

PORTO 1990/2000: EVALUATION OF ENVIRONMENTAL BURDENS FROM MSW MANAGEMENT USING LIFE CYCLE ASSESSMENT

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SUMMARY: The environmental burdens to air and water resulting from the MSW management practices in the municipality of Porto were evaluated for 1990 and 2000 using the model developed by White et al (White et al, 1995). The operations considered in the study are collection, sorting, biological treatment, thermal treatment and landfilling. Savings from energy and recycling of recovered materials are also quantified. For each pollutant, the main source, among the operations considered, was identified. Results have shown that landfilling was the main source for air and water emissions in 1990, followed by collection. In 2000, thermal treatment was the main source for air pollutants and landfilling the main source of water pollutants, in both cases followed by collection. In 1990, collection was the main source for air emissions of particulates, CO, NO_x, SO_x to air, and of Organic compounds, Phenol and Fluoride to water. In 2000 it was the main source of NO_x to air and TOC, phenol, total metals and fluoride to water. Biological treatment was the main source of N₂O and nitrate to air in 1990 and of BOD, COD and ammonia to water in 2000.

1. INTRODUCTION

Municipal solid waste (MSW) management have been considered in Portugal one of the most important environmental issues. The main reasons for this major role include: the increase in the amount of waste produced; the need for new facilities for waste treatment and disposal which raised questions related with its locations and approval by municipalities and citizens; the continuously increasing costs of waste collection and treatment with citizens complains and disagreement or the need of municipalities to support these higher costs; and the awareness of citizens for questions related with the environment in general including the environmental burdens resulting from waste treatment and collection.

In Portugal, the MSW management is committed to municipalities that are in some cases organized in multimunicipal associations. In the city of Porto, the second largest city in Portugal, MSW is collected by municipal services also responsible for its transport to the treatment units

belonging to LIPOR, a company participated by 8 municipalities of the region that is responsible for MSW treatment and disposal.

In the last decade of the 20th century, also due to legislative pressure from the European Union, large changes were implemented in waste management collection and treatment/disposal systems in Portugal in order to achieve governmental goals but also to reduce the associated environmental burdens. In this paper, environmental burdens for air and water resulting from the MSW management practices in the municipality of Porto were evaluated for 1990 and 2000 using a model developed by White et al (White et al, 1995). The operations considered in this study are all used in the management practices and include: collection, sorting, biological treatment, thermal treatment and landfilling. Savings in energy consumption and in emissions resulting from recovered materials that replace virgin materials were also quantified. For each pollutant, the main source, among the operations considered, was identified. The pollutants included in the study are: (i) air pollutants - particulate, CO, CO₂, CH₄, NO_x, N₂O, SO_x, HCl, HF, H₂S, Total hydrocarbons (HC), Chlorinated hydrocarbons, Dioxins/furans, NH₃, As, Cd, Cr, Cu, Pb, Hg, Ni, Zn; (ii) water pollutants – BOD, COD, Suspended solids, TOC, AOX, Chlorinated hydrocarbons, Dioxins/furans, Phenol, Ammonia, Total metals, As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Zn, Cl, F, NO₃ and Sulphide.

2. PORTO: FROM 1990 TO 2000

The first step in this study was data collection for the description of the municipality in terms of population and waste production, characterization and management practices from collection to the final disposal. Personal contacts with Porto municipality environmental department (Xará, 2002) and with LIPOR (Xará, 2005), statistics (INE, 2001) and technical publications (LIPOR, 2000) were the main sources of the data. In the municipalities belonging to LIPOR, MSW are collected and transported by the municipalities to LIPOR treatment sites for further processing. From 1990 to 2000, there was a meaningful evolution concerning both the collection frequency and schemes and of the disposal and treatment units available.

2.1. Population

Porto is the second largest city of Portugal, with an area of 43 km². In 1990, Porto had around 302 500 inhabitants and the average number of individuals per household was 2.67. In 2000 the population in Porto decreased to 263 100 and the average number of individuals per household also decreased to 2.1.

