

SLUDGE AND WASTE WATER APPLICATION FOR ENERGY PLANTATION – CASE STUDY FROM LODZ REGION IN POLAND

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ABSTRACT

Within renewable energy sources available in Poland, biomass seems to have the largest potential, estimated to 90%. About 70% of renewable energy should be obtained from agricultural production of energy plants. Climatic conditions in Poland (vegetation period of 210-215 days and precipitation of 500-700 mm) are profitable for willow plantation. The natural productivity can be as high as 14 Mg d.m. per ha. However, the productivity can be increased by using waste water for irrigation and sludge for fertilisation.

For decades an area of 4 500 ha of Ner River valley was used as a part of municipal wastewater treatment system for Lodz city. The valley has specific soil-water conditions with deep sandy alluvial soils and shallow groundwater table. During the irrigation process the inflow of wastewater on an artificially formed border check infiltrates into the soil and fills the available porosity.

Average outflow from wastewater treatment plant in Lodz (2 m³/s) and sludge daily production of 30 - 35 Mg d. m. (app. 170 Mg dewatering sludge) can be utilised on energy biomass plantation (e.g. *Salix Viminalis* or grasslands) located in the Ner River valley.

KEYWORDS

Short rotation plantation; Irrigation; Fertilisation; Willow; Renewable energy; Recycling of nutrients

1. SHORT ROTATION PLANTATION (SRP) IN POLAND

Within renewable energy sources available in Poland, biomass seems to have the largest potential, estimated to 90%. About 70% of renewable energy should be obtained from agricultural production of energy plants. Predicted energy use in present year is approximated to 4000 PJ, in which 87 PJ should be produced from energy plants. Making assumption that 1 ha of short rotation plantation (SRP) gives about 310 GJ of energy, over 200 thousand ha of SRP is needed to reach the goal for 2005. To reach the goal of the 9% share of renewable

energy sources in energetic balance of Poland in 2010 and assuming annual energy needs for 5000 PJ, about 600 - 1000 thousands ha of SRP will be needed [7].

Climatic conditions in Poland (vegetation period of 210-215 days and precipitation of 500-700 mm) are profitable for willow plantation and other plants cultivation. The natural productivity of willow can be as high as 14 Mg d.m. per ha. However, the productivity can be increased by using irrigation and fertilisation.

According to recent data of Polish Ministry of Agriculture and Rural Development (MRiRW) about 5.5 thousand hectares of *Salix* plantations (over 500 plantations) is established in Poland. However those data do not cover the real area of SRP, because does not include plantations which produce biomass for farm internal needs (eg. heating farmstead buildings, etc.) and many small plantations (of area less than 1 ha).

Advantages of SRP:

- Lower cost of energy (1/3 of cost compared with coal)
- Possible sludge utilisation (over 360 thousands Mg of d.m. sludge is produced every year)
- Possible wastewater tertiary treatment
- Workplace (1 person taking care of 20 ha plantation will earn 3750 Euro a year)
- Cost biomass production (235 Euro per ha) – subvention (55 Euro per ha) – price of biomass 25 Euro per Mg of d.m. * 14 Md d.m. = profit of about 235 Euro per ha.

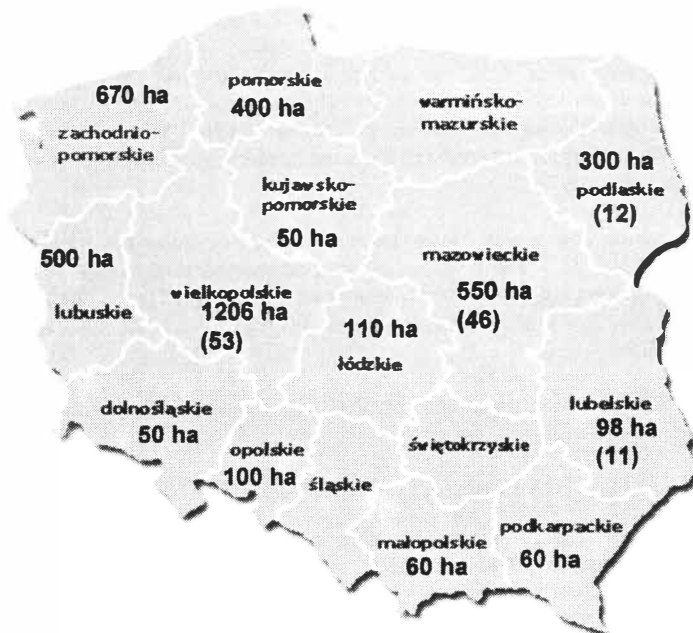


Figure 1. Voivodships with the largest and the lowest *Salix* plantations area. Number of plantations shown in brackets. Based on official data from MRiRW (in black) and other sources (in blue).

