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Life Cycle Assessment of organic waste management strategies: an Italian case study

C. Buratti*, M. Barbanera, F. Testarmata, F. Fantozzi

CRB – Biomass Research Centre, Via G.Duranti, 63, 06125 Perugia, Italy

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ABSTRACT

The aim of the paper was to evaluate the environmental burden of the organic waste management systems implemented in Umbria region in Italy, in order to provide useful information for taking strategic decisions aimed at the improvement and optimization. The two most widespread scenarios were analyzed: source-segregated collection followed by organic fertilizer production and not-differentiated collection followed by mechanical and biological treatment and disposal in landfill of the biostabilized material. The environmental performance was assessed through Life Cycle Assessment methodology, assuming one ton of organic waste as functional unit. Most of data for life cycle inventory were provided by actual facilities while background data were obtained from EcoInvent database. The alternative scenarios were compared through the IMPACT 2002+ method and the assessment was carried out on both midpoint and endpoint levels.

Results showed that the landfilling of the undifferentiated organic waste has the least impact on the analyzed impact categories, except on the Global Warming, mostly due to the uncollected methane released by the landfill. As regards the aerobic composting of the source-segregated organic fraction, the efforts to reduce the impact should be mainly focused on the reduction of the air emissions (hydrogen sulfide, particulate, ammonia and NMVOC) from the biostabilization process.

Furthermore the sensitivity analysis indicated that the increase of the biogas collection efficiency could significantly improve the performance of the not-differentiated collection scenario.

1. Introduction

Life Cycle Assessment (LCA) methodology (ISO, 2006a,b) can support decision making by public and private actors in order to find the best solution for the municipal solid waste (MSW) management. The opportunity to take into account the characteristics of the territory, as well as those of the waste disposal and treatment plants is one of the main advantages of this tool. Many applications are focused on the use of the LCA methodology as a decision support tool in the selection of the best MSW management strategy, from an environmental point of view, in a wide range of countries including Italy (Brambilla Pisoni et al., 2009; De Feo and Malvano, 2009), Spain (Bovea et al., 2010), Sweden (Eriksson et al., 2005), Germany (Wittmaier et al., 2009), China (Dong et al., 2013), Belgium (Belboom et al., 2013), and the U.S. (Kong et al., 2012).

This trend was also encouraged by the European Waste Framework Directive (EC, 2008), that emphasized the role of Life Cycle Thinking in the definition and evaluation of more sustainable strategies for MSW management.

A management of the organic fraction (OF) different from landfills and alternative management options such as composting, anaerobic digestion, as well as other conversion technologies are currently popular topics for discussion among policy makers, regulators, and waste management industries. The EU Landfill Directive 99/31/EC established a reduced amount of the biodegradable

Abbreviations: ABF, aerobic biological facility; ATO, optimal territorial area; BT, biological treatment; CP, compost production; DM, dry matter; LF, landfilling; LCA, life cycle assessment; LTP, leachate treatment plant; MBT, mechanical and biological treatment; MSW, municipal solid waste; MT, mechanical treatment; MTF, mechanical treatment facility; NMVOC, non-methane volatile organic compounds; OF, organic fraction; PP, power production; rMSW, residual municipal solid waste; rMSW DF, dry fraction of residual municipal solid waste; SOF, stabilized organic fraction; SS, source segregated; SSOF, source segregated organic fraction; TR, transport; WBTP, wastewater biological treatment plant.

* Corresponding author.
E-mail addresses: cinzia.buratti@unipg.it (C. Buratti), barbanera@crbnet.it (M. Barbanera), testarmata@crbnet.it (F. Testarmata), francesco.fantozzi@unipg.it (F. Fantozzi).

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fraction of MSW going directly to landfills. Based on the amount of MSW generated in 1995, the Directive imposed a mandatory stepwise reduction of 25%, 50% and 65%, respectively, by 2006, 2009 and 2016.

The Italian waste management system is ruled by the Italian Legislative Decree no. 152 (ILD, 2006), which specifies as priority measures the prevention and reduction of waste production and its harmfulness followed by measures such as recovery of waste through recycling, reuse, or any other action aimed at extracting secondary raw materials and at using waste as energy source.

The management of MSW in Italy is achieved through an integrated system, divided into Optimal Territorial Areas (ATO). The ATO is a special form of cooperation between local authorities, with legal, regulatory autonomy, within the organizational and budgetary resources allocated to it by the municipalities, the Province, and the Region because of its functions transferred or delegate.

