DEMONSTRATION ACTIVITY REPORT

WP 5.3

THE CITY OF ŁÓDŹ
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ANNEX 3

Experimental plantation at the protection zone of the Wastewater Treatment Plant in Łódź (The Ner River): Sewage system management for environment quality and positive socio-economic feedbacks

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CONTENT:

1. Introduction

The demonstration activities and related research were conducted in the protective zone of the Wastewater Treatment Plant (WWTP) in Łódź, in the catchment of the Ner River. The Ner river (natural flow of about 0,3 m3/s) receives municipal and industrial wastewater (average outflow of 2,5 m3/s) from the Łódź agglomeration, which contaminates both the river and its valley with nutrients, heavy metals and organic compounds.

The Waste Water Treatment Plan (WWTP) produces 70 000 ton of sewage sludge (200 tons/24 h), which causes additional economic and ecological issue. The sewage sludge can be used for non-food agriculture e.g., in short rotation forestry (energetic willow plantation), provided that the heavy metals content is kept within the limits laid down in the Polish legislation. Such a solution is being tested in an experimental willow plantation located in the protection zone of the Wastewater Treatment Plant WWTP.

The general aim of the research and demonstration project was to demonstrate the alternative ways of the sewage treatment plant management in urban areas by harmonization of traditional technology of water treatment with ecological methods of sewage sludge utilization, heavy metals removal and bioenergy production.

The demonstration activities included:

1) Establishing and exploitation of the willow plantation for sewage sludge utilization, biomass production and heavy metals removal;
2) Regular monitoring and research of the above processes for their optimization and adaptive assessment management;
3) Assessment of sewage sludge toxicity based on commercial and standardized ecotoxicological bioassays for screening the toxicity of soil and sediments, and elaboration of methods for minimizing toxicity of the sewage sludge substratum to willows; and
4) Development of the Decision Support System (mathematical model) for management of willow plantations for sewage sludge utilization, based on the literature review and the obtained results.

2. Demonstration activities

2.1. Establishment of the willow plantation and its monitoring

The willow plantation was established in 2004 in the area of restricted exploitation of the Water Treatment Plant. Currently, the plantation has the area of 70 ha. In order to achieve the goals of the demonstration projects, an additional experimental willow plantation, which covers 6,2 ha, has been established within this area at the beginning of SWITCH (Fig. 1). The experimental plantation have been divided into 4 experimental fields (I, II, III, IV) with different clones of energetic willow (Fig. 2):

- experimental field number I: fields 1- 5, *Salix viminalis* clones;
- experimental field number II: fields 6 – 7, Tordis (*Salix schwerini* x *S. viminalis*) x *S. viminalis;*
- experimental field number III: fields 8 – 9, *Salix viminalis gigantean*;

- experimental field number IV: fields 10 – 11, *Salix viminalis* (clone 192) (authors: The City of Łódź Office);

The sewage sludge was applied to the fields in different doses in order to enhance biomass production. The applied doses of sewage sludge were calculated based on the regulations of the decree of the Ministry of the Environment (Dz.U.Nr 134, position 1140). The dose of 11,5 tons/ha/years of sewage sludge was applied, which is equal to the 3-year dose. The maximum doses have been limited by the heavy metal content.

The following parameters were measured in the monitoring process:

- Survivability of willow;
- Condition of willow;
- Content of heavy metals in the plant tissues;
- Content of heavy metals in the soil with sludge.

The plantation is owned by the City of Łódź Office, and is now being maintained by one of the City's associations.