Problems with implementation of SRP:

- *Salix* plantations in Poland are not subsidised from EU sources.
- EC gave consent to appropriation of 55 thousands Euro from the national budget. It gives only 10 Euro per ha of SRP (direct subventions to agricultural cultivated area amounts 55 Euro per ha).
- Only two energy plant species *Salix sp.* and *Rosa multiplora var.* can be subsidised.
- To get subvention the farmer has to sign long term agreement with biomass recipient, who is concerned with conversion of biomass to the source of energy (fuel).
- High costs of installation modernisation

Other significant energy biomass sources in Poland

Among other biomass sources, straw and hay may play significant role as a source of energy. Surplus mass of straw in Poland is estimated on 9-12 mln Mg per year what gives technical potential of 195 PJ. It is a cheapest available fuel. However, installations for combustion of straw are very expensive. Actually, only 1% of produced straw (25 mln Mg per year) is used as an energy source.

The oldest biomass source of energy is wood. Mass of wood available for use as a fuel amounts 8,8 mln Mg per year (technical potential 57,6 PJ). According to ECBREC in 2002 in Poland wood biomass was used in both large (> 500 kW – 180 installations) and small (< 500 kW – 110 thousands installations) heating plants.

The other available biomass source of energy is biogas produced from manure, sludge or wastes stored on landfills. Technical potential of biogas from manure is estimated on 37,5 PJ. Additional 100 PJ can be obtained from wastewater sludge and similar potential from landfills. However, production of biogas from sludge can be profitable, if the volume of treated wastewater is higher than 20 thousands m³ per day. Dried and bicket sludge (90% of d.m.) can also be used as a fuel in burning process (potential of 9,2 MJ per kg).

Water and nutrient sources for energy biomass production

Sludge produced in the wastewater treatment process can be used as a source of energy not only directly, as mentioned above. It can also be used as a source of nutrients for energy biomass production if applicated as fertiliser on SRP. The actual annual production of sludge approximates 360 thousands Mg of d.m. Predicted number of produced sludge in near future is about 420 thousand Mg of dry matter within a year. On 1 ha of SRP up to 10 Mg of sludge can be utilised. It can bring to the farmer additional income of about 35 PLN per Mg of sludge. The availability of sludge for SRP is high, because only 7.5% of produced sludge reaches the chemical norms for agricultural use.

Wastewater itself can also be non expensive and easy available source of nutrients and water for SRP. At the end of 2004 over 2000 wastewater treatment plants was operated, with average flow between 50 and 100 000 m³ d⁻¹. The number of people connected to those plants was over 20 mln. In treated wastewater about 29,4 thousands Mg of organic pollutants (BOD₅) and 3,1 thousands Mg of phosphorus is discharged to receivers during the year. Using wastewater for SRP irrigation and fertilisation would advantage in joined treatment and high and stable biomass production.

2. SITE DESCRIPTION

According to the water framework directive highly degraded rivers must aim to reach "good ecological status" until 2015. In some regions technical solutions like building wastewater treatment infrastructure could be not sufficient due to high concentration of wastewater amount in small region without large enough receiving water body. The example can be Lodz region, where the total amount of wastewater discharged is as high as 2 m^3 per second compared with 10 times lower receiver natural flow. This wastewater – river water ratio is too high to make possible reaching the good status of the river ecosystem without enormous expenditure of money, chemicals and energy spending on treatment process. Even if it's possible from technical point of view it doesn't make sense because in most treatment plant investment, the self-purification process is taken under consideration as the last step of treatment. That makes it to be cost-effective and keeps the social costs of treatment acceptably low, what is one of assumptions of sustainable development. But the Ner River seems to have lost the ability of self-purification. The contaminants which are stored in bed sediments and irrigated valley soil could be released slowly causing internal contamination.

Ner River is small lowland river of $0,2 \text{ m}^3$ natural flow. The city of Lodz discharges $2 \text{ m}^3/\text{s}$ of wastewater and for decades Ner was the receiver of such amount crude wastewater. Therefore the river average concentration of nitrogen amounted to 23 mgN/L and phosphorus $11,6 \text{ mgP/L}$ (loads: 2898 tons N/year and 1462 tons P/year respectively). The self purification was mainly effected by irrigation of grasslands in the valley (about 4500 hectares) what gave more than 1300 tons of nitrogen and about 200 tons of phosphorus removed with the yield.

