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Use of Sewage Sludge in the Production of Plant Biomass for Energy: Biological and Economic Conditions

Abstract

The goal of this article is a presentation of the legal, biological, and economic conditions of energy production using biomass, especially taking into account the application of sewage sludge certified for natural use in agriculture. Any increase in the production of biomass necessitates the introduction of cheap and highly–efficient plant production technologies that are environmentally–friendly. Use of certified sewage sludge can increase the economic efficiency of energy crops and have a beneficial impact on the environment.

1. Introduction

Care for the natural environment in combination with concurrent climate change and a diversification of the power engineering mix are directing the attention of experts at the need to produce energy from renewable sources in order to satisfy the energy needs of Poland (Grzesik and Romanowska-Duda

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2009, Romanowska et al. 2011). This direction is in line with European Union policy. The assumed "3x20" targets, including the achievement of a 20% share in renewable energy by the year 2020, obligates all European Union member states to achieve this goal. Such action is aimed at making Europe independent of imported fuel and price fluctuations on world market.

The planned 20% share of energy from renewable energy sources is an average value for the countries of Europe. Poland has obligated itself to achieve a 15% value in renewable energy sources for the whole of energy used in the country by the year 2020. The national action plan assumes a 19% share for electricity, 17% for thermal energy, and 10% for transportation biofuels. The share of electrical energy derived from renewable energy sources amounted to 7.86% at the end of 2011. Initial assumptions had put the value at 8.85%. This energy shortage in Poland indicates a need to create stable, long–term principles for supporting domestic producers.

2. Conditions for acquiring energy from renewable sources

Among the most rapidly developing areas of the green economy in Poland is renewable energy, especially as based on biomass. Another growth area is biofuels that are attracting the attention of farmers, as is the construction of modern sewage treatment plants (Romanowska-Duda et al. 2011, Kacprzak et al. 2012). Apart from direct subsidies and a credit system, companies planning the development products supporting the green economy can count on the support of the Ministry of Environment in the form of the GreenEvo – Green Technology Accelerator. Alternative energy sources are achieving unheralded public acceptance. Governments around the world are setting concrete targets for the renewable energy sector that are favorable for companies producing energy, including from plant biomass.

Biomass delivers 3% of total primary energy in the industrialized nations. It is mainly used in heating applications and in combined electricity and heat generating plants. Currently, the market encompasses home heating, major industrial and municipal combined electricity and heat generating plants, and co–combustion in major coal–based power plants (Grzesik et al. 2011).

According to projections up to the year 2050, global use of biomass for heating and industrial power engineering will double. In line with scenarios assuming a normal course of events, the share of energy received from biomass will increase from the present 1.3% of all energy produced to 2.4%–3.3% by the year 2030. This means an average annual growth rate of 5%–6%.

Increasing efficiency and developing new technologies is an exceptionally important component factor of the green economy. In many fields there exists the possibility of optimizing products, including energy crop biomass and energy extracted from it. In implementing optimum technologies for acquiring plant biomass, it is possible to decrease the negative environmental impact of municipal waste and increase the area of such crops by using bio–stimulators on marginal soils that are not used in food production (Grzesik and Romanowska-Duda 2009a, Romanowska-Duda et al. 2009, Grzesik et al. 2011a).

The surface area of devastated and degraded soils that require recultivation and management at the end of 2011 amounted to 64,000 ha (0.2% of the total surface area of the country). The degree of these degradation and devastation processes does not show any major differentiation by voivideship (province)—from 0.1% of the total surface area of the Podkarpackie Voivodeship to 0.4% of the Dolnośląskie and Śląskie voivodeships. However, it is a significant problem in highly industrialized areas. Only 1,770 ha were recultivated in 2011, and a total of 629 ha were developed, mainly for forestry and agricultural objectives (Concise statistical yearbook of Poland 2012).