2.2. Waste production

Porto was responsible for 43% of the waste processed by LIPOR municipalities in 1990. In 2000, this value accounts only for about 30% due to the admittance of another municipality to the group. The mean MSW production was 383 kg/person.year in 1990 and 551 kg/person.year in 2000.

2.3. Waste collection

Waste collection in 1990 included kerbside collection of mixed waste and selective glass collection in glass banks. In 2000, the collection systems included: mixed waste kerbside collection, door-to-door collection 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.

2.3.1. Mixed collection

In 1990, mixed MSW accounted for was about 115 000 ton and kerbside collection in plastic bags or community containers took place 6 times a week. 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. In 2000, kerbside collection of mixed waste took place 6 times a week. The mixed waste accounts for 96.4% of the total waste collected. Due to the lack of data, it was assumed that fuel consumption on collection was 30 L/1000 properties served.

2.3.2. Selective collection

In 1990, the selective collection included only glass. There were 364 glass banks in the city, where approximately 1 050 ton of glass were disposed.

The kerbside dry recyclables collection started in September 2000 and took place once a week for each fraction - paper/cardboard and plastic/metal packaging. Colored 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 and glass were accepted as well as other types of waste not considered in this study, as for example wood and bulky wastes. Only 2% of the packages and 1% of the paper were collected door to door, all the rest were collected from central sites and collection banks.

2.4. Waste characterization

Mixed waste composition (% by weight) is presented in Figure 1 for 1990 and 2000. In 1990, 93% of the metallic fraction are ferrous materials and 66% of the plastic fraction is assumed to be plastic film. In 2000, the metallic fraction includes 87% of ferrous metals and the plastic fraction includes 66% of plastic film. The total selective collection in 2000 (3,6% of the total amount collected) comprises: packages – 6,6%, paper/board – 36,8%, glass – 54,2% and plastics – 2,4%.

2.5. Waste disposal

The treatment methods available in 1990 include composting - 20% of mixed waste, landfilling - 80% of mixed waste, and glass recycling. In 2000, the mixed waste is sent to composting - 19.7%, incineration - 79.2% and landfilling - 1.1%. Waste fractions separately collected were transported to a central sorting unit operated by LIPOR, where separated material was further sent to recyclers.

2.5.1. Central sorting

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.

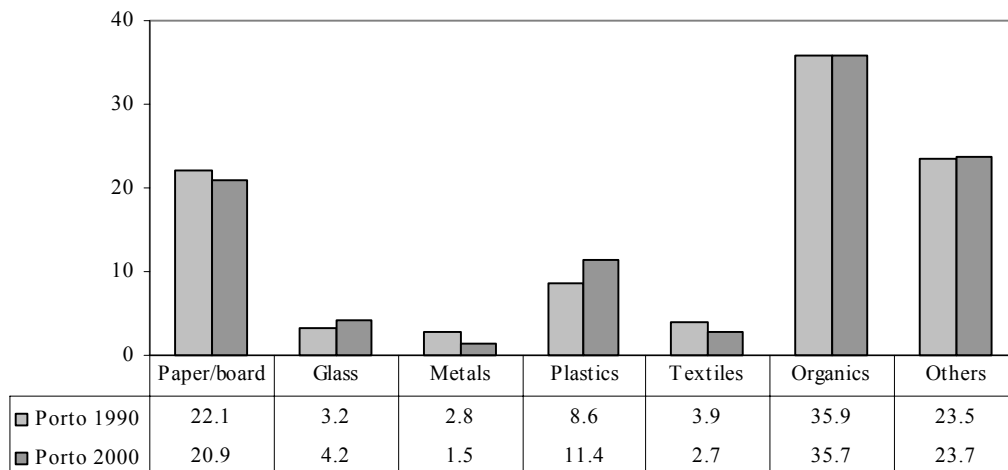


Figure 1. Mixed waste composition (% by weight) in 1990 and in 2000 in Porto municipality.

2.5.2. Composting

In 1990, 6% of ferrous metals and 17% of non-ferrous metals was recovered in the composting plant. The compost produced was totally marketed and the residual waste from sorting operations was placed in the landfill closely located (100 m). In 2000, the recovery of ferrous metals is assumed to be 100%. All the compost was marketable and the sorting residue was sent to a landfill 15 km away.

2.5.3. Incineration

The incineration plant is a mass-burn incinerator with energy recovery, producing electricity with an assumed efficiency of 20%. 90% (assumed) of the ferrous scrap is recovered from the bottom ashes. The non-hazardous waste produced by the incineration plant was sent to a landfill 15 km away. During that year, the fly ashes (hazardous waste) were transported to a landfill, of another MSW management system, located 300 km away.

2.5.4. Landfilling

The landfill gas was collected with an assumed efficiency of 40% and burned without energy recovery and 70% of the leachate was collected and treated. The fuel consumption for waste spreading operations was assumed as 0.6 L/ton of waste.

3. RESULTS AND DISCUSSION

The environmental burdens for air and water resulting from the MSW management practices in the municipality of Porto were calculated for 1990 and 2000 using the model developed by White et al (White et al, 1995). Results are presented on Figures 2 and 3. Values below zero are not represented because of the logarithmic scale used to allow for the inclusion of all the emissions in different ranges. These values are indicated in the legend of each figure. These negative values mean that the amount of pollutant avoided by energy or materials recovery is higher than the emission from the waste management operations.

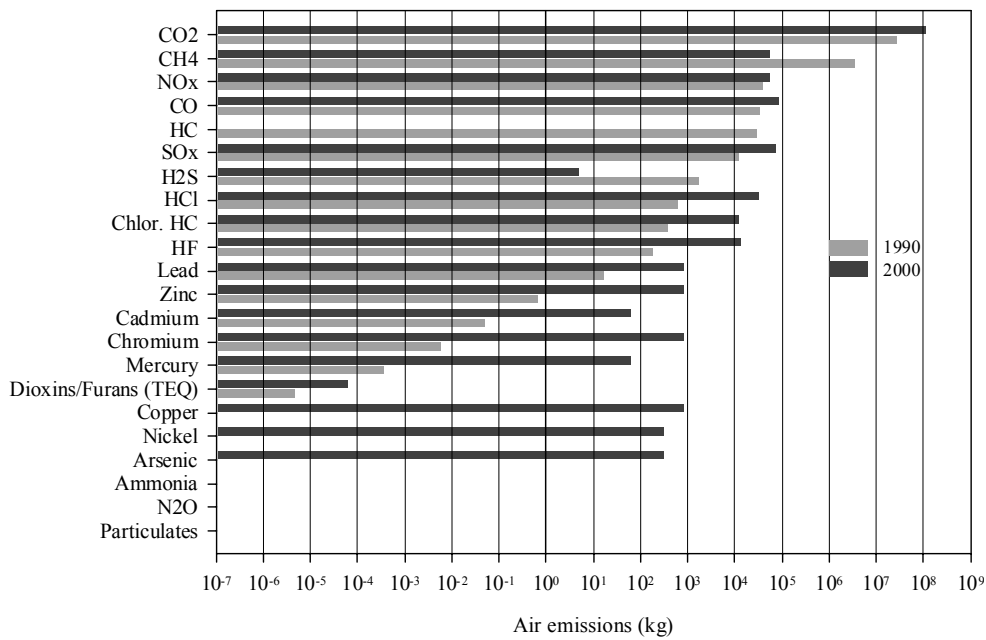


Figure 2. Air emissions (kg) resulting from MSW management in 1990 and 2000 in Porto municipality. Emissions below zero are not represented: Particulates, N₂O and Ammonia for 1990 (-1.57x10⁴; -17.7; - 4.19 kg respectively) and 2000 (-7.62x10⁴; - 3.71x10³; -1.26x10² kg respectively) and also HC for 2000 (-8.98x10⁴ kg).