The valley has specific soil-water conditions with deep sandy alluvial soils and shallow groundwater table. During the irrigation process the inflow of waste water on an artificially formed border check infiltrates into the soil and fills the available porosity. Excess of water flows as surface runoff towards open drainage ditches (*see Figure 2*). The natural soil-plant system is a dynamic medium for absorbing, treating and utilising the wastewater constituents. It works as a mechanical, chemical and biological filter, which is renewed through systematic agricultural use. The research made by Matczak [9] showed that irrigation system made significant contribution to reduction of nutrients and other pollutants. In wastewater flowed through irrigation system reduction of nitrogen ranged from 33 to 89%, phosphates – from 23 to 91%, potassium and BOD respectively: 24-66% and 50-77%. Unfortunately, in some areas, wastewater irrigation effected also in contamination of soil with hazardous metals. The role of sewage irrigation, however controversial with its side effects of soil contamination, was invaluable for lower rivers ecosystems like Warta and Odra. It was the most important factor which reduces the enormous load of contaminant flowing through the Ner River. We should emphasise that relatively small Ner in 1996 was a receiver of 3,5 % of total sewage from Poland. Therefore its impact on pollutants load to Baltic Sea was significant.

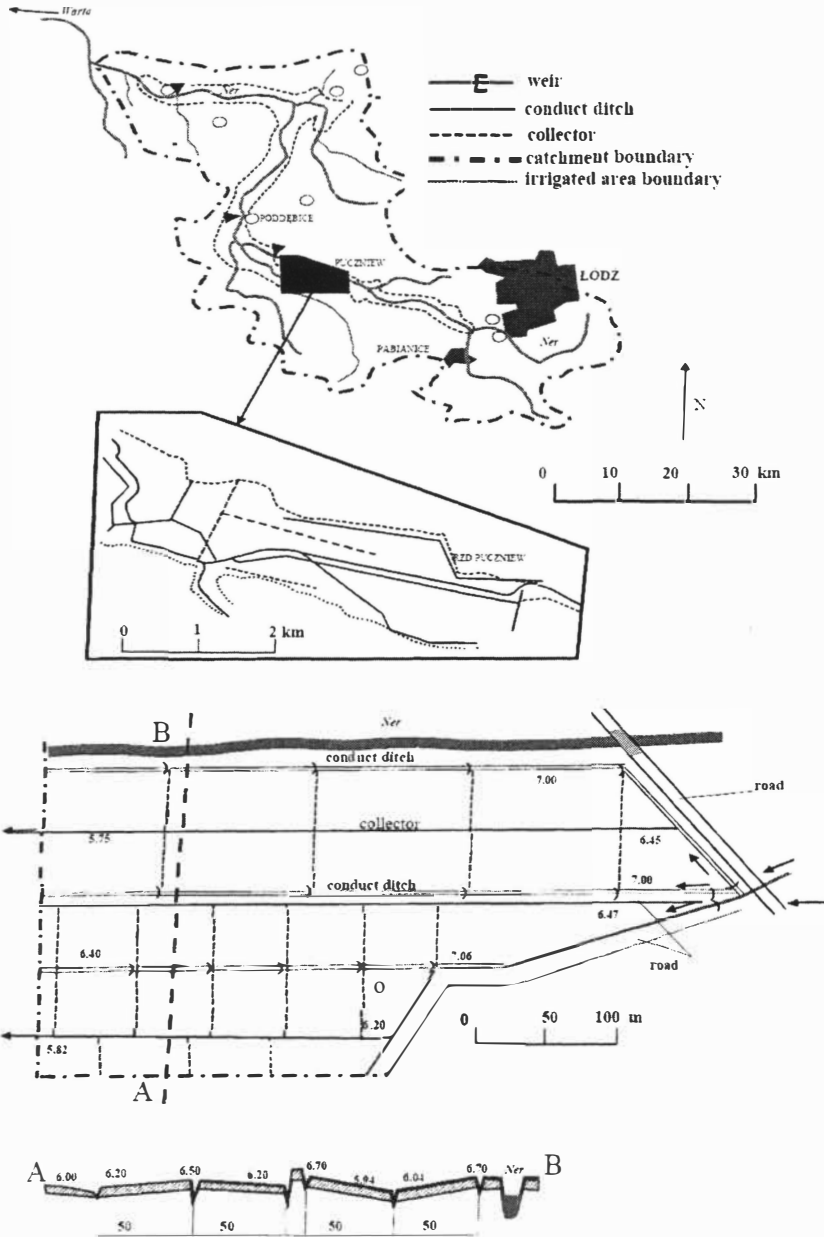


Figure 2. Ner river drainage catchment, range and scheme of irrigation system [10,11].

