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USING RISK ANALYSIS IN SELECTING LCA SCENARIOS FOR EVALUATING THE ENVIRONMENTAL IMPACT OF THE SEWAGE SLUDGE

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ABSTRACT

This paper presents a method of using risk analysis in order to establish the most suitable scenarios used in the Life Cycle Assessment of the sewage sludge, based on the European trends and legal framework, but also tailored for the Romanian wastewater sector. This method has as a result the selection of the most promising cradle-to-grave scenarios for sewage sludge, scenarios that meet the principles of the green economy - improving human well-being, while significantly reducing environmental risks and ecological scarcities.

Keywords: sludge management, LCA, risk analysis, environmental impact

1. Introduction

The continuous degradation of the environment caused by the increasing anthropogenic pressures raised some issues as headlines for public agenda all around the world: ozone depletion, greenhouse effect, land use and scarcity of raw materials, acidification, eutrophication, summer smog, winter smog, heavy metals, carcinogenic substances, waste, respiratory effects, ionising radiation, eco-toxic substances.

The current global environmental challenges drive societies to implement new sustainable ways of using resources and manage waste.

Sludge management is an area that rises great issues regarding the environmental impact. This study reveals a risk assessment methodology for wastewater sludge, from a cradle-to-grave perspective, taking into account the social, economic, technical and environmental characteristics of the Romanian wastewater sector. The considered options for beneficial use and disposal of sludge are: digestion in order to obtain biogas, application to agricultural lands, mono-incineration in a dedicated incinerator or co-incineration with biomass waste, pelletizing or disposal to sanitary landfills.

The selection of the most appropriate sludge treatment technology is a key factor in the application of integrated sewage sludge managements system. Together with economic and social considerations, this approach would help sludge managers design more sustainable management systems. Decision makers should combine in an optimum way the alternatives for sewage sludge handling, considering all available information on technical, economic and environmental issues.

2. Pathways for sludge management in Romania

The National Wastewater Sludge Management Plan[3] analyzes various scenarios of evolution regarding the quantity of wastewater sludge from treatment plants by 2040,estimating an increase up to 500.000 tons DM by 2020.

The wastewater treatment consists in a complex of mechanical, physical, chemical and

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biochemical processes. These processes have as a result a primary effluent– the treated water and a number of by-products consisting in the materials resulted in the separation process. From a quantitative perspective, the most important by-product that results from the wastewater treatment process is the sludge.

According to EU negotiations, by December 31, 2018, Romania has the obligation to enter into full compliance with EC Directive 91/271 / EEC. All cities with more than 2000 inhabitants should be served by wastewater treatment plants and so the sludge production will increase.

The available data on the current situation regarding the sludge management in our country are synthesized in the National Wastewater Sludge Management Plan.

3. Risk and hazards associated to the sludge management

The paper analyzes and compares the risks generated by five solutions of neutralizing the wastewater sludge:1.disposal on landfill 2.drying 3.pelletizing 4.incineration 5.fertilizing

In Romania, disposal as a sludge management option is used in proportion of 91%, followed by the agricultural land application. Environmental issues related to the recycling of sewage sludge on land include the risk of nutrient leaching, impact on soil biodiversity and greenhouse gas emissions (e.g. CH4 and N2O). In addition, the increasingly restrictive targets for the continuous reduction of biodegradable wastes sent to landfills make land application of MSS (municipal sewage sludge) an unattractive management option.

The risk analysis presented in this paper uses the Preliminary Hazard Analysis (PHA) methodology. PHA uses a generic approach, with an initial macroscopic stage where hazard sources are identified, scenarios for undesired events are recognized and ranked using a grid of Severity ×Probability and safety barriers suggested [2].

A microscopic stage then analyzes in detail the major risks identified during the first stage.

