Alternative Sewage Sludge Management Routes in Cyprus

A. Kylili [1], P.A. Fokaides [1] , D. Nicolaides [1] , P. Polycarpou [2] , A. Dalias [2]
[1] School of Engineering, Frederick University, Nicosia, 1036, Cyprus
[2] Agricultural Research Insitute, Nicosia

Abstract

The common practices of sludge treatment used until recently are seen as not being sufficient any more, mainly due to severe limitations set by national legislations. Therefore, alternative practices, which will be more environmental friendly, financially viable and practical must be adopted for the treatment of the specific material. The aim of this paper is to present the environmental performance and potential environmental benefits of treating sewage sludge for its use as biogas, by employing a Life Cycle Assessment (LCA) approach.

Keywords

Sewage sludge, biofuels, biogas, life cycle assessment (LCA)

01. Introduction

Sewage sludge is an inevitable by-product of the treatment process of wastewater, which is rapidly increasing due to the fast industrial development, population growth, the fact that landfill sites are becoming increasingly difficult to come by and the more stringent environmental regulations. The continuously increasing generation of sewage sludge is regarded as one of the most challenging problems of environmental control. Common practices of sludge disposal and/or treatment used until recently have either been abandoned (e.g. ocean dumping), or are being looked upon less favourably, especially when viewed through the prism of sustainable development and practices, (e.g. landfilling), or have been connected to peripheral problems (e.g. spreading of sludge on reclaimed land, which has been connected to possible contamination of subsurface waters). Overall, existing practices for the disposal of wastewater sludge are seen as not being sufficient any more, a view corroborated by several, and often forbidding limitations set by national legislations. Therefore, alternative practices, which will be more environmental friendly, financially viable and practical must be adopted for the treatment of the specific material (Nicolaides, 2012). Such disposal problems can be drastically reduced, if sludge can be recycled and reused as a fertiliser for agricultural use and soil reclamation.

The key objective of this work is to demonstrate the environmental performance and potential environmental benefits of treating sewage sludge for biogas for the case of Cyprus. This is achieved through the implementation of a Life Cycle Assessment (LCA) methodology, evaluating the potential impact of the defined sewage sludge treatments system at selected environmental impact categories. The paper also thoroughly reviews research that focuses on the potential of treating sewage sludge for biogas production. The results of this work lead to some significant conclusions regarding the potential of sewage sludge recycling and also provide a drive for further research in both the local scientific community and the relevant decision- makers.

02. Background

The variable routes and process systems for the treatment of sewage sludge that are available today permit the recovery of valuable minerals and energy from a hazardous waste. Accordingly, the life-cycle environmental performance of different sewage sludge treatment systems, taking a detailed look to the potential of energy generation and carbon emissions savings is an active research field in literature. The review work of Hijazi et al. (2016) performed on LCA studies of biogas systems from around Europe concluded that in all studies the biogas scenarios had lower Greenhouse Gases (GHG) intensities than their reference systems. The study of Houillon and Jolliet (2005) compared six different scenarios of wastewater sludge treatment using LCA approached. The results revealed that avoided burdens by co- products are imperative in terms of energy consumption and pollutants' emissions. The energy production and emissions mitigation of a typical domestic wastewater treatment system from its construction to its operational and maintenance stage were assessed, in which different combinations of biogas use and sludge processing lines for industrial or household applications were investigated in the work of Chen and Chen (2013). It was concluded that the reuse of biogas and sludge was key in the system's overall energy balance and environmental performance that it could offset the cost in the plant's installation and operation. Also, the study of Mills et al. (2014) compared five technology configurations, including conventional Anaerobic Digestion (AD) with Combined Heat and Power (CHP), Thermal Hydrolysis Process (THP) AD with CHP, THP AD with bio-methane grid injection, THP AD with CHP followed by drying of digested sludge for solid fuel production, THP AD followed by drying, pyrolysis of the digested sludge and use of the both the biogas and the pyrolysis gas in a CHP. The study has found that the post AD drying options perform well however the configuration used to create a solid fuel to displace coal was the most sustainable solution. The aim of the work of Sadhukhan (2014) was to analyse the environmental performance of sewage sludge application in energy generation and agricultural processes using an integrated Monte Carlo simulation and LCA framework, and thereby rank the technologies according to avoided primary impact potential evaluations for the case of the UK. As a general conclusion, the application of digested sludge as fertiliser was causing more toxicity impacts, compared to the biogas production for the natural gas grid. A cost-combined LCA was conducted by Xu et al. (2014) to estimate the environmental and economic burdens of 13 sewage sludge treatment scenarios in China. The findings showed that AD is the suitable approach to reduce environmental and economic burdens as it reduces dry mass volume and applies energy recovery. Landfill and incineration technologies had the highest and lowest environmental burdens, respectively. Garrido-Baserba et al. (2015) similarly performed an analysis of five alternative configurations for sludge treatment, from which supercritical water oxidation was determined as the most adequate option when economic and environmental criteria are considered equally important, and thermophilic AD in the case economics are prioritized over the environmental aspects. A number of studies, including Xu et al. (2015) and Eriksson et al. (2016) also evaluated the enhancement of biogas production and environmental performance of sewage sludge treatment through its co-digestion with food waste.

