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Comparative assessment of municipal sewage sludge incineration, gasification and pyrolysis for a sustainable sludge-to-energy management in Greece

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ABSTRACT

For a sustainable municipal sewage sludge management, not only the available technology, but also other parameters, such as policy regulations and socio-economic issues should be taken in account. In this study, the current status of both European and Greek Legislation on waste management, with a special insight in municipal sewage sludge, is presented. A SWOT analysis was further developed for comparison of pyrolysis with incineration and gasification and results are presented. Pyrolysis seems to be the optimal thermochemical treatment option compared to incineration and gasification. Sewage sludge pyrolysis is favorable for energy savings, material recovery and high added materials production, providing a 'zero waste' solution. Finally, identification of challenges and barriers for sewage sludge pyrolysis deployment in Greece was investigated.

1. Introduction

Municipal sewage sludge (MSS) disposal faces significant environmental problems related to air emissions, threat to public health and contamination of soil and water resources, requiring therefore an appropriate treatment and careful management (Aggelakis et al., 2005). While world's sludge production is on a relentless growth curve, environmental quality requirements for sludge are becoming increasingly stringent, disposal outlets are decreasing and economic pressures require low-cost solutions (EU, 2012). The amount of MSS production in the EU27 was estimated at 11.5 million tons of dry solids for 2010 and it is expected to rise to 13.0 million tons in 2020 (EC, 2008).

Disposing sewage sludge to landfills is considered a beneficial use only when such disposal includes methane recovery for energy production. However, methane operations are relatively rare in most existing WWTPs (Waste Water Treatment Plants). However, due to o the limited capacity of available landfills, alternative beneficial uses are receiving greater attention. Valorisation of the nutrient components of MSS by considering the soil conditioning and fertilization is a beneficial use of sludge, especially in the case of forests and energy crops (Meeroff and Bloetscher, 1999; Wang et al., 2008; O'Connor, 1996). However, use of sludge on land in the EU will not change dramatically in the future due to legislative restrictions. The proportion of recycled sludge to agriculture will remain almost constant across EU (42% in 2010) expecting to reach 44% in 2020 (Kelessidis and Stasinakis, 2012) as shown in Table 1.

Looking forward to adoption of an efficient municipal sewage sludge management, to energy recovery should be considered by thermal routes. Although, high cost of power generated from sludge is a major barrier for the implementation of thermal routes, however, investments for sludge to power can become attractive if one considers the increase of energy prices in the international market by ~20%. Thermal treatment methods include combustion/incineration and the 'advanced' or 'emerging' pyrolysis and gasification methods. The incineration share will raise slightly, (EC, 2008). Dewatered MSS has been successfully used for producing building materials (e.g. concrete, bituminous mixtures) and also in road construction (Aziz and Koe, 1990; Tay and Show, 1991; Anderson et al., 1996). Incineration ash residues can be used to produce road construction materials or concrete aggregates (Takeda et al., 1989; Lisk, 1989). MSS can be extensively used in cement manufacturing as a cheap alternative energy resource (Fytili and Zabaniotou, 2008) with substantial energy and environmental savings due to reduced CO_2 emissions.

However, selection of a particular, stand-alone sludge thermal treatment system should not be based primarily on technical insight, but it should also integrate all related social and

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Table 1
Annual MSS production, disposal routes in EU27 countries (EC, 2008).

Member state	Sludge[a] (Ktds/a)	Recycle[a] (%)	Incin/[a] (%)	Landfill[a] (%)	Other[a] (%)	Sludge[b] (tds/a)	Recycle[b] (%)	Incin[b] (%)	Landfill[b] (%)	Other[b] (%)
Greece	260	5	0	95		260	5	40	55	10
Bulgaria	47	50	0	30	20	151	60	10	10	20
Ireland	135	75	0	15	10	135	75	10	5	10
Cyprus	10	50	0	40	10	17.62	50	10	30	10
Latvia	30	30	0	40	30	50	30	10	30	30
Estonia	33	15	0	–	85	33	15	0	–	85
Lithuania	80	30	0	5	65	80	55	15	5	25
Finland	155	5	0	–	95	155	5	0	–	95
Malta	10	0	0	100	–	10	10	0	–0	–
Luxemburg	10	90	5	–	5	10	80	20	–	–
Hungary	175	75	5	10	5	200	60	30	5	5
Poland	520	40	5	45	10	950	25	10	20	45
Romania	165	0	5	95	–	520	20	10	30	40
Slovakia	55	50	5	5	40	135	50	40	5	5
Spain	1,280	65	10	20	5	1,280	70	25	5	–
France	1,300	65	15	5	15	1,400	75	15	5	5
Italy	1,500	25	20	25	30	1,500	35	30	5	30
UK	1,640	70	20	–	10	1,640	65	25	–	10
Chech Rep.	260	55	25	10	25	260	75	20	5	5
Slovenia	25	5	25	40	30	50	15	70	10	5
Portugal	420	50	30	20	–	750	50	40	5	
Austria	273	15	40	>1	45	280	5	85	>1	10
Denmark	140	50	45	–	5	140	50	45	–	5
Germany	2,000	30	50	0	20	2,000	25	50		25
Belgium	170	10	90	–	–	170	10	90	–	–
Netherlands	560	0	100	–	–	560	–	100	–	–
EU27 total	11,564	42	27	14	16	13,047	44	32	7	16