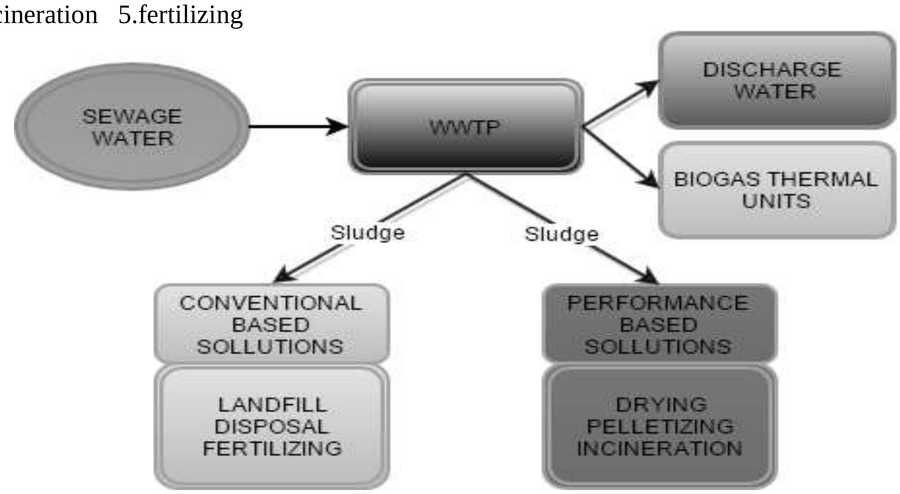

Figure 1 Sludge management routes

4. PHA applied to sludge management pathways

Table 1 Risk matrix

CONSEQUENCE			PROBABILITY					
			1	2	3	4	5	6
			Very Unlikely	Un likely	Rarely	Possible	Likely	Very Likely
6	Catastrophic	Personnel death, major pollution of the environment, complete loss of the plant						
5	Severe	long time invalidity for more than 1 person, severe						

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		pollution, damage cost < 1000 000$						
4	Major	serious injuries for more than 1 person, pollution effects more than 1 year, machine damage over 50 % (10000 – 100000$)						
3	Moderate	medical treatment more than 3 days, less than 1 year pollution effects, > 10000$ costs						
2	Minor	medical treatment less than 3 days, visible pollution effects, < 48 hours stop working						
1	Negligible	no required medical treatment, malfunction solved without stopping the process						

Table 2 Risk levels association

RISK LEVEL	CONSEQUENCE – PROBABILITY ASSOCIATION
1 MINIMUM	(1,1); (1,2); (1,3); (1,4); (1,5); (1,6); (2,1)
2 LITTLE	(2,2); (2,3); (2,4); (3,1); (3,2); (4,1)
3 MEDIUM	(2,5); (2,6); (3,3); (3,4); (4,2); (5,1); (6,1)
4 MAJOR	(3,5); (3,6); (4,3); (4,4); (5,2); (5,3); (6,2)
5 VERY BIG	(4,5); (4,6); (5,4); (5,5); (6,3)
6 MAXIMUM	(5,6); (6,4); (6,5); (6,6)

Table 3 Possible consequences list for sludge landfill disposal [5]

Risk factors description	Maximum possible consequence	Cons. Index	Prob. Index	Risk level	Risk index
1. Accumulation of HM, pathogens, organic pollutants and salts in soil	bad influence of the agriculture and inhabitants health	**6**	**4**	**5**	**5**
2. GHG (e.g. CH4 and N2O).	Environmental pollution	**2**	**5**	**3**	**3**
3. Leakage of sludge from the transporting tanker	Car accidents	**6**	**1**	**3**	**3**
4. Rise of the producing sludge quantity	Warping of the sludge disposal area	**3**	**6**	**4**	**4**
5. Increasing level of ecological standards	Financial deficit of the company	**3**	**6**	**4**	**4**
6.Contracting bacteria/viruses during inhalation or dermal contact	Intestinal lung or other infections, Hepatitis A / B, HIV	**6**	**3**	**5**	**5**

