokrzyskie	20	22	22	19	17
Warmińsko-mazurskie	16	33	30	17	4
Wielkopolskie	15	26	33	15	11
Zachodniopomorskie	14	31	31	15	9

Source: based on *Environment*, Dariusz Bochenek (Editor), CSO, Regional and Environmental Surveys Division, Warsaw, 2011.

4.3. Nitrogen

The mineral nitrogen content in the soil is one of the defining elements of soil fertility. Its quantity is dependent on many environmental factors such as the type, forecrop, species of cultivated plant, and applied dosages of nitrogen and natural fertilizers as well as the granulometric soil composition. The use of nitrogen fertilizer increased from 48.4 to 66.3 kg ha^{-1} over the years 1999–2010 (CSO, 2011b). Analysis of the regional differentiation of mineral nitrogen content in Polish soils shows that the lowest content is characteristic of the soils of eastern and southeastern Poland, but primarily the soils of the Pomorskie and Warmińsko–Mazurskie voivodeships. On the other hand, the soils of the Śląskie and Dolnośląskie voivodeships have the greatest abundance of this component

(Igras and Lipiński 2006). Permanent plantations of energy crops are characterized by significantly greater efficiency in nitrogen utilization as compared with traditional crops. The increased efficiency of nitrogen uptake decreases the leaching away of nitrates. Following vegetation, many species of energy plants withdrawn large quantities of micro– and macro–elements into their roots. Thanks to this they are not removed with the biomass harvest (Faber 2008).

4.4. Organic Matter

The quantity of organic matter in the soil is a basic indicator of its quality. It defines its physical and chemical properties (sorption and buffering capacity) and the processes of biological change that is important to the functioning of the habitat (biological activity). High humus content in the soil is a factor stabilizing its structure, decreasing susceptibility to compacting as well as degradation resulting from water and wind erosion. The maintenance of soil humus resources is also important from the point of view of the sequestering of carbon dioxide from the atmosphere. Intensive use of the soil by monoculture destroys the soil structure, and leads to excessive aeration of habitats as well as the mineralization of humus, thus freeing large amounts of carbon dioxide into the atmosphere. CO_2 emissions from the soil are a significant part of the total balance of emissions from various sectors of the economy. In the cultivation of energy crops, a certain quantity of carbon assimilated by plants finds its way into the soil with falling leaves and dying roots. Over 80% of this quantity is transformed into CO_2 as a part of the soil respiration process, while the remainder is sequestered as a result of gradual transformation into humus. Growth in the carbon content of the soils of such plantations acts to indirectly improve the texture, water capacity, and fertility of the soil. This process is dependent on climate conditions, the granulometric makeup of the soil, and its initial humus content (Jug et al. 1999). The quantity of sequestered carbon in the soil in the case of energy plant cultivations is of importance with respect to the overall carbon balance and therefore the greenhouse gas emission balance. It is assumed in LCA analyses that the emission of greenhouse gases in the cultivation of willow and miscanthus is significantly lower than in the case of cultivation of rape, green areas, and wheat (Clair et al. 2008; Faber 2008). The natural variety in humus content in soils is determined by factors including granularity, location in the terrain, and water relations. Among anthropogenic factors, the organic matter content of the soil is most influenced by land use (i.e. agriculture, meadow, forest), intensity of cultivation, selection of cultivated plants, and level of natural and organic fertilization. Changes in the content of organic matter in soils are coupled with two opposed processes—mineralization and deposition. The process of mineralization leads to a lowering of organic content in the soil. The process of deposition results in an increase in humus content due to the continuous adding of organic matter from sources such as post–harvest remnants and natural and organic fertilization (Stuczyński et al. 2007). Loss of humus is an important indicator of worsening habitat conditions and soil fertility. Growth in the area of agricultural land used exclusively for plant production in farms lacking any animal husbandry, thus deprived of the natural and organic fertilization that are significant elements shaping soil humus resources, has been taking place in certain regions of the country. In the case of perennial energy plant plantations, sewage sludge may serve as a source of organic matter fertilization, which is simultaneously a way for its utilization. The average content of soil humus in Poland is 2.2%. In line with international criteria, humus content below 3.5% is considered a symptom of desertification. Taking such an approach, 89% of the surface area of Poland's agriculturally useable soils should be classed as soils of low organic matter content and be considered threatened by drought. Obviously, this is a consequence of the specifics of Polish soils. They have a large share of soils formed from sands and light soils of low water capacity, which in a natural way determines conditions of humus accumulation. Studies indicate the existence of a strong trend of humus content loss, mainly in soils originally rich in organic matter, linked with changes in soil water relations, more intensive use, and drainage (Stuczyński et al. 2007).