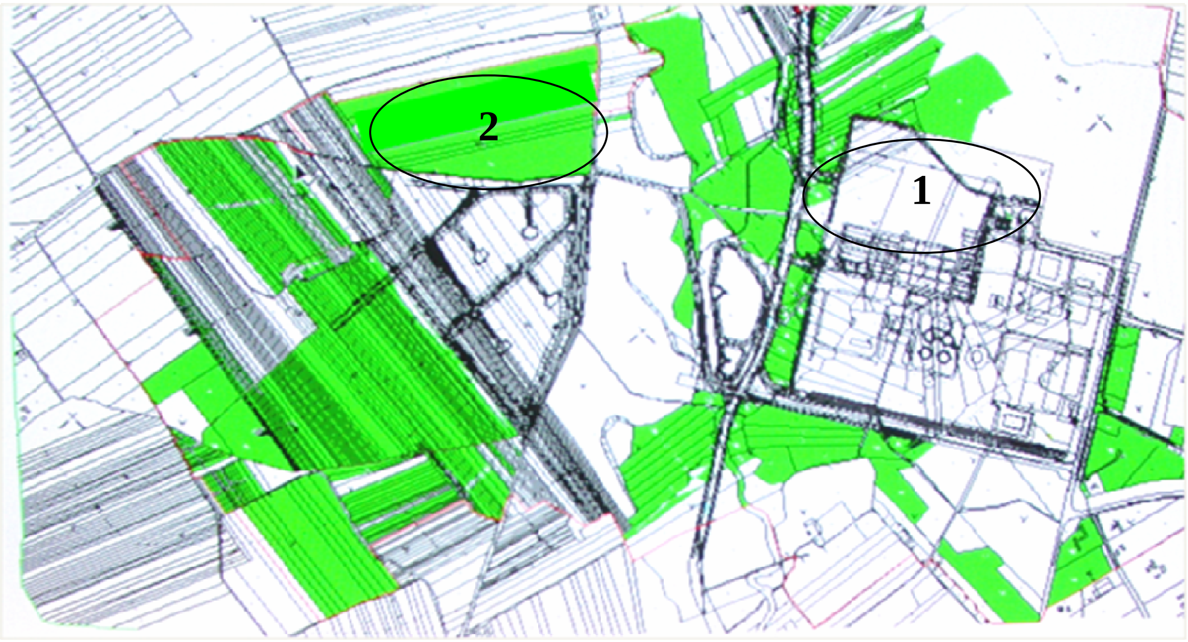

Figure 1. Location of willow plantation (authors: The City of Łódź Office): 1 – The main building of Water Treatment Plant; 2 –The experimental willow plantation.

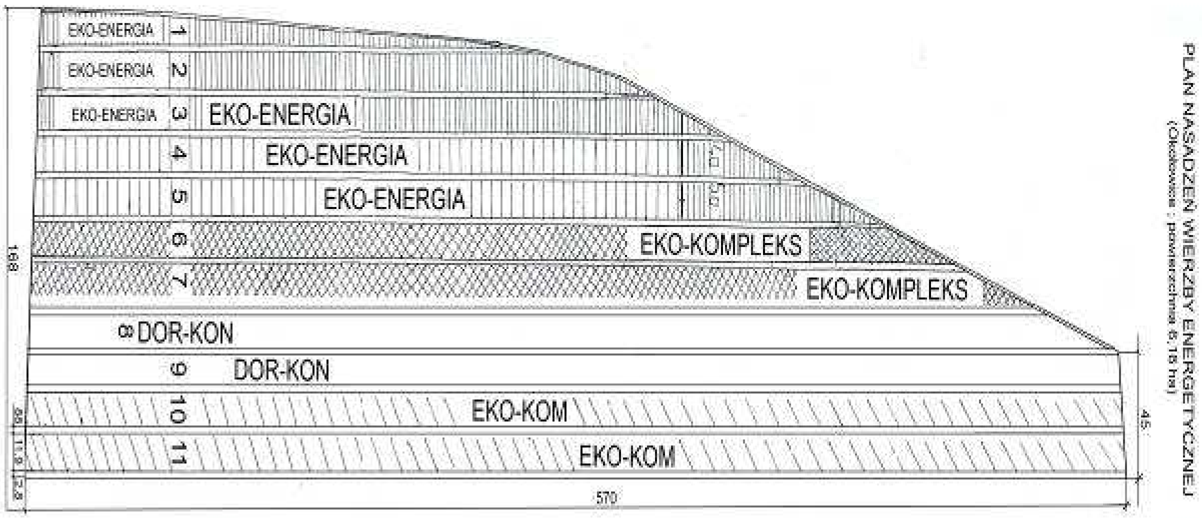

Figure 2. The experimental willow plantation including the divisions into the experimental fields.

2.2. Biomass production

The biomass produced on the plantation has been harvested in January 2005, January 2006, January 2007, in December 2007 and December 2009 (Fig. 3).