The least expensive technologies, those whose implementation costs are the lowest, have the greatest chances for large–scale implementation. It is for this reason that the production of energy crops for biomass and its co–combustion in existing power–generating boilers has the greatest chances of development (Grzesik et al. 2011b). Adapting electricity and combined electricity and heat generating plants to use this technology requires only moderate investment outlay. Depending on technical solutions, the share of biomass for co–combustion amounts to 8%–12%, where in more advanced technologies it achieves a level of 40%–60%. High hopes for the intensification of biomass production for energy needs are tied with the application of processed sludge from municipal sewage treatment plants, which fosters the rapid growth of plants while the problem of storing sludge is simultaneously solved through its use in agriculture (Grzesik and Romanowska-Duda 2009c, Romanowska-Duda et al. 2009).

3. Using sewage sludge in agricultural production: EU legislative basis

Council Directive 86/278/EEC of June 12, 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (Official Journal of the European Union L 181 of July 4, 1986, p. 6 and L 377 of December 31, 1991, p. 48. Article 3) is a basic legal act on the use of sewage sludge. The purpose of this directive on the use of sewage sludge in agriculture is the defining of principles governing its use so it do not bring about a worsening of the quality of the soil and agricultural products. The directive assumes that the sludge from sewage treatment plants from domestic and municipal sewage effluent as well as effluent from other sewage treatment plants cleaning sewage of a composition similar to that of the effluent from domestic and municipal sources may be used in agriculture pursuant to the provisions of the directive, bearing in mind the provisions of directives 75/442/EEC and 78/319/EEC. This reservation indicates that sludge from cesspools and similar systems designated for sewage treatment may be used in agriculture, depending on conditions considered necessary by the given member state in order to protect human health and the environment and only if its application is regulated by regulations established by the given member state.

In its turn, Polish law has created the Act on Waste of April 27, 2001 (Journal of Laws 2001, No. 62, item 628, with subsequent amendments and Journal of Laws 2010, No. 185, item 1243, uniform wording) as well as the Directive of the Minister of Environment of July 13, 2010 on Municipal Sewage Sludge (Journal of Laws 2010, No. 137, item 924). Pursuant to these legal acts, municipal sewage sludge is defined as originating from sewage treatment plants from digestion chambers or other systems for the treatment of municipal sewage effluent as well as other effluent of a composition similar to that of municipal sewage. It may find application in agriculture after prior processing.

Municipal sewage sludge may be used in:

1. Agriculture, for the growing of all agricultural produce allowed for trading, including crops designated as fodder,
2. The recultivation of land, including land designated for agricultural use,
3. The growing of plants designated for composting, and
4. The growing of plants not designated for food or fodder.

Such sludge may be provided to the owners, tenants, or other persons managing the property on which it is to be used only by the producer of the sludge. The producer bears responsibility for the proper application of municipal sewage sludge as specified in items 1–4 (Bień et al. 1998, Jarosz – Rojczyk 2004).

Municipal sewage sludge may be used if conditions relating to the following are met:

- The use of the sludge causes no worsening of soil quality,
- Sanitary standards for the applied sludge,
- Heavy metal content in the sludge,

- Heavy metal content in the topsoil (0–25 cm), and
- Soil pH (5.6).

The preparing of sewage sludge for use in agriculture involves (Miksch and Sikora 2010):

- Biological, chemical, thermal, or other processing lowering the susceptibility of the sludge to putrification and eliminating hazards to the environment and human health,
- Subjecting the sludge to testing in terms of meeting defined sanitary standards, and
- Conducting tests with respect to heavy metal content in line with regulations.

Dosages of sewage sludge as used are established separately for each batch, taking into account the type of soil on which it is to be used, its manner of usage, plant phosphorus and nitrogen demand, and sludge quality. Dosage levels are defined by the directive in line with their purpose (e.g. agriculture, land recultivation, growth of plants for composting).

