Assessment of Options for Sustainable Management of Psittalia's Wastewater Sludge

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Abstract: Sewage sludge is a serious problem due to the high treatment costs and the risks to environment and human health. This paper addresses the management of wastewater sludge produced in WWTP Psittalia, (Athens, Greece), and applies the basic concepts of sustainability to this problem, that is examines each of the options to handle the sludge with regard to environmental impacts, legislation framework, technical implementation, economical feasibility and social acceptance. In this study the following alternative options for sludge treatment and disposal were considered: i) Composting of sludge, ii) Landfilling, iii) Use in agriculture (with direct application on land), iv) Combustion in special installation or co-combustion in cement kilns. Although the primary goal is to exhibit, demonstrate and focus on the methodology of finding a solution, it is suggested that for the dehydrated sludge, considering the special features of this case, a viable management method seems to be the composting method and for the dried sludge the co-incineration in cement kilns.

Key-Words: wastewater sludge, sustainability, Psittalia, sludge management

1 Introduction

Sewage sludge, also known as biosolids, is the solid byproduct of the wastewater treatment. It contains water (as high as 95% of its volume) and non-toxic organic compounds, nitrogen, phosphorus components, toxic pollutants (heavy metals, PCBs, PAHs, dioxins), pathogens and other microbiological pollutants and inorganic compounds such as silicates and aluminates. The fundamental problem of the sludge is in fact that all these compounds are present in one mixture. As Rulkens (2004) states "...sewage sludge is a serious problem due to the high treatment costs and the risks to environment and human health... there is no such thing as a uniform and unique system which is most sustainable". For the disposal of sewage sludge landfill is currently the practice adopted in Greece (Mavridou *et al.*, 2001). According to European Environmental Agency (EEA, 2001) data, 90% of sludge produced in Greece is disposed of in landfills and a 10% is used in agriculture.

The goal of this study is the application of the principles of sustainability, that is the analysis from a technical, economic, environmental, legal and social viewpoint, to the management options for the stored and daily produced dehydrated sludge, as well as dried sludge to be produced in the future, at the Psittalia Wastewater Treatment Plant (WWTP) in Athens, Greece. The WWTP receives the domestic wastewater, the pretreated industrial wastewater and the collected surface runoff water of the greater Athens area (average wastewater flow 750.000 m^3/day). The treated wastewater is discharged into the Saronikos Bay.

Dehydrated sludge from primary treatment was produced since 1994 (300t/d) and was transported to the Ano Liosia landfill at a cost of 14-20€/t. In 2003 the landfill managers facing serious slope stability problems and outcry by the local community refused to accept additional sludge quantities. The Athens water supply company EYDAP, which operates the WWTP, constructed storage cells on the Psittalia island to temporarily store the produced sludge. Since 2004 when secondary treatment was initiated (production of dehydrated sludge 500-700t/d 30% of Dry Mass - DM) the available storage space on the island has increasingly become inadequate. It is expected that in 2007-2008 the sludge drying facility will be in operation and the sludge production will be 300t/d of dried sludge 90-95%DM.

Several authors have emphasized the need of multiple sludge management options, the unique features of each individual case, the importance of public involvement into the decision making process, and the need to balance the economic,

