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Environmental impact of municipal solid waste management using Life Cycle Assessment: The effect of anaerobic digestion, materials recovery and secondary fuels production

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ABSTRACT

Material and energy recovery from waste is significantly growing its importance in the last decades aiming to reduce the primary resources exploitation and the excessive recourse to incineration and landfilling. Several processes, technologies and methods can be chosen to design a proper waste management system (WMS) so that an objective comparison between alternatives has to be made. To this end, Life Cycle Assessment (LCA) can be used to compare possible alternative scenarios and create an evaluation grid where different environmental parameters are reported. The aim of this work was to compare the environmental impacts of four different scenarios already analysed for technological and economic aspects in a previous work. The scenario taken as base case referred to a real waste management system applied in Caserta Province, an area of 924,614 inhabitants in the Campania region of Southern Italy. The base scenario considers the household separation of waste in five fractions addressed to material recovery (polyethylene, polyethylen-terephtalate, polypropylene, metals, cellulosic fibers, …), composting (biowaste) and incineration (residual waste). The results of the LCA demonstrated that the best scenario is that one including the highest separate collection rate technically and economically feasible to be carried out i.e. 60%, the recourse to anaerobic digestion and biogas production to treat the biowaste separately collected and the maximization of the re-processing of recyclable materials such as PET, HDPE, glass, metals, … In particular, the Global Warming Potential decrease of 166% and the Eutrophication Potential decrease of 646%, when the alternative scenario, including the recalled features is compared to the base-case one. The most important result is that the raised separate collection of recyclable materials utilized as substitutes of raw materials and of biowaste utilized for production of renewable energy helps to mitigate the direct and indirect burdens connected to the overall life cycle of goods production.

1. Introduction

In the last decades, there has been a growing social awareness in respect of environmental issue correlated to the planet "waste" by inducing the proliferation of several proposal to threat the waste in a sustainable way. National and international policy frameworks represented a driven force for this outbreak of technologies and processes [1–3].

The current policy address regarding the solid waste disposal is based on the concept of circular "global" management, a step forward respect to the simply integrated approach. In practice, the

Abbreviations: EFA, energy flow analysis; EP, Eutrophication Potential; GWP, Global Warming Potential; LCA, Life Cycle Assessment; LCI, Life Cycle Inventory; LCIA, Life Cycle Impact Assessment; MBT, Mechanical-Biological Treatment; MFA, Material Flow Analysis; MRW, Mixed Recyclable Waste; MRF, Material Recovery Facility; MSW, Municipal Solid Waste; PE, PolyEthilene; PET, PolyEthilenTerephatalate; SFA, Substance Flow Analysis; WMS, Waste Management System; WtE, Waste to Energy.

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waste is seen as a part of the global economic chain and its recovery is convenient, sustainable and essential. The actualization of this vision needs a waste management system (WMS) integrated in the industrial and urban pattern. At the moment the waste management is a standalone system, disconnected by the industrial pattern. The secondary materials are the only points of connection with the industry. A further tentative to connect the WMS to the industrial pattern has been the standardization of the rules to produce the Solid Secondary Fuel (SSF). The utilization of SSF in the traditional cement kiln and steel industries is another point of connection. Anyway, far to be fully integrated, the WMS must be designed to increase the number of connection points with the traditional economy in order to make realistic the circular concept.

Therefore, how a WMS has to be constituted to enforce this connection to industrial fabric? Answer is not unique: depending on waste type, site of production, economy of the region the best WMS can be designed by choosing between alternatives [1–3]. Alternative management system could produce different interactions with the surroundings by means of variables related to environmental, social and economic issues. All these variables depend on the processes included in the system and define the overall waste management sustainability. Environmental, economic and social variables are strongly correlated to the process that leads to the choice of the “best” municipal solid waste management system; the LCA is often used to make the evaluation and comparison between alternatives [2–9]. The integrated design of a WMS must deal with the waste source and with the composition of the collection which is affected by the efficacy of the household waste diversion. By regarding the municipal solid waste, an indiscriminate increase of diversion rate, that is defined as the ratio between the household waste sorted into different fractions (glass, paper&cardboard, mixed recyclable materials, biowaste and the rest) and the total amount of waste, is not necessarily the best choice. In fact, its indiscriminate increasing can lead to worsening of waste quality because of the foreign materials increasing in both biowaste and recyclable waste by creating quality depletion in the recycled goods [10,11].