Table 1. Allowable dosages of municipal sewage sludge

Usage of Municipal Sewage Sludge	Dosages of Municipal Sewage Sludge (tones of dry weight)	Remarks
• Agriculture • Reclamation of land for agricultural purposes	3 t d.w. ha^{-1} $year^{-1}$	Cumulative dose should not exceed 6 t d.w. ha^{-1} 2 $year^{-1}$ 9 t d.w. ha^{-1} 3 $year^{-1}$
• Reclamation of land for other purposes • Cultivation of plants intended for compost production • Cultivation of plants not intended for human consumption and animal feed	15 t d.w. ha^{-1} $year^{-1}$	Cumulative dose should not exceed 30 t d.w. ha^{-1} 2 $year^{-1}$ 45 t d.w. ha^{-1} 3 $year^{-1}$

Source: Regulation of the Minister of Environment of 13 July 2010 on the municipal sewage sludge (OJ 2010r. No. 137, item. 924).

Soil tests are performed (reference methods) prior to using sludge in agriculture. These include testing the soil acidity (pH), heavy metal content, and available phosphorus content (P_2O_5 mg/100 g of soil). The acidity of the soil designated for the use of sludge cannot be lower than pH = 5.6 and the heavy metal content in the soil should be in agreement with the directive.

In order to safeguard the natural environment against the application of inappropriate sludge to the soil, the sewage sludge producer is obligated to:

- Subject the municipal sewage sludge to testing,
- Perform tests on the soil for heavy metal content prior to using the sludge on it,
- Provide the owner, tenant, or other person managing the property with the test results (sludge and soil) as well as with information relating to dosages of the sludge that may be used on various soils, and
- The owner, tenant, or other person managing the property on which municipal sewage sludge is used is obligated to store documents relating to sludge and soil test results as well as information regarding sludge dosages used for a period of five years.

The sewage sludge producer is bound to complete a sludge transfer and receipt card (Journal of Laws 2010, No. 249, item 1673) containing the address and signature of the farmer receiving the sludge during supply of the product. This document is kept by the producer as proof of the transfer of the sludge. The producer is obligated to maintain records of municipal sewage sludge in line with the new card (Journal of Laws 2010, No. 249, item 1673).

The producer of plants using sewage sludge should have a copy of the analyses of test results relating to the soil (pursuant to the directive) on which the tested sludge was used, the document relating to the chemical composition of the sewage sludge, and information on dosages as defined by the producer, in line with the provisions of the directive. The farmer should also keep the test results (sludge/soil) for a period of five years and observe the above–specified interdictions. The described documents should be from the sludge producer. The farmer has the right to demand the above–specified documents and may refuse acceptance of the sludge if they are not provided. Inspections were conducted on farms throughout Poland over the years 2009–2010. Uncovered shortcomings included failure to observe sludge dosages as stemming from the provisions of the directive as well as failure to conduct soil tests prior to the application of sludge. Legal penalties may be applied for failure to adhere to the directive.

Pursuant to the Directive of the Minister of Environment, sewage sludge cannot be used on land where fruit plants (this does not apply to orchards) and vegetables are grown, that are used for growing under covers or designated for growing berry bearing plants and vegetables, where the edible portions are in direct contact with the soil (within ten months preceding harvesting or during harvesting) and are eaten raw. This ban also encompasses very permeable soil, i.e. loose and weakly clayey sands as well as light clayey sands if the water table is at a depth of less than 1.5 m below grade level as well as in areas used as pastures and meadows, terrain with a slope greater than 10%, and soils designated for the production of plants consumed directly by people. The prohibition further includes flood plains, lands temporarily flooded and swampland as well as areas temporarily frozen, snow covered, and the strip of land of a width of 50 m directly adjacent to the shores of lakes and channels. Sludge cannot be used on land located within a distance of less than 100 m from water sources, dwellings, and food production plants. The ban is also effective in areas of protected inland water reservoirs (if acts of local law do not state differently – Article 58 of the Water Code), and on land subject to indirect protection of water source zones (if acts of local law do not state differently – Article 58 of the Water Code).