environmental, and social aspects (Bellehumeur *et al.*, 1997; Campbell, 2000; Hospido *et al.*, 2005).
In the case of the Psittalia WWTP the problem is complicated because of the scale of the treatment plant and the amounts of sludge produced there. Also, the trucks hauling the sludge from the WWTP to the Ano Liosia landfill must take routes through densely populated areas. The residents have constantly protested due to the odours generated from the dehydrated sludge and the health risk perceptions of the public.
Also, another point of confusion derives from the fact that, although the main decision maker is EYDAP, other stakeholders such as Ministry of the Environment and Public Works, the city authorities (more than seven local communities are involved), the landfill operator, the prefecture officials, individual citizens and engineering consulting companies all have contradictory interests, views and perceptions.
The need for a systemic approach for sustainable sludge management is demonstrated by the recent history of sludge management decisions made by EYDAP. Having as main concern to handle the sludge with the minimum economic cost per ton of sludge managed, EYDAP offered a contract to the low bid contractor who proposed gasification. The project was cancelled due to social disapproval and inability to get the necessary licenses. The next bidder proposed a patented quick composting method (humification) within the landfill site. Yet the company was unable to find a permanent solution due to fierce opposition of the landfill workers and nearby residents. Recently EYDAP had to sign a contract to ship 60.000t of dehydrated sludge to Germany, where it will be finally managed, at a cost three times higher than the other two options tried.
The first part of this paper outlines the context within which the sludge management problem is to be solved. Then the problem is formulated using a systemic approach for the management of both the dehydrated sludge and the dried sludge. A group of appropriate criteria setting the main constraints for the decision problem is presented next and four alternative options for sludge management are considered and evaluated. Lastly, we discuss some conclusions and suggestions for future similar cases.

2 The sludge management decision context

Figure 1 presents schematically the wastewater treatment and the sludge production process in the Psyttalia WWTP. The primary sludge (3-4% DM) is thickened through gravity settling to a 6% DM and the secondary sludge is thickened with the use of mechanical sludge thickening tables. The two flows of sludge are digested in mesophilic anaerobic conditions in four anaerobic tanks of total volume 80.000m^3. The produced biogas is used to generate electricity and heat that is used inside the WWTP. The digested sludge, with a content of 5%DM, follows a stage of thickening and afterwards through four centrifuges it is dewatered to 28-30% DM content. The dehydrated sludge is currently accumulated inside three constructed cells for a post-treatment option, which until 2004 was landfilling. After 2007 a sludge drying unit is planned to start operation inside the WWTP. The post-treatment of the dried sludge has not been defined yet. Table 1 presents indicative concentration values of major pollutants in the Psyttalia WWTP flows. Based on the design, after secondary treatment the final effluent satisfies the limits of the EC Directive 91/271, but no concentration data were available to the authors to support achievement of this goal.

Table 1: Indicative mean concentration values of chemical pollutants in the Psyttalia WWTP flows (units in mg/l)

	TSS	BOD_5	COD	TKN	TP
Wastewater inflow	400	400	900	50	15
After primary treatment	150	250	500	40	10
Directive 91/271 EC limit	35	25	125	10*	1

*: a reduction of 70% of the initial inflow concentration is alternatively acceptable

Source: EYDAP (personal communication)

2.1 Legal Framework

Several EEC Directives affect sludge management of which most important are the 86/278 on the use of sewage sludge in agriculture, setting limits for the concentrations of heavy metals in the sludge, the 91/271 on urban wastewater treatment which will increase the quantity of produced sludge and the 99/31 calling for a decrease in the landfilled biodegradable domestic wastes. According to Article 5 by 16 July 2006 (2010 for Greece) the waste must decrease to 75% and by 16 July 2016 (2020 or Greece) reach 35% of the total quantity of biodegradable domestic wastes produced in 1995.