Table 4 Possible consequences list for sludge drying [2]

Risk factors description	Maximum possible consequence	Cons. Index	Prob. Index	Risk level	Risk index
1. High operating cost	Financial deficit	**4**	**2**	**3**	**3**
2. Manufacturer not integrated on the market	Low performances	**2**	**2**	**2**	**2**
3. Higher temperatures than prescript	Fire incidents	**5**	**2**	**3**	**3**
4. Lower temperatures than prescript	Finite product does not comply	**2**	**4**	**3**	**3**
5. Equipment overloading	Equipment damage	**4**	**1**	**2**	**2**
6. Higher humidity in the Sludge	Need of extra energy	**2**	**5**	**3**	**3**
7.Contracting parasites, bacteria or viruses during	Intestinal lung Hepatitis A / B, HIV	**5**	**2**	**3**	**3**

Table 5 Possible consequences list for sludge pelletizing

Risk factors description	Maximum possible consequence	Cons. Index	Prob. Index	Risk level	Risk index
1. High operating cost	Financial deficit	**4**	**2**	**3**	**3**
2. Manufacturer not integrated on	Low performances	**2**	**2**	**2**	**2**

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the market					
3. High temperatures Auto ignition	Fire incidents	**5**	**1**	**3**	**3**
4. Not following strictly the technological process	Earlier failures of the equipment	**3**	**4**	**3**	**3**
5. Equipment overloading	Equipment damage	**3**	**2**	**2**	**2**
6. Higher humidity in the Sludge	Finite product does not comply	**2**	**5**	**3**	**3**

Table 6 Possible consequences list for sludge incineration [2]

Risk factors description	Maximum possible consequence	Cons. Index	Prob. Index	Risk level	Risk index
1. High operating cost	Company financial deficit	**3**	**1**	**2**	**2**
2. Installation manufacturer not integrated on the market	Low equipment performances	**2**	**3**	**2**	**2**
3. Not following strictly the technological process	Starting fire, equipment damage, injuries	**5**	**3**	**4**	**4**
4. Harmful emissions(NO_x , SO_2)	Population affected , Pollution	**2**	**4**	**3**	**3**
5. HM remains in the ash	Environmental pollution	**2**	**5**	**3**	**3**
6. Higher humidity in the introduced raw material	Need of higher amount of energy	**1**	**5**	**3**	**3**
7. Few incinerators specialised in sludge neutralisation	pollution of the storage area, high incineration prices	**3**	**4**	**3**	**4**

Table 7 Possible consequences list for sludge used for fertilizing

Risk factors description	Maximum possible consequence	Cons. Index	Prob. Index	Risk level	Risk index
1. Accumulation of HM,pathogens, organic pollutants in soil	Bad influence of the agriculture and inhabitants health	**5**	**3**	**4**	**4**
2. GHG (e.g. CH4 and N2O).	Environmental pollution	**2**	**5**	**3**	**3**
3. Leakage of sludge from the transporting tanker	Car accidents	**6**	**1**	**3**	**3**
4. Sludge dehydration costs overcomes the benefits	Warping of the sludge disposal area	**3**	**6**	**4**	**4**
5. The sludge is not carefully spread in the area	Financial deficit of the company	**3**	**6**	**4**	**4**
6.Contracting parasites, bacteria or viruses during inhalation or contact	Intestinal lung Hepatitis A / B, HIV	**5**	**3**	**4**	**4**

Global risk calculation

$$L_{gr} = \frac{\sum_{i=1}^{n} n \cdot R_i \cdot r_i}{\sum_{i=1}^{n} n \cdot r_i} \qquad (1)$$

Table 8 Global risk values for each activity

No.	Type of risk	Specific values	Formula parameters
1	Global risk level for sludge landfill disposal	4,17	
2	Global risk level for sludge drying	2,79	$\mathbf{L_{gr}}$ – Level of global risk
3	Global risk level for sludge pelletizing	2,75	$\mathbf{r_i}$ - Risk factor index
4	Global risk level for sludge incineration	3	$\mathbf{R_i}$ – Risk level
5	Global risk level for sludge used in fertilizing	3,72	**n** – Number of risk factors

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5.1 Risk-based design scenarios for sludge management

The goal of this study is to evaluate the environmental and economic risks of the sludge treatments used in Romania and to develop an innovative system (configuration), that can be used as an LCA scenario, for sludge management pathways.