Successive regulations are found in the Directive of the Minister of Environment (Point II, items 13–21 of the Attachment to the Directive of the Minister of Environment on the R10 Recuperation Process, Journal of Laws 2007, No. 228, item 1685) on sludge and slurry from industrial sewage treatment plants that may be used for fertilizing or improving the soil by their application to the soil surface, assuming the meeting of all requirements as defined in this directive.

4. Rational use of sewage sludge in sustainable environmentally–friendly intensification of bioenergy crops

The recycling of sewage sludge is one of the most important challenges facing wastewater management in Poland and other countries of the European Union (Tchobanoglous et al 2004). Domestic sewage treatment plants provided services for only 66% of the population (89% in cities, and only 31% in rural areas, which are home to approximately 39% of the population – temporary data) in 2911. Seven cities were not served by sewage treatment plants in that same year. Approximately 15% of industrial facilities had no sewage treatment plants and dumped their sewage directly into waters or the earth. Modern sewage treatment plants, with high–level biogene removal, serve only 497 towns and cities and 630 rural municipalities in Poland. These facilities treated 1,013 hm^3 of sewage effluent, which is 80% of the effluent delivered by the urban and rural sewage systems (Concise statistical yearbook of Poland 2012).

To date, one of the most popular methods of recycling is the use of municipal sewage sludge as a fertilizer component containing many valuable ingredients in the form of micro– and macro–elements vital to the growth and development of plants. Agricultural use means that basic components such as phosphorus and nitrogen for plants as well as other nutrients and organic substances contained in the sludge are introduced into the soil to improve it and may replace traditional chemical fertilizers. It is in this context that there is an urgent need to apply a safe path for the utilization of sewage sludge. It is assumed that in the future the agricultural use of sewage sludge shall be one of the recycling options in addition to combustion. Combustion facilitates the generation of thermal energy and electricity. However, its downside is the loss of nutrients contained in the sludge, including phosphorus, which is a vital nutrient for living organisms. Many of the world's experts have proposed the recovery of phosphorus mass from sewage on a level of 75%. This strategy has led to the development of new technologies for the processing of sludge, taking into account the recovery of phosphorus and the heavy metals it contains. Two technologies have been proposed in Sweden—bio–Con and Cambi–KREPRO, They are presently in their implementation phases. They shall be encompassed by cost and environmental impact assessment. Both technologies use sulfuric acid to dissolve the phosphorus, which is successively recovered and used as fertilizer.

The volume of municipal sewage sludge being produced has been growing recently. Data from the National Waste Management Program (KPGO) show that there will be a systematic increased in the quantity of sewage sludge from municipal sewage treatment plants in the upcoming years. By the year 2014 it should reach over 700,000 Mg (KPGO, *Polish Monitor*, No. 11, 2003). Growth in sludge mass shall certainly continue until such a time as Poland builds a sufficient quantity of sewage treatment facilities capable of serving all wastewater producers.

The trend in sludge management noted in Poland is essentially similar to the one formed in the countries of Western Europe. Recent years have seen the taking on of importance of methods allowing for diversified recycling of sludge, especially including nature–oriented use. There is a backing away from the depositing of sludge in dumps or its sinking in the sea. Thermal methods for utilizing sewage sludge are also gaining in importance. Additional sanitation using calcium compounds is sometimes necessary in order to fully and positively sanitize sludge after aerobic stabilization. In addition to its bactericidal effect, calcium in the form of CaO results in a decrease in organic substances, decreased water content, and decreased metal mobility (Baran and Turski 1999; Krzywy 1999, Romanowska-Duda et al 2007).

Sewage sludge is characterized by significant variety in physical properties and chemical composition that are dependent on sewage effluent properties and treatment and processing technologies. The fertilization properties of sludge are characterized by significant content of organic substances, nitrogen, phosphorus, calcium, magnesium, sulfur, and a quantity of valuable micro–elements, including cobalt, copper, nickel, and zinc. Also valuable are the organic substances maintaining the structure of the soil and influencing its water, thermal, and sorbent properties as well as biological life. Undesirable sludge components that may limit its use in nature are heavy metals and pathogens (Bojarowska et al. 1982; Siuta 1988; 1997, 1998). Studies to date show that in most cases the content of heavy metals is within allowable limits (Bernacki and Pawłowska 1994, 1996).