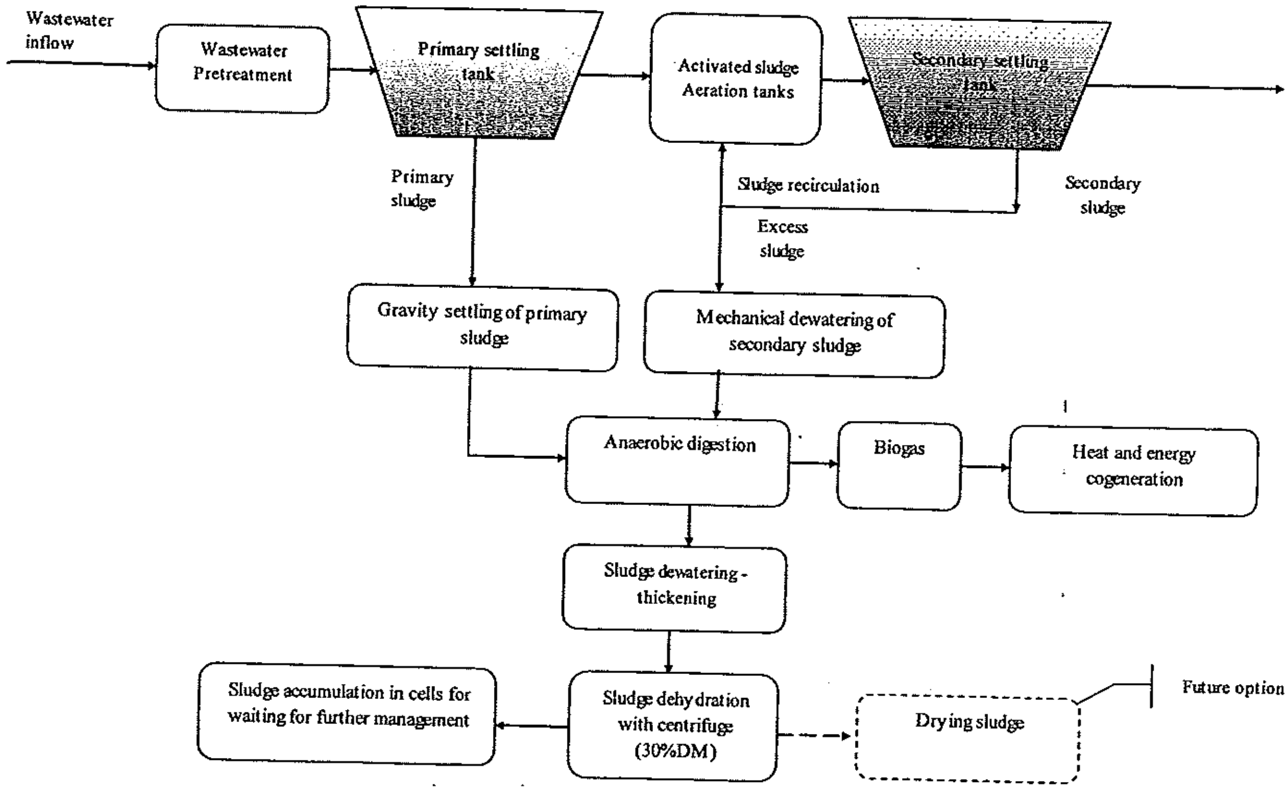

Figure 1: Schematic representation of wastewater treatment and sludge management inside the Psyttalia WWTP

The Regional Plan for Solid Waste Management in the greater Athens area prohibits combustion and proposes the utilization of sludge as recyclable material. There is some evidence that the concentrations of at least two heavy metals (Zn and Cr) in the Psittalia WWTP sludge are greater than the limits set by Greek legislation for on land application (Mamais *et al.*, 2000). The currently discussed amendment to Directive 86/278/EEC on sewage sludge proposes limits to the concentrations of synthetic organic compounds in sludge used in agriculture (Table 2). Fountoulakis *et al.* (2005) found that the concentrations of NPE in the Psittalia WWTP sludge are greater than the proposed limits. The amended limits for concentrations of heavy metals are also expected to be substantially lower. Table 3 summarizes the existing and proposed limits in different countries.

In accordance to current Greek legislation implementing the European Union Directives an environmental impact assessment study (EIA) should be submitted by the proponent as a means for granting operation permit for wastewater sludge management projects. This piece of legislation has been criticised for lacking a proactive role in managing impacts at a higher level of decision making where important decisions about the project's environmental performance have already been made (Dalal-Clayton and Sadler, 2005). The discussion over environmental efficiency and effectiveness led to the enactment of the Strategic Environmental Assessment (SEA) Directive (CEC, 2001) that aims at foreseeing and mitigating negative impacts at an early stage of decision making.