4.5. Soil Compaction

The increase in mechanized work in the field during sowing and harvesting agricultural products often leads to excessive compaction of the soil in both the tilled layer and the subsoil, especially in highly developed countries. Heavy machines and tractors moving over the fields cause the excessive compaction of soil layers, even up to a depth of > 0.9 m. Excessive compaction impedes penetration of the soil by the roots of cultivated plants that, subject to such unfavorable conditions, have limited access to water and nutrients. Moreover, pore size decreases, the percentage of pore surface area filled with water at field capacity increases, and the temperature of the soil falls. This influences the activity of soil organisms by decreasing the indicator of organic substance decomposition and the freeing of nutrient components for plants. Soil compaction results in lower infiltration, which results in an increase in surface off–flow and the creation of stagnant ponds without drainage. The susceptibility of soils to compaction is dependent on soil water content at the moment of the operation. Soil containing less water is more resistant to compaction than soil that is humid or wet. The soils in Poland demonstrate significant diversity in susceptibility to compression, which is due to differences in granulometric makeup and organic matter content. The total soil surface area highly vulnerable to compaction resulting from improper cultivation techniques due to equipment with excessive loads and subject to conditions of excessive moisture amounts to approximately 2.6 million ha, which is approximately 15% of agricultural land use. The soil cover of the Dolnośląskie (41.2%), Małopolskie (40.5%), Opolskie (34%), and Podkarpackie (33.6%) voivodeships is characterized by a large share of soils susceptible to compaction (Stuczyński et al. 2007). Excessively moist cohesive alluvial soils as found in river valleys provide particularly unfavorable conditions for cultivation during periods of cultivation work. The effects of compaction on these soils is long–term and difficult to reverse.

4.6. Soil Erosion

Water erosion is a significant threat to soil quality. The level of threat of soil erosion through surface water is dependent on the slope of the land, susceptibility of the soil to washing away, and the level of annual precipitation. In order to decrease the still rather high current threat of erosion by surface water it is necessary to apply erosion–preventing land improvements in areas where it is present. This includes the transformation of agricultural land use into protective land use. This applies to over 2.2 million ha, where approximately 500,000 ha are very strongly threatened by water erosion. Assuming the continued withdrawing of areas from arable land in favor of forestation, tree planting, and other agricultural uses (energy crop plantation, orchards, and permanent green areas) with soil–protective functions, a decrease in the range and intensiveness of both water and wind erosion should be expected (Stuczyński et al. 2007). In the case of Poland, 27.6% of agriculturally used soils are threatened by wind erosion, where the figure for water erosion is 28.5%. This factor is worth considering in selecting species of perennial energy plants. The common osier (*Salix viminalis*), switchgrass (*Panicum virgatum*), black locust (*Robinia pseudoacacia*), and multiflora rose (*Rosa multiflora*) are species used in fighting erosion processes. They bring about a decrease in the susceptibility of the soil to washing away by reinforcing it with their root systems, absorbing the energy of raindrops, holding a part of the precipitation in above–grade organs, and decreasing the velocity of water flow by increasing the roughness of the land surface (Węgorek 2008). Soil drought and the global trend for increased average monthly temperatures may lead to a drying of the soil below its average natural moisture content. As a consequence, this may significantly increase the range and intensity of water erosion on arable land (Stuczyński et al. 2007).

4.7. The Occurrence of Trace Elements

Information regarding the state of agricultural use soil pollution by heavy metals in Poland is based on the results of broad studies on the chemistry of Polish soils conducted over the years 1992–1997. Over 99% of the soil in Poland is found to contain copper, nickel, and lead on a natural background level (0 degree) or at a slightly higher level (I degree). In line with approved criteria, such soils are considered uncontaminated. With respect to cadmium and zinc, this share amounts to over 98%. A total of 21.5% of the agricultural soil of the Śląskie Voivodeship is contaminated with cadmium in the II to V degree range, where 4% are soils that are strongly or very strongly contaminated. There is also lead and zinc pollution. This fact is tied with the operation of zinc and lead ore mining and processing (emission of particulate matter) and the occurrence of ore–bearing rock outcrops on the surface. Higher metal content on a level exceeding boundary values also occurs locally in the soils of other regions historically burdened with the effects of metal ore mining and processing (Głogów, Lubin, Chrzanów, Olkusz). On the basis of the above data as well as legal regulations currently in effect in Poland, it may be stated that over 99% of the surface area of agricultural land, on a national scale, meets criteria for metal content as required for agricultural soils. In many areas, in spite of a low level of trace metal content in the soil, an exceeding of allowable amounts has been noted in plants. Cadmium accumulation in plants, which is most frequent, is primarily linked to the strong acidification of the soil, which is responsible for its high bio–accessibility. This indicates a need to take into account soil properties in developing criteria for assessing metal pollution (Stuczyński et al. 2007).

