

Environmental assessment of home composting

Joan Colón ^{1,2}, Julia Martínez-Blanco ³, Xavier Gabarrell ^{1,3}, Adriana Artola ^{1,2}, Antoni Sánchez ^{1,2}, Joan Rieradevall ^{1,3} and Xavier Font ^{1,2,*}

¹ Department of Chemical Engineering, Universitat Autònoma de Barcelona, 08193, Edifici Q Bellaterra (Barcelona), Spain.

² Composting Research Group (GICOM), Department of Chemical Engineering, Universitat Autònoma de Barcelona, 08193, Edifici Q Bellaterra (Barcelona), Spain.

³ Institute of Environmental Science and Technology (ICTA), SosteniPrA, Universitat Autònoma de Barcelona, 08193, Edifici C, Bellaterra (Barcelona), Spain.

* Corresponding author:

Tel: +34935814480; Fax: +34935811018.

E-mail address: xavier.font@uab.cat

Pre-print of: Colón, J. et al. "Environmental assessment of home composting" in Resources, conservation and recycling (Ed. Elsevier), vol. 54, issue 11 (Sep. 2010), p. 893-904. The final version is available at DOI 10.1016/j.resconrec.2010.01.008

Abstract

In this study the environmental burdens of home composting were determined using the life cycle assessment (LCA) tool. Data used for the LCA study such as gas emissions (CH_4 , N_2O , NH_3 and Volatile Organic Compounds -VOC-), tools and composter characteristics were obtained from an experimental home composting process of leftovers of raw fruits and vegetables (LRFV). Stable compost with a high content of nitrogen and organic matter was obtained. Neither pathogens nor phytotoxic compounds were found in the final compost. In relation to gaseous emissions, only volatile organic compounds (0.32 kg VOC/Mg LRFV) were detected, even though ammonia, methane and nitrous oxide emissions were also measured. Regarding environmental burdens, the composter was the major contributor to the total home composting process impact for the impact categories of abiotic depletion, ozone layer depletion, and cumulative energy demand. Gaseous emissions (based on our own measurements and literature data) caused the greatest contribution to the acidification, eutrophication, global warming and photochemical oxidation potentials.

Keywords:

Home composting; backyard composting; life cycle assessment; gas emissions; environmental impacts; waste management; municipal solid waste.

1. Introduction

The management of the organic fraction of municipal solid wastes (OFMSW) is a growing problem due to the rapid collapse of landfills, the “not in my backyard” practice and the potential contamination and loss of organic resources derived from landfilling.

Furthermore, in 1999, the European Union Landfill Directive (Council of the European Union, 1999) required the Member States to reduce the amount of biodegradable waste being dumped, promoting the adoption of measures to increase and improve sorting activities at the origin, such as recovery and recycling. Composting, which can be defined as the biological decomposition and stabilization of organic substrates under controlled, thermophilic and aerobic conditions, is one of the most frequently used alternatives to landfill (Haug, 1993; European Commission, 2008). In addition to the reduction of the total amount of wastes being dumped, composting kills most of the pathogenic microorganisms and reduces odour compounds obtaining a valuable product named compost. Compost can be applied as a fertiliser, organic amendment or growing medium, improving soil physical properties and increasing both water retention and the supply of essential nutrients (McConnell et al., 1993; Jakobsen, 1995; Hargreaves et al., 2008; Martínez-Blanco et al., 2009).

Composting of OFMSW has been considerably developed and studied at industrial level and it is widely reported in literature (Haug, 1993; Slater and Frederickson, 2001; Sharma and Campbell, 2003; Amlinger et al., 2008; Blengini, 2008; Ruggieri et al., 2008; Colón et al., 2009). However, at a smaller scale, composting can be developed at home, a process that has been scarcely studied from a technical and scientific point of view (Jasmin and Smith, 2003; Chanakya et al., 2007; Amlinger et al., 2008). Home composting, or

backyard composting, which means the composting of biowaste as well as the use of the compost in a private garden (European Commission, 2008), presents some potential benefits in comparison to industrial composting. Home composting avoids the collection of an important part of municipal solid wastes, thus reducing the economic, material and energetic investments in infrastructures (Jasmin and Smith, 2003; Ligon and Garland, 1998; McGovern, 1997). It implies less land use and, finally, it allows a more specific control of the composting process and the organic materials treated.

Although these benefits are evident, home composting can present some concerns. The OFMSW is mainly composed of vegetables, fruits, food scraps and garden wastes. Among these, the latter two have been troublesome because of slow decomposition rates due to poor nutrients or physical state (Chanakya et al., 2007). Meat, fish, fats or cooking and salad oils may create problems with flies, rodents and odours. Moreover, fruit wastes rapidly decompose to produce organic acids and significant amounts of leachate, which may need some mixing with absorbing materials (dry wastes) to have the adequate composting conditions (Chanakya et al., 2007). Other studies have shown that during home composting pollutants such as methane, ammonia or nitrous oxide are emitted to the atmosphere (Amlinger et al., 2008).

In this framework, a study that comprises the environmental performance of the whole home composting process is of high interest. Life Cycle Assessment (LCA) is an appropriate tool to carry out this type of study. LCA is a methodological tool to study the environmental aspects and potential impacts through the entire life of a product or service, from the extraction of raw materials, the production, the use and the final disposal. That means: developing an inventory of relevant inputs and outputs of the system (inventory analysis), assessing their potential impacts (impacts assessment) and interpreting the results in relation to the proposed targets (interpretation) (International Organisation for Standardisation, 2006).

Although industrial composting and waste management systems have been studied using LCA (Dalemo et al., 1997; Sonesson et al., 2000; Diggleman and Ham, 2003; Sharma and Campbell, 2003; Diaz and Warith, 2006; Güereca et al., 2006), data on the real performance of full-scale composting facilities have not been commonly used in these studies. Moreover, to our knowledge, there are few references in literature on home composting LCA (Dalemo et al., 1997; Lundie and Peters, 2005). In these studies few data regarding the physicochemical properties of the final compost and the gaseous emissions are reported, which are crucial to determine the real performance of the home composting process.

The main objectives of this study are to prepare a detailed inventory of energy and material resources consumed during home composting, to determine the environmental impacts associated to home composting, to detect its critical stages from an environmental point of view and to assess the quality of the produced compost.

2. Experimental methodology

2.1. Organic materials

The material treated in the composter was composed of leftovers of raw fruit and vegetables (LRFV). This type of waste (mainly green and vegetal waste) is usually recommended for home composting purposes. LRFV were obtained from Mercabarna, the Barcelona city (Barcelona, Spain) markets supplier.

Pruning wastes (PW) obtained from a composting plant located at Castelldefels (Barcelona, Spain) were used as bulking agent to provide enough porosity and to prevent leachate generation. Table 1 shows the properties of these organic materials and the specific properties of the mixture (1.3:1 LRFV:PW, v:v) used for composting.

2.2. Experimental composting procedure

The composter was placed outdoors in the Department of Chemical Engineering of the *Universitat Autònoma de Barcelona* (Mediterranean region) in open, shady conditions on a paved surface. The composter was started up and conducted to reach the steady state conditions before starting data collection. The experimental period necessary to obtain the data required in the Life Cycle Inventory comprised 96 days, from February to May 2008.

The composter, 70x70x103 cm (Figure 1), was made of high density polyethylene (HDPE) and it was supplied by Compostadores SL (model 400 RRR, Barcelona, Spain). The composter has a lateral system of natural ventilation to guarantee aerobic conditions. The organic waste was poured to the upper part of the composter and was extracted through the lower panels. The composter was fed once a week. The experimental procedure followed in home composter feeding was:

- a) PW were shredded by means of an electric garden chipper (BOSCH AXT 2500 HP, Barcelona, Spain).
- b) LRFV and PW were mixed in a volume ratio of 1:1 or 2:1, depending on the moisture content (determined using the fist test according to The US Department of Agriculture and The US Composting Council, 2001) of the material in the composter. The average ratio obtained during the experimental period was 1.3:1 (LRFV:PW).
- c) The organic mixture (LRFV+PW) was poured into the composter. An average of 14.3 kg of LRFV and 3.7 kg of PW were added to the composter each week. This amount corresponds to the average quantity of OFMSW generated by a four-member Spanish family (Ministerio de Medio Ambiente, 2008).

- d) Upper layers of the composter were weekly mixed with a commercial tool specially constructed for this purpose (mixing tool, Compostadores SL, Barcelona, Spain). Moisture content of the material was adjusted by adding tap water or wet vegetal fraction, when necessary.
- e) The organic material was composted for approximately 12 weeks. Compost was extracted (0.05 m^3) through the lower panel and it was immediately analyzed. Four extractions of compost were carried out during all the experimental period. A total amount of 110 kg of compost were extracted. No sieving was necessary since it was considered that the obtained compost could be directly applied to soil.

2.3. Determination of gaseous emissions

2.3.1. Measurement of gaseous compounds concentration, oxygen and temperature

Ammonia was analyzed in situ using an Industrial Scientific multigas sensor (model iTX-T82, Industrial Scientific, Vertex, Spain) with an ammonia detection range from 0 to 200 mL/m^3 and a temperature range from 20 to 50°C.

Gas samples for total volatile organic compounds (VOCs) and nitrous oxide (N_2O) determination were obtained at the surface of the composting material (top of the composter) using 1 L Tedlar bags and an air pump (SKC Universal de Luxe, Vertex, Spain).

