# Evaluation of MSW Management Practices in Portugal Using Life Cycle Assessment

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## Abstract
This paper describes a case study where the evolution of MSW management practices for three municipalities in Portugal were analyzed using the Life Cycle Assessment technique. This evolution was mainly due to legislative pressures that led to changes in MSW collection and treatment or disposal systems implemented between 1990 and 2000. The municipalities participating in the study were Porto, Maia and Gondomar, all part of LIPOR, the intermunicipal entity responsible for the MSW management of 8 municipalities in the Porto region.

Environmental burdens from these two management scenarios were calculated based on an inventory model developed by White et al. (1995), using some on-site specific parameters related with the system's operation conditions. Results show the advantage of the 2000 practices, both in terms of energy consumption and emissions of gases with greenhouse effect.

## 1 Introduction
In Portugal, the MSW management is the responsibility of the municipalities that are nowadays organized into 30 associations to allow for optimization of infrastructure investment and operation costs reduction. LIPOR is a company committed to manage the MSW of 8 municipalities of the Porto region, which includes the municipalities of Porto, Maia and Gondomar. Porto is the second largest city of Portugal, has an area of 43 $km^2$ and a population density of 7,034 inhab/$km^2$ (INE, 2001). Maia and Gondomar are municipalities adjacent to Porto, with a rural component, covering 77 and 137 $km^2$ and having 1,213 and 1,045 inhabitants per square kilometre (INE, 2001), respectively. In 1990, Porto was responsible for 43% of the waste produced in the LIPOR municipalities. In 2000, this value accounted for about 30% due to the admittance of the eighth municipality to the group. In LIPOR, the MSW is collected by the municipalities that transport the waste to the LIPOR treatment sites. From 1990 to 2000, some changes were implemented in the waste collection practices and in the waste treatment options. Some of these changes were implemented due to the requirements from European legislation.

This paper presents part of the results obtained in the study aimed at evaluating the environmental burdens associated with the MSW management practices, from collection to final disposal, in these three municipalities in 1990 and in the year 2000, namely the quantification of energy consumption and the emissions of greenhouse gases. This analysis was made using an LCI model which considers the life cycle of waste from collection to final disposal, providing an understanding of the environmental effects associated with the evolution in the environmental burdens from waste management practices between 1990 and 2000.

## 2 MSW in Porto, Maia and Gondomar: from 1990 to 2000

The collection of data was the most consuming task in this study. Both personal contacts with LIPOR and the environmental departments of the municipalities of Porto (CMP), Maia (Maiambiente) and Gondomar (CMG), and statistic and technical publications (LIPOR, 2000) available were the main sources of data. All data were possible to obtain through the principal author. There was an increased difficulty on data from 1990 mainly in relation to waste collection in the municipalities of Maia and Gondomar, since the frequency of waste collection was not the same for the entire municipality region and data on different collection circuits is not available. The assumptions for these and other situations are adequately identified.

In 1990, Porto had around 302,500 inhabitants and the average number of individuals per household was 2.67. The mean MSW production was 383 kg/person/year. Mixed MSW accounted for was about 115,000 ton and kerbside collection in plastic bags or community containers took place 6 times a week. There were also 364 glass banks in the city, where approximately 1,050 ton of glass was disposed. Mixed waste composition (% by weight) is presented in Figure 1. In the metal fraction 93% is ferrous materials and in the plastic fraction 66% is assumed to be plastic film. The treatment methods available in 1990 include composting (20% of mixed waste), landfilling (80% of mixed waste) and glass recycling. It was assumed that the plastic bags for mixed waste disposal were used bags mainly from shopping and other purposes, a usual practice in Portugal. Due to the lack of data, it was assumed that fuel consumption on collection was 30 L/1000 properties served. In the composting plant, 6% of ferrous metals and 17% of non-ferrous metals was recovered. The compost produced was totally marketed and the residual waste from sorting operations was placed in the landfill located 100 m from the composting plant. The landfill site, with a gas collection system (40% collection efficiency), is lined and also has a leachate collection and treatment (70% collection efficiency). The fuel consumption for waste spreading operations was assumed 0.6 L/ton of waste.

In 1990, the population in Maia was around 93,000 inhabitants and the average number of individuals per household was 3.08. The mean MSW production was 287 kg/person.year. Mixed MSW accounted for was around 26,600 ton and kerbside collection in plastic bags or community containers took place 2 times a week from. The glass collected from glass banks was assumed 109 ton. Mixed waste composition (% by weight) is presented in Figure 1. In the metal fraction,

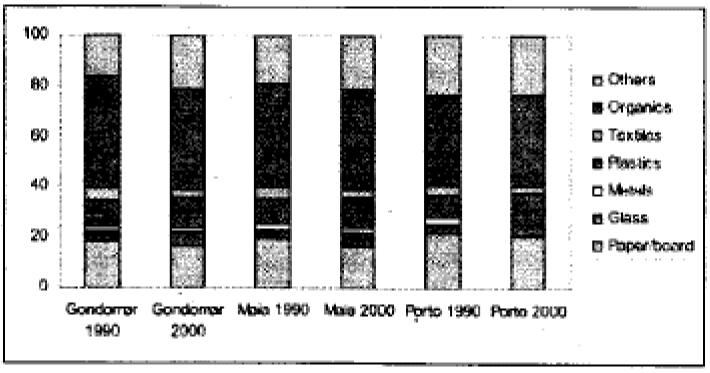


Fig. 1: Waste composition in 1990 and 2000 (% by weight).

91% is ferrous materials and in the plastic fraction 73% is assumed as film.

In 1990, Gondomar had around 143,200 inhabitants and the average number of individuals per household was 3.08. The mean MSW production was 208 kg/person.year. Mixed MSW accounted for was around 29,600 ton and kerbside collection in plastic bags or community containers took place 2 times a week. The amount of glass collected from glass banks was 168 ton. Mixed waste composition (% by weight) is presented on Figure 1. In the metal fraction, 94% is ferrous materials and in the plastic fraction 66% is assumed as film. The treatment methods available and the operating conditions for both Maia and Gondomar, are the same described for Porto, including the weight percentage distribution of mixed waste between landfill and composting.

From 1990 to 2000, there was a meaningful evolution concerning both the collection frequency and schemes and the disposal and treatment units available.

In 2000 the population in Porto decreased to 263,100 and the average number of individuals per household also decreased to 2.1. The average MSW production was 551 kg/person.year. The collection systems included: mixed waste kerbside collection, that took place 6 times a week; kerbside collection (door-to-door) of two fractions of dry recyclables (paper/cardboard and plastic/metal packaging); and two types of voluntary bring systems - central collection sites and collection banks. The kerbside dry recyclables collection started in September 2000 and took place once a week for each fraction. Coloured LDPE 20 g plastic bags were used for that purpose: a yellow one for plastic/metal packaging, and a blue one for paper/paperboard. The environmental burdens from bag production are also included in this study. The collection banks included containers for packages, paper/board and glass. In central collection sites, plastics, paper/paperboard, glass were accepted as well as other types of waste not considered in this study, for example wood and bulky wastes. The mixed waste accounts for 96.4% of the total waste collected. Its composition is presented in Figure 1. The metal component includes 87% of ferrous metals and the plastic component includes 66% of film. The total selective collection (3.6% of the total amount collected) comprises: packaging materials – 6.6%, paper/board – 36.8%, glass – 54.2% and plastics – 2.4%. From these, only 2% of the packaging materials and 1% of the paper was collected door to door, all the rest was collected from central sites and collection banks. As previously, due to the lack of data, it was assumed that the average fuel consumption on these collection operations was 30L/1000 properties served. Waste fractions separately collected were transported to a central sorting unit operated by LIPOR, where separated material were sent to recyclers. In this unit, the consumption of electrical energy and diesel are respectively 30.7 kWh and 2.17 L per ton of waste. The residue from this operation is transported to the incineration plant which is located 15 km from there. The mixed waste is sent to composting (19.7%), incineration (79.2%) and landfilling (1.1%). The incineration plant is a mass-burn incinerator with energy recovery, producing electricity with an assumed efficiency of 20%. About 90% (assumed) of the ferrous scrap is recovered from the bottom ash. The non-hazardous waste produced in the incineration plant was sent to a landfill 15 km away from the incineration plant. During that year, the fly ash (hazardous waste) from the incineration plant was transported to a landfill, of another MSW management system, located 300 km away. In the composting plant, the recovery of ferrous metals is assumed as 100%. Here, all the compost was marketable and the sorting residue was sent to a landfill 15 km away. In the landfill, the diesel consumption for waste spreading and compacting operations was assumed 0,6 L/ton of waste. The landfill gas was collected with an assumed efficiency of 40% and burned without energy recovery; 70% of the leachate was collected and treated.

In 2000, the population in Maia increased to 120,100 and the average number of individuals per household also increased to 2.5. The average MSW production was 410 kg/person.year. The collection systems were similar to the collection in Porto during that year, except for the frequency of mixed waste collection that took place 5 times a week. The mixed waste accounts for 93.0% of the total waste collected. Its composition is presented in Figure 1. The metal component includes 81% of ferrous metals and the plastic component includes 67% of film. The total selective collection (7.0% of the total amount collected) comprises: packaging materials – 24.6%, paper/board – 37.5%, glass – 27.5% and plastics – 10.4%. From these, 87% of the packaging materials and 21% of the paper was collected door to door, all the rest was collected from central sites and collection banks. The fuel consumption for collection, central sorting unit and incineration plant operating conditions are similar to those in Porto. The mixed waste was sent to composting (23.1%), incineration (75.8%) and landfilling (1.2%).

In 2000 the population in Gondomar increased to 164,100 and the average number of individuals per household also decreased to 2.5. The average MSW production was 391 kg/person.year. The collection systems are similar to the collection in Porto during that year, including the frequency of mixed waste collection. The mixed waste accounts for 97.8% of the total waste collected. Its composition is presented in Figure 2. The metal component includes 87% of ferrous metals and the plastic component includes 40% of film. The total selective collection (2.2% of the total amount collected) comprises: packaging materials – 8.0%, paper/board – 23.7%, glass – 62.4% and plastics – 5.9%. From these, 76% of the packaging materials and 49% of the paper was collected door to door, all the rest was collected from central sites and collection banks. The fuel consumption for collection, central sorting unit and incineration plant operating conditions are equal to those in Porto. The mixed waste was sent to composting (1.4%), incineration (95.4%) and landfilling (3.2%).

## 3 Results and discussion

Energy consumption and emissions of carbon dioxide, methane and nitrous oxide resulting from MSW management in Porto, Maia and Gondomar in 1990 and in 2000 were calculated using the LCI model from White et al. (1995) The emissions of the greenhouse gases were aggregated using the Global Warming Potentials weighting factors recommended from the Intergovernmental Panel on Climate Change (IPCC, 1996) as follows: 1 for carbon dioxide, 21 for methane and 310 for nitrous oxide. The results are summarized in Figures 2 and 3. The net energy use in 2000 is negative due to the electrical energy produced in the incineration process, which represents a clear advantage of the management system in 2000 compared with the one in 1990. The energy consumption in Porto in 1990 is meaningfully higher, which is due to the relatively large amount of waste produced in this municipality. This disadvantage become an advantage in 2000 because Porto had the greatest energy production due to the amount of waste incinerated. For the other municipalities, both in 1990 and 2000, the energy consumption or production respectively was proportional to the waste produced. The results per ton of waste are only meaningful different in 1990 for the municipality of Porto, probably due to the waste collection that took place more often. Concerning greenhouse gases emissions, total GWP in 2000 is higher than in 1990 for all the municipalities mainly due to the amount of waste involved. According to the total waste produced, the ranking, both in 1990 and 2000, shows Porto with the highest value followed by Gondomar and Maia. The highest increase in total GWP occurred for Gondomar, and the lowest for Porto which is apparently due to the increase on waste production. The ranking in absolute values for GWP per person is different for 1990, where Maia shows a value higher than Gondomar probably due to the high increase on waste production per person in Gondomar that almost duplicated compared to the production in 1990. However, the increase on GWP per person from 1990 to 2000 was higher in Porto than in Maia which appears now in the third place. The sit-

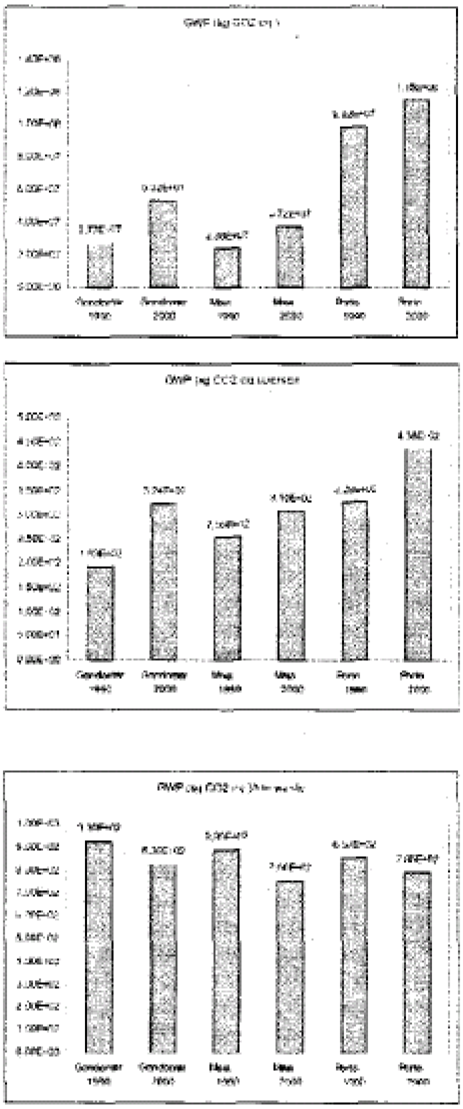

**Fig. 2:** Annual contribution to GWP from waste management practices in Gondomar, Maia and Porto (total, per person and per ton of waste).

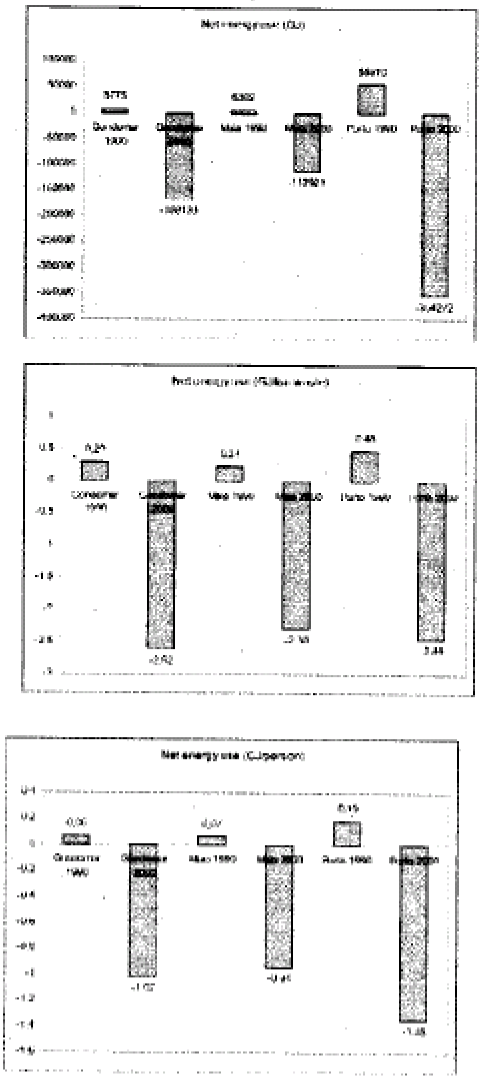


Fig. 3: Net energy use on waste management practices in Gondomar, Maia and Porto (total, per person and per ton of waste).

uation is quite different when one analyses the GWP per ton of waste: it decreases from 1990 to 2000 for the three municipalities, representing a meaningful advantage on the management practices in the year 2000. In 1990, the highest value is for Gondomar, followed by Maia and Porto. The variation between 1990 and 200 was higher for Maia followed by Gondomar and Porto. In 2000, Gondomar still has the highest GWP per ton of waste but Maia has the lowest value.

From this analysis, it is possible to conclude that from the energy conservation and greenhouse gases emissions perspective, management options conducted both by municipalities, in relation to collection schemes and treatment, and disposal options operated by LIPOR between 1990 and 2000 lead to positive results.

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