The Life Cycle Assessment (LCA) is a decision support used in order to assess the environmental performance or to identify the system

with the best performance through a comparative analysis of different scenarios.

The results of the analysis depend primarily on how the scenarios are defined, which sludge fractions are assumed to be sent to certain treatments/destinations and in what amounts. This paper analyses several sludge management options, with the aim of exploring and determining the global risk that the possible treatment have, in order to set up the preliminary phase of an LCA.

Based on the authors previous and currently research, there have been identified several risks, for the main pathways of sludge management. With the increased insights into the strengths and weaknesses of the systems structure or comes the ability to prioritize attention on those areas that have the lowest safety levels. Therefore, there have been analysed alternative (innovative) solutions so the main risks or drawbacks of the conventional solution to be by passed. The method is known as Risk Based Design [4].

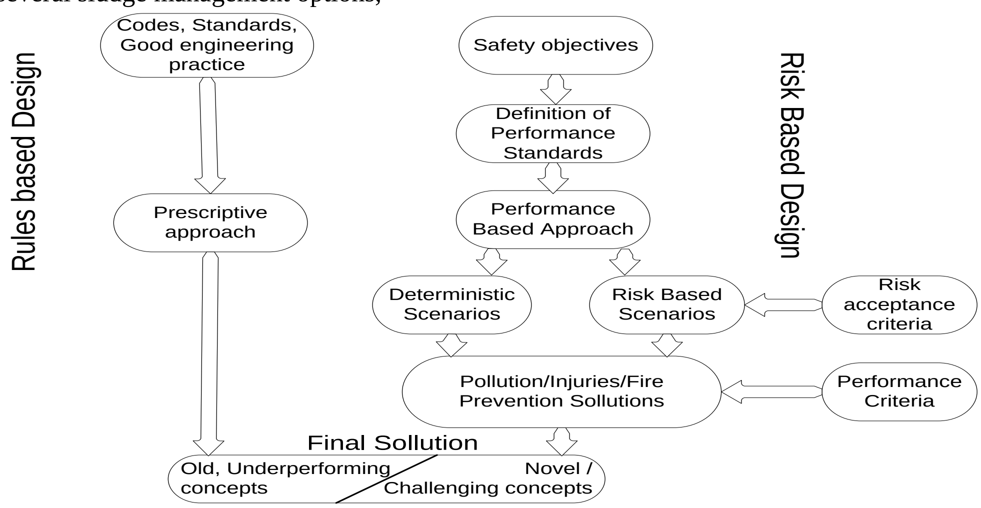

Figure 2 Comparison of Prescriptive (Conventional) versus Performance Based Approaches

There are many benefits from using risk-based methods. First and foremost among these is the ability to optimize the system. "Traditional" management techniques will tend to over strengthen some aspects of the system and insufficiently address others. RBD, on the other hand, allows the manager to address uncertainties associated with the process and identify areas that may be over- or under designed. Furthermore, analysis of safety levels of new and unique situations can be made and compared with those deemed "safe," which cannot be done using other methods.