Total VOCs content (including methane) of gaseous samples was determined as total carbon content (C-VOCs) by Gas Chromatography (Agilent Technologies 6890N, Barcelona, Spain) using a flame ionization detector (FID) and a dimethylpolysiloxane 2 m x 0.53 mm x 3.0 μm column (Tracsil TRB-1, Teknokroma, Barcelona, Spain). This column permits the determination of the total C-VOCs in a unique peak. The volume injected was 250 μl and the

analysis time was 1 minute. The gas chromatography operating conditions were as follows:
(a) oven temperature isothermal at 200 °C; (b) injector temperature 250 °C; (c) FID temperature 250 °C; and (d) carrier gas He at 1.5 psi pressure.

Nitrous oxide content from gaseous samples was determined by Gas Chromatography (Hewlett Packard 5890 series II gas chromatograph, Madrid, Spain) using a thermal conductivity detector (TCD) and a GS-CarbonPlot 30 m x 0.53 mm x 3.0 µm semicapillary column (Agilent Technologies, Barcelona, Spain). The volume injected was 500 µl and the analysis time was 4 minutes. The gas chromatography operating conditions were as follows:
(a) oven temperature isothermal at 40 °C; (b) injector temperature 180 °C; (c) TCD temperature 200 °C; and (d) carrier gas He at 10 psi pressure. The detection limit was 10 ppmv. In both cases, chromatography data were acquired and quantified by Empower™ 2 software (Waters Associates Inc., USA).

Methane analysis was carried out by an external certified laboratory (Applus+ S.A., Barcelona, Spain). The detection limit was 10 ppmv.

Temperature of the composting material was measured by means of a Pt-100 temperature probe (HD 2307.0 RTD ThermoMeter, Desin Instruments, Spain). Ambient temperatures were obtained from the *Universitat Autònoma de Barcelona* weather station.

Oxygen within the composting matrix was measured by means of an air pump (SKC Universal Deluxe, Vertex, Spain) connected to an oxygen probe (Lutron DO-5510, Lutron Co. LTD., Taiwan).

2.3.2. Estimation of mass emission rate for each pollutant

To determine gaseous emissions the methodology developed by Cadena et al. (2009) and Colón et al. (2009) was adapted to home composting. Air flow velocity and ammonia, nitrous oxide, methane and VOCs concentrations were simultaneously measured on the

material surface of the composter in order to calculate the gas outlet emission rate (mg/s). Air velocity at the exit of the composter (upper surface) was determined using a thermo-anemometer (VelociCalc Plus mod. 8386, TSI Airflow Instruments, UK) and a Venturi tube (Veeken, 2002). To avoid potential interferences in air velocity determination caused by wind and air turbulences, the Venturi tube was placed inside a protective plastic container that was open at its bottom and its top to allow air circulation through the Venturi. Pollutant concentration and air velocity values were equal at different points of the composter surface at the same time of measurements. Thus, a unique measurement point at the center of the composter upper surface was considered representative of the entire surface. The product of each pollutant concentration (mg/m^3) and air velocity (m/s) results in the mass flow of a given compound released per composter surface area unit (mg/s per m^2). The pollutant mass flow per area unit (mg/s per m^2) was multiplied by the composter entire upper surface area (0.31 m^2), thus giving the outlet mass flow emission (mg/s) for each compound.

2.4. Compost analytical methods

Moisture and organic matter content, N-Kjeldhal, pH and bulk density of the material were determined following the standard methodology proposed by The US Department of Agriculture and The US Composting Council (2001). Porosity was determined by air pycnometry (Ruggieri et al., 2009). C/N ratio was calculated assuming that the carbon content is 55% of the volatile solid fraction (Tiquia et al., 1996).

Seed germination test was performed according to Tiquia et al. (1996). After 7 days of incubation of 10 seeds of *Cucumis sativus* and 10 seeds of *Phoenix dactylifera* at 25°C , the seed relative germination percentage and the relative root length of the seeds were determined. Seed germination percentage and root elongation were also measured using

distilled water as control experiment. The percentages of relative seed germination, relative root elongation and combined germination index were calculated according to equations (1), (2) and (3).

$$\text{Relative seed germination (\%)} = \frac{\text{Seeds germinated in final compost extracts}}{\text{Seeds germinated in control}} \times 100 \quad (1)$$

$$\text{Relative root growth (\%)} = \frac{\text{Mean root length in final compost extracts}}{\text{Mean root length in control}} \times 100 \quad (2)$$

$$\text{Combined germination index} = \frac{(\% \text{ Relative seed germination}) (\% \text{ Relative root growth})}{100} \quad (3)$$

All germination indices were calculated using three replicates.

Static Respiration Index (RI) was used as a measure of biological activity of the material and was determined as described by Barrena et al. (2005). RI was expressed as mg of oxygen consumed per g of organic matter and per hour ($\text{mg O}_2 \text{ g}^{-1} \text{ organic matter h}^{-1}$). RI is presented as an average of a triplicate measurement. Analyses of compost were carried out for each compost extraction from the composter (four extractions during all the experience).

Pathogen indicator analysis (*Escherichia coli* and *Salmonella* sp.) were carried out by a certified external laboratory (Applus+ Agroambiental S.A., Barcelona, Spain).

2.5. Life cycle assessment methodology

To quantify the environmental impacts associated to home composting the environmental tool of Life Cycle Assessment was used. According to ISO 14040 (International Organisation for Standardisation, 2006), there are three main phases in a LCA study: the goal and scope definition, the inventory analysis and the impact assessment.

The software SimaPro v. 7.07.1 (PRé Consultants, 2006) was used to evaluate the environmental impact of home composting. Only the obligatory phases defined by the ISO

14040 regulation (International Standardisation Organisation, 2006), namely classification and characterization, were performed.

The impact assessment method used was CML 2001, which was based on the CML Leiden 2000 method developed by the Center of Environmental Science of Leiden University (Guinée, 2001). The impact categories included were: abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone layer depletion potential (ODP), photochemical oxidation potential (POP) and a flow indicator, the cumulative energy demand (CED).

3. Life cycle inventory of home composting

3.1. Goal and scope definition

The main objectives of the LCA were to quantify and evaluate the environmental impacts of home composting and to detect its critical phases from an environmental point of view.

The key function of the system was the management of the organic waste to obtain compost that can be used as organic amendment or fertilizer. Therefore the functional unit (FU) selected was the management of 1 Mg of leftovers of raw fruit and vegetables (LRFV) to obtain compost. This is the reference to which the inputs and outputs of the system were related (International Organisation for Standardisation, 2006).

The limits of the studied system exclusively covered the home composting process and are represented in Figure 2 with a dashed line. The system included (i) raw materials required for the manufacture of the different elements and tools used during the process, (ii) electricity and water consumption, (iii) the transport and management of the dumped waste generated by

the system (plastic bags, gloves, etc.) and (iv) gaseous emissions and leachate generated during home composting.

When LCA is applied to complex systems (i.e. involving multiple products and recycling systems) the burden allocation procedures should be defined. For the system studied the “cut-off” methodology defined by Ekvall and Tillman (1997) was used. According to this, environmental burdens should be assigned to the system that it is directly responsible of them. Thus, impacts of waste dumping, for example, are fully attributable to the system being studied; whereas burdens of recycled or reused waste would not be accounted since it is considered that they should be attributed to the system that use such waste as a material source (Ekvall and Tillman, 1997; Finnveden, 1999; Johns et al., 2008).

In this study, an exhaustive data inventory for the home composting process was elaborated, including energy and material resources, emissions and wastes. Most of these data were experimentally obtained from a real home composting process. To complete the life cycle inventory (LCI), literature sources and the Ecoinvent database v2.0 (Swiss Centre for Life Cycle Inventories, 2007) were used. The specific information sources used are compiled in Table 2. Throughout the inventory two average distances were considered for transportation: regional distance (50 km) and national distance (500 km). For each distance the appropriate vehicle were considered: a van of 3.5 Mg of MAL (Maximum Authorised Load) and a lorry of 16 Mg of MAL, respectively.

3.2. Life Cycle Inventory

3.2.1. Obtaining LRFV and PW

It was considered that both LRFV and PW were generated in the same house where the composter was set up. LRFV were collected in a polypropylene domestic bin (8 L) located in the kitchen. No transport was considered neither for LRFV nor PW. In addition no

shredding was considered for LRFV, but it was necessary for PW in order to adjust porosity and particle size (Ruggieri et al., 2009). It was necessary to collect 0.24 Mg PW/Mg LRFV.

3.2.2. Tools and composter

Environmental loads associated to the procurement of primary materials, to the manufacture and transport of the tools and the composter were considered. The data needed to calculate these environmental burdens for the inventory were obtained from the database Swiss Centre for Life Cycle Inventories (2007) and from producers and distributors of the devices, considering their lifespan.

Seven tools were currently used for the home composting process: a polyethylene bag to collect the shredded PW; a shovel of steel and wood; an iron-made mixing tool; a watering can made of polypropylene used to maintain the moisture of the composting material; a pair of cotton gloves; an electric garden chipper (2500 W), which was supposed to be used collectively (i.e. by a community of 10 neighbours); and a composter made of high density polyethylene (HDPE) with a capacity of 0.4 m³ and a weight of 28 kg. It was considered that the shovel, the watering can and the cotton gloves were also used in the garden for other purposes. Consequently, only a 15% of their total burdens were finally attributed to the home composting process. The composter and the tools are represented as separate stages in the inventory and the results.