03. Methodology

The sewage sludge treatment for agricultural use system under investigation is presented in Fig.1. GaBi software (Version 6) adopted the model to implement a ‘gate-to-gate’ LCA based on the principles described in the ISO 14040 Standard (ISO, 2006) for the investigation of the system’s environmental performance. The functional unit of the system has been defined as one tonne of sewage sludge dry solids, while for the purposes of this study; the CML 2001 (CML, 2001) methodology was employed. CML is the methodology of the Centre for Environmental Studies of the University of Leiden and one of the most widely used impact assessment methodologies (Laurent et al., 2014). It focuses on a series of environmental impact categories expressed in terms of emissions to the environment. The impact categories which were examined in this study are listed below:

- Global Warming Potential (GWP 100 years),
- Acidification Potential (AP),
- Eutrophication Potential (EP),
- Ozone layer Depletion Potential (ODP, steady state),
- Resource Depletion, Mineral, Fossil, and Renewable (ADP elements & fossil),
- Photochemical Ozone Creation Potential (POCP).

The process and the system boundaries of the sewage sludge treatment for agricultural use system under investigation is illustrated in Figure 1. Typically, the removal of moisture from sewage sludge is achieved by centrifugation followed by drying (Chen and Kuo, 2016). Similarly, the first life cycle stage of the sewage sludge is gravity thickening, a process that requires electricity and coagulation agents such as the use of polymers. The thickened sewage sludge then proceeds to the AD stage, where the reduction of the organic carbon content in the sludge is achieved due to the development of pathogenic fauna. The main products of AD is sludge with a lower C:N ratio and biogas with a high methane content (Cieślik et al., 2015). Biogas is a biofuel and therefore can be used for recovering energy or generate electricity (Xu et al., 2014). In this study, the sludge after AD is considered for use in agriculture and soil reclamation. Prior to its use as a fertiliser, the sludge is required to be prepared to meet with legal regulations and be suitable for its desired end-use (Suthar, 2010; Roig et al., 2012). Drying is a simple process, where the water content of the sludge is further reduced for densification and stabilization purposes. It is also worth mentioning that the environmental impacts associated with the construction of the wastewater treatment facility, the transportation of the untreated sewage sludge to the facility, and the transportation of the final fertiliser to the fields are not included in this LCA. Accordingly, any potential impacts during these life- cycle phases were found outside the defined system boundaries.

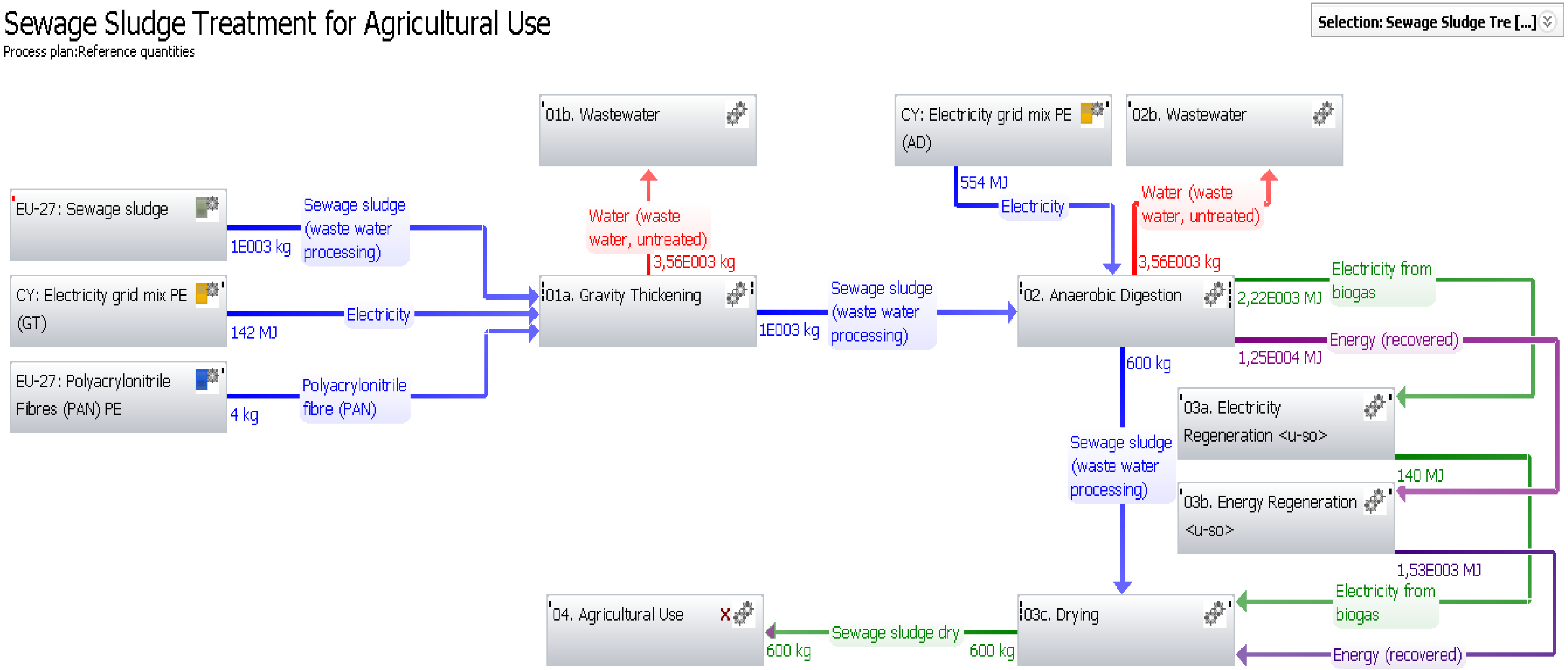

Figure 1 Process and system boundaries of sewage sludge treatment for agricultural use system

The Life Cycle Inventory (LCI) assembles the flows within the sewage sludge treatment for agricultural use system boundaries. It is comprised of the ‘gate-to-gate’ input and output resources, energy, and waste. The credibility of an LCA study is highly dependent upon the accuracy and comprehensiveness of its LCI. The LCI used in this study is provided in Table 1.

Table 1 Life Cycle Inventory (LCI) of sewage sludge treatment for agricultural use system under investigation (Xu et al., 2014)

System Processes		Inputs	Amount	Units	Outputs	Amount	Units
01.	**Gravity Thickening**	Sewage sludge	1000	kg	Sewage sludge	1000	kg
		PAM	4	kg	Wastewater	3,56	m^3
		Electricity	39,5	kWh			
02.	**Anaerobic Digestion**	Sewage sludge	1000	kg	Sewage sludge	600	kg
		Electricity	153,85	kWh	Wastewater	3,56	m^3
					Electricity Regenation	615,38	kWh
					Energy Regeneration	12500000	kJ
3.	**Drying**	Sewage sludge	600	kg	Sewage sludge (treated, dry)	600	kg
		Electricity	39	kWh			
		Energy	1530000	kJ			
4.	**Agricultural Use**	Sewage sludge (treated, dry)	600	kg			

04. Results and Discussion

The results of the LCIA, summarised in Table 2, indicate the coagulation agents, which in this case is a polymer that are necessary for gravity thickening of the sewage sludge. Given that climate change has evolved into an influential factor in the decision- making of both the public and the private sector, it probably provides the strongest indication for the environmental performance and sustainability level of the system to the non- scientific communities. The total GWP of the sewage sludge treatment for agricultural use system is 190 kg of CO_2-equivalent, of which the production of the polymer is responsible for the 70% of the impact. The electricity consumption for the gravity thickening stage is the second most influential process for the specific environmental impact category, followed by the electricity consumption required for the AD. The impact categories associated with tropospheric processes and pollution, namely photochemical ozone formation and acidification, have also been chosen for analysis in this paper in view of the fact that they directly affect the human health. AP and POCP illustrate comparable results to the GWP impact category. The environmental burden for the polymer production used in the gravity thickening stage represents the 75% of the total impact for both categories category. Accordingly, the required energy demand for the gravity thickening is the 20% of the total impact for the AP and the 25% for the AP categories. A different picture is drawn in the case of Ozone Depletion, an environmental impact strongly associated with policy regulations and influences political action. The electricity consumption for the AD stage is the most significant contributor of the ODP impact with 3.12 kg of R-11 equivalent, compared to 0.14 and 0.04 kg of R-11 equivalent for the polymer manufacturing and use and energy demand for the gravity thickening, respectively. Regarding the ADP categories, closely related to the carbon emissions and the depletion of non-renewable energy resources, a great percentage of the environmental impact is attributed to the manufacturing of the polymer. More specifically, the impact of the specific process represents the 47% of the total impact for the ADP elements and 65 % for the ADP fossils categories. Significant is also the contribution of the AD stage in the ADP elements category – responsible for 40% of the total impact. It is also noteworthy that the drying stage, due to the fact that it utilises electricity and energy generated by the biogas in the previous stages, it appears to have no contribution to the environmental burden of the system; although it has been previously stated in literature that drying does not always require an additional supply of energy and therefore carries no extra costs in sewage sludge treatment management (Cieslik et al., 2015).

Furthermore, the life- cycle non- renewable energy consumption and carbon dioxide emissions, evaluated by the LCA tool is also indicative of their environmental performance of the sewage sludge treatment for agricultural use system. The total energy embodied into the final product of the system, ie. the treated sludge for agricultural application, was calculated to 2890 MJ, of which 80MJ are sourced from renewable energy resources. Also the system itself for the treatment of 1 tonne of sewage sludge dry matter emits 183 kg of CO2.

Table 2 Life Cycle Impact Assessment (LCIA) results of sewage sludge treatment for agricultural use system under investigation

System Processes	**Environmental Impact Categories**					
	GWP [kg CO2-Equiv.]	**AP [kg SO2-Equiv.]**	**ODP [kg R11-Equiv.]**	**ADP Elements [kg Sb-Equiv.]**	**ADP Fossils [MJ]**	**POCP [kg Ethene-Equiv.]**
01. Gravity Thickening (Electricity Consumption)	34,31	0,29	0,04	0,15	435,87	0,02
01. Gravity Thickening (PAN Manufacturing)	133,65	1,13	0,14	0,58	1697,70	0,06
02. Anaerobic Digestion (Electricity Consumption)	21,45	0,06	3,11	0,50	448,97	0,01
TOTAL	189,42	1,48	3,29	1,23	2582,54	0,08

05. Conclusions

The treatment of sewage sludge for energy generation and agricultural use is a promising and environmental-friendly means for the final disposal of this, otherwise, toxic and difficult to handle waste material. The aim of this work was to demonstrate the environmental performance and potential environmental benefits of treating sewage sludge for energy generation for the case of Cyprus. The results of the LCA study performed revealed some significant conclusions not only regarding the overall potential of sewage sludge recycling, but important factors for the environmental impact of specific life cycle stages. The findings concluded that the coagulation agents that are necessary for gravity thickening of the sewage sludge play a substantial role in the overall sewage sludge treatment process. In particular, a great percentage, more than 70%, of the environmental impact of the process for the GWP, AP, ADP fossils, and POCP impact categories. Also noteworthy is the contribution of the AD stage in the ozone and resources depletion impact of the sewage sludge treatment process under investigation. This work provides a drive for further research in sewage sludge treatment and recycling in Cyprus for both the local scientific community and the relevant decision- makers.