The willow was yielded from plots of the plantation of different age (sequential cutting). The biomass obtained is presented in Table 1.

Figure 3. The cutting of willow in a section of the plantation.

Table 1. The biomass of the willow obtained from the plantations

Date of cutting	The age of the willows' roots	The age of the willows' steams	Surface area [ha]	Biomass per ha	Total biomass [t]
Jan 2005	1	1	5,16	0,43	2,21
Jan 2006	1	1	47,58	0,64	30,28
Jan 2007	1	1	6,04	0,25	1,54
	2	1	16,22	3,77	61,08
Dec 2007	3	2	20,19	10,03	202,60
	4	3	5,16	11,80	60,90
Dec 2009	5	3	9,00	11,11	100,00
TOTAL			**109,35**		**458,61**

2.3. Energy production and other benefits

In the course of duration of the SWITCH demonstration project, the project at the WWTP and the willow plantation started to produce the following benefits:

- Total **production of biomass** on the willow plantation at the WWTP since the beginning of the project (2006-2009) reached 458,61 t (harvested total area of plots: 109,35 ha);
- The biomass produced is an equivalent to 2063,745 MWh of energy.
- In 2008, this biomass was used as a source of heat energy by the "Giewont" housing estate in the city of Łódź; **The housing estate used the biomass for heating and has become the first one of this kind (demonstration) in Łódź**
- After 2008, the biomass was used as a source of heat energy in the town of Parzęczew located in the Łódź region. It met 50% of the heat energy needs of the following recipients: public buildings (1 school, 1 police office, 1 post office, 1 health service centre) and 3 blocks of flats used by Parzęczew residents;
- Total **income from the biomass** since the year 2004 (planting and establishment of plantation) till the end of 2009 (last harvesting) reached18344 euro;
- Reduction of the **CO_2 emission** by the "Giewont" housing estate **reached 121 tones kg per year**;

2.4. Reduction of sewage sludge toxicity and increase of biomass production

There were two methods of toxicity reduction tested:

- mixing of sewage sludge with compost, and
- Vermicomposting.

A. Mixing with compost

Effect of toxicity on biomass growth, *Salix viminalis* was fertilized with: sediment from Sulejów Reservoir, compost from the WWTP compost facility in Łódź, mixture of compost and sewage sludge, sewage sludge from Waste Water Treatment Plant in Łódź. Experiment was carried out during one vegetation season.

The highest biomass was obtained from the area with sediments (2,04 t s.m./ha), whereas the lowest, with the exception of control, with sewage sludge (0,49 t s.m./ha; Fig. 4).

According to Usman and coworkers (2006) the most important index which indicates the reduction of soil toxicity is the value of biomass obtained. The results demonstrate that adding of compost to the sewage sludge contributes to decreasedtoxicity of sewage sludge and efficiently increase the biomass of willow. However the reduction of the heavy metal content in sewage reaching the WWTP is the key activity that may increase the efficiency of the sewage sludge used on the plantation., This can be achieved by adopting stricter local regulations and law enforcement. Cooperation with the Łódź Learning Alliance is of crucial importance in this process.