For the garden chipper, the mixing tool and the composter a transport in a lorry of 16 Mg MAL and a distance of 500 km from the producer to the house were considered, since they were specific tools and were not produced everywhere. Such hypothesis is discussed and justified in Section 3.3. The rest of the tools (polyethylene bag, shovel, watering can and gloves) were transported by car a distance of 50 km from the supplier.

3.2.3. Energy and water consumptions

Pruning waste shredding was the only stage where electricity was necessary. The garden chipper consumed 90 MJ/Mg PW, corresponding to 2.4 h/Mg LRFV. Occasionally, watering of the organic material in the composter was necessary due to its low moisture. Overall, 10 L of water were used during the entire experimental period.

3.2.4. Gaseous emissions and leachate

Gaseous emissions generated during the home composting process were directly emitted to the atmosphere as it typically occurs in home composting. CH₄, N₂O, NH₃ and VOCs emissions were considered.

As it is stated above, the composter was placed on a paved surface that allows to easily detecting leachates when produced and also their collection if necessary.

3.2.5. Waste management

According to the cut-off methodology (Ekvall and Tillman, 1997) and considering that HDPE, polypropylene, steel and iron should be recycled or recovered, only the dumping of the wooden shovel and the gloves were considered. The landfill was placed at a regional distance from the home composter (50 km) and the wastes were transported with a municipal solid waste collection truck (21 Mg of MAL).

3.3. Hypothetical system scenarios

Environmental impacts for several hypothetical scenarios obtained by modifying relevant considerations were assessed to perform a sensitivity test for gaseous emissions and composter material.

The first scenario (S1) was studied to investigate the effect of the material and manufacturing process of the composter on the whole system. S1 considers a composter made of plastic mix that is a mixture of several recycled plastics, such as HDPE or PP, instead of raw HDPE (initial scenario S0). It is considered that these recycled plastics are melted and moulded but they cannot be recycled again. Then at the end of its useful life time the recycled plastic composter is landfilled. Collection and transport of the household source selected packaging waste (Iriarte et al., 2009), the fabrication process and the dumping of the composter at the end of its useful life were accounted in scenario S1. Manufacturing data were obtained from Ecoinvent 2.0 (Swiss Centre for Life Cycle Inventories, 2005).

Since the emissions of N_2O , CH_4 and NH_3 are reported to have an important contribution in some of the impact categories considered (Guinée, 2001) and although those compounds were not detected within the detection limits of the analytical methods used, a sensitivity analysis was performed for these emissions. The total impact of home composting was evaluated considering the best and the worst case scenarios for gaseous emissions: scenarios S2 and S3, respectively. The ranges in these scenarios considered are stated in Section 4.1.3.

The organic waste supplied to the home composter (S0) corresponded to the mean organic waste production of a 4-member household in Spain (Ministerio de Medio Ambiente, 2008). However, the production of organic wastes per person is different depending on the country. This is due to the differences on the diet (mainly to perishable food items) and to the management of pruning wastes from parks and gardens in each country. In the European Union (Smith et al., 2001; European Communities, 2005) a minimum production of 9.6 kg per

household and week was reported in the United Kingdom, while the maximum production reported was 24.3 kg per household and week in Denmark. The effect of waste production is considered in scenarios S4 and S5 corresponding to the minimum and maximum production respectively.

4. Results

4.1. Analytical results

4.1.1. Temperature profiles and material hygienisation

Figure 3 shows temperature profiles corresponding to the composting process and the maximum and minimum ambient temperatures, showing a significant variability. Temperature values within 20 and 65°C were measured in the composter during this study. This variability has been mainly attributed to two factors: (i) the variability of the outside temperature and (ii) the low thermal isolation of the composter due to its small volume. The average temperature during the period studied was 37.4°C. This temperature is below the thermophilic range, and although it is appropriate for microorganism growth, the material hygienisation (destruction of pathogens and viable weed seeds) cannot be assured. Hygienisation is usually considered to take place when all the composting material has been exposed to temperatures above 55°C for a minimum of 4 h (Hoitink and Keener, 1993). However, the relatively long residence time of the waste in home composters allows the natural decay of pathogens to occur (Jasmin and Smith, 2003). Pathogen analysis carried out on the obtained compost from the fourth compost extraction (Table 3) showed that the final compost is hygienised since *Salmonella* was not detected and less than 10 CFU/g of *Escherichia coli* were found.

4.1.2. Compost physicochemical characterization

According to Table 3, high quality compost was obtained by using the home composting technology. The values of the most important properties such as organic matter content, nitrogen content and respiration index were found within the proposed limits (Giró, 1994; Giró, 2001; California Compost Quality Council, 2001).

Organic matter content was close to 50%. The static respirometric index of the home compost was $1.11 \text{ mg O}_2 \text{ g}^{-1} \text{ organic matter h}^{-1}$. This value corresponds to a high level of stability. It should be emphasized that all the samples analyzed had a very similar respirometric index (standard deviation of $0.01 \text{ mg O}_2 \text{ g}^{-1} \text{ organic matter h}^{-1}$); therefore stable compost was always obtained. The high nitrogen content, with an average of 2.42%, is also noteworthy, since this value is higher than the minimum recommended (Giró, 1994). These values demonstrate a high fertilizing capacity and low nitrogen losses during the composting process in form of ammonia emissions.

Compost pH was slightly higher than the recommended (Giró, 1994); however these values are typical in the composting of organic wastes, especially in the case of the OFMSW (Barrena et al., 2008).

A seed germination test was carried out to determine the compost phytotoxicity. The relative seed germination results corresponded in all cases to 100%, indicating that no phytotoxic compounds were present in compost. Additionally, the relative root growth results were, in all cases, higher than 100%. The combined germination index for *Cucumis sativus* and *Phoenix dactylifera* was 123% and 155% respectively, indicating that the compost actually had a positive effect on plant growth. Combined germination indices higher than 100% indicate a positive effect of the compost on the relative germination index and/or the relative root growth index.

4.1.3. Leachate and gaseous emission inventory

Leachate generation and gaseous emissions could be influenced by different factors. Among them, the amount of waste added to the composter and the temperature achieved during the process can be of great influence. The following results on leachate generation and gaseous emissions and thus, the LCA of the home composting process presented in this work were obtained under the conditions reported in Section 2.2 and when composting LRFV.

During the experimental period, no leachate generation was observed. It must be pointed that other authors reported leachate generation from 0.1 to 0.5 m³/Mg of biowaste (Amlinger et al., 2008). Generation of leachate is a possible source of nitrogen losses, normally in the form of ammonia, and an environmental load associated to eutrophication. Several studies have observed important losses of nutrients (especially nitrogen) in leachate when composting several types of manure (Parkinson et al., 2003; Sommer, 2001). The losses are within the range of 25-35% of the initial nitrogen. However, references on leachate production in the OFMSW composting are practically inexistent, since usually the losses in leachate are minimal unless the objective of composting is to produce leachate in some extent (Ming et al., 2007).

During the entire studied period, ammonia, methane and nitrous oxide emissions were below the detection limits of the analytical methods used (1 ppmv, 10 ppmv, 10 ppmv respectively). In relation to VOCs (Figure 4), emissions in the range of 0 to 0.06 mg/s were measured. According to these values it can be estimated that for home composting, 320 g VOCs/Mg LRFV were emitted to the atmosphere. Since no methane was detected, all VOCs were considered non-methane VOCs. No data have been found in literature in relation to VOCs emissions during home composting. However, there are some laboratory studies (Diggelmand and Ham, 2003; Diaz and Warith, 2005) and some theoretical data (Muñoz and

Rieradevall, 2002) estimating VOCs emissions ranging from 1690 to 4300 g VOCs/Mg OFMSW and 590 to 1700 g VOCs/Mg OFMSW respectively. Pagans et al. (2006a) reported VOCs emissions of 62 mg VOCs/m³ under controlled laboratory composting conditions.

In relation to ammonia emissions this is, to our knowledge, the first study where no emissions were detected. Amlinger et al. (2008) reported ammonia emissions during home composting ranging from 474 to 972 g NH₃/Mg OFMSW. Ammonia and methane concentrations were higher at temperatures above 40-50°C (Amlinger et al., 2008). At temperatures above 40°C mesophilic activity is reduced and degradation is continued by the thermophilic microorganisms. pH typically increases under these conditions and can easily reach values ranging 8.0-9.0, which releases ammonia from excess nitrogen (Haug, 1993). Pagans et al. (2006b) reported a correlation between ammonia emissions and process temperature, indicating that the higher the temperature is, the higher the ammonia emissions are. Accordingly, mesophilic temperatures observed in the composter of the present study can be the responsible for the absence of ammonia emissions.

He et al. (2000) reported that no methane was emitted during the composting of OFMSW. On the contrary, Amlinger et al. (2008) measured methane emissions in backyard composting in a range of 788 to 2185 g CH₄/Mg fresh matter and Jasmin and Smith (2003) measured methane concentrations inside the composter at a range of 1000 to 2000 ppmv. Jasmin and Smith (2003) demonstrated that methane measured in a home composter that has not been mixed was higher than that of the mixed material. Experiments performed at large scale by Beck-Friis et al. (2000) measured methane values ranging from 20 to 85000 ppmv in non-aerated windrows turned once a month. Also, a significant decrease in methane emissions was observed when the non-aerated windrows were turned once a week (values ranged from <1 to 100 ppmv). Even though these experiments were performed at a different scale than home composting, this is an indication of the importance of mixing to reduce CH₄ emissions.