References

Chen, S., & Chen, B. (2013). Net energy production and emissions mitigation of domestic wastewater treatment system: A comparison of different biogas–sludge use alternatives. *Bioresource technology*, *144*, 296-303.

Chen, Y. C., & Kuo, J. (2016). Potential of greenhouse gas emissions from sewage sludge management: a case study of Taiwan. Journal of Cleaner Production.

Cieślik, B. M., Namieśnik, J., & Konieczka, P. (2015). Review of sewage sludge management: standards, regulations and analytical methods. *Journal of Cleaner Production*, *90*, 1-15.

CML, 2001. CML's impact assessment methods and characterisation factors. Leiden University, Institute of Environmental Science (CML).

EN ISO 14040:2006: E. Environmental management - Life cycle assessment – Principles and framework (ISO 14040:2006)

Eriksson, O., Bisaillon, M., Haraldsson, M., & Sundberg, J. (2016). Enhancement of biogas production from food waste and sewage sludge–Environmental and economic life cycle performance. *Journal of Environmental Management*, *175*, 33-39.

GaBi 6: Software-System and Databases for Life Cycle Engineering. Copyright, TM. Stuttgart, Echterdignen. 1992-2013

Garrido-Baserba, M., Molinos-Senante, M., Abelleira-Pereira, J. M., Fdez-Güelfo, L. A., Poch, M., & Hernández-Sancho, F. (2015). Selecting sewage sludge treatment alternatives in modern wastewater treatment plants using environmental decision support systems. *Journal of Cleaner Production*, *107*, 410-419.

Hijazi, O., Munro, S., Zerhusen, B., & Effenberger, M. (2016). Review of life cycle assessment for biogas production in Europe. *Renewable and Sustainable Energy Reviews*, *54*, 1291-1300.

Houillon, G., & Jolliet, O. (2005). Life cycle assessment of processes for the treatment of wastewater urban sludge: energy and global warming analysis.*Journal of cleaner production*, *13*(3), 287-299.

Laurent, A., Clavreul, J., Bernstad, A., Bakas, I., Niero, M., Gentil, E., et al.,2014. Review of LCA studies of solid waste management systems – Part II: Methodological guidance for a better practice. Waste Manage. 34, 589-606.

Mills, N., Pearce, P., Farrow, J., Thorpe, R. B., & Kirkby, N. F. (2014). Environmental & economic life cycle assessment of current & future sewage sludge to energy technologies. *Waste management*, *34*(1), 185-195.

Nicolaides, D. (2012). Potential use of sewage sludge as a construction material. In: Zorpas, A. A., & Inglezakis, V. J. (eds), Sewage Sludge Management: From the Past to Our Century. Nova Science Publishers, pp. 297-311.

Righi, S., Oliviero, L., Pedrini, M., Buscaroli, A., & Della Casa, C. (2013). Life cycle assessment of management systems for sewage sludge and food waste: centralized and decentralized approaches. *Journal of Cleaner Production*, *44*, 8-17.

Roig, N., Sierra, J., Martí, E., Nadal, M., Schuhmacher, M., & Domingo, J. L. (2012). Long-term amendment of Spanish soils with sewage sludge: effects on soil functioning. *Agriculture, ecosystems & environment*, *158*, 41-48.

Sadhukhan, J. (2014). Distributed and micro-generation from biogas and agricultural application of sewage sludge: Comparative environmental performance analysis using life cycle approaches. *Applied Energy*, *122*, 196-206.

Suthar, S. (2010). Pilot-scale vermireactors for sewage sludge stabilization and metal remediation process: comparison with small-scale vermireactors.*Ecological Engineering*, *36*(5), 703-712.

Xu, C., Chen, W., & Hong, J. (2014). Life-cycle environmental and economic assessment of sewage sludge treatment in China. Journal of Cleaner Production, 67, 79-87.