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Environmental Implications of the Valorisation of the Residual Fraction Refused by MBT Plants

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In a previous research developed by authors, it was published a methodology for estimating the energy content of the residual fraction refused by the Zaragoza´s mechanical–biological treatment (MBT) plant located in Zaragoza, Spain. The present study is based on a developed environmental evaluation method, that uses the Life Cycle Assessment (LCA) methodology, with the aim to evaluate the environmental implications, in terms of net CO_2 emissions equivalent, of the valorisation of this residual fraction, taking into account the CO_2-equivalent (eq.) emissions produced by the collection system, including transport stages, the MBT plant and the CO_2-eq. emissions avoided by the Municipal Solid Waste (MSW) recovery (energy and material) method used. As a case study, the MSW management system in the ecocity Valdespartera, which is attended by the Zaragoza's MBT plant, has been studied, taking into account a stationary vacuum waste collection and transport system for approximately 10,000 homes. Based on the application of the developed methodology to the case study, the environmental implications of the valorisation of the residual fraction refused by this MBT plant, which collects residual household waste from 62 municipalities in four regions of Aragon – Zaragoza, Ribera Baja del Ebro, Campo de Cariñena, and Campo de Belchite, are evaluated. Results allow detecting significant technical and environmental findings that could be used for promoting essential changes in the upstream of the MBT plant. Also, these results are relevant to help municipal decision makers in order to develop energy and material recovery, and disposal programs.

1. Introduction

Over the last decade in European countries, mechanical–biological treatment (MBT) plants for residual household waste have become an important technology in waste management (Tintner et al., 2010, Pires et al., 2011). There are two types of streams that can be identified in an MBT plant – upstream and downstream – which represent, respectively, the input and output streams (e.g. residual household waste and residual fraction, respectively). Currently, in many countries, the residual fraction from these plants is disposed of in a landfill with few recovery actions (Aranda Usón et al., 2012b). From a cleaner production perspective, environmental implications of the residual fraction are useful for generating innovative strategies to manage the upstream. These strategies seek to help municipal decision makers develop energy and material recovery, and disposal programs. Therefore, the proper estimation of the environmental implications of the residual fraction refused by MBT plants is essential for planning and promoting different methods to decrease its environmental impact, to lower the consumption of energy resources, and to reduce economic costs.

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Taking into account the two types of streams identified in an MBT (upstream and downstream), the composition and the higher heating value HHV of the downstream (e.g., residual fraction), is useful for generating innovative strategies to manage the upstream (Aranda Usón et al., 2012b). This scheme has been applied to this research considering an environmental evaluation of the different recovery treatment scenarios of the residual household waste, including the environmental implications of the valorisation of the residual fraction refused by the MBT plant.

Nowadays, there are some studies on the scientific literature that are focused on different aspects of the environmental impact of several waste treatments including collection systems and using the Life Cycle Assessment (LCA) methodology (Feo and Malvano, 2009, Aranda Usón et al., 2012a). Despite most of these being specific case studies considering some methods or stages of the MSW management system, e.g. MBT plant (Abeliotis et al., 2012, Papageorgiou et al., 2009), some estimations can vary widely, indicating the need for more efforts. The present study is based on a developed environmental evaluation method published by authors (Aranda Usón et al., 2012, Aranda Usón et al., 2012a) with the aim of evaluating the environmental implications, in terms of CO_2 emissions equivalent, of the residual fraction from MBT plants, taking into account the available waste collection system, the treatment plant and the different alternatives of disposal of the residual fraction.

As a case study, the environmental implications of the valorisation of the residual fraction refused by Zaragoza´s MBT plant, through the analysis of the MSW management system in the ecocity Valdespartera, located in Zaragoza, Spain, was studied. To this end, the developed environmental evaluation method, that uses the LCA methodology, is applied as a tool to estimate the CO_2-equivalent (eq.) emissions produced by the collection system, including transport stages, the MBT plant and the CO_2-eq. emissions avoided by the MSW recovery (energy and material) method used. One important aspect of this research is that there are no relevant previous studies that have specifically focused on an evaluation of the environmental implications of the valorisation of the residual fraction refused by MBT plants, taking into account the collection and transport system, the operation of the MBT plant and the different waste recovery treatment scenarios (energy and material), integrated into a single system whose function is to recover the value of the MSW.