Therefore, correct aeration and mixing of the composter could provoke a decrease in methane emissions. In the present study, the composter was mixed once a week and the measures of interstitial oxygen content were around 15%, which indicates the prevalence of aerobic conditions.

According to other studies, the release to the atmosphere of nitrous oxide during the OFMSW composting was very low. In a laboratory study, He et al. (2000) measured concentrations up to 8 ppmv during the first two days. After this initial period, nitrous oxide concentrations decreased reaching values close to atmosphere level. Beck-Friis et al. (2000), measured concentrations <1 ppmv in non-aerated windrows turned once a week. On the contrary, Amlinger et al. (2008) measured nitrous oxide emissions ranging from 192 to 454 g N₂O/Mg OFMSW during backyard composting. Nitrous oxide was not detected in the present study.

In accordance with the above values, the emissions of NH₃, CH₄, N₂O and VOCs can be established for the initial scenario (S0) and for the hypothetical scenarios (S2 and S3), in order to perform a sensitivity analysis (Table 4). Scenarios S2 and S3 represented the best-case and the worst-case situation regarding gaseous emissions during the organic waste decomposition, respectively. The gaseous emissions considered were:

- Ammonia emissions: since detection limit of the equipment was 1 ppmv, it was supposed that the ammonia emission was half this emission concentration, thus 0.025 kg NH₃/Mg LRFV was accounted in the initial scenario. S2 and S3 correspond to the minimum (0 ppmv NH₃) and the maximum (1 ppmv NH₃) emissions under the detection limit, respectively.
- Methane emissions: an emission of 0.3 kg CH₄/Mg LRFV was accounted in S0. This value corresponds to an emission of 5 ppmv (the intermediate value under the detection limit). Scenarios S2 and S3 correspond to a minimum emission of 1 ppmv CH₄ and a

maximum of 10 ppmv CH₄ (the detection limit), respectively.

- Nitrous oxide emissions: the detection limit of the experimental methodology used was 10 ppmv (1.56 kg N₂O/Mg LRFV); however Amlinger et al. (2008) reported maximum N₂O emissions under this detection limit (0.45 kg/Mg biowaste). Then in this case N₂O emissions in the initial scenario (S0) were supposed to be 0.2 kg N₂O/Mg LRFV (half the maximum reported by Amlinger et al., 2008). Hypothetical scenarios S2 and S3 consider 0.4 kg N₂O/Mg LRFV and 0.04 N₂O/Mg LRFV, respectively.
- Volatile organic compounds emissions: the emission factor was 0.32 kg VOC/Mg LRFV as it was directly measured from the home composter.

4.2. Environmental impact assessment of home composting

4.2.1. Environmental assessment by items

From the LCI and the emission data obtained during the experimental home composting cycle, the environmental assessment study was performed (Table 5). According to this, the home composting system entailed the consumption of 468 MJ eq per Mg of LRFV and the emission of 83 kg of CO₂ eq per Mg of LRFV (Table 5). Values of energy consumption on large scale composting facilities reported in literature (Cadena et al., 2009; Blengini, 2008; Fricke et al., 2005) varies between 200 and 580 MJ/Mg of biowaste. However, these values only correspond to energy consumption during the composting process, not including energy consumed during the construction of the plant and the machinery used. Energy consumed during the home composting process was due to the garden chipper and was calculated as 21.5 MJ/Mg LRFV (Table 2). Martínez-Blanco et al. (2009) reported a high total energy consumption, including process, plant and machinery construction.

1 The environmental impacts attributable to each considered item (domestic bin,
2 composter, tools, electricity, water, emissions and waste dumping) used in home composting
3 are summarized in Figure 5 and the complete results are shown in Table 5.

4 The composter was the major contributor for abiotic depletion (ADP), ozone layer
5 depletion (ODP) and cumulative energy demand (CED) reaching values of 74, 83 and 73%,
6 respectively. Additionally composter burdens represent between 15 to 31% for acidification
7 (AP), eutrophication (EP) and global warming (GWP).

8 As shown in Table 5, the main responsible for the impact produced by the composter
9 was the HDPE production, contributing more than 52% to all the categories except for the
10 ozone layer depletion potential (ODP). In this category the manufacturing process clearly
11 produced the highest burdens.

12 Regarding gaseous emissions, as it is shown in Figure 5, they were the main impacting
13 item for AP, EP, GWP and photochemical oxidation (POP). In Table 5 the specific
14 contribution of each gas was depicted. Nitrous oxide emissions had an important role in
15 GWP, accounting for 72% of the total impact. Methane emissions also contribute to this
16 category but only in 8%. Concerning ammonia emissions, its contribution was 56% to EP and
17 32% (nearly the same as the composter) to AP. VOCs emissions constitute the main part of
18 the POP value, being more than 96% of the total impact in this category but did not cause any
19 impact to the rest of categories.

20 Figure 6 shows the contribution of each gas contaminant (N_2O , CH_4 , NH_3 and VOCs)
21 to the global gaseous emissions impact in some impact categories. As it can be observed,
22 ammonia is the responsible of AP and EP impacts produced due to gaseous emissions. N_2O is
23 the main contributor to GWP while VOCs are the main contributors to POP. These results
24 indicate that mitigation of N_2O could significantly reduce the contribution of home

composting to GWP. The same could be stated for NH₃ in reference to AP and EP and for VOCs in reference to POP.

Next in importance was electricity (Figure 5), which was consumed by the garden chipper. Its contribution increased up to 27% for AP but was negligible for POP.

Regarding tools, they entailed less than 12% of the impact for all the categories. As shown in Table 5, the three tools with the highest impact were the garden chipper, the mixing tool and the gloves, in this order.

Finally, the LRFV collection bin, the added water and the waste dumping produced an impact lower than 1.2% in all the categories.

4.2.2. Environmental assessment of hypothetical system scenarios

As can be seen in Table 6, scenario S1, presented considerably lower impacts (between 6 and 52% lower) than the initial scenario (S0) for ADP, AP, GWP and CED. However, S1 had a higher impact than the initial scenario for EP and ODP (88 and 4% more, respectively) and nearly the same for POP. The replacement of the HDPE as raw material of the composter by recycled plastic implies an impact reduction due to the energy, resources and emissions saved during the production of the composter. However, landfilling of the composter at the end of its useful life considerably increases the environmental loads for EP and slightly for GWP and POP. Regarding the small increase in ODP, it is due to the fact that composter manufacturing process is the most impacting process for this category, and it is also necessary for the plastic mix composter (S1). Additionally S1 scenario accounts for more transport.

The results for impact scenarios (S2 and S3) that dealt with changes in gaseous emissions are also shown in Table 6. In Figure 6 the contributions of the gaseous emissions to each impact category are shown. Variations in AP and EP (Table 6) were due to changes in

1 ammonia emissions; such variations increase or decrease the impact around a third or a half,
2 respectively. GWP differences (a reduction of 74% for S2 and an increase of 80% for S3)
3 were mainly due to variations in emissions of nitrous oxide and, secondly, of methane. VOCs
4 represent the main contribution to POP since variations in methane emissions entailed
5 differences below 1%. Therefore, gaseous emissions produced, which were closely related to
6 the management of the home composter and the type and the amount of treated waste, had an
7 important influence on the total impact of the system as well as on its environmental viability
8 in front of other treatments.

9 Regarding to the effect of the amount of organic waste fed to the composter (scenarios
10 S4 and S5) the effect on the studied impact categories varies depending on the scenario
11 considered. In the scenario S4 (low organic waste supply) an increase between 2 and 79% was
12 calculated depending on the impact category. The highest increments are reported for ADP,
13 ODP and CED (Table 6). This increment is due to the fact that environmental impacts related
14 to the production; transport and management of the residues of the tools and the composter
15 are divided by a lower amount of waste composted. Otherwise, in the case of scenario S5
16 environmental impacts per Mg are reduced between 1-24%. The higher reductions are
17 reported for ADP, ODP and CED (Table 6).

18 On the other hand, a comprehensive sensitivity analysis was also made for the
19 transport (data not shown) considering regional, national and European (2000 km) distances.
20 The variation in impact categories values due to changes in transport distances were below
21 3% relating S0. The low influence of transport on environmental impacts is due to that no
22 waste transport was considered, since wastes are treated on site. Transport is attributable only
23 to tools and to the composter with a lifespan from 3 to 12 years. Then, under the studied
24 conditions, the origin (regional, national or European level) of the tools and the composter has
25 a low importance on the environmental impact of the studied system.

1 Finally, as home composting is highly dependent of the expertise of each person, the
2 effect of a lower turning frequency has also been considered. In this case it has been supposed
3 that, due to a lower turning frequency; CH₄ emissions will be greater reaching a value of
4 2.185 kg CH₄/Mg (Amlinger et al, 2008). The values of this sensitivity analysis showed (data
5 not reported) that all the impact categories remained constant (in reference to S0) except
6 GWP and ODP which increased 53% and 8% respectively.

7 Unfortunately, these results cannot be compared to other studies since, to our
8 knowledge, there are no references related to LCA of home composting. However, although
9 Amlinger et al. (2008) do not perform a LCA, they reported interesting data on home
10 composting emissions that have been used in this paper. Among these values, Amlinger et al.
11 (2008) reported a CO₂ equivalent process emission between 76 and 187 kg CO₂ eq/Mg. From
12 our results an emission of 30 to 148 kg of CO₂ eq/Mg of LRFV has been calculated, including
13 emissions from energy, tools and process. At the light of these results it can be stated that it is
14 very important to perform an accurate LCI and, due to the importance of greenhouse gases
15 emissions, their quantity must be accurately measured. It is also very important to report the
16 experimental conditions, and the exact type of waste composted.