4.8. Agro–Climatic Conditions

To a great extent, the worsening of the climatic water balance in the growing season and the increasingly frequent occurrence of deficits of precipitation shape the production potential of habitats. Global warming is causing not only an increase in heat resources, which in Poland's climate zone is one of the positive effects of climate change, but also increases the variability of weather changes over successive years. It is subject to such conditions that possibilities of cultivating other thermophilous plants such as miscanthus and switchgrass increase. Analyses of harvest weather indexes (the impact of meteorological elements on plant harvests achieved in Poland) confirm that the greater variability in the sequence of meteorological conditions over recent years may be the reason behind the occurrence of greater than to date losses in harvests due to the passage of unfavorable weather. A less optimistic scenario of climate change in which the increase in temperature is not accompanied by an increase in atmospheric precipitation is being observed in Poland. This situation shall have a negative effect on the water balance. There will be a further worsening of hydrological conditions for agriculture in those areas of Poland that have had the lowest water balance. This necessitates the undertaking of action aimed at adapting agriculture to present and future climate conditions (Stuczyński et al., 2007). Multi–year cultivation of energy plants usually produces greater volumes of biomass than the growing of traditionally cultivated plants. It is for this reason that they have greater water demands. This signifies that subject to Polish conditions it will be necessary to grow such crops on land with a water table above 2 m. Under such conditions, plants can supplement insufficient precipitation by up–taking water from groundwater up to 200 mm. In the large–area sowing of such plants, the decreased supply of groundwater through precipitation should be taken into account. This premise forces the need to analyze in detail the hydrological effects of such plantings in the area of specific watersheds as well as the country as a whole. There is a negative climate water balance in most areas in Poland. As a result of the expected change in climate this situation may worsen from -10% for the optimistic scenario to -50% for the pessimistic one. Thus, what is necessary is serious consideration as to the locating of energy crop plantations. It should be expected that unfavorable water conditions will restrict the size of land area available for perennial energy plants in Poland to about one million ha (Faber 2008).

5. Conclusion

Biomass is the source of 10% of world energy consumption. Growth in the share of energy derived from biomass is relatively slow because there are still a large number of unknowns. There is the problem of stability of supplies and levels of biomass reserves are insufficient to satisfy energy and heat production needs. It is not known if the utilization of biomass is economically viable at current and future fossil fuel prices, especially assuming no system of subsidies. The most significant reason for promoting the production of biomass for energy purposes is the desire to work against climate change. Application of life cycle assessment (LCA) for biofuels and their production allows for a fuller assessment of their environmental impact. Natural conditions for plant production in Poland are worse in comparison with other European countries. Large scale cultivation of energetic plants is a sustainable method of use uncultivated and degraded soils. Environmentally–friendly management allows to draw additional benefits from energetic plants cultivation in the form of healthier, clean air, water, and soil, and better management of space and waste.

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Streszczenie

PERSPEKTYWA ZRÓWNOWAŻONEJ PRODUKCJI ROŚLIN ENERGETYCZNYCH W POLSCE

Zapotrzebowanie w Polsce na bioenergię w kontekście realizacji celów gospodarki energetycznej jest stymulowane przez szereg czynników, w tym potencjał biomasy pochodzący z upraw rolniczych. Celem artykułu jest wskazanie na perspektywę *zrównoważonej produkcji roślin energetycznych w Polsce poprzez produkcję całkowitej biomasy jako głównego odnawialnego źródła energii wykorzystywanego w krajach Europy, a wspieranego przez obecnie obowiązującą Dyrektywę Parlamentu Europejskiego i Rady 2009/28/WE z dnia 23 kwietnia 2009 r. w sprawie promowania stosowania energii ze źródeł odnawialnych (OŹE). Najistotniejszymi powodami promowania produkcji biomasy roślinnej na cele energetyczne jest chęć przeciwdziałania zmianom klimatycznym i redukcja emisji gazów cieplarnianych. W artykule wskazano na znaczną rolę analizy LCA (Life Cycle Assessment) dla biopaliw i ich produkcji. Zwrócono uwagę na warunki agroklimatyczne i glebowe uwarunkowania produkcji biomasy w Polsce oraz ekonomiczny aspekt jakim jest wskaźnik waloryzacji rolniczej przestrzeni produkcyjnej (WWRPP).*