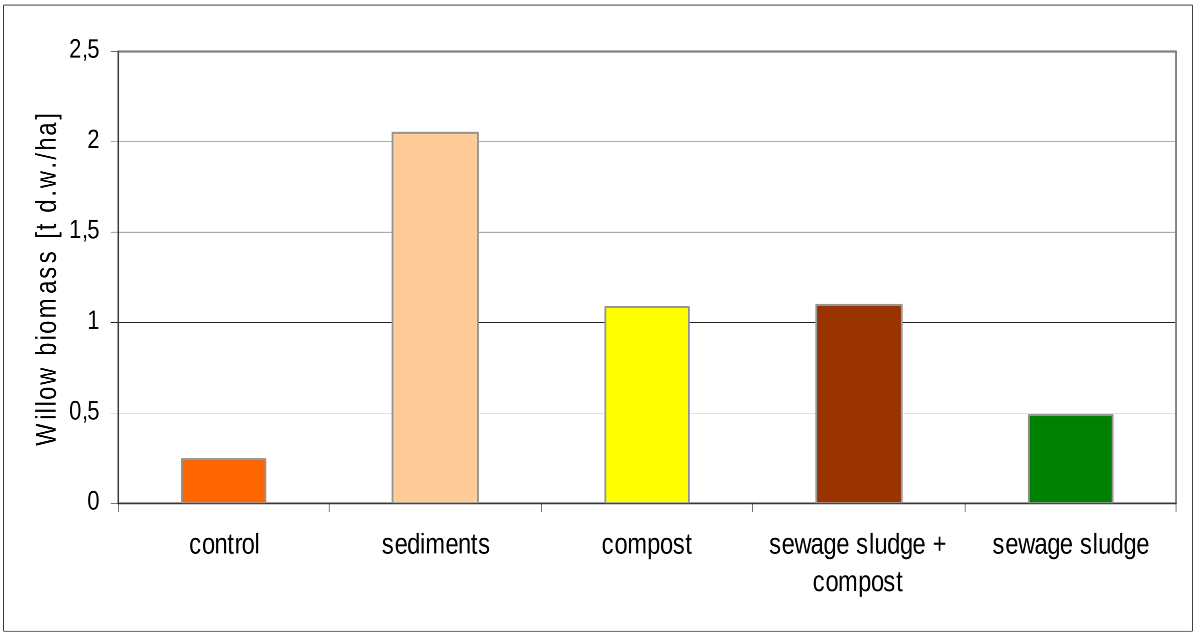

Figure 4. The biomass production

B. Vermicomposting

Vermicomposting is a method which uses earthworms to stabilize natural and anthropogenic (e.g. municipal and industrial sewage sludge) organic wastes (Graziano & Casalicchio, 1987, Elvira et al.,1996). The most common earthworm species in vermiculture include Eisenia fetida, Eisenia andrei, Dendrobena veneta and Lumbrcus rubellus. These species are resistant to anaerobic conditions and high concentrations of heavy metals. On average, one individual consumes an equivalent of its weight (ca1g.) and excretes 50 - 60%. Vermicompost (biohumus) compared to traditional compost (produced without use of earthworms) and sewage sludge is characterized by a number of qualities: enhaced microbial activity (Edwards, 1988), increased degree of mineralization of the substrate, and thus greater availability of biogenic elements to plants (Atiyeh et al., 2000; Ndegwa & Thompson, 2001), homogenity, better aeration and odourlesness (Kocik et al., 2007), three times faster decomposition and stabilization than plain sewage sludge (Mitchell, 1978).

Vermicomposting is a socially acceptable way of waste utilization even in municipal areas as it is characterized by neutral odour of soil. It is a cost-efficient method, which increases yield of biomass and renewable energy. In the experimental area, willow trees fertilized with vermicompost obtained 30% bigger yield (roots, shoots and leaves) comparing to those grown on plain sewage (Fig. 5). This may be due to enhanced microbial activity caused by earthworm excrements.