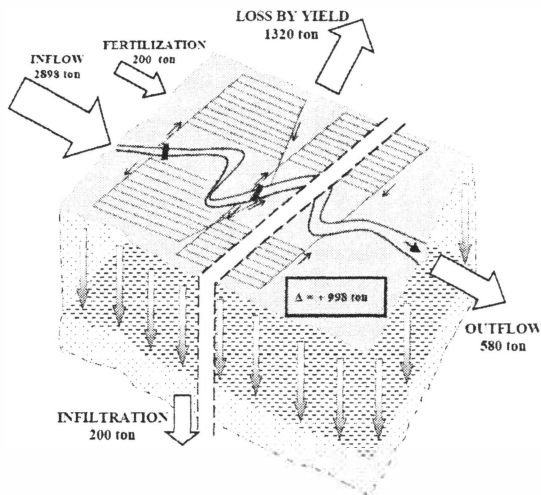


Figure 3. Total nitrogen balance in the Ner river valley irrigation system [10,11].

In late '90 the treatment plant was started up and the water quality, however much better, still didn't reach satisfactory level – most of chemical parameters remain high and the water is still classified in 5 – the worst quality range. The wide irrigation system existing in the river valley is still used but because of regress in agriculture the production is not as intensive as in the past. The main purpose of this system was to produce fodder for animals. The results of many investigations made in the valley have shown that average reduction of nitrogen and phosphorus in irrigation system amounted to 80% and 78% in the valley scale (see Figure 3 and Figure 4) [10, 11]. At present the inflow is much lower and percentage reduction could not be so high, however it remain very important factor in river restoration.

When wastewater irrigation is used distribution of pollutants could be wide and prospective need of reclamation possible [1, 4]. But ecological effect of nutrients recycling shouldn't be passed over. Many scientists point out that using waste water, which are rich in nutrients for irrigation, is one of the right solution [5, 8]. The role of closing nutrients cycling in the environment, as the way of making environment sustainable, is more and more often described in the literature [2]. The constructed wetlands which are often used for purification are a good example.

The form and the way of nutrients distribution should be discussed. It could be done, obviously, in two ways: wastewater irrigation and fertilisation with sludge. But if irrigation is needed anyhow – we can use irrigation system as the another wastewater treatment step and bring sludge fertiliser as nutrients source separately. It seems not to be very cost-effective and sustainable solution of wastewater and sludge problem.

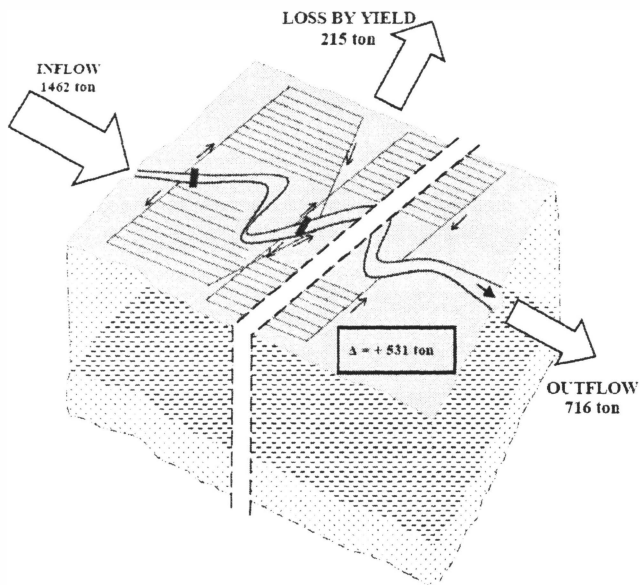


Figure 4. Total phosphorus balance in the Ner river valley irrigation system [10,11].

3. SLUDGE UTILIZATION AND ENERGY PLANTATION

Treating wastewater in WWTP (Wastewater treatment plant of Lodz) result in production of surplus sludge which is difficult to utilise. Using sludge as a fertiliser and for degraded soil restoration in many cases gave very good results. The content of nutrients and organic matter in sludge from treatment plant is higher than in commonly used manure. The nutrients are released slowly and easy to absorb by plants. But sludge can also contain harmful chemicals (especially heavy metals), pathogens and parasites what depends on genesis of the sludge and type of purification process.