2. Methodology

Equations 1-3 and Table 1 summarise the evaluation method used in this research. Table 1 shows a matrix for a general study. This matrix represents the difference between the amount of CO_2-eq. emissions emitted for a MSW management system "i" and the amount of CO_2-eq. emissions avoided for a MSW recovery scenario "j". The elements of the matrix are shown in Table 1, β_{ij} can be written as:

$$\beta_{ij} = E_{gi} - E_{aj} \tag{1}$$

$$E_{gi} = \sum_{x=1}^{x=n} E_{gx} \tag{2}$$

$$E_{aj} = \sum_{y=1}^{y=m} E_{ay} \tag{3}$$

Where E_{gx} is the CO_2-eq. emissions that have been produced by "n" subsystems of the MSW management system "i" and E_{ay} is the CO_2-eq. emissions avoided by "m" recovery methods considered for the MSW recovery scenario "j". The elements of the matrix β_{ij} can be positive or negative. In this first case, the generated emissions are higher than those avoided in each particular scenario. The second case, which involves a negative or zero value, occurs when the avoided emissions are higher or equal than to those generated, respectively.

The amount of the CO_2-eq. emissions emitted (E_{gi}) includes the CO_2-eq. emissions due to MSW collection, which is integrated of the CO_2-eq. emissions due transfer and transport from the collection points to the central collection station and from there to the MBT, the CO_2-eq. emissions due to the operation of the MBT treatment plant, and the CO_2-eq. emissions due to the treated products' operations in the recovery facilities. On the other hand, in order to estimate the amount of CO_2-eq. emissions avoided for a set of considered recovery methods (E_{aj}), is necessary to quantify the amount of each fraction recovered for material and energy recovery in the MBT plant. This could be calculated taking into account the different output flows of this plant and its fraction recovered rate. The fraction recovered rate and the biological treatment rate are the percentage of material separated for recycling in the sorting process and biologically treated organic matter (e.g. for obtaining biogas for electricity production and compost for soil fertilisation). In addition, the amount of CO_2-eq. emissions avoided from different material recovery methods for the recyclable materials (e.g. ferrous and non-ferrous metals, paper/cardboard and plastics), compost and biogas for 1 tonne of material recovered in an MBT has been reported by several studies (Papageorgiou et al., 2009, Abeliotis et al., 2012, EPA, 2006).

Table 1: Net CO2-eq. emissions – Matrix of the relationship between MSW management systems and the MSW recovery scenarios

MSW recovery scenario j↓	1	2	3	← MSW management system i
1	β_{11}	β_{12}	β_{13}	
2	β_{21}	β_{22}	β_{23}	

The LCA methodology is useful for analysing the environmental impact caused by any type of process and product (Tukker, 2000). The most up-to-date structure of the LCA is proposed by the ISO 14040:2006 guidelines (ISO, 2006) and divides the assessment procedure into four basic steps: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment and (4) interpretation. The principal phases of an LCA study where the dynamic character and the interrelation of the four phases can be seen. In this study, the environmental impact has been determined at the midpoint level. A midpoint impact category indicator is considered a result point in the cause-effect chain (environmental mechanism) of a particular impact category somewhere between stressor (a set of conditions that may lead to an impact) and impact category indicator at endpoint level (like damage to human health and damage to ecosystem quality) (Rebitzer et al., 2004). To this end, the IPCC 2007 GWP 100a V1.02 impact assessment method was used in order to quantify and compare the potential environmental impact of the life cycle inventory (LCI) by using the Software SimaPro v.7.3.

2.1 Goal and scope definition

The main objective of this study is to determine the environmental implications, in terms of CO_2 emissions equivalent, of the valorisation of the residual fraction refused by MBT plants by applying LCA methodology as a tool to estimate the CO_2-eq. emissions rigorously.

The functional unit is a key element that provides a reference to which the inputs and outputs can be related (Rebitzer et al., 2004). In this study the functional unit is 1 tonne of MSW collected and treated in an MBT plant.