5.2 The innovative solution

In the purpose of decreasing the effects of: 1. HM, pathogens, persistent organic pollutants, soluble salts accumulation in soil

2. Warping of the

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sludge disposal area as a consequence of sludge quantity increasing

3. Financial deficit of the company -consequence of ecological standards increasing level

4. Contracting parasites, bacteria or viruses during inhalation or dermal contact

The article authors analyzed, based on practical experiences, each of the three alternative solutions, as can be find in the photos bellow:

Figure 3 Practical experiments on sludge neutralization

5.3 Energy input – output analysis

Table 9 Sewage sludge properties

Daily average quantity [t/day]	Lower heat value [MJ / kg]	Organic matter [g / kg]	Water content
15,8	12,5	429	72 - 75 %

Table 10 HUBER Belt Dryer characteristics

Capacity	Th. energy demand	Electric energy demand	Energy sources
0.3 to 4 t/h (> 4 t/h in multi-line installations)	0.8 to 0.9 kWh/kg water evaporation	0.03 to 0,15 kWh/kg water evaporation	Exhaust heat, vapour, thermal oil, gas, oil,

In the purpose of rising the Lower heat value of the sludge, it was experimented the idea of mixing it with different sort of biomass. The selected types of biomass was Corn stalks/stover, with a Lower heat value of 17 MJ / kg and Forest Residues with 18 MJ / kg. The selection was made on the consideration of predominance in the area.

The dryer was selected based on - drying plant is also achieving the pelletizing operation. Also, fully automatic 24 hours/7 days operation with low drying temperatures.

For the calculation of the heat needed we considered a 75 % of sludge humidity and a thermal energy demand of 0,85 MWh /tone of water. It results a 9,57 MWh thermal energy for drying the 15,8 t/day of sludge. After sludge drying operation, at 10 % water content, the remained quantity of raw material, to be used for pelletizing is 2,1 tones/day.

Before introducing in the pelletizer, the sludge will be mixed with the milled biomass, in equal proportion.

Related to the pelletizing machine it must be considered a 10 % coefficient of impurities loss. In this way it will result 3,8 tones / day of pellets.

The next step is the selection of the CHP plant in order to turn into profit the processed sludge and implicit the resulted pellets [6].

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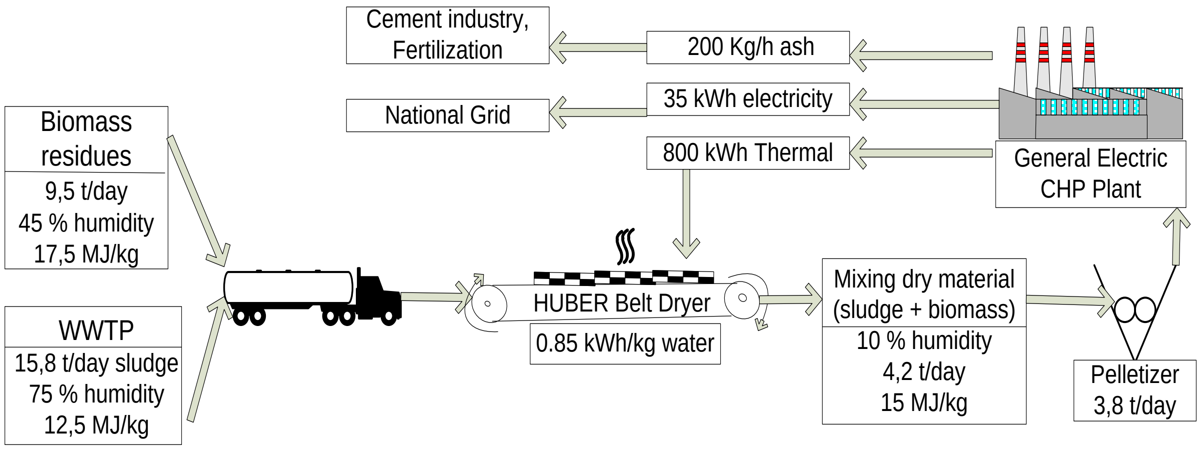

Figure 4 Sludge neutralization process configuration

We consider a daily schedule of 17 hours of function, realized in two working shifts. In this way, from the 3800 kg of pellets will result a consumption of 224 kg / h.