Polish and EU law characterise sludge which could be used as a fertiliser for agriculture and non-food plantation. The limit concentrations of hazardous metals are shown in *Table 1*. As shown in the table, the sludge from WWTP meets all conditions to be used for non-food plantation and for restoration as well. But critical factor is also in this case is metal concentration in soil. This limitation, according to Liwski studies [6], could be the main obstacle for sludge utilisation in this way especially in most contaminated profiles located near WWTP like Konstanyńów but also Jezew. Polish law specify also dose of sludge that could be applied as a fertiliser. According to the law the first dose is as height as 250 Mg d.w. per hectare and it could be applied during first 3 years and next years sludge disposing is limited to 10 Mg per hectare.

Table 1. The limit contents of metals in sludge which could be use as fertiliser [11].

Metal	Average content in sludge from WWTP plant	Limit metal contents [mg per kg dry weight of sludge]					
		When using for:		non-agriculture land	Non-food plantation	EU 1986/276/EEC	Directive
Agriculture	Restoration						
lead	57	500	1000		1500	750 – 1200	
cadmium	5,8	10	25		50	20 – 40	
mercury	3,2	5	10		25	16 – 25	
nikel	138	100	200		500	300 – 400	
zinc	1553	2500	3500		5000	2500 – 4000	
copper	413	800	1200		2000	1000 – 1750	
chromium	207	500	1000		2500	-	

The main advantage of using sludge as fertiliser is lower fertiliser purchase costs or even profits: the treatment plants administration pays sludge receivers for sludge utilisation from 30 to 100 PLN for Mg of dry weight.

Willow *Salix viminalis* is one of several plants used on energy plantation and wastewater treatment [3] and it seems to be the best for studied case. Water demand of this plant is high, so it could be cultivated on irrigated parts of Ner valley even if heavy metal-contaminated [13]. As a non-food plantation it could be also fertilised with the sludge contaminated with heavy metals. To get 20 tones per hectare crop of willow dry biomass the plant need about 150 kg of nitrogen, 18 kg of phosphate and 60 kg of potassium [12], therefore we should to estimate available nutrients content in soil, sludge and irrigation water. However priority of this plantation could be sludge and sewage utilisation and heavy metals phytoremediation not only biomass production.

WWTP of Lodz produces about 35 Mg of sludge dry weight daily. If we assume that during 20 years of using willow plantation for sludge utilisation we bring in 250 Mg/ha for land reclamation during first 3 years and 10 Mg/ha each next year. We can utilise total amount of 420 Mg sludge per hectare. It results in 21 Mg/ha per year average. To utilise all sludge produced at WWTP will be need about 650 hectare of willow plantation. Without first reclamation dose, applying only 10 Mg/ha per year, the area need for sludge utilisation would amount 1300 hectare. Both scenarios are possible to implement because estimating area available for setting up willow plantations is 4000 hectares.

4. CONCLUSIONS

1. Short rotation plantations (SRP) represent an economic solution for high efficient biomass production and low-cost wastewater and sludge treatment, on the other hand they can contribute to the local independence from external fossil fuels and their price fluctuation, to less environmental pollution and more local employment.
2. Before qualify the area where energy plantation could be set up and area for sludge fertilisation, determination of soil condition is needed. The areas where the hazardous metals concentration limits in the soil are exceeded could be use for energy plantation but without sludge fertilisation. In this cases nutrients should be provided with irrigation only.

The concentration of willow plantations in relatively small area will effect with establishing industrial infrastructure for willow biomass processing and distribution and make it much more cost-effective way to provide renewable energy in this region.

3. Selection of the areas for sludge utilisation should be proceeded by heavy metals content soil analysis. At the areas where limits are exceeded (industrial areas according to classification) recultivation is needed. This kind of areas in Ner river valley occurred locally, on small surfaces, mainly in local depressions where the sludge has been accumulated during winter irrigations.
4. The irrigation system in Ner river valley was for decades the most important factor of reducing the river pollution. Huge amount of nutrient was removed with the yield before reached the river mouth but on the other hand the big amount of contaminants left in the soil and make it locally useless for food production. In the age of Water Framework Directive and the new standards of environmental protection the changes in land use are needed but the irrigation system should be used continuously. It must be included in a new vision of river basin management.
5. The main changes should be applied to plant and agriculture production structure in the valley. On the metal contaminated area energy plantation should be established, and part of area which meets requirements could be used for sludge fertilisation. It could solve the problem of sludge from WWTP storing. Additionally the irrigation with Ner river water will improve the water quality and moisture soil condition needed for willow growing.

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