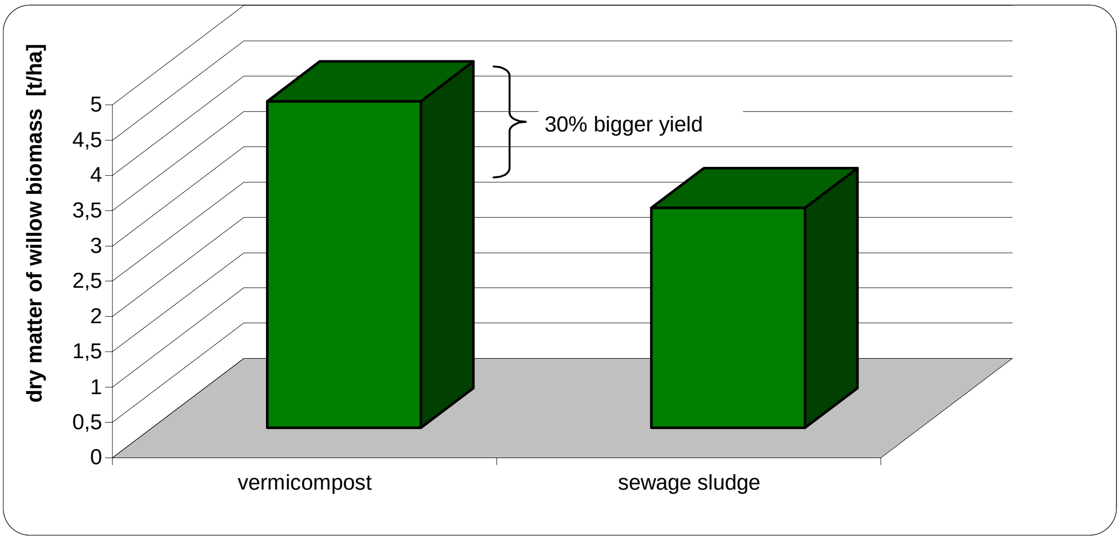

Figure 5. Willow biomass obtained in the mesocosm experiment.

2.5. Heavy metals removal

Phytoremediation is defined as bioremediation by using plants, applicable for the removal or degradation of organic and inorganic pollution in soil, water and air.

The appropriately managed willow, with species and varieties adapted to the groundwater level, can be an efficient ecohydrological tool for optimisation of nutrients and heavy metals management in urban systems. The accumulation and rate of metals' uptake depends on: the amount of metals in an applied sewage sludge, the amount of organic matter in substratum, the substratum's reaction and the groundwater level.

Table 2 demonstrates efficiency of remediation of nutrients (N, P ,K) and heavy metals by their accumulation in willow tissues, according to the results of the current study.

The results indicate that the concentration of heavy metals (Pb, Cd, Hg, Ni, Cu, Cr) in willows were notn significantly different from those described in the literature (Vervaeke et. al 2003; Bungart and Hüttl 2001; Tlustoš et. al 2007; Börjesson 1999; Berndes et. al 2004; Greger et. al 2005; Adler et. al 2005; Borkowska and Lipiński 2007) (Table 1). Only in case of zinc, the current results indicate the lower concentration of this element in willow (ranged between 29,65 and 54,23 mg/kg d.w.), than the values reported in literature. The amount of zinc which was taken up by willow presented by Stoltz and Greger (2002), Nissen and Lepp (1997) and Vervaeke et al. (2003) was: 852 mg/kg d.w., 315.49 mg/kg d.w. and 146.1 mg/kg d.w, respectively. In case of the efficiency of metals storage, the highest amount of metals in biomass during the study was detected after the fourth year.

Table 2. The content of heavy metals and nutrients in the plants tissues from WWTP in 2007.

	The experimental plantation			
[mg/kg d.w]	**area 1**	**area 2**	**area 3**	**area 4**
Pb	15,23	10,23	5,60	8,70
Cd	0,42	0,21	0,35	0,11
Hg	0,01	0,04	0,12	0,17
Ni	2,01	1,95	0,85	1,21
Zn	35,42	29,65	54,23	48,72
Cu	5,20	4,56	15,65	14,56
Cr	8,56	4,75	6,59	8,56
SUM	**66,85**	**51,39**	**83,39**	**82,03**
N	7800	5800	7200	6900
P	1100	800	1500	1400
K	4200	2800	4980	5980
SUM	**13100**	**9400**	**13680**	**14280**

2.6. Mathematical Model for Decision Support System

A mathematical model was developed based on literature review and the results of the SWITCH research. The aim of the model is to support decisions for the management of the WWTP system for an optimal use of the sewage sludge, heavy metals accumulation, biomass production, and income generation. It considers relationships between:

- biotic and abiotic environment parameters influencing willow growth and biomass production (module “Biomass production”);
- efficiency of heavy metals accumulation and calculations of possible sewage sludge doses (module of “Utilization sewage sludge”);
- economic benefits offered by the chosen management option (module “Economics”).

The model is addressed to the WWTP managers, other stakeholders and authorities managing sewage treatment plants. It addresses both ecological and economic aspects.

The users can set up such parameters as the ground water level, humidity of soils, soil pH, density of seedling, soil nutrients content (nitrogen, phosphorus, potassium), weeds biomass, heavy metals and organic matter content in soil and sewage sludge).

The model calculates biomass yield, the amount of heavy metals removed, the sewage sludge applied and the income generated after a four-year cycle of production.

