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# Environmental comparison of alternative treatments for sewage sludge: An Italian case study

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ABSTRACT

A Life Cycle Assessment (LCA) was applied to compare different alternatives for sewage sludge treatment: such as land spreading, composting, incineration, landfill and wet oxidation. The LCA system boundaries include mechanical dewatering, the alternative treatment, transport, and final disposal/recovery of residues. Cases of recovered materials produced as outputs from the systems, were resolved by expanding the system boundaries to include avoided primary productions. The impact assessment was calculated using the CML-IA baseline method. Results showed that the incineration of sewage sludge with electricity production and solid residues recovery collects the lowest impact indicator values in the categories human toxicity, fresh water aquatic ecotoxicity, acidification and eutrophication, while it has the highest values for the categories global warming and ozone layer depletion. Land spreading has the lowest values for the categories abiotic depletion, fossil fuel depletion, global warming, ozone layer depletion and photochemical oxidation, while it collects the highest values for terrestrial ecotoxicity and eutrophication. Wet oxidation has just one of the best indicators (terrestrial ecotoxicity) and three of the worst ones (abiotic depletion, human toxicity and fresh water aquatic ecotoxicity). Composting process shows intermediate results. Landfill has the worst performances in global warming, photochemical oxidation and acidification. Results indicate that if the aim is to reduce the effect of the common practice of sludge land spreading on human and ecosystem toxicity, on acidification and on eutrophication, incineration with energy recovery would clearly improve the environmental performance of those indicators, but an increase in resource depletion and global warming is unavoidable. However, these conclusions are strictly linked to the effective recovery of solid residues from incineration, as the results are shown to be very sensitive with respect to this assumption. Similarly, the quality of the wet oxidation process residues plays an important role in defining the impact of this treatment.



## 1. Introduction

The vast growth of world population and its urbanization produces the rise of the volume of wastewater generated, and then of sewage sludge (Hong et al., 2009). Wastewater treatment processes aim at reducing pollutant concentrations in the processed water before reintroducing it into downstream water bodies. The wastewater is treated to concentrate pollutants into sludge, therefore only the efficient and environmentally friendly management of these final residues will avoid pollutants being redirected to the environment.

Sludge treatment systems generally consist of a preliminary phase of thickening, dewatering and sometimes stabilization, followed by several different main treatments, such as land spreading, composting, incineration and landfilling. Application of sewage sludge to agricultural land has been generally considered a good practical option because the N, P and K content of sludge provides high fertilizer value and the organic matter acts as a useful soil conditioner. On the other hand, a number of factors are making land spreading increasingly difficult such as transporting

*Abbreviations:* AnD, Anaerobic Digestion; APCR, Air Pollution Control Residues; CM, Scenario of current management; COD, Chemical Oxygen Demand; COM, Composting; DM, Dry Matter; FGT, Flue Gas Treatment; FM, Scenario of future management; INC, Incineration; LCA, Life Cycle Assessment; LDF, Landfill; LFG, Landfill Gas; LSP, Land Spreading; pCOD, Particulate Chemical Oxygen Demand; TS, Total Solids; TSS, Total Suspended Solids; TVS, Total Volatile Solids; VSS, Volatile Suspended Solids; WO, Wet Oxidation; WWTP, Wastewater Treatment Plant.

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time and distance between utilities producing the sludge and suitable agricultural land, while there are also public concerns associated with pathogen transfer from sludge to crops, and the accumulation of heavy metals in agricultural soils (Donatello and Cheeseman, 2013). Composting is a controlled microbial process, under aerobic conditions, that converts biodegradable organic waste materials into usable products such as agricultural fertilizers. On the other hand, incineration is one of the best known waste treatment processes and it significantly reduces the volume of disposed sewage sludge. It is a good solution in densely populated regions where people have to deal with the problem of high quantities of sludge production and low land availability (Cieślik et al., 2015). Conventional incineration usually must be preceded by predrying of sewage sludge to obtain between 18 and 35% dry solid content, usually about 25% (Houillon and Jolliet, 2005). However, in Italy and according to Eurostat data, landfill remains the major disposal route for sewage sludge, followed by land spreading. Considering Europe consists of 28 countries, the most commonly used disposal method in 2012 was land spreading, followed by incineration and then composting and landfill (Eurostat, 2016).

Wet Oxidation (WO) is an alternative solution to incineration of sewage sludge (Bertanza et al., 2015a; Debellefontaine and Foussard, 2000). WO consists in the oxidation of organic and inorganic pollutants at medium temperature (150–360 °C) and high pressure (30–250 bar), using pure oxygen as the oxidizing agent (Chung et al., 2009). This process can be applied to sewage sludge with a solid content of 5–7% (Bertanza et al., 2015b). The organic matter is transformed mainly into carbon dioxide and water vapor emitted to air. The process generates also a mineral residue that must be transported to an ultimate waste storage center (Houillon and Jolliet, 2005) and an aqueous effluent that is sent to a WWTP for further processing. On the other hand, the high capital cost and the operating problems are serious disadvantages in this technology (Debellefontaine and Foussard, 2000).

The final choice of the appropriate management and treatment process most suitable for sewage sludge is of course deeply related to the local conditions. However a systematic evaluation of the benefits and drawbacks linked to the different possibilities should be performed. Environmental impacts and resources depletion can be evaluated by applying Life Cycle Assessment (LCA). This is one of the most well-known and widely applied methodologies to compare environmental impacts of systems and to evaluate their sustainability in an entire life cycle (Tarantini et al., 2007). Many researchers have applied LCA to sewage sludge management analyzing the most well-known treatments (Suh and Rousseaux, 2002; Peters and Rowley, 2009; Liu et al., 2013; Xu et al., 2014) and specific treatment technologies (Svanström et al., 2004; Hospido et al., 2005; Peregrina et al., 2006). Houillon and Jolliet (2005) have studied a WO process comparing it with conventional treatments, but only from a global warming and a non-renewable, primary energy, point of view. Furthermore, LCA studies are at times supported by economic analysis (Murray et al., 2008; Hong et al., 2009; Garrido-Baserba et al., 2015).

In this study, LCA is applied to assess alternatives to sewage sludge treatment. The compared treatments are: land spreading, composting, incineration, landfill and wet oxidation. The LCA analysis is carried out, then reported and described according to the LCA phases (EN ISO 14040:2006; EN ISO 14044:2006): the goal and scope definition and the inventory analysis are presented in the materials and methods section, while the impact assessment and the interpretation will be discussed in the results section.

Finally an existing study case is analyzed, which was related to the overall amount of sludge (32,170 t of dewatered sludge in 2015) produced by five WWTPs, located in central Italy, and managed by G.I.D.A. S.p.A.

## 2. Materials and methods

### 2.1. Goal and scope definition

The purpose of this LCA study was to compare the environmental impacts and the resources depleted in five treatments applied to sewage sludge. The considered alternative solutions are:

1. Mechanical dewatering and land spreading (T1-LSP)
2. Mechanical dewatering, composting and application on agricultural land (T2-COM)
3. Mechanical dewatering, incineration and residues disposal (T3-INC)
4. Mechanical dewatering and landfill (T4-LDF)
5. Mechanical dewatering of 61% of sludge, wet oxidation and residues disposal (T5-WO)

The LCA boundaries of the analyzed systems include the mechanical dewatering, the alternative treatments, transportation and final disposal of residues from the main processes. Within the system boundaries, the production processes for utilities, fuels, chemicals and manufactured materials entering the processes and the generated emissions are included. Impacts caused by the construction of plants are not included within the system boundaries. Recovered materials produced as outputs from the systems, for example compost or electricity, were resolved by expanding the system boundaries to include avoided primary productions due to material and/or energy recovery from sewage sludge (European Commission, 2010; Finnveden et al., 2009). In particular, the primary productions avoided for each treatment, include:

- Fertilizers substituted by sewage sludge spread on land or by compost used on land (T1-LSP, T2-COM);
- Electric energy produced by the Italian energy mix substituted by the electricity produced by engines fed by landfill gas and biogas (this last produced by the anaerobic digestion of the WWTP where the landfill leachate is assumed to be treated) (T4-LDF);
- Inert materials substituted by the recovered solid residues occurring as a result of the incineration process (T3-INC);
- Raw sodium chloride substituted by the sodium chloride recovered from the air pollution control residues of incineration FGT, in the case of using sodium bicarbonate as the acid gas reactant (T3-INC);
- Electric energy produced by the Italian energy mix substituted by the electricity recovered from the incineration process (T3-INC).

Mechanical dewatering was required in all the treatments. For T1-LSP, T2-COM, T3-INC and T4-LDF mechanical dewatering was applied to the whole amount of sewage sludge. Whereas, in T5-WO, mechanical dewatering was applied to only 61% of the total amount of sewage sludge; this was required in order to feed the wet oxidation process with an input stream characterized by 6.5% dry matter content.

The functional unit assumed for the treatment comparisons was 1 ton of dry matter of sewage sludge (tDM).

Inventories for the entering utilities, fuels, chemicals and manufactured materials entering the processes, for substituted products (electricity, fertilizers, inert, etc.), for final disposal of residues to landfill and for wastewater treatment were retrieved from Ecoinvent 3.0 (Ecoinvent Database, 2015). The impact assessment method used, was CML-IA baseline (Guinée, 2002). CML-IA is a LCA methodology developed by the Center of Environmental Science (CML) of Leiden University in The Netherlands. The method