2.2 Target area and quality data

The Zaragoza´s MBT plant is located in the autonomous community of Aragon in north-east Spain. This plant receives the residual household waste from MSWs from 62 Aragonese municipalities, which are distributed in four regions, namely, Zaragoza (23), Ribera Baja del Ebro (10), Campo de Cariñena (14) and Campo de Belchite (15). The mass flows of Zaragoza´s MBT plant can be identified taking into account five different output flows per 1 tonne of residual household waste fed in it: (i) material recovery (6.51 %), biogas (2.00 %), compost (12.00 %), air emissions, lecheates (27.50 %) and residual fraction (51.99 %) (Aranda Usón et al., 2012b). Within the mentioned area is located the ecocity Valdespartera in the city of Zaragoza. At the present time, this ecocity has the first stationary vacuum waste collection system installed in the Autonomous Community of Aragon. This system was designed to collect residual household waste and packaging from 9687 flats with an estimated population of 30,000 inhabitants including schools, shops, bars and restaurants, etc. The household waste generated in 2011 of general fractions: packaging, rest waste, paper/cardboard and glass, are 2,969; 16,278; 3,010 and 1,261 t/y, respectively, taking into account an occupancy rate of 100 %, an average solid waste generation of 0.438 t/y per capita and an average value of the physical composition of residual household waste presented by Aranda Usón et al. (2012b).

2.3 System description

Figure 1 shows the stages involved in the MSW management system studied.

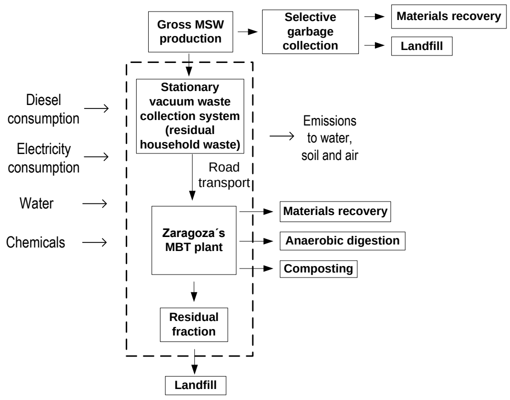

Figure 1: Current system of MSW management used in the studied area

Firstly, a residual household waste collection and transport system based on stationary vacuum waste collection system is presented (Aranda Usón et al., 2012a). This system was designed taking into account a maximum capacity of collection of waste generated by a 100 % occupancy rate in the ecocity Valdespartera. Several indoor and outdoor collection points are available for the rest waste and packaging. After residents drop bags through a chute these are stored inside underground containers and, according a collecting schedule, transported by vacuum to a central collection point which is located the centre of the collection network. This collection method uses electricity to collect household waste and compact it into a container according to the waste fraction. When this container is full it is transported by a truck as a single load to the Zaragoza´s MBT plant. Finally, transport includes the diesel consumption of driving a truck with a single load a total distance of 19.8 km. Secondly, the operation of the MBT plant which includes the different mechanical and biological processes that take place in the treatment plant, is presented (Aranda Usón et al., 2012b). The rejected materials obtained from the different plant processes are currently compacted into bales and sent for disposal in a landfill without energy recovery.

2.4 Life cycle inventory

Table 2 shows the LCI for 1 tonne of MSW collected in the ecocity Valdespartera and treated in Zaragoza´s MBT plant. The composition of the residual fraction going to disposal in a landfill from Zaragoza´s MBT plant and secondary raw material derived from MBT processing that can be recovered and biologically treated, has been obtained using the methodology proposed by Aranda Usón et al. (2012b) and taking into account the composition of the residual household waste. The recycling of materials saves emissions as if offsets virgin materials that would have otherwise been used in the manufacturing of various products (Papageorgiou et al., 2009). The quantity of the fractions recovered for material and energy recovery has been calculated taking into account the different output flows per 1 tonne of residual household waste fed in the MBT plant and its fraction recovered rates. In case of the Zaragoza's MBT plant, these fraction recovered rates were estimated as 78.36, 18.82, 4.79 and 79.51 % for organic material, paper/cardboard, plastic and metal, respectively (Aranda Usón et al., 2012b).