As already mentioned above, the assessment of the environmental performance of a given solid waste management can be developed by using analytical tools such as material and substance flow analysis (MFA, SFA), energy flow analysis (EFA), risk analysis; in particular, the comparison between different scenarios can be developed by using the LCA tool. This tool uses the output data obtained by MFA, SFA and EFA as input data to the inventory and allows to compare alternative scenarios by means of a series of indexes. The MFA and LCA tools are then integrated and able to give a complete series of results about evolution of the WMS.

In this paper the base case scenario is related to a WMS referred to a wide area included in the Caserta Province having an extension of about 275 km^2, 316.000 inhabitants and a production of municipal solid wastes (MSWs) equal to 148.750 ton per year. The scenario includes the household separation of waste, e kerbside collection, the treatment of each waste flow collected by the householders, recycling and recovery of secondary materials and fuels. The industrial facilities that manage the collected waste are both of private and public ownership; they include a Mechanical-Biological Treatment (MBT), a Waste To Energy plant (WtE), several platforms to pre-treatment of recyclable waste (platform) and several Material Recovery Facilities (MRF) to sort the recyclable waste collected as a mix (Mixed Recyclable Waste - MRW). The alternative scenarios have been designed by following the EU guideline about hierarchy [12,13] and the comparative analysis has been made by using the LCA procedure to evaluate the best scenario regarding the environmental concerns starting by the considerations already reported in the previous work [10]. The objectives of the assessment is to define which of the compared scenarios is the best one, if any, by an environmental point of view. The combination of techno-economical and environmental information drives towards the most sustainable choice in term of waste management planning.

2. Methods and tools

The LCA is a general methodological framework introduced to assess all the environmental impacts related to a product, process or activity by identifying and evaluating the overall resources consumed as well as all the emissions and wastes released into the environment [14,15]. This represent a method that can be used to compare such technologies – scenarios - processes and to evaluate their environmental performances allowing decision makers to be correctly informed [16].

Standard ISO 14040 [17] and 14044 [18] define the four basic steps of the assessment procedure, well described and commented in Refs. [19,20]:

a) Goal and scope definition, which includes the preliminary assumptions about the aim of the study, the functional unit and the boundary of the system.
b) Life cycle inventory (LCI), which consists in the collection and analysis of all material and energy input and output that cross the border between the product or service system and the environment over its whole the life cycle. The input and emission flow are termed *environmental burdens.*
c) Life cycle impact assessment (LCIA), where the environmental impact of the activity is assessed with the use of impact indicators.
d) Life cycle interpretation, which aims to evaluate possible changes or modifications of the system that can reduce its environmental impact.

The LCI is the core of the LCA study and its compilation needs of a lot of reliable data, often taken by on site visit at the real operating facilities of interest. In this paper the LCI is not reported in detail because it can be found in a related previous work [13]. The paper reporting the LCI utilized the MFA as methods to compile the database. This method allowed to obtain all input, output and intermediate flows related to the system under study. In particular, the system has been represented as a flow diagram made by unit processes represented by blocks. Each block was a unit processes. The MFA has been applied to the system and to each unit process as sub-system with a level of detailed analysis more high than usual.

The GABI 7.2.1.12 software, developed by Thinkstep [21] is used for the evaluation of the energetic and environmental impacts of the various processing steps. Two characterization methods have been chosen: Cumulative Energy Demand (CED) provided by Huijbregts M.A.J., Hellweg S., Frischknecht R., Hendriks H.W.M., Hungerbühler K. and Hendriks A.J. [22] and the CML 2 step up by the Centre of Environmental Science of University of Leiden [23]. This is the most comprehensive characterization method specific for Europe which includes quantification of impacts on water, air and land.

The first one has been used to calculate the total energy demand of the activity under study. In fact, the CED method investigates the energy use throughout the life cycle of the analysed system, including direct as well as indirect consumptions of energy due to, e.g., the production of additives or construction materials.

The CML 2 method is applied to evaluate the environmental impacts. In particular, the following environmental impact categories have been selected: