

# LIFE CYCLE INVENTORY FOR MUNICIPAL SOLID WASTE MANAGEMENT OPTIONS

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## Abstract

A CASE STUDY WAS DEVELOPED FOR A REGION SIMILAR TO PORTO (PORTUGAL), IN ORDER TO DEMONSTRATE THE USE OF LIFE CYCLE INVENTORY AS A TOOL FOR ASSESSING THE ENVIRONMENTAL IMPACT OF MUNICIPAL SOLID WASTE (MSW) MANAGEMENT SYSTEMS, AND OBTAIN PRELIMINARY DATA ON ENERGY CONSUMPTION AND GLOBAL WARMING POTENTIAL ASSOCIATED WITH SEVERAL MSW TREATMENT OPTIONS. TYPICAL MSW PRODUCTION AND COMPOSITION OF THAT REGION WAS ASSUMED AS WELL AS EIGHT DIFFERENT SCENARIOS ACCORDING TO THE TREATMENT METHOD USED: LANDFILLING, COMPOSTING, INCINERATION AND BIOGASIFICATION. IN THE PARTICULAR CASES OF COMPOSTING AND BIOGASIFICATION BOTH ALTERNATIVES OF USING THE COMPOST AND EITHER ITS LANDFILLING OR INCINERATION WERE EVALUATED. THE OBTAINED RESULTS SHOW A SURPLUS OF ENERGY FROM INCINERATION OF ALL MSW AS WELL AS THE COMPOST, WHEN THERE IS NO MARKET FOR IT. LANDFILLING PRESENTS THE HIGHEST GLOBAL WARMING POTENTIAL, FOLLOWED BY THE INCINERATION SCENARIO.

## 1. Introduction

Municipal waste managers are usually faced with the need of justifying existing or planned waste management options. Also, European Commission recognizes strategic targets both in terms of waste management options and recycling rates, as well as the need of selecting management options taking into account the risks for environment and health [1].

Several models using life cycle assessment technique have been developed to predict and compare the environmental impact of MSW management systems, allowing the identification of environmental burdens, thus advantages and disadvantages associated with different waste management scenarios.

The objectives of the present case study is twofold: (i) follow the consequences of waste management policy taken for the region through its environmental effects; and, (ii) provide a preliminary data on the environmental consequences of two alternatives for treating organic matter in MSW, respectively biogasification and composting. The results obtained from the analysis of these different scenarios are also useful for the development of a life cycle inventory model for the region.

## 2. Model and methodology

An already established inventory model developed by White et al [2], whose assumptions are listed in Appendix, was used to quantify the energy consumption and emissions of carbon dioxide, methane and nitrous oxide associated with the MSW collected during one year in an hypothetical region similar to Porto, a city

in the north of Portugal with a population of about 300 000 inhabitants. A MSW production of 300 kg/person.year with the composition shown on Figure 1 was assumed as well as that MSW are commingled collected in plastic bags, every week days. Eight scenarios corresponding to different management options were established as shown in Table 1. Basic options consider landfilling, composting, incineration and biogasification. However, in both cases of composting and biogasification three alternatives were built, respectively using the compost as soil conditioner, or, by contrary, either landfilling or incinerating it. Compost may be difficult to market due to the quality requirements imposed and the excess of offer relatively to consumption.