It must be taken into consideration the need of heat for the dryer: 0,85 kWh / kg of water.

From the 15,8 t/day of sludge at a 75 % humidity and 9,5 t/day of biomass residues at a 45 % humidity, it results a daily quantity of vaporised water of 16,15 tone.

In this way, the needed of heat will be 13.727 kWh/day, or 807,4 kWh /hour.

From the Data Sheet of CHP plant manufacturers we select a General Electric model which produces 35 kWh electricity and 800 kWh thermal energy.

6. Conclusions

Traditionally energy recovery from sewage sludge features Anaerobic Digestion (AD) with biogas utilisation in combined heat and power (CHP) systems. However, the industry is evolving and a number of developments that extract more energy from sludge are either being implemented or are nearing full scale demonstration.

There are several ongoing research projects that are investigating if it is technically feasible to use a low temperature dryer to dry all of the digested sludge from a wastewater plant. Many studies in the past have conducted extensive LCA for sludge treatment techniques. The present study focuses on the on traditional disposal routes for the wastewater treatment by-product (sludge),but also presents an approach that integrates non-traditional pathways for our country (based on the results of the risk analysis conducted in chapter 4): drying, pelletizing (mixed with wood biomass) and incineration, with many benefits that result from a proper sludge management: reducing of the volume, eliminating the high costs of sludge disposal, energy recovery, lower greenhouse gases emissions

Considering the fact that the industry is evolving and a number of developments that extract more energy from sludge are either being implemented or are nearing full scale demonstration, there is the need to develop innovative, integrated solutions, tailored for the current Romanian situation.

The technical solution that has been proposed is just an example based on laboratory studies, in order to demonstrate the methodology. In reality the technical solutions could be very different.

The present study presents a non-traditional pathways for our country: drying, pelletizing (mixed with wood biomass) and incineration, with many benefits that result from a proper sludge management: reducing of the volume, eliminating the high costs of sludge disposal, energy recovery, lower greenhouse gases emissions.

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REFERENCES

1. Samolada, Zabaniotou, Comparative assessment of municipal sewage sludge incineration, gasification and pyrolysis for a sustainable sludge-to-energy management in Greece, Waste Management 34 (2014) 411–420, www.elsevier.com/locate/wasman
2. P.Thivel, Y. Bultel, F. Delpech, Risk analysis of a biomass combustion process using MOSAR and FMEA methods, Journal of Hazardous Materials 151 (2008), www.elsevier.com/locate/jhazmat
3. Elaborarea politicii nationale de gestionare a namolurilor de epurare, Strategia nationala de gestionare a namolurilor, Partea 1, Iunie 2011, Directia Generala AM POS Mediu
4. Micaela Demichela, Gianfranco Camuncoli, Risk based decision making. Discussion on two methodological milestones, Journal of Loss Prevention in the Process Industries 28 (2014) 101e108, www.elsevier.com/locate/jlp
5. AFSCME. Risky Business: An AFSCME Health and Safety Guide for Water and Wastewater treatment Plant Workers.2000, www.afscme.org/health/riskybtc.htm
6. Beibei Liu, Qi Wei, Bing Zhang , Jun Bi, Life cycle GHG emissions of sewage sludge treatment and disposal options in Tai Lake Watershed, China, Science of the Total Environment (2013) 361–369
7. [7] Murray A, Horvath A, Nelson KL. Hybrid life-cycle environmental and cost inventory of sewage sludge treatment and end-use scenarios: a case study from China. Environ Sci Technol 2008;42:3163–9.
8. Peters GM, Rowley HV. Environmental comparison of biosolids management systems using life cycle assessment. Environ Sci Technol 2009;43:2674–9.
9. Sharma G, Campbell A. Life cycle inventory and life cycle assessment for windrow composting systems. The University of New South Wales: Recycled Organics Unit; 2006.