Not without significance is the C:N ratio in the sludge, which is in the 5.7–16.7:1 range (Krzywy and Iżewska 2004). This guarantees that in using sludge as a fertilizer, the nitrogen it contains will not be subject to biological sorption. At the same time, humification processes involving the organic matter introduced into the soil with the sludge will proceed properly. Compared with manure and liquid manure, sludge contains significantly more nitrogen and phosphorus as well as calcium and magnesium. The fertilization value of sludge is ranked as being more favorable as compared with manure or mineral fertilizers (Gorlach and Mazur 2002).

5. Potential use of biomass for energy

In Poland, the acquiring of energy from biomass has significant advantages over other renewable energy source technologies because of the potential for growing energy crops on marginal (poor) soils. However, this very promising market is, to a great extent, undeveloped. Thus, there is a lot of space facilitating the intensification of biomass production for energy goals that is environmentally friendly through the use of new agro–technologies for the growing of energy crops while simultaneously monitoring environmental bio–indicators in order to protect natural resources (Grzesik and Romanowska-Duda 2009a, Grzesik et al 2011a, b).

Biomass derived from energy crops has already proved itself as being technically feasible and cost effective in the production of renewable energy. Success is dependent on such factors as the regular supply of this plant raw material. A properly and sustainably managed energy economy should create buffer stores and build a greater and more diverse biomass sector on a global scale. At the same time, steps should be taken to improve logistics, which will make it possible for companies to produce energy at competitive prices. Increasing the supply of biomass requires the application of modern agro–technology using environmentally–friendly bio–stimulators, organic municipal products, the use of poor, undeveloped soils that are not appropriate for food production, and the improvement and development of the currently weak logistics behind the delivery of the plant raw materials in the Łódź region as well as the country as a whole (Grzesik et al. 2009).

The use of biomass in power engineering and combined electricity and heat generating plants in Europe is on the rise. The enormous energy potential resting in biomass is stirring the interest of global companies. Among examples is the energy giant GDF Suez, which uses various types of biomass in the combustion process in its eight electricity generating plants in Belgium, the Netherlands, Poland, and Brazil. Each of these countries can receive emission credits in line with the provisions of the Kioto Protocol. GDF Suez has declared that it will build the world's largest energy–generating block using biomass in Poland. It will have a rating of 190 MW and be capable of supplying over 400,000 households.

The demand for biomass has grown recently. With its existing potential and the sustainable management of farmland, Poland can become a powerhouse in its production in Europe. According to the Institute of Soil Science and Plant Cultivation (IUNG) of Puławy, Poland has at its disposal an area of over 600,000 ha that can be dedicated to energy crop plantations and is capable of producing over 10,000,000 tons of biomass per annum, which can generate a revenue in the area of PLN 2.5–3.0 billion creating a new direction in industry—agrofuel. This venture will significantly improve Poland's chances of meeting its obligation to produce 15% of its energy from renewable sources by the year 2020.