The emissions of the greenhouse gases

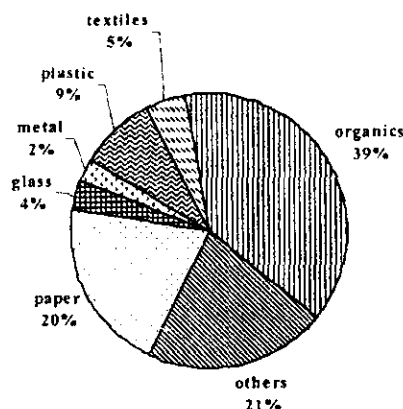


Figure 1. MSW composition for the region studied

Table 1

Summary of the management scenarios built

|             |   |
|-------------|---|
| Scenario 1  | Commingled collection<br>Landfilling all MSW  |
| Scenario 2  | Commingled collection<br>Incineration with energy recovery<br>90% of ferrous metals are recovered from bottom ash; ultimate residues are landfilled   |
| Scenario 3a | Commingled collection<br>Presort of all wastes categories other than paper and organics; 90% of ferrous metals are recovered<br>Composting of paper and organics with market for the compost produced<br>Landfilling of sorting residues  |
| Scenario 3b | Commingled collection<br>Presort of all wastes categories other than paper and organics; 90% of ferrous metals are recovered<br>Composting of paper and organics; no market for the compost produced<br>Landfilling of sorting residues and compost produced  |
| Scenario 3c | Commingled collection<br>Presort of all wastes categories other than paper and organics; 90% of ferrous metals are recovered<br>Composting of paper and organics; no market for the compost produced<br>Landfilling of sorted residues; compost incineration; ultimate residues (fly ashes and bottom ashes) are landfilled |
| Scenario 4a | Commingled collection<br>Presort of all wastes categories other than paper and organics; 90% of ferrous metals are recovered<br>Biogasification of paper and organics; market for the compost produced<br>Landfilling of sorting residues   |
| Scenario 4b | Commingled collection<br>Presort of all wastes categories other than paper and organics; 90% of ferrous metals are recovered<br>Biogasification of paper and organics; no market for the compost produced<br>Landfilling of sorting residues and compost produced   |
| Scenario 4c | Commingled collection<br>Presort of all wastes categories other than paper and organics; 90% of ferrous metals are recovered<br>Biogasification of paper and organics; no market for the compost produced<br>Landfilling of sorting residues; compost incineration; ultimate residues are landfilled                        |

Table 2

Annual energy consumption and greenhouse gases emissions

| Scenarios | Energy consumption (GJ) | Air emissions (kg)    |                       |                        | GWP                   |
|-----------|-------------------------|-----------------------|-----------------------|------------------------|-----------------------|
|           |                         | CO <sub>2</sub>       | CH <sub>4</sub>       | N <sub>2</sub> O       |                       |
| 1         | 66 431                  | 2,14x10 <sup>+7</sup> | 3,37x10 <sup>+6</sup> | 5,35x10 <sup>+1</sup>  | 9,22x10 <sup>-7</sup> |
| 2         | -248 321                | 7,43x10 <sup>+7</sup> | 0,00                  | -2,39x10 <sup>+3</sup> | 7,36x10 <sup>-7</sup> |
| 3a        | 69 180                  | 2,21x10 <sup>+7</sup> | 4,05x10 <sup>+5</sup> | -7,22x10 <sup>+1</sup> | 3,06x10 <sup>-7</sup> |
| 3b        | 70 202                  | 2,55x10 <sup>+7</sup> | 9,99x10 <sup>+5</sup> | -7,13x10 <sup>+1</sup> | 4,65x10 <sup>-7</sup> |
| 3c        | -12 047                 | 4,67x10 <sup>+7</sup> | 4,05x10 <sup>+5</sup> | -6,73x10 <sup>+2</sup> | 5,50x10 <sup>-7</sup> |
| 4a        | 9 810                   | 2,54x10 <sup>+7</sup> | 4,05x10 <sup>+5</sup> | -5,10x10 <sup>+2</sup> | 3,37x10 <sup>-7</sup> |
| 4b        | 10 423                  | 2,74x10 <sup>+7</sup> | 7,62x10 <sup>+5</sup> | -5,09x10 <sup>+2</sup> | 4,32x10 <sup>-7</sup> |
| 4c        | -38 926                 | 4,02x10 <sup>+7</sup> | 4,05x10 <sup>+5</sup> | -8,70x10 <sup>+2</sup> | 4,84x10 <sup>-7</sup> |

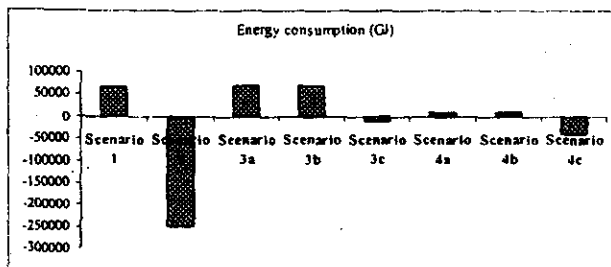


Figure 2. Annual energy consumption for waste management scenarios built

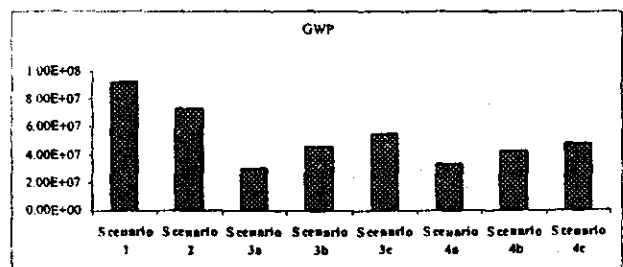


Figure 3. Annual contribution to global warming potential corresponding to the different scenarios