Several authors (e.g. Fisher, 2002; Therivel, 2004) agree that there are at least five main potential benefits of SEA in comparison with EIA. First, SEA allows for a wider consideration of impact management and evaluation of alternatives. Second, SEA can be used to support strategic action formulation for sustainable development. Thirdly, it can increase efficiency of tiered decision making including strengthening of Project EIA. Fourthly, it allows for a systematic and effective consideration of the environment at higher tiers of decision making and finally, wider consultation and participation of the public is possible rendering more acceptable strategic actions and projects.

At the time of writing, EU member states are in the process of introducing the provisions of the SEA Directive into their domestic legal system. Greece is currently considering the appropriate legislative framework for the SEA Directive's implementation.

Given the lack of experience in similar strategic assessment exercises, this paper aims at providing a useful guide on methodological efforts regarding the application of SEA in Greece. Furthermore, in view of the emergence of Sustainability Impact Assessment at an EU level, the adoption of an integrated approach in impact methodology at a Greek context is even more challenging. The evaluation of not only environmental but also socioeconomic alternatives in wastewater sludge management schemes can therefore provide the missing 'added value' to the application of the SEA Directive in par with the emerging Sustainability Assessment agenda in the European Union.

Table 2: Proposed limits of concentrations of organic compounds and dioxins in sludge used in agriculture

Organic Compound	AOX	LAS	DEHP	NPE	PAH	PCB
Limit (mg/kg DM)	500	2.6	100	50	6	0,8
Dioxines Limit (ng TE/kg DM)				PCDD/F 100		

Source: 3rd Draft Working Document on Sludge (2000)

Table 3: Limits (mg/kg DM) of concentrations of heavy metals in sludge used in agriculture according to existing legislation in various countries

Metal	Directive 86/278/EEC	3rd Draft Amendment	Greek Legislation	EPA 503 Rule		German Legislation
				*	**	
Cd	20-40	10	20-40	85	39	10
Cr (III)	-	1	500 (10 Cr6)	3	1.2	900
Cu	1.000-1.750	1	1.000-1.750	4.3	1.5	800
Hg	16-25	10	16-25	57	17	8
Ni	300-400	300	300-400	420	420	200
Pb	750-1.200	750	750-1.200	840	300	900
Zn	2.500-4.000	2.5	2.500-4.000	7.5	2.8	2.5

*for any sludge applied on land, ** for sludge of high quality

2.2 Public-stakeholder acceptance and perceptions

The social component is a significant aspect of the problem, because the residents of Keratsini and several other neighboring areas complain for the odours emitted by the sludge stored on the Psittalia island, while the Ano Liosia residents object to the sludge landfilling. Social outcry result in project delays and cost overruns which can be avoided by involving the stakeholders early into the decision process. Special interest groups, local authorities and involved participants are many and they often hold contradictory opinions, e.g. EYDAP, Ministry of Public Works and the Environment, the landfill operator, engineering consulting and residents.

Facing similar citizen complains about odours, the city of Montreal recruited forty-three individuals living adjacent to a landfill and a composting site and trained them to make odour observations. The citizens' perception was then correlated to the wind direction and velocity and other meteorological data (Heroux *et al.*, 2004). This approach could be used in the Psittalia case.

Bellehumeur *et al.* (1997) report that an advisory committee representative of the population of a small community in Canada studied the possible sludge management solutions and made recommendations to municipal decision-makers. Although it is true that Athens is a huge metropolitan center, where such methods would be much more difficult to implement, EYDAP could take some actions to inform and organize public meetings presenting the problem with a holistic approach.

2.3 Economic considerations

The cost (€/tDM) varies significantly for the different management options. The cost depends on the size of the treatment facility and the local conditions. Proper comparison of alternatives requires taking into account all costs, including operational and external/environmental cost. The latter is hard to estimate, except for gas emissions. The use of sludge in agriculture has the minimum average total cost of 107-160 €/tDM, while landfilling and combustion in special facility have the maximum total cost of 260-360 €/tDM. Application of composted sludge on land and use of sludge for landscape restoration have a moderate total cost of 210-250 €/tDM. In all cases total costs include mainly capital investments and operation costs (European Commission, 2002). Preliminary analysis of available data shows that from 1994 EYDAP had increased costs to handle the sludge. After the start of operation of secondary treatment in 2004 the cost of handling the sludge has almost doubled, exceeding €6 million annually.