17 Anyway, it should be pointed out that several authors have recently emphasised other
18 positive aspects of compost application such as the replacement of chemical fertilizers, the
19 effects of carbon sequestration or the improvement of soil properties (Favoio and Hogg,
20 2008; Martínez-Blanco et al., 2009). In the framework of home composting, these issues,
21 although out of the scope of this paper, could be the focus of future studies in this field.

22 23 **5. Conclusions** 24

1 The main conclusion from this study is that home composting is a suitable treatment
2 option for organic wastes such leftovers of raw fruit and vegetables (LRFV), from the
3 technical and environmental point of view.

4 The physicochemical properties of the final compost obtained were in the range of
5 high quality and stable compost. Although temperatures did not reach the thermophilic level,
6 hygienisation occurred. High content of organic matter and organic nitrogen along with an
7 adequate degree of stability and the absence of phytotoxic compounds made the obtained
8 compost suitable as organic amendment or fertilizer.

9 Regarding gases emissions only VOCs were detected (an emission factor of 0.32 kg
10 VOCs/Mg LRFV was determined), whereas ammonia, methane and nitrous oxide were
11 always below the detection limit (1 ppmv, 10 ppmv, 10 ppmv respectively). To investigate the
12 effect of NH_3 , N_2O and CH_4 emissions under these detection limits, different scenarios have
13 been studied.

14 In relation to the environmental assessment analysis, the composter was the major
15 contributor for abiotic depletion, ozone layer depletion and cumulative energy demand mainly
16 due to the production of raw materials for the composter fabrication. The composter
17 accounted between 73-83% of the total impact for these categories and up to 31% for the
18 others. Emissions were relevant contributors to acidification (with 32% due to NH_3),
19 eutrophication (with 56% also due to NH_3), global warming (with 80% mainly due to N_2O)
20 and photochemical oxidation (with 97% mainly due to VOCs). Electricity consumed by the
21 garden chipper represented an important contribution to acidification (31%).

22 Overall it was calculated that the home composting system entailed the consumption
23 of 468 MJ eq and the emission of 83 kg of CO_2 eq per Mg of LRFV. However, the scenario
24 assessment performed indicates that the emission of CO_2 equivalents can vary from 30 kg of

CO₂ eq per Mg of LRFV for the best case scenario considered to 148 kg of CO₂ eq per Mg of LRFV for the worst case scenario.

The use of recycled plastic as composter material could entail a reduction up to 52% in the environmental burdens due to raw material, energy and emissions saved apart from eutrophication and ozone layer depletion. The variations in nitrous oxide and ammonia emissions entailed changes in global warming potential over 64%, for the former, and changes in acidification and eutrophication over 32%, for the latter. In reference to the effect of the amount of organic waste supplied, a reduction of the impacts was reported when high amounts of organic waste were composted.

Acknowledgements

The authors wish to thank the financial support received by the Spanish *Ministerio de Ciencia e Innovación* (Project CTM2009-14073-C02-00) and by *Diputació de Barcelona*. Joan Colón thanks *Universitat Autònoma de Barcelona* for the award of a pre-doctoral fellowship. Julia Martínez thanks *CUR* from the *Departament d'Innovació, Universitats i Empresa de la Generalitat de Catalunya* and *European Social Found* for the award of a pre-doctoral fellowship. Help was received by the *Xarxa de Referència en Biotecnologia* of the *Generalitat de Catalunya*.

References

- Amlinger, F., Peyr, S. and Cuhls, C., 2008. Green house gas emissions from composting and mechanical biological treatment. *Waste Manage. Res.*, 26: 47-60.
- Barrena, R., Vázquez, F., Gordillo, M., Gea, T. and Sánchez, A., 2005. Respirometric assays at fixed and process temperatures to monitor composting process. *Bioresource Technol.*, 96: 1153-1159.
- Barrena, R., Vázquez, F. and Sánchez, A., 2008. Dehydrogenase activity as a method for monitoring the composting process. *Bioresource Technol.*, 99: 905-908.
- Beck-Friis, B., Pell, M., Sonesson, U., Jönsson, H. and Kirchmann, H., 2000. Formation and emission of N₂O and CH₄ from compost heaps of organic household waste. *Environ. Monit. Assess.*, 62: 317-331.
- Blengini, G.A., 2008. Using LCA to evaluate impacts and resources conservation potential of composting: A case study of the Asti District in Italy. *Resour. Conserv. Recycl.*, 52: 1373-1381.
- Cadena, E., Colón, J., Sánchez, A., Font, A., Artola, A., 2009. A methodology to determine gaseous emissions in a composting plant. *Waste Manage.* 29: 2799-2807.
- California Compost Quality Council, 2001. CCQC-Compost Maturity Index, Technical Report. California.
- Chanakya, H.N., Ramachandra, T.V., Guruprasad, M. and Devi, V., 2007. Micro-treatment options for components of organic fraction of MSW in residential areas. *Environ. Monit. Assess.*, 135: 129-139.
- Colón, J., Martínez-Blanco, J., Gabarrell, X., Rieradevall, J., Font, X., Artola, A. and Sánchez, A., 2009. Performance of an industrial biofilter from a composting plant in the removal of ammonia and VOCs after material replacement. *J. Chem. Technol. Biotechnol.* 84: 1111-1117.
- Compostadores SL, 2008. Home page: <http://www.compostadores.com>
- Council of the European Union, 1999. Directive 1999/31/EC, of 26 April 1999 on the landfill of waste.
- Dalemo, M., Sonesson, U., Bjorklund, A., Mingarini, K., Frostell, B., Jonsson, H., Nybrant, T., Sundqvist, J.O. and Thyselius, L., 1997. ORWARE - A simulation model for organic waste handling systems 1: model description. *Resour. Conserv. Recycl.*, 21: 17-37.

1 Diaz, R. and Warith, M., 2006. Life-cycle assessment of municipal solid wastes:
2 Development of the WASTED model. *Waste Manage.*, 26: 886-901.

3 Diggelman, C. and Ham, R.K., 2003. Household food waste to wastewater or to solid waste?
4 That is the question. *Waste Manage. Res.*, 21: 501-514.

5 Ekvall, T. and Tillman, A., 1997. Open-Loop Recycling: Criteria for allocation procedures.
6 *Int. J. Life Cycle Assess.*, 2: 155-162.

7 European Commission, 2008. Green paper on the management of bio-waste in the European
8 Union.

9 European Communities, 2005. Waste generated and treated in Europe; Luxembourg.

10 Favoino, E., Hogg, D., 2008. The potential role of compost in reducing greenhouse gases.
11 *Waste Manage. Res.*, 26: 61-69.

12 Finnveden, G., 1999. Methodological aspects of life cycle assessment of integrated solid
13 waste management systems. *Resour. Conserv. Recycl.*, 26: 173-187.

14 Fricke, K., Santen, H., Wallmann, R., 2005. Comparison of selected aerobic and anaerobic
15 procedures for MSW treatment. *Waste Manage.* 25:799-810.

16 Giró, F., 1994. Proposta de normativa de qualitat per al compost de residus municipals a
17 Catalunya (in Catalan). Junta de Residus. Generalitat de Catalunya.

18 Giró, F., 2001. Capítulo 7. Operación de una Planta para Producción de Compost.
19 Tratamiento de la FORM procedente de la recogida selectiva en origen (in Spanish).
20 In: Feijoo, G. and Sineiro, J., (Eds.), *Residuos: Gestión, minimización y tratamiento*.
21 Santiago de Compostela, Spain, pp. 123-176.

22 Güereca, L.P., Gassó, S., Baldasano, J.M. and Jiménez-Guerrero, P., 2006. Life cycle
23 assessment of two biowaste management systems for Barcelona, Spain. *Resour.*
24 *Conserv. Recycl.*, 49: 32-48.

25 Guinée, J.B., 2001. Life cycle assessment; An operational guide to the ISO standards. Part 1
26 and 2. Ministry of Housing. Spatial Planning and Environment (VROM) and Centre of
27 Environmental Science (CML), The Netherlands.

28 Hargreaves, J.C., Adl, M.S. and Warman, P.R., 2008. A review of the use of composted
29 municipal solid waste in agriculture. *Agr. Ecosyst. Environ.*, 123: 1-14.

30 Haug, R., 1993. The practical handbook of the compost engineering. Lewis Publishers, Boca
31 Raton.

32 He, Y., Inamori, Y., Mizuochi, M., Kong, H., Iwami, N. and Sun, T., 2000. Measurements of
33 N₂O and CH₄ from the aerated composting of food waste. *Sci. Tot. Environ.*, 254: 65-
34 74.