**Appendix**  
Assumptions from the model used

(values expressed by ton is related to ton of wastes)

|   |   |
|---|---|
| <p><b>Landfill</b><br/>Diesel consumption in the operation of landfill = 0,6l/ton<br/>Collection efficiency of landfill gas = 40%<br/>There is no energy recovered from landfill<br/>Landfill gas volume produced by wastes (Nm<sup>3</sup>):<br/>Paper = 250<br/>Glass = 0<br/>Ferrous metals = 0<br/>Non-ferrous metals = 0<br/>Plastic-film = 0<br/>Plastic-rigid = 0<br/>Textiles = 250<br/>Organics = 250<br/>Others = 0<br/>Compost = 400<br/>Bottom ash = 0</p> <p>Landfill gas composition (g/Nm<sup>3</sup>):<br/>CO<sub>2</sub> = 883,93<br/>CH<sub>4</sub> = 392,86<br/>N<sub>2</sub>O = 0</p> <p>Flare exhaust gas (g/Nm<sup>3</sup>):<br/>CO<sub>2</sub> = 1964,29<br/>CH<sub>4</sub> = 0<br/>N<sub>2</sub>O = 0</p> <p><b>Incineration</b><br/>Transport distance to hazardous waste landfill = 2 km<br/>Transport distance to non-hazardous waste landfill = 10 km<br/>Filter dust production = 0,032 ton/ton<br/>% of ash re-used = 0%<br/>Electricity generation efficiency = 20%<br/>Bottom ash production by wastes (ton/ton):<br/>Paper = 0,084<br/>Glass = 0,9<br/>Ferrous metals = 0,85<br/>Non-ferrous metals = 0,9<br/>Plastic-film = 0,09<br/>Plastic-rigid = 0,06<br/>Textiles = 0,075<br/>Organics = 0,077<br/>Others = 0,42</p> <p>Electricity consumption = 70 kWh/ton<br/>Natural gas consumption = 0,23 m<sup>3</sup>/ton<br/>CH<sub>4</sub> emission = 0 g/ton<br/>N<sub>2</sub>O emission = 0 g/ton<br/>CO<sub>2</sub> emission by waste (g/ton):<br/>Paper = 1128500<br/>Glass = 0<br/>Ferrous metals = 0<br/>Non-ferrous metals = 0<br/>Plastic-film = 2336700<br/>Plastic-rigid = 2492500<br/>Textiles = 1209200<br/>Organics = 563900<br/>Others = 1025900</p> | <p><b>Composting</b><br/>Fraction of paper and organics removed as residue during the pre-sort = 5%<br/>Transport distance to landfill = 10 Km<br/>Energy consumption = 30 kWh/ton<br/>Compost production = 0,5 ton/ton<br/>CO<sub>2</sub> emission = 320 kg/ton<br/>CH<sub>4</sub> emission = 0 g/ton<br/>N<sub>2</sub>O emission = 0 g/ton</p> <p><b>Biogasification</b><br/>Fraction of paper and organics removed as residue during the pre-sort = 5%<br/>Transport distance to landfill = 10 Km<br/>Energy consumption = 50 kWh/ton<br/>Compost production = 0,3 ton/ton<br/>CO<sub>2</sub> emission = 440 kg/ton<br/>CH<sub>4</sub> emission = 0 g/ton<br/>N<sub>2</sub>O emission = 0 g/ton</p> <p><b>Fuel, electricity, raw materials and transport</b><br/>Diesel production and use:<br/>Non-hazardous waste = 0,0057 ton/1000l<br/>Energy consumption = 44,1 GJ/1000l<br/>CO<sub>2</sub> emission = 3036258 g/1000l<br/>N<sub>2</sub>O emission = 41 g/1000l<br/>CH<sub>4</sub> emission = 0</p> <p>Polyethylene production:<br/>Non-hazardous waste = 0,0885 ton/ton<br/>Energy consumption = 98,1 GJ/ton<br/>CO<sub>2</sub> emission = 1691657 g/ton<br/>N<sub>2</sub>O emission = 70 g/ton<br/>CH<sub>4</sub> emission = 0</p> <p>Electricity production and use:<br/>Non-hazardous waste = 0,0491 ton/MWh<br/>Energy consumption = 9,5 GJ/MWh<br/>CO<sub>2</sub> emission = 441657 g/MWh<br/>N<sub>2</sub>O emission = 70 g/MWh<br/>CH<sub>4</sub> emission = 0</p> <p>Natural gas production and use:<br/>CO<sub>2</sub> emission = 2061211 g/1000m<sup>3</sup><br/>CH<sub>4</sub> emission = 0</p> <p>Diesel consumption of a 20ton truck = 0,321l/km<br/>Savings from ferrous metals recovery:<br/>Energy consumption = 12,4 GJ/ton<br/>CO<sub>2</sub> emission = 0<br/>N<sub>2</sub>O emission = 176 g/ton<br/>CH<sub>4</sub> emission = 0</p> |
|---|---|

corresponding to these scenarios were aggregated using global warming potential weighting factors according to the recommendations of the Intergovernmental Panel on Climate Change [3]: 1 for carbon dioxide, 21 for methane and 310 for nitrous oxide.

### 3. Results and Discussion

The results obtained are summarized on the Table 2 and Figures 1 and 2.

Regarding to energy consumption, scenario 2 - incineration of all MSW - shows a clear surplus of energy. Scenarios where compost is not marketable and is incinerated, also present a positive balance, but not so high. Landfilling and composting, with market for the compost, or its landfilling, are the most energy consuming situations with equivalent values.

In the point of view of global warming potential, scenarios 1 and 2, respectively landfilling and incineration, accounts for the major contribution when compared to the scenarios where organic and paper fractions are subjected to a biological treatment. In this case there is no significant difference between composting and biogasification, despite a small advantage for the biogasification option. When not considering the end-use of compost produced, the compost incineration - scenarios 3c and 4c - has more global warming potential than its landfilling - scenarios 3b and 4b.

### 4. Conclusions

As far as energy consumption is concerned, the results obtained through this inventory model show a clear advantage of incineration, since it has a very positive balance. With this respect the worst situations are landfilling and composting of organics and paper fractions, except when compost is further incinerated.

In terms of global warming potential, the most favorable situation is the biological treatment of organics and paper followed by using the compost produced as soil conditioner. This advantage is shortened when compost is not marketable, thus must be either landfilled or incinerated.

Biogasification presents a visible advantage over composting in terms of energy consumption.

### 5. References

[1] Anonymous, A UE e a Gestor dos Resíduos. Serviço das Publicações Oficiais das Comunidades Europeias, Luxembourg, 2000.

[2] White et al, Integrated Solid Waste Management: A life cycle inventory, Blackie A&P, Glasgow, U.K., 1995.

[3] IPCC, Guidelines for National Greenhouse Gas Inventories, volume 3, Intergovernmental Panel for Climate Changes, 1996.

## USE OF SUSTAINABLE DEVELOPMENT INDICATORS FOR ASSESSMENT OF THE SUSTAINABILITY OF SOCIAL-ECONOMICAL SYSTEM

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Complication and many-side of Sustainable Development Process, enwrapping other unconnected aspects complicate the monitoring process of achieved progress. In this connection the necessity of use such mechanisms arise, as on the one hand reliable and understandable informational basis would be submitted, on the other hand the main problems would be identified and elaboration of adequate and effective solution in accordance with long-term aims of Sustainable Development would be capacitated. Such mechanisms are the Sustainable Development Indicators.

The United Nations Development Programme (UNDP) in the working program on development of indicators has determined the goals: they should be tools for a manual of acceptance of political solutions, directional on sustainable development, meliorating of the information and data gathering and to allow to conduct comparative analysis and analysis in concrete country on a state and advance in achievement of sustainable development.

By the UN Commission on Sustainable

Development is designed in 1995 and proposed the list from 130 detecting indicators permitting to value a state and dynamics of usage of a natural potential as on national and at a regional level. To the advantages of this system of indexes it is possible to refer it integral nature: the system of the proposed detecting instruments is constructed by a principle DSR - driving forces-state-reaction. Besides for it the accessibility of the information and comparability at an international level is characteristic. Such countries as Canada, Belgium, Tunis use the system of indexes of the UN Commission on Sustainable Development (CSD) for ecological monitoring of programs of development. In anticipation of 10th anniversary of acceptance of the Program of progressing of the states of a planet on so-called RIO+10 process, 22 countries of a world, the members of the UN CSD are involved in the process of testing of the proposed detecting instruments with the purpose of eliciting lacks and poposals on upgrading the list. The countries of Central Asia, including Kazakhstan, within the framework of the pilot project UNDP