Table 2: The main LCI of a stationary vacuum collection system at load factor of 100% and for the treatment of 1 tonne of MSW in Zaragoza's MBT plant

Stage	Input	Output	Unit		Source
Collection	Electricity		kWh/y	962,327	(Aranda Usón et al., 2012a)
Transport	Transport to Zaragoza's MBT plant		tkm/y	381,081	(Aranda Usón et al., 2012a)
MBT plant	Water		t/t MSW	0.536	(Abeliotis et al., 2012)
	Electricity		kWh/t MSW	80	(Papageorgiou et al., 2009)
	Diesel		kg/t MSW	0.8	(Papageorgiou et al., 2009)
	Sulfuric acid		kg/ t MSW	0.789	(Abeliotis et al., 2012)
	NAOH		kg/ t MSW	0.095	(Abeliotis et al., 2012)
	Chlorine		kg/ t MSW	0.406	(Abeliotis et al., 2012)
		Residual fraction	t/ t MSW	0.519	(Aranda Usón et al., 2012b)
		Compost	t/ t MSW	0.120	(Aranda Usón et al., 2012b)
		Biogas	t/ t MSW	0.020	(Aranda Usón et al., 2012b)
		Paper/cardboard	kg/ t MSW	30.69	(Aranda Usón et al., 2012b)
		Plastic	kg/ t MSW	5.15	(Aranda Usón et al., 2012b)
		Metal	kg/ t MSW	29.42	(Aranda Usón et al., 2012b)

3. Results and discussions

Two recovery scenarios were studied for the ecocity Valdespartera: (i) the actual collection and transport system taking into account the current recovery rates for the Zaragoza's MBT plant, where all the residual fraction is landfilled, paper/cardboard, plastics and metals are recovered for recycling and biogas and compost are produced from the organic matter of the residual household waste, (ii) the actual collection and transport system taking into account 214 kg CO_2-eq. emissions avoided per tonne of MSW considering a recovery scenario of: 40 % of the produced compost for soil fertilisation, 100 % of ferrous material recovery, 85 % of aluminium recovery, and 55 % of the produced RDF incinerated in a cement plant with landfilling of the remaining compost, RDF and other rest fractions (Abeliotis et al., 2012). Additionally, two MSW management system scenarios were studied taking into account, in both cases, a modification of the load factor of the collection system from 100 % to 13 % considering the first and second studied recovery scenarios, respectively. Net CO_2-eq. emissions per tonne of MSW collected from vacuum collection system in ecocity Valdespartera, at a load factor of 100 % and 13 %, was estimated as 33.2 and 146.9 kg CO_2-eq./t, respectively (Aranda Usón et al., 2012a). The results of both MSW management systems and recovery scenarios are shown in Table 3.

Table 3: Net kg CO_2-eq. emissions – Matrix of the relationship between the MSW recovery scenarios and the MSW management systems studied

MSW recovery scenario j↓	1	2	← MSW management system i
1	-112.55	1.15	
2	-180.80	-67.00	

For the recovery scenarios studied it can see that the emissions avoided are greater than those generated for both scenarios in the MSW management system 1 (100 % load factor of the collection system), nevertheless the best performance occurs at a second recovery scenario (-180.8). However, for the recovery scenarios studied it can see that the emissions avoided are lower than those generated for the first scenario in the MSW management system 2 (13 % of load factor of the collection system) (1.15), however the best performance occurs at a second recovery scenario (-67).

4. Conclusions

Results from the evaluation of the current MSW management system of the ecocity valdespartera show that, when the recovery scenario includes the production and energy recovery of RDF from the residual fraction a better environmental performance is achieved in comparison with the current recovery scenario in Zaragoza's MBT plant. Nevertheless, when the collection system is operating at load factors less than 100 %, the environmental benefits in terms of CO_2-eq. are penalised due the increase of emissions generated during the collection and transport at a load factor of 13 %. In this case, the net CO_2-eq. emissions could be positive (1.15 net kg CO_2-eq. emissions) making that with the current waste management system, the emitted CO_2-eq. emissions are higher that the CO_2-eq. emissions avoided due the recovery scenario. Results help to recognise the most efficient and sustainable MSW management system, establishing scientific criteria for the design and planning of several recovery scenarios for the valorisation of the residual fraction refused by MBT plants.

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