In the Voivodeship of Łódź, a typical agricultural voivodeship that can serve as an example in the development of renewable energy in Poland, energy crop plantations currently occupy over 300 ha and available total biomass (originating from not only the energy plantations) is estimated at approximately 18,000 tons. At the same time, current demand for biomass amounts to at least 60,000 tons. Expectations are that within three to five years, this demand must grow to at least 100,000 tons, which is six times more than today. Assuming that the average output of an energy willow plantation (starting with the third–year harvest) amounts to approximately eleven tons per hectare, achieving a planned amount of 100,000 tons requires approximately 10,000 hectares for planting. Fallow and set–aside land (Grades V–VI) in the Voivodeship of Łódź currently accounts for 123,887 ha (11% of arable land). Grains will have to be grown on a part of this fallow and set–aside land—that with for favorable conditions—as a deficit is beginning to appear in the voivodeship. Energy crops should be grown on the remaining fallow and set–aside land with soils of the lowest quality. In order to prevent the monoculture cultivation of energy crops, plant species biodiversity should be applied, where the plants should be adapted to specific environmental conditions. The main structures taking part in implementing the production of biomass for energy will be small– and large–area farmers, power engineering companies, local government, and sewage treatment plants that, thanks to developed technologies, will be able to provide produced sludge to farmers (instead of costly and hazardous storage) for nature–oriented use in the production of energy crops. Currently, in connection with the growing demand for biomass, the price achieved for energy produced from it is coming dangerously close to the price of energy produced using coal dust. Possibilities for lowering it include increased yields per unit area and decreased costs of biomass production. This goal is served by the development of economical technologies that use free sludge from municipal sewage treatment plants and lagoons instead of costly artificial fertilizers that additionally contributes to environmental pollution. The developed technologies can be used in Poland and Europe. They are related to the latest trends in the production of biomass for energy purposes. The research to date of the authors of this paper indicates the potential for significantly increasing biomass by using low–quality soils. This will play a role in improving the energy security of Poland as well as an increase in the living standard of energy crop producers and in the efficiency of acquiring renewable energy by power engineering companies. At the same time, this solves the very serious problem of storing municipal sludge. This venture as well as the development of technology acts to accelerate the rate of innovativeness throughout the whole of the value chain creating ecological sustainability in the product life cycles and technological processes, while opening up new possibilities in the service sector. Such progress is a locomotive for development and the creation of jobs. Government support is vital on a national and global level in order to manage this gargantuan task, as is the development and perfecting of new and efficient technologies for acquiring renewable energy, including from biomass. It is assumed that in the long–term the technologies for producing renewable energy will, to a great extent, replace traditional ways of producing energy from fossil fuels. This tendency is already underway and there is no retreat.

6. Economic prognoses for the use of sewage sludge in the countries of Europe

Use of bioenergy in the countries of Europe will grow in the nearest future in order to meet requirements for producing renewable energy as directed by the European Union. Biomass of energy plant produced on a greater scale will play a major role in the growth of energy production (EEA 2006). The short rotation system (SRC) for producing biomass for the generation of heat or electricity, or both, has been identified as the most energy–saving technology for conversion from coal in order to decrease greenhouse gas emissions (Styles and Jones 2007). It is for this reason that it is considered a promising way to satisfy European demand for energy using renewable sources and increasing energy security.

SRC refers to biomass production and cultivation management systems, including agro–technology involving the preparing of the soil, fighting weeds, planting plants, fertilization, harvesting, etc. Bioenergy systems must be land–efficient and should bring about an increase in the amount of energy produced per hectare. Such systemic cultivation is more cost–effective than in case of traditional farming. It is also economically attractive, which has an impact on encouraging and coaxing farmers to cultivate bioenergy plants (Berndes et al. 2008, Ericsson et al. 2009). One way is application of wastes, including sewage effluent and sludge, to energy plantations. This method has been acknowledged as one of the most attractive ways of achieving environmental and energy goals, while simultaneously increasing farmer incomes (Dimitriou and Aronsson 2005).

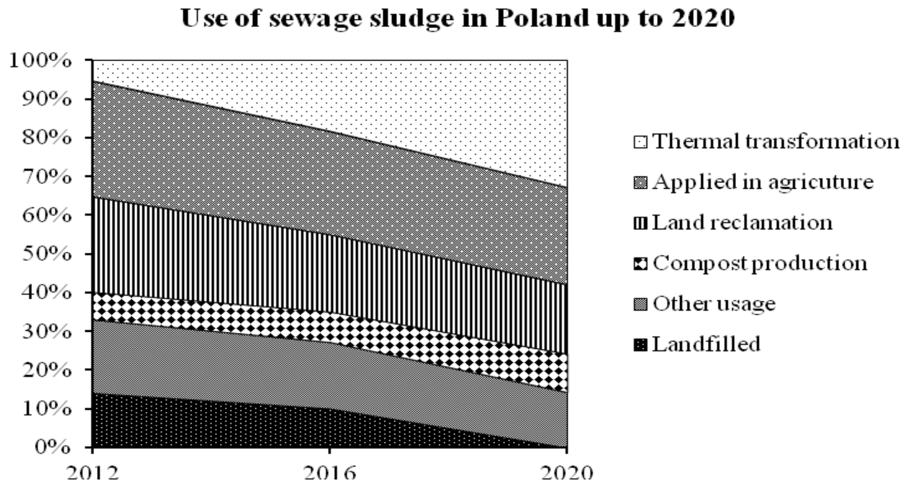
According to Central Statistical Office (GUS) projections, the quantity of thermally utilized sludge will increase up to the year 2014, as will the quantity of stored sludge. The application of sludge for the production of plants designated for composting will also increase.