In Italy, about 10.8 million tons of OF, consisting of food and green waste, are currently produced yearly and about 42% is recovered by source segregated (SS) collection (ISPRA, 2013a). The source segregated organic fraction (SSOF) is mainly (about 78%) sent to aerobic biological pretreatment, in order to obtain a high quality compost. The other fraction of the OF is contained in the residual municipal solid waste (rMSW), characterized by a mean biodegradable concentration of 32% w/w (ISPRA, 2013a). Actually, about 40% of the rMSW is subjected to mechanical and biological treatment (MBT), in order to stabilize the biological degradable components. In the widespread scenario, the MBT facility operates the mechanical treatment, such as shredding, screening, and metal sorting of the rMSW in order to separate the rMSW OF from the other recyclable materials. The rMSW OF is then biologically pretreated to reduce its reactivity and mass, obtaining the stabilized OF (SOF). About 59% of the SOF is actually disposed of in landfills (ISPRA, 2013a).

The actual environmental burden of OF diversion from landfills has yet to be thoroughly evaluated and whether such a diversion provides significant environmental benefits must be answered. Laurent et al. (2014), in a Literature review, showed that there is no consensus about which treatment is the best option for the organic fraction both because LCA studies depend on local specificities and furthermore there are a rather limited number of studies about OF management systems. In particular, only few of the studies have attempted to cover multiple environmental impacts, with most tending to focus mainly on climate change (Morris et al., 2013). Therefore, as remarked by Morris et al. (2013), additional studies are necessary to determine the best option for the organic waste management with regard to environmental impacts other than climate change.

The aim of this study is to compare the environmental impacts caused by two most widespread OF management methods in Italy: source segregated collection for the production of high quality compost and undifferentiated collection with landfill disposal after the mechanical and biological stabilization.

As case study area, a district of the Umbria Region was selected, in which a mechanical treatment facility, a biological treatment facility, and a landfill are present.

2. Materials and methods

2.1. Case study area

According to the ruling of the Regional Planning for the Urban Solid Waste Management, the Umbrian territory has been divided into 4 ATOs. The case study area refers to the ATOs no. 1 and 2, with a population of 550,000 inhabitants, producing around 525 kg of waste per capita per year: 225 kg (43%) is collected separately and 66 kg (12.5%) is the food waste fraction (ARPA Umbria, 2013). The organic waste management in the studied area is shown in Fig. 1.

The rMSW produced in this territory is sent to a mechanical treatment facility (MTF), where the waste stream enters a bag opener and is then conveyed to the first metal separation section, before screened with drum sieves. The waste stream passing through the sieve holes (100 mm diameter) is the rMSW OF which, after metal separation, is sent to the aerobic biological facility (ABF). The dry fraction of the rMSW (rMSW DF), after metal separation, is sent to a mechanical press, obtaining bales which are disposed of in landfill. This fraction still contains a certain percentage of organic matter that has not been possible to separate. In the same site of the MTF, there is also a wastewater biological treatment plant (WBTP) with activated sludge process. The plant treats the wastewater produced in the MTF site as well as sludge from septic tanks and sewage waters of the city nearby. The wastewater first passes through a bar screen and a sediment/oil separator and then is sent to denitrification and oxidation-nitrification sections, followed by final clarification of the effluent. The ABF is located 25 km away from MTF site. The rMSW OF and the SSOF are conveyed at the ABF site, where the waste streams are sent to a continuous flow aerobic basin, with an aerated floor, on which moves a crane bridge with screws used to stir and move the waste from the inlet to the outlet section. After about four weeks, the SSOF is placed in windrow heaps over a concrete platform for further aerobic treatment (62 days), while the rMSW OF, become stabilized (SOF), is disposed of in landfill. The platform is also equipped with ducts and electric fans to supply air to the waste. Before the biological treatment, only the SSOF is mixed with the green waste, while the obtained compost is refined by screening to remove contaminants such as plastic, glass and metals; this flow (Refuse), still containing a fraction of organic waste, is disposed of in landfill. In addition to the ABF, pollution control units are operating for the purification of the various air streams: biofilters, bag filters, and cyclone filters are used.

In the same site there are also a landfill and a leachate treatment plant (LTP). The landfill covers an area of 18 ha and the waste layer is at some points as much as 35 m deep. Biogas extracted from the wells is carried out by conveyance piping system to the combustion engines used to produce electricity. LTP consists of two sections: pretreatment unit, where takes place the equalization and the sedimentation, and the reverse osmosis unit, that produces permeate (discharged into the river) and concentrate (recirculated into the landfill) streams.

2.2. Goal definition

The goal of the study was to compare the environmental burden of the two most common options in Italy for the organic waste disposal, using life cycle approach.

The study is focused on the case of Umbria, a central Region of Italy, with 43% of total separate collection of municipal waste. High-quality data coming from specific mechanical and biological plants are used. The scenarios analyzed are:

1. undifferentiated collection, mechanical and biological treatment, and disposal of in landfill;
2. source-separated collection and production of high quality compost.

The study is performed in compliance with the four steps specified by the International Standardization Organization (ISO) standards (ISO, 2006a,b). The LCA was constructed using SimaPro software version 7.2. Currently, many LCA impact methods have been developed and widely used (Rodríguez et al., 2011), such as