- 1 Hoitink, H.A.J. and Keener, H.M., 1993. Science and engineering of composting: design,
2 environmental, microbiological and utilization aspects. Renaissance Publications,
3 Worthington.
- 4 International Organisation for Standardisation, 2006. ISO 14040. Environmental
5 Management. Life Cycle Assessment-Principles and framework, Geneva.
- 6 Iriarte, A., Gabarrell, X. and Rieradevall, J., 2009. LCA of selective waste collection systems
7 in dense urban areas. Waste Manage., 29: 903-914.
- 8 Jakobsen, S.T., 1995. Aerobic decomposition of organic wastes II: Value of compost as a
9 fertilizer. Resour. Conserv. Recycl., 13: 57-71.
- 10 Jasmin, S. and Smith, S., 2003. The Practicability of Home Composting for the Management
11 of Biodegradable Domestic Solid Waste. Centre for Environmental Control and Waste
12 Management, Department of Civil and Environmental Engineering, London.
- 13 Johns, W.R., Kokossis, A. and Thompson, F., 2008. A flowsheeting approach to integrated
14 life cycle analysis. Chem. Eng. Process., 47: 557-564.
- 15 Ligon, P. and Garland, G., 1998. Analyzing the costs of composting strategies. Biocycle, 39:
16 30-37.
- 17 Lundie, S. and Peters, G.M., 2005. Life cycle assessment of food waste management options.
18 J. Cleaner Product., 13: 275-286.
- 19 Martínez-Blanco, J., Muñoz, P., Antón, A. and Rieradevall, J., 2009. Resour. Conserv.
20 Recycl., 53: 340-351.
- 21 McConnell, D.B., Shiralipour, A. and Smith, W.H., 1993. Agricultural Impact - Compost
22 Application Improves Soil Properties. Biocycle, 34: 61-63.
- 23 McGovern, A., 1997. Home composting makes major impact. Biocycle, 38: 30.
- 24 Ming, L., Xuya, P., Youcai, Z., Wenchuan, D., Huashuai, C., Guotao, L. and Zhengsong, W.,
25 2008. Microbial inoculum with leachate recirculated cultivation for the enhancement
26 of OFMSW composting. J. Haz. Mat., 153: 885-891.
- 27 Ministerio de Medio Ambiente, 2008. Plan Nacional Integrado de Residuos 2007-2015.
28 Anexo 14. Madrid.
29 ([http://www.mma.es/secciones/calidad_contaminacion/residuos/planificacion_residuos](http://www.mma.es/secciones/calidad_contaminacion/residuos/planificacion_residuos/borrador_pnir.htm)
30 [/borrador_pnir.htm](http://www.mma.es/secciones/calidad_contaminacion/residuos/planificacion_residuos/borrador_pnir.htm)).
- 31 Muñoz, I. and Rieradevall, J., 2002. Análisis del Ciclo de Vida aplicado a diferentes
32 alternativas de Gestión de Residuos Urbanos y Lodos de depuradora según el Plan
33 Integral de Gestión de Residuos Urbanos de Gipuzkoa en 2016 (in Spanish). Institute

- of Environmental Science and Technology-Universitat Autònoma de Barcelona, Barcelona.
- Pagans, E., Font, X. and Sánchez, A., 2006a. Emission of volatile organic compounds from composting of different solid wastes. Abatement by biofiltration. *J. Hazard. Mat.*, 131: 179-186.
- Pagans, E., Barrerna, R., Font, X. and Sánchez, A., 2006b. Ammonia emissions from the composting of different organic wastes. Dependency on process temperature. *Chemosphere*, 62: 1534-1542.
- Parkinson, R., Gibbs, P., Burchett, S. and Misselbrook, T., 2004. Effect of turning regime and seasonal weather conditions on nitrogen and phosphorus losses during aerobic composting of cattle manure. *Bioresource Technol.*, 91: 171-178.
- PRé Consultants, 2006. SimaPro software version 7.0.2. PRé Consultants, The Netherlands.
- Ruggieri, L., Gea, T., Mompeó, M., Sayara, T. and Sánchez, A., 2008. Performance of different systems for the composting of the source-selected organic fraction of municipal solid waste. *Biosystems Eng.*, 101: 78-86.
- Ruggieri, L., Gea, T., Artola, A. and Sánchez, A., 2009. Air filled porosity measurements by air pycnometry in the composting process: a review and a correlation analysis. *Bioresource Technol.*, 100: 2655-2666.
- Sharma, G. and Campbell, A., 2003. Life cycle inventory and life cycle assessment for windrow composting systems. Department of Environment and Conservation, University of New South Wales, Recycled Organics Unit, Sydney.
- Slater, R.A. and Frederickson, J., 2001. Composting municipal waste in the UK: some lessons from Europe. *Resour. Conserv. Recycl.*, 32: 359-374.
- Smith, A., Brown, K. and Ogilvie, S., 2001. Waste Management Options and Climate Change. Final Report. European Commission, DG Environment, Luxembourg.
- Sommer, S.G., 2001. Effect of composting on nutrient loss and nitrogen availability of cattle deep litter. *Eur. J. Agron.*, 14: 123-133.
- Sonesson, U., Björklund, A., Carlsson, M. and Dalemo, M., 2000. Environmental and economic analysis of management systems for biodegradable waste. *Resour. Conserv. Recycl.*, 28: 29-53.
- Swiss Centre for Life Cycle Inventories, 2007. Ecoinvent Data v2.0, Duebendorf.
- Tiquia, M.S., Tam, N.F.Y. and Hodgkiss, I.J., 1996. Effects of composting on phytotoxicity of spent pig-manure sawdust litter. *Environ. Poll.*, 93: 249-256.

- 1 The US Department of Agriculture and The US Composting Council, 2001. Test methods for
2 the examination of composting and compost. Edaphos International, Houston.
- 3 Veeken, A., de Wilde, V. and Hamelers, B., 2002. Passively Aerated Composting of Straw-
4 Rich Pig Manure: Effect of Compost Bed Porosity. *Compost. Sci. Util.*, 10: 114-128.
- 5 WSOFM (Washington State Office of Financial Management), 2008. Schedule A – Capital
6 asset commodity class code list and useful life schedule. State Administrative &
7 Accounting Manual, section 30.50.10. (www.ofm.wa.gov/default.asp)

Pre-print

Tables

Table 1. Physicochemical properties of the input material.

	Leftovers of raw fruit and vegetables	Pruning wastes	Mixture 1.3:1 (LRFV:PW)
Moisture (% , wb)	88.69	25.58	74.47
Organic matter (% , db)	87.83	71.94	77.82
N-Kjeldhal (% , db)	1.91	1.53	1.67
C/N ratio	25.3	25.9	25.7
Respiration index (mg O ₂ g ⁻¹ organic matter h ⁻¹)	-	-	2.01

wb: wet basis; db: dry basis; LRFV: Leftovers of raw fruit and vegetables; PW: Pruning wastes.

Table 2. Summary of compost production inventory for the home composting process. Values are related to the treatment of 1 Mg of LRFV (functional unit).

Sub-part	Element	Flow	Amount	Lifespan (years)	Units per Mg of LRFV	Source
Inputs						
Obtaining LRFV and PW	LRFV collection bin	PP	0.048	7	kg	Swiss Centre for LCI (2005) and WSOFM (2008)
Composter	Composter	HDPE	3.122	12	kg	Compostadores SL (composter supplier), Swiss Centre for LCI (2005) and WSOFM (2008)
	Transport	Transport	1.561	-	tkm	
Tools	Garden chipper	Steel	0.174	10	kg	Compostadores SL (2008), Swiss Centre for Life Cycle Inventories (2005), WSOFM (2008) and own measurements.
		HDPE	0.174	10	kg	
	Bag for PW collection	PP	0.045	3	kg	
	Shovel	Steel	0.017	12	kg	
		Wood	0.009	12	kg	
	Mixing tool	Iron	0.078	12	kg	
	Watering can	PP	0.002	12	kg	
	Gloves	Cotton	0.007	6	kg	
	Transport by lorry ^a	Transport	0.213	-	tkm	
	Transport by van ^b	Transport	0.008	-	tkm	
Water consumption	Moistening water	Tap water	50.870	-	L	Own measurements
Energy consumption	Garden chipper consumption	Electricity	21.567	-	MJ	Own measurements
Outputs						
Compost production	Compost	Compost	560.332	-	kg	Own measurements
Gas emissions	CH ₄ emissions	CH ₄	0.300 ^(*)	-	kg	^(*) Own measurements and Amlinger et al. (2008)
	N ₂ O emissions	N ₂ O	0.200	-	kg	
	NH ₃ emissions	NH ₃	0.025 ^(*)	-	kg	
	VOCs emissions	VOCs	0.320 ^(*)	-	kg	
Waste management	Waste management in landfill	Wood	0.009	-	kg	Compostadores SL (2008), Swiss Centre for LCI (2005), WSOFM (2008) and own measurements.
	Waste management in landfill	Cotton	0.007	-	kg	
	Transport to the landfill	Transport	0.002	-	tkm	

- 1 LRFV, leftovers of raw fruit and vegetables; PW, pruning waste; PP, polypropylene; HDPE, high density polyethylene;
- 2 VOCs, volatile organic compounds
- 3 ^a It includes Garden chipper and Mixing tool that were transported from a distance of 500 km.
- 4 ^b .It includes Bag for PW collection, Shovel, Watering can and Gloves that were transported from a distance of 50 km.

Pre-print

Table 3. Physicochemical properties of final compost obtained from the home composter. Average value and standard deviation are presented for each parameter. Limits of the compost quality Spanish legislation are also shown.