Table 2. Total sewage sludge (thousands of tons of dry matter) from municipal wastewater treatment plant generated during the year in Poland and their use (application in agriculture, application in land reclamation including reclamation of land for agricultural purposes, thermal transformation, application in cultivation of plants intended for compost production, landfilled and other usage)

	Year				
	2000	2005	2008	2009	2010
Total	359,8	486,1	567,3	563,1	526,7
Applied in	-	66	112	123,1	109,3
Land	-	120,6	105,8	77,8	54,3
Compost	25,5	27,4	27,5	23,5	30,9
Thermal	5,9	6,2	6	8,9	19,8
Landfilled	151,6	150,7	91,6	81,6	58,9
Other usage	176,8	115,2	224,4	248,2	253,5

Source: based on Environment (2011) CSO, Regional and Environmental Surveys Division ISSN 0867-3217.

Figure 1. Projections for sewage sludge use in Poland up to 2020



Source: Grabowski Z. (2011), *Termiczne przekształcanie osadów ściekowych na przykładzie STUO w Krakowie,* IV Forum Gospodarka osadami ściekowymi, Warsaw.

There is a big demand on the domestic market as well as in the Voivodeship of Łódź for modern, cost–effective plant production technologies, including energy crops for poor and degraded soils where plants are not cultivated for food. Energy crop production, even on medium–quality soils (Cultivation Grades III–IV), has been unprofitable or barely profitable to date in comparison with gardening. In the case of poor soils (Cultivation Grades V–VI), such production mostly results in losses and, for this reason, is not undertaken.

The application of sewage sludge makes the production of energy crops profitable on poor soils, has a positive impact on the environment, does not compete with food production, makes possible the development of land that has not as of yet been used agriculturally or land of low productivity, and expands the job market for people living in the area (Cogaliastro et al 2001).

The economics trump cards of introducing this technology are obvious on a national scale. In just the Voivodeship of Łódź, a typical agricultural region, the benefits of applying renewable technologies include:

- The introduction of many species of plants for use for a multitude of direction and a capacity to grow them on low–quality soils (including Cultivation Grades V–VI, which account for 17.71% of the arable land in voivodeship and whose surface area amounts to 170,000 ha). Most of the proposed species, except for those designated for the acquisition of energy, can be used as animal feed, including as silage. Moreover, these plants clean the soil of toxic contamination and some have additional utilitarian qualities.