2.4 Environmental impacts

The various sludge treatment and disposal options have serious environmental impacts. Landfilling may affect human health and degrade ecosystems (gas emissions (CH_4, CO_2), surface and groundwater pollution, soil pollution). In combustion the main impacts are gas emissions, e.g. acid gases and dioxins, climate change, and disposal of the produced ash. In on land recycling (use in agriculture, composting) the impacts involve human health, animal health and the possibility of heavy metals, pathogens and hazardous materials entering the food chain, in addition to air pollution, suspended matter and odour emission to the air. Finally, during transport of sludge, the main impacts are odour emission and release of dust and leachate (in the case of dehydrated sludge).

3 Problem Formulation

Figure 2 shows schematically the present and future sludge management problem. The following alternative options for the sustainable sludge treatment and disposal were considered: i) Composting of sludge, ii) Landfilling, iii) Use in agriculture (with direct application on land), iv) Combustion in special installation or co-combustion in cement kilns.

The option to ship the sludge to another country to be treated there, was excluded because of extremely high cost and moral issues.

The option of the use of natural constructed wetlands (perhaps on islands) was excluded because the time rate of the method and the space available would be inadequate to treat the excessive amounts of sludge.

Also, the option of gasification is excluded because demonstration of the technological feasibility is minimal.

3.1 Evaluation criteria

In the context of sustainable management, each option was evaluated on the following set of criteria:

C1. Cost (€/t DM)

C2. Production of useful products and/or energy reclamation

C3. Social dimension - Risk perception - Reaction and acceptance from public

C4. Technical feasibility – implementability

C5. Protection of environment

C6. Protection of human health

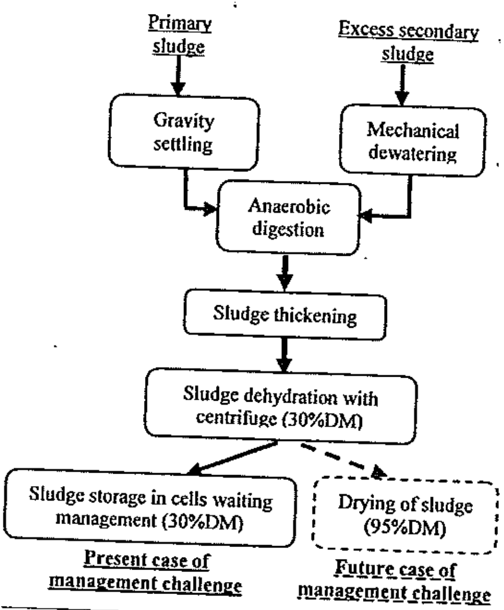

Figure 2: Sludge handling inside WWTP and the two distinct challenges for sustainable management

3.2 Exclusion Criteria

The following three exclusion criteria were used:

EC1. The concentrations of heavy metals in the sludge should be below the limit concentrations specified in national legislation Joint Ministerial Decision KYA 80568/4225/1991 Official Gazette 641/07-08-1991.

EC2. The organic fracture that enters landfills should be reducing according to national legislation KYA 29407/3508/2002 to 75% by 2010, to 50% by 2013 and to 35% by 2020 of the total degradable municipal wastes produced in 1995.

EC3. The process of composting demands a water content of approximately 55%.

According to the above criteria for each case the following management options are unattainable:

A. For the management of the dehydrated sludge

The option of the sanitary landfilling is excluded because of criterion EC2.