Physicochemical properties	Extraction 1	Extraction 2	Extraction 3	Extraction 4	Average	Compost quality legislation
Moisture (% , wb)	48.33	43.75	52.36	31.35	44 ± 9	25-40 ^a
Organic matter (% , db)	51.34	42.19	51.54	52.17	49 ± 5	≥40 ^a
pH (extract 1:5 w:v)	8.43	8.23	7.97	8.68	8.3 ± 0.3	6.5-8 ^a
Electrical conductivity (mS/cm, extract 1:5 w:v)	6.2	5.13	5.73	2.4	5 ± 1	≤6 ^a
N-Kjeldhal (% , db)	2.02	2.14	3.01	2.4	2.4 ± 0.5	≥2 ^a
Respiration index (mg O ₂ g ⁻¹ organic matter h ⁻¹)	1.1	1.11	1.12	1.1	1.11 ± 0.01	0.5-1.5 ^b
Bulk density (kg/L)	0.42	0.44	0.47	0.36	0.42 ± 0.05	-
Porosity (%)	60.9	58	55.1	60	59 ± 3	-
<i>Salmonella</i> (presence/absence in 25 g)	na	na	na	nd	nd	nd ^a
<i>Escherichia coli</i> (CFU/g)	na	na	na	<10	<10 (CFU/g)	<1000 (CFU/g) ^a

wb: wet basis; db: dry basis; w:weight; v:volume.

^a Regulation proposal for municipal solid waste compost in Spain (Giró, 1994)

^b Range for stable compost according to California Compost Quality Council (2001)

na: not analyzed

nd: not detected

Table 4. Gaseous emissions considered in the initial scenario and in the hypothetical system scenarios

Scenarios	N ₂ O	CH ₄	NH ₃	VOCs
	kg contaminant/Mg LRFV			
S0	0.20	0.30	0.025	0.32
S1/S4/S5	0.20	0.30	0.025	0.32
S2	0.04	0.06	0.000	0.32
S3	0.40	0.60	0.050	0.32

Pre-print

Table 5. Total and partial impact results for home composting with initial scenario considerations.

Impact category		ADP	AP	EP	GWP	ODP	POP	CED
		kg Sb eq/Mg	kg SO ₂ eq/Mg	kg PO ₄ ⁻⁻⁻ eq/Mg	kg CO ₂ eq/Mg	kg CFC-11 eq/Mg	kg C ₂ H ₄ /Mg	MJ eq/Mg
Unit		LRFV	LRFV	LRFV	LRFV	LRFV	LRFV	LRFV
Inputs								
LRFV collection bin		2.07E-03	5.38E-04	5.00E-05	1.54E-01	2.97E-08	3.18E-05	4.97E+00
Composter	Plastic production	1.04E-01	2.03E-02	1.61E-03	5.99E+00	6.19E-10	1.93E-03	2.41E+02
	Manufacturing process	3.43E-02	1.58E-02	1.23E-03	3.97E+00	1.94E-06	7.65E-04	9.03E+01
Tools	Transport	3.62E-03	2.80E-03	6.05E-04	5.18E-01	8.08E-08	9.34E-05	8.72E+00
	Garden chipper	1.44E-02	6.67E-03	6.99E-04	1.46E+00	1.46E-07	4.47E-04	3.31E+01
	Bag for PW collection	1.60E-03	3.69E-04	3.54E-05	1.06E-01	1.19E-09	2.29E-05	3.84E+00
	Shovel	6.55E-04	4.53E-04	5.28E-05	7.80E-02	3.78E-09	2.90E-05	1.53E+00
	Mixing tool	3.03E-03	2.09E-03	2.42E-04	4.04E-01	1.72E-08	1.33E-04	6.57E+00
	Watering can	7.38E-05	1.91E-05	1.78E-06	5.49E-03	1.05E-09	1.13E-06	1.77E-01
	Gloves	1.04E-03	1.67E-03	2.27E-04	1.62E-01	3.22E-09	5.67E-05	2.11E+00
	Transport	8.62E-04	5.83E-04	1.16E-04	1.24E-01	1.84E-08	3.23E-05	2.12E+00
Moistening water		1.07E-04	7.08E-05	5.07E-06	1.58E-02	7.59E-10	4.96E-06	3.14E-01
Garden chipper consumption		2.63E-02	3.43E-02	1.75E-03	3.59E+00	1.95E-07	1.27E-03	7.30E+01
Outputs								
Gaseous emissions	CH ₄ emissions	0	0	0	6.77E+00	0	1.77E-03	0
	N ₂ O emissions	0	0	0	5.92E+01	0	0	0
	NH ₃ emissions	0	4.00E-02	8.75E-03	0	0	0	0
	COVs emissions	0	0	0	0	0	1.33E-01	0
Waste management		1.03E-04	6.86E-05	1.73E-04	1.94E-02	2.40E-09	3.51E-06	2.40E-01
TOTAL		1.92E-01	1.26E-01	1.55E-02	8.26E+01	2.44E-06	1.40E-01	4.68E+02

Impact categories: ADP, Abiotic depletion potential; AP, Acidification potential; EP, Eutrophication potential; GWP, Global warming potential; ODP, Ozone layer depletion potential; POP, Photochemical oxidation potential; CED, Cumulative energy demand.

Table 6. Comparison of the environmental impacts for the different scenarios studied. Initial scenario (S0) is considered as the base scenario (100% of contribution of each category), whereas the rest of scenarios are normalized to this base scenario. Scenario S1 considered a composter made of recycled plastic mix. Scenarios S2 and S3 represented the best-case and the worst-case regarding gaseous emissions during the organic waste decomposition, respectively. Scenarios S4 and S5 performed the highest and the lowest potential organic waste supply in European countries.

Impact category	Units	Initial scenario	Plastic mix composter	Best Case for emissions ¹	Worst case for emissions ¹	Low Organic waste supply ²	High organic waste supply ²
		S0	S1	S2	S3	S4	S5
ADP	kg Sb eq/Mg LRFV	1.92E-01	48	100	100	175	78
AP	kg SO ₂ eq/Mg LRFV	1.26E-01	86	68	132	135	89
EP	kg PO ₄ ⁻³ eq/Mg LRFV	1.55E-02	188	44	156	126	91
GWP	kg CO ₂ eq/Mg LRFV	8.26E+01	94	36	180	114	96
ODP	kg CFC ⁻¹¹ eq/Mg LRFV	2.44E-06	104	100	100	179	76
POP	kg C ₂ H ₄ eq/Mg LRFV	1.40E-01	99	99	101	102	99
CED	MJ eq/Mg LRFV	4.68E+02	50	100	100	173	78

Impact categories: ADP, Abiotic depletion potential; AP, Acidification potential; EP, Eutrophication potential; GWP, Global warming potential; ODP, Ozone layer depletion potential; POP, Photochemical oxidation potential; CED, Cumulative energy demand.

¹ Gaseous emissions considered in each scenario are reported in Table 4.

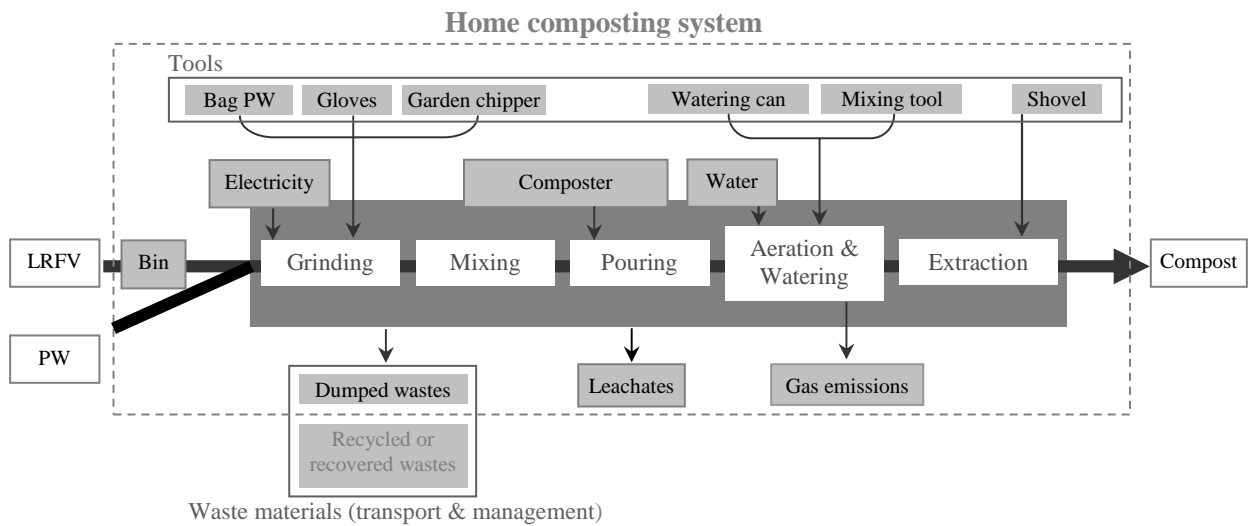
² Low and high organic waste supply were 9.6 and 24.3 kg per household and week respectively (Smith et al., 2001; European Communities, 2005).

Figures

Figure 1. A picture of the composter used in this study.



Figure 2. Definition and boundaries of the home composting system studied including the main composting stages and the input and output flows considered.



LRFV, leftovers of raw fruit and vegetables; PW, pruning waste.

Figure 3. Temperature profiles. The bold solid line (—) represents the temperature profile of the composter. The thin solid (—) and dotted lines (···) represent the minimum and the maximum ambient temperatures respectively. Upper arrows represent the organic material loads to the composter.