- The development of low–quality soils where no agricultural production is conducted or production is minimal, which results in growth of the job market and a decrease in unemployment.
- The nature–oriented management of sludge from municipal sewage treatment plants, the storage of which is costly and hazardous to the environment. In the Voivodeship of Łódź alone, the nature–oriented use of sludge by energy plantations may bring the utilities at least PLN 60 million in savings, assuming that the sewage treatment plants add PLN 100 to each ton of supplied sludge certified for nature–oriented use, where one hectare of plantation needs fifty tons of sludge as fertilizer, where energy crops in the voivodeship should encompass approximately 34,000 ha (20% of Grade V and VI soils) in the nearest future. It is assumed that on a national scale, energy crops shall be grown on two, or perhaps even four million hectares, i.e. 20% of the whole of arable land (Tytko 2009). An additional trump card is the decrease in very costly sludge ingredients.
- The decrease in outlay for artificial fertilizer and chemical plant protection products, and improved environmental conditions. Plantation owners in the Voivodeship of Łódź cultivating energy crops over an area of 34,000 ha have the potential to save at least PLN 24 million per annum as a result of the decrease in the cost of mineral fertilization, assuming that basic fertilization using mineral fertilizer that is detrimental to the environment costs only PLN 1,000/ha.
- The justifiability of using sewage sludge in the systemic cultivation of energy crops has been investigated in several countries in Europe, where it was deemed an inexpensive alternative method to fertilization using chemical fertilizer (Aronsson and Perttu, 2001). Numerous study results indicate the major potential in applying sewage sludge and effluent in order to increase the profitability of energy crop cultivation by decreasing the costs of fertilization and increasing the production of biomass (Dimitriou and Rosenqvist 2011, Grzesik et al. 2007, Grzesik and Romanowska-Duda. 2009b,c).

Table 3. Theoretical Estimates of Land Required if All Available Sewage Sludge (ss) and Wastewater (ww) Is Applied to SRC, and Resultant Increases in Renewable Energy in Various EU Countries

	Population (Millions)	SRC area to be fertilised with all available ss (t ha)	SRC area to be fertilised with all available ww (t ha)	Arable land surface with SRC fertilised with ss (%)	Arable land surface with SRC fertilised with ww (%)	Energy produced from SRC if all ss applied (PJ)	Energy produced from SRC if all ww applied (PJ)
EU27	495.13	35673	1505	34	1.4	5636.3	309.2
Czech Rep.	10.29	824	34	32	1.3	117.1	6.4
Estonia	1.34	107	4	17	0.7	15.3	0.8
Finland	5.28	422	17	19	0.8	60.1	3.3
Germany	82.31	5931	250	50	2.1	937.0	51.4
Hungary	10.07	604	25	17	0.7	114.6	6.3
Latvia	2.28	183	8	16	0.7	26	1.4
Lithuania	3.38	271	11	15	0.6	38.5	2.1
Poland	38.13	3052	116	26	1	434	23.8
Romania	21.57	1295	53	15	0.6	245.5	13.5
Slovakia	5.39	486	19	37	1.5	61.4	3.4
Slovenia	2.01	161	7	93	3.8	22.9	1.3
Sweden	9.11	505	23	19	0.9	103.7	5.7

Source: Dimitriou, I., Rosenqvist, H. (2011), Sewage sludge and wastewater fertilisation of Short Rotation Coppice (SRC) for increased bioenergy production - biological and economic potential "Biomass and Bioenergy" 35(2): 835-842.

7. Conclusions

The required increase in energy production using biomass, a basic source of renewable energy, requires the application of new, highly–efficient, and less costly plant production technologies that are not in competition with food production. Certified sewage sludge, the storage of which is challenging, costly, and very hazardous to the environment, may be used in the production of biomass for energy on poor soils where plants for consumption are not cultivated. Their use decreases the costs of energy crop production, improves properties and biological life in the soil, and significantly increases biomass yields.

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Streszczenie

BIOLOGICZNE I EKONOMICZNE UWARUNKOWANIA ZASTOSOWANIA OSADÓW ŚCIEKOWYCH W PRODUKCJI BIOMASY ROŚLINNEJ NA CELE ENERGETYCZNE

Celem artykułu jest przedstawienie prawnych, biologicznych i ekonomicznych uwarunkowań produkcji energii z biomasy roślinnej, ze szczególnym uwzględnieniem zastosowania osadów ściekowych mających certyfikat przyrodniczego wykorzystania w rolnictwie. Zwiększenie produkcji biomasy wymaga wprowadzenia tanich i wysokowydajnych technologii produkcji roślin przyjaznych środowisku. Zastosowanie certyfikowanych osadów ściekowych zwiększa efektywność ekonomiczną upraw energetycznych i korzystnie wpływa na środowisko.