The option of use in agriculture is excluded because of ambiguity regarding the concentrations of heavy metals and of organic synthetic compounds (criterion EC1) (Fountoulakis *et al.* 2005; Mamais *et al.* 2000). Also there is no tradition of use of sludge by farmers in Greece and the fertilizer industry has no interest to use the sludge for such purpose.

B. For the management of the dried sludge

The option of sanitary landfilling is excluded because of criterion EC2.

The option of composting is excluded because of criterion EC3.

The option of use in agriculture is excluded again due to incomplete knowledge on the concentrations of heavy metals and some indications that may be higher than the limits (criterion EC1).

4 Problem Solution

As it was presented in problem formulation there are two distinctive cases: the final management of the dehydrated sludge and of the dried sludge.

4.1 Management of the dehydrated sludge

4.1.1 Evaluation of the Compost option

1. Regarding criterion C1 of cost and according to ISWA and EEA (1997) in European level there is a mean value of 125-300€/tDM, assumed as low to high cost of composting. Here there should be a distinction between the open composting methods (less expensive) and closed composting methods (more expensive).
2. Regarding C2 (production of useful product or energy recovery), the composted sludge can be used as topsoil in rehabilitated old landfills or for land reclamation purposes in regions with restricted access to public. Especially for Greece large amounts of compost are needed to act as a final cover for rehabilitation of old landfills and dump sites. The use of compost as a material of topsoil for the final cover of an old landfill has the ability to oxidize the methane gas emitted from the landfill (Humer and Lechner, 2001). Another usage of composted sludge includes recovering/improving of soil fertility as an organic additive in fire-affected land (Tarrason *et al.*, in press).
3. Regarding C3 (public perception of risk for this method) it is expected that the opposition will be modest. The main drawback in Psittalia's sludge case is that the location of the composting was in close vicinity to residential areas and met fierce opposition by the public.
4. Regarding C4 (technical feasibility) the closed composting methods are technologically more intensive in contrast to the open composting methods e.g. the windrow method.
5. Regarding C5 (environmental impact) during the compost process there is production of odours, e.g. NH_3, but the final product does not contain pathogen microorganisms and can be used in various applications. Caution and attention should be paid in the concentrations of heavy metals. The humification process has the advantage of diluting compost with the addition of soil material.
6. Regarding C6 (protection of human's health) this option scores high since the final compost presents negligible risks from pathogens.

4.1.2 Evaluation of the Landfilling option

This solution is excluded because of criterion EC2. If it was not to be excluded it would be a cheap option for EYDAP (15,4€/t of dehydrated sludge 30%DM) for the next 10 years thanks to a contract between EYDAP and the Ano Liosia Landfill Operator. At European level though some mean values are 100-300€/tDM (ISWA & EEA 1997).

Regarding C3, C5 and C6 the impacts would be probably low, except for residents near the landfill who have to sustain all the nuisances caused by the landfill operation.

Regarding C4 (technical feasibility), the process is well known and an operating landfill exists. However it is necessary to follow the appropriate rules for co-landfilling of large amounts of municipal wastes with successive amounts of dehydrated sludge.

4.1.3 Evaluation of the Use in agricultural option

This solution is excluded because of criterion EC1. There is limited conflicting evidence whether some heavy metal concentrations exceed the standards. Considering this option as acceptable, the following could be noted:

1. Regarding C1, the cost at European level is reasonable at 75-200€/t DM. However in Greece there is no 'tradition' of recycling the sewage sludge in agriculture.
2. Regarding C2, this option is an excellent way of regaining phosphorus and nitrogen as well as organic material in fields, minimizing the use of fertilizers.
3. Regarding C3, it is expected that the perception of danger by the public would be high and the acceptance negative.
4. Regarding C4, this option is achievable with no sophisticated technology. But, in Greece a period of training would be needed to master this practice, since there is lack of tradition in utilization of sludge.

5. Regarding C5, it is considered environmentally friendly option, as long as the metal concentrations abide to the imposed limits. Measurements in WWTPs in western and southern Greece show that lands which have been used for some years are already saturated in heavy metals and should be abandoned. In the rest of the lands a limited time of use is still possible on the condition that these will be carefully monitored (Kouloumbis *et al.*, 2000).
6. Regarding C6 (impacts on human health), there is fear for pathogens, heavy metals and organic toxic compounds interacting through food chain and so affecting animal and human health.

4.1.4 Evaluation of Combustion option

1. Regarding C1, this option has a high cost in the order of 318€/t DM (European Commission, 2002). According to (ISWA and EEA, 1997) the cost lies in a range between 225-400€/t DM.
2. Regarding C2, there is reclamation of energy since heat is produced, though nutrients are lost.
3. Regarding C3, it is certain that the combustion will be greatly opposed to by the public. The co-combustion of sludge, e.g. in cement kilns, will be more acceptable since the installations of cement kilns are already in operation. The cost is minimized for co-combustion in cement kilns.
4. Regarding C4 a new installation is a complicated project and requires sophisticated machinery and equipment, e.g. state-of- the-art air emission control technology. The high content of water in the dehydrated sludge should pose a problem both in combustion and co-combustion.
5. Regarding C5 (impact on the environment), there may be emissions to air of particles, noxious gases (SO_x, HCl), dioxins, heavy metals and greenhouse gases, leachate production from ash treatment, wastewater creation from flue gas treatment etc.
6. Regarding C6 (human health), there is the positive aspect of elimination of pathogenic bacteria, but there is problem with heavy metals from the ash treatment, gas emissions and volatile heavy metals.

4.2 Management of the dried sludge

The option of composting in this case is excluded because of EC3 (low water in the dried sludge).
The option of landfilling is excluded not only because of EC2 but also because the dried sludge is regarded as a useful product rather than a waste.
Generally, thermally dried sludge is more easily handled due to less volume and weigh (only 5% water content), with fewer odours produced and has been subject to safe hygienisation. Public opposition is expected to be less.
The greatest advantage in having sludge in a dry form as compared with various other methods is the possibility of 'marketing' the product for a number of applications: fertiliser/soil conditioner in agriculture and forestry, fuel in cement kilns or power plants, topsoil for landscaping etc. Of course, it is required a high initial investment cost relative to other methods (ISWA and EEA, 1997).

4.2.1 Evaluation of Combustion option

1. Regarding C1 the cost for co-combustion of dried sludge in cement kilns would be cheaper rather than building a new incineration facility.
2. Regarding C2 heat will be recovered and in the case of usage in cement kilns fossil fuels would be saved.
3. Regarding C3 new incineration facility exclusively for the dried sludge is likely to be rejected by the public, since pollution in the city of Athens is already an acute problem.
4. Regarding C4 there exists the know-how from the cement industries, which can handle a standardized product like granulated dried sludge.
5. Regarding C5 although the total mass of heavy metals will be conserved after drying they are transported from the labile phases in the wet sludge to more stable fractions in the dry and kilned sludge. This transformation of metal content due to thermal treatment is more significant at 900°C (Zorpas *et al.*, 2001) and thus pose less environmental threats of heavy metals spreading.
6. Regarding C6 caution should be paid just like in the case of dehydrated sludge combustion.

4.2.2 Evaluation of Use in agriculture

1. Regarding C1, the cost would entail mainly transportation costs and handling with the latter costing less in comparison with the dehydrated sludge.
2. Regarding C2, it would be more practical for the farmers to use a standardized product similar in form with the usual fertilizers.
3. Regarding C3, it is expected positive attitude from the public due to the lack of odours and pathogens.
4. Regarding C4, the implementation of the dried sludge in fields is more than feasible.
5. Regarding C5 and C6 caution should be paid for meeting the strictest legislative limits to avoid pollution and spreading by heavy metals in agriculture fields and thus protecting human health.