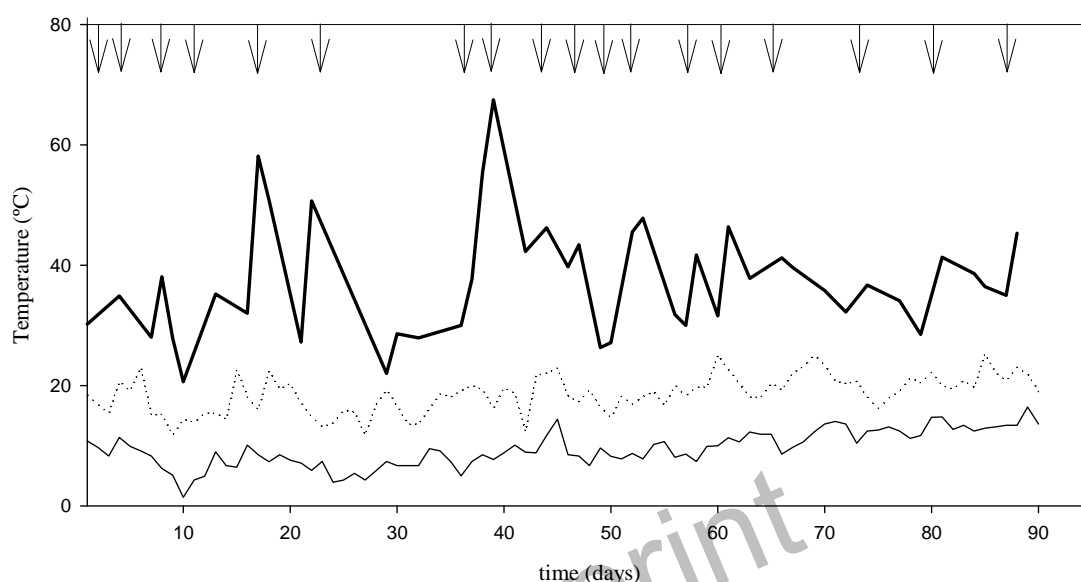
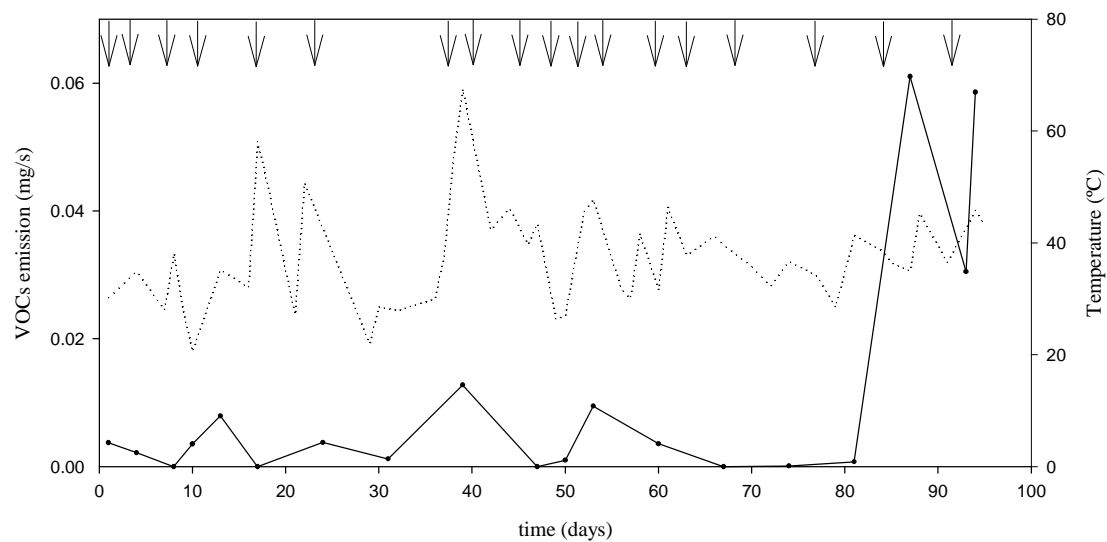
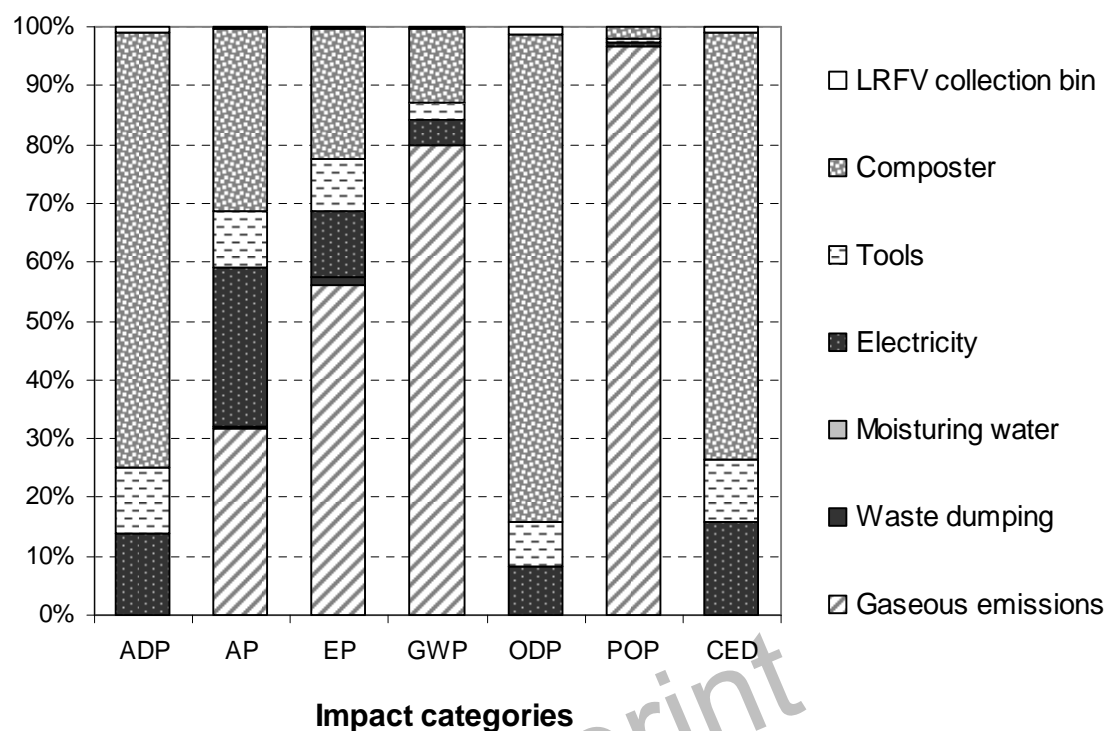


Figure 4. VOCs emissions during home composting (solid line). The temperature profile is also shown (dotted line). Upper arrows represent the organic material loads to the composter.



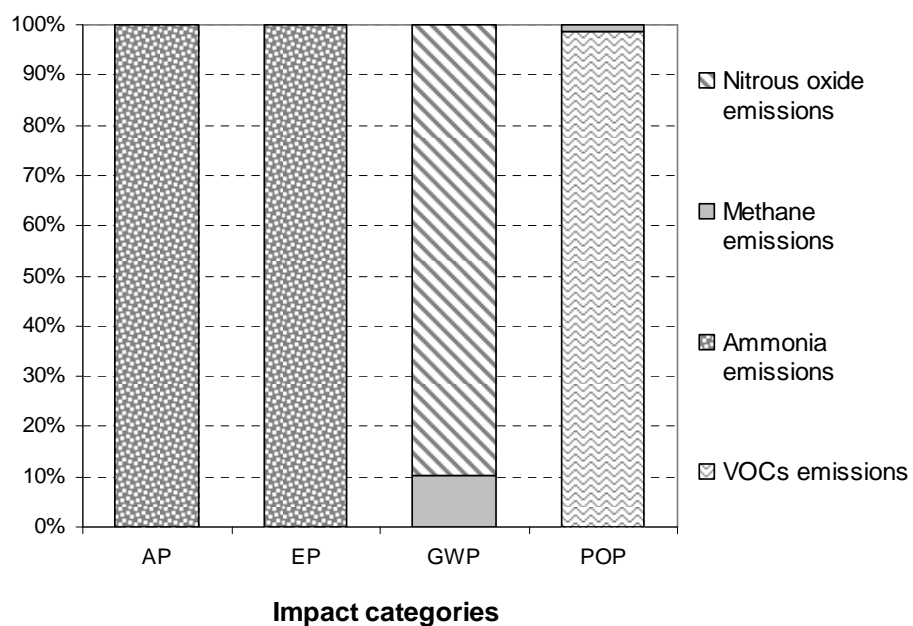
Pre-print

Figure 5. Contribution (in percentage) of the items considered in the initial scenario of home composting to its total environmental impact.



Impact categories: ADP, Abiotic depletion potential; AP, Acidification potential; EP, Eutrophication potential; GWP, Global warming potential; ODP, Ozone layer depletion potential; POP, Photochemical oxidation potential; CED, Cumulative energy demand.

Figure 6. Contribution (in percentage) of each gas contaminant (N_2O , CH_4 , NH_3 and VOCs) to the total environmental impact of the gaseous emissions of home composting for the impact categories affected (AP, EP, GWP and POP). Data is referred to the initial scenario.



Impact categories: AP, Acidification potential; EP, Eutrophication potential; GWP, Global warming potential; POP, Photochemical oxidation potential; CED, Cumulative energy demand.