[a] Reflects statistical data for 2010.
[b] Reflects to predictions for 2020.

environmental activities. The "sludge-to-energy" approach is feasible with substantial benefits similar of those that any renewable energy source presents: decreasing the energy dependency of the WWTP and greenhouse gas emissions. Sludge-to-energy is technically feasible if the recovered energy could be directly used for operating the WWTP, resulting in reduction of conventional electricity consumption (Manara and Zabaniotou, 2012). Another approach called "sludge-to-fuel" (STF) involves a process that converts the organic matter of sludge into a combustion oil using a solvent, under atmospheric pressure and mild temperatures in the range of 200–300 °C (Millot et al., 1989) or alternatively, at high pressures (~10 MPa) combined with high temperatures (Itoh et al., 1994). The produced oil is characterised by a high heating value (~90% of common diesel fuel) and can be sold to offsite users or refineries (Hun, 1998).

In Greece, according to recent statistical data (YPEKA, 2010), the current use of sludge in agriculture is very limited (0.15%) and estimations predict an increase up to 5% by 2020, as shown in Table 1. Due to the absence of established limits concerning water and pathogens content of MSS, local farmers are opposed and skeptical about the extensive use of sludge in agriculture. (Aggelakis et al., 2005). MSS use in agriculture is limited due to another important reason which is related to the use of CaO for the destruction of the pathogens which in addition to the destruction has a parallel negative impact on soil composition and fertility. In Greece, MSS is mostly used as an alternative fuel in existing cement kilns. Composting is particularly encouraged in Greece, reaching the share of 45.78% (YPEKA, 2010) as it is shown in Table 1.

In this study, the selection of the most promising sewage sludge-to-energy method, that meets the goal for a "sustainable development", was attempted. The aim of the present study was the comparative assessment of 3 energy recovery options (incineration, pyrolysis, gasification) for municipal sewage sludge (MSS) in Greece through SWOT analysis, taking into account their current status of development. SWOT analysis tool, initially invented by Albert S. Humphrey, designed to be used in the preliminary stages of decision-making; technologies and methods are compared in the base of economic, environmental and social metrics (Siomkos, 2004; Samolada and Zabaniotou, 2012). It was selected for application, since it has been proved to be a useful planning tool to understand the Strengths, Weaknesses, Opportunities and Threats of both processes and plans (UNEP 2009; Siomkos, 2004).

2. Legislation and sustainable integrated MSS management

Municipal sewage sludge (MSS) is defined as the *final solid residue* produced during municipal waste water treatment. It is classified as a solid waste with the code of 19 08 05 according to the European Catalogue of Wastes (EEL 47/16-2-2001; Directive 2000/532/EK). MSS is also considered as a "*specific stream*" of non-dangerous solid wastes, which has to be treated according to a National Strategic Approach [Ministerial Order 50910/2003] with the objective of landfills minimization. MSS environmental management has to meet all the basic principles of the Wastes Framework Directive applied since December 12th 2010 [EU, Directive 2008/98/EC].

The European Catalogue of Wastes was introduced in the Greek law by the Ministerial Order 50910/2003 along with the Producers Responsibility (PR) principle according to which the "waste producer" is responsible for its effective and environmental discharge. [Presidential Decree 148/2009]. The Sewage Sludge Directive 86/278/EEC which was adopted with the Ministerial Order 80568/4225/1991 in the Greek law, seeks to encourage the use of sewage sludge in agriculture and to regulate its use in such a way as to prevent harmful effects on soil, vegetation, animals and man. To this end, it prohibits the use of untreated sludge on agricultural land unless it is injected or incorporated into the soil.

MSS has been utilized in agricultural applications for several years, while it is restricted to prevent health risks to humans and livestock due to potentially toxic components, heavy metals, pathogens, and persistent organic pollutants and to the high amounts of soluble salts, which may affect the soil properties negatively. The presence of human pathogens in sewage sludge has led