5 Conclusions and Suggestions

This study reviewed the costs, the legal framework, the special features of the Psittalia sludge management problem, the feasibility of profitable utilization of the sludge after additional treatment, the environmental impacts and the social concerns for each management option. The conclusions of the study are summarized in the following:

1) The dehydrated sludge from the Psittalia WWTP cannot be used in agriculture at present, because there is evidence of concentrations of some heavy metals higher than the regulated limits. However it is emphasized that use of sludge in agriculture is the management option with least cost and fewest environmental impacts, provided that the legislated limits are met. When the sludge drying facility is in place at Psittalia, the on land application of sludge may become more easily acceptable due to greatly reduced volume, transport costs and odours.

2) Composting combined with on land disposal of treated sludge has several advantages such as elimination of pathogens and odours, closed systems to accelerate the process, minimization of the required space for treatment. However, in Greece no specific system is in effect for controlling and standardizing the process. The final product must be disposed of in areas with restricted access to the public or be used as topsoil in rehabilitated old landfills.

3) Combustion in modern facilities that treat the fumes and conform to the strictest standards is the method with the highest external-environmental and total cost. Disposal of the solid residuals is also required. Combustion is likely to face the most serious public opposition due to the wide perception of high risk of failures during operation. In the greater Athens area it is hard to find a location to construct a combustion facility. On the other hand combustion in cement kilns is a viable possibility, because the extremely high temperatures destroy all toxic organics and the heavy metals practically are bonded on the cement. However, the cement industry will not accept sludge as fuel, unless it is a standardized product with known and constant physicochemical properties and thermal capacity. Therefore, co-combustion in cement kilns may be applicable only to dried sludge.

Table 4. Impact (criteria/alternatives) matrix from a technical/research point of view transformed into an ordinal scale (3-6-9) for the post-treatment of dewatered sludge.

		Suggested options	*Composting*	*Sanitary Landfilling*	*Agricultural use*	*Incineration in separate installation*	*Incineration in cement kiln*
	Criteria	Weight of criteria	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	Cost (€/t DM)	[illegible]	3	9	6	3	3
2	Production of useful products and/or energy reclamation.	[illegible]	9	3	6-9	6-9	6-9
3	Social dimension - Risk perception- reaction and acceptance from public	[illegible]	9	9	3-6	3	9
4	Technical feasibility-implementation	[illegible]	9	9	3-6	3	9
5	Protection of the environment	[illegible]	9	3-6	3-6	3-6	3-6
6	Protection of the human health	[illegible]	9	9	3-6	6	6

4) Sludge landfilling is not favored due to the recent trend to reduce the organic fraction that is disposed of in landfills. The experience with the Ano Liosia landfill has shown that the improper practices have led to creeping and slope sliding, causing intense social unrest. There is no consensus on the legislated new sites for landfills and the prospect of disposing sludge will amplify social opposition.

5) Sludge management is largely affected by the composition of the sludge. The industrial wastewater is the major source of toxic compounds, but some domestic activities also have a secondary contribution. To reduce heavy metals and organic pollutants it is necessary to implement systematic control of effective pretreatment of industrial

wastewater and substitution of toxic compounds with other less toxic.

From a technical, economic, environmental, legal and social assessment of the various sludge management options, it is concluded that composting-humification with disposal of the final product in areas with restricted access to the public or for as topsoil in rehabilitated old landfills is the preferable option. For dried sludge combustion in cement industry is preferable, if the use in agriculture is not possible. Finally, the decision-making organizations must realize that the selection of a sludge management scheme is not an exercise to find the least cost alternative, but rather a multicriteria problem which itself requires funding to be solved properly. Table 4 presents an impact matrix with the criteria and alternatives for the sludge management problem transformed into an ordinal scale (3-6-9). Additional research is required to clarify and make more precise the ordinal scale 1-9 for each criterion in the four alternative solutions. Also, for the determination of the weight of each criterion there is a need to balance the points of view of the final decision maker and of all other stakeholders.

The public must be involved at all stages, especially the users of the final product, so that the proposed solution is accepted. In a sustainable society it must be understood that the treatment residuals are intermediate products, not wastes, in the production chain and they have significant nutrient and energy content.

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