A. Module of “Biomass production”

The module estimates potential production of biomass (Fig. 6). The user can set: the amount of plants per ha, the pH of soil, the biomass of weed during the two initial years, the potential amount of animals on the plantation per ha, the groundwater level. It is also possible to include the aspects of forecasted temperature and atmospheric precipitation.

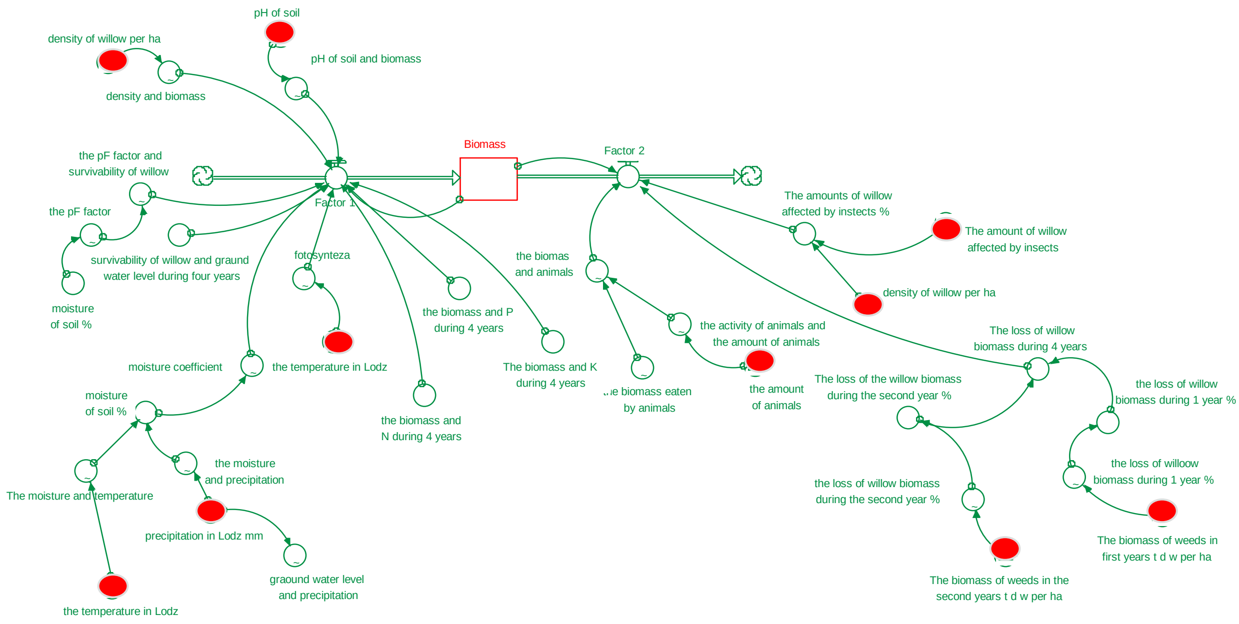

Figure 6. The "Module of biomass production"

B. Module of "Utilization of sewage sludge"

In this module two parameters were included: the efficiency of soil and sediments remediation (the accumulation of metals in willow's biomass and the rate of the uptake of metals), and the calculation of the sewage sludge doses possible to apply on a willow plantation. The user can change the amount of metals in sewage sludge (mg/kg d.w. sewage sludge), the contents of N, P, K in sewage sludge, the amount of the organic matter (%). It is also possible to calculate the sewage sludge doses.

The user of models can determine the sewage sludge doses that can be applied on the willow plantation, after including in the model physical and chemical parameters. These doses are in accordance with the Polish law regulations (Dz. U. No 134, item 1140. On the basis of the results obtained by the user with an aid of this model, the user receives the information on the dose, which is specified in tons and can be used per one hectare of land, the total amount of metals (g/ha/3 years), and N, P i K (kg/ha/3 years).

C. Module of "Economics"

The user can set the size of plantation (ha), the price biomass and caloric/energetic value, with the assumption that willow caloricity is twice lower than this of the coal: The caloric value of 1 ton d.w. is 10,4 GJ/t (Szczukowski, 2002). In the current model, the assumed price of purchase was about 80 zł/t while the cost of 1 GJ about 8 zł.

3. References

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