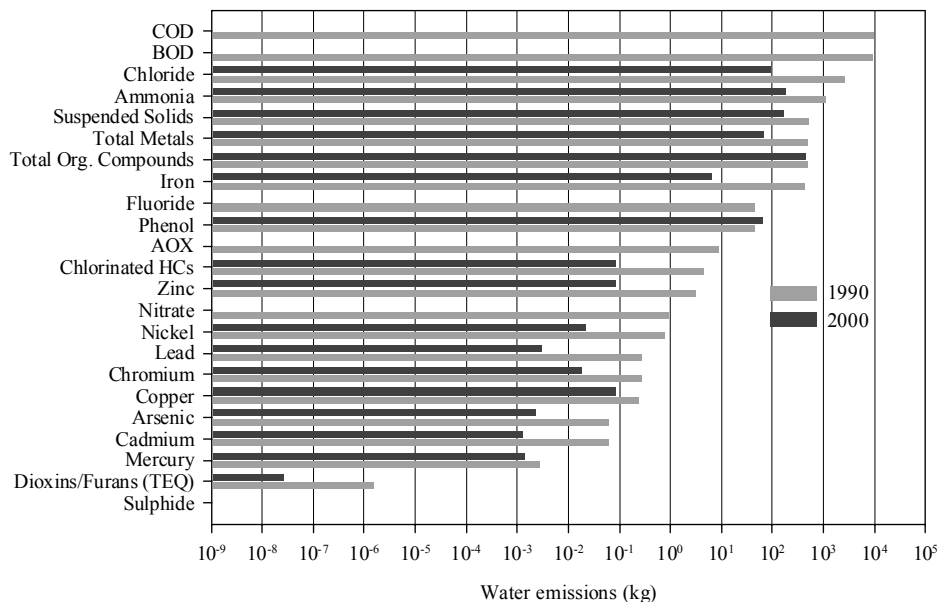


Figure 3. Water emissions (kg) resulting from MSW management in 1990 and 2000 in Porto municipality. Emissions below zero are not represented: Sulphide, Nitrate, AOX, Fluoride, BOD and COD for 2000 (-11.7; -59.3; -4.63; -15.0; -2.87x10³; -3.71x10⁴ kg respectively).

The contribution of each waste management operation to the total emissions of each pollutant was also quantified. For 1990 the operations include: collection, biological treatment, landfilling and recycling savings. For 2000, besides these, also sorting and thermal treatment were considered. Results of air emissions in 1990 are presented in Figure 4 and for water emissions in Figure 5. Figures 6 and 7 present results respectively for air and water emissions for 2000. For each pollutant the contribution of each operation is expressed as percentage of the total presented on previous figures (Figures 3 and 4). In these plots, negative values for a certain operation represent avoided emissions from energy or materials recovery except for recycling savings for which a negative value represents an increase in the emissions amount when comparing recovered with virgin materials.

Results on Figure 2 show the predominancy of CO₂ emissions to air followed by CH₄, NO_x, CO and SO_x for both years and also total hydrocarbons (HC) for 1990. For these gases, emissions in 2000 are higher than those in 1990, except for CH₄ and HC. The landfilling process is the single source of CH₄ emission in 1990 and in 2000 - the decrease from 1990 to 2000 is due to the lower amount of waste disposed in the landfill (see Figures 4 and 6). The HC emissions have a contribution from all the processes involved in both years. In 1990, the main sources are the landfill and the collection process. In 2000 the energy recovered from the thermal treatment and the electricity produced, avoid the emission of a meaningful amount of HC in such a way that the overall balance of HC emissions is negative. All the processes involved in the waste management system in 1990 and in 2000 are sources of the other gases referred, in different amounts.

For CO₂, the contribution of the landfill in 1990 and of thermal treatment in 2000 is the most important. The collection operations were the main NO_x sources in both years. Also collection is the larger contributor to CO emissions in 1990 but the thermal treatment is also an important source in 2000. For SO_x the contribution of collection in 1990 is the most important whereas in 2000 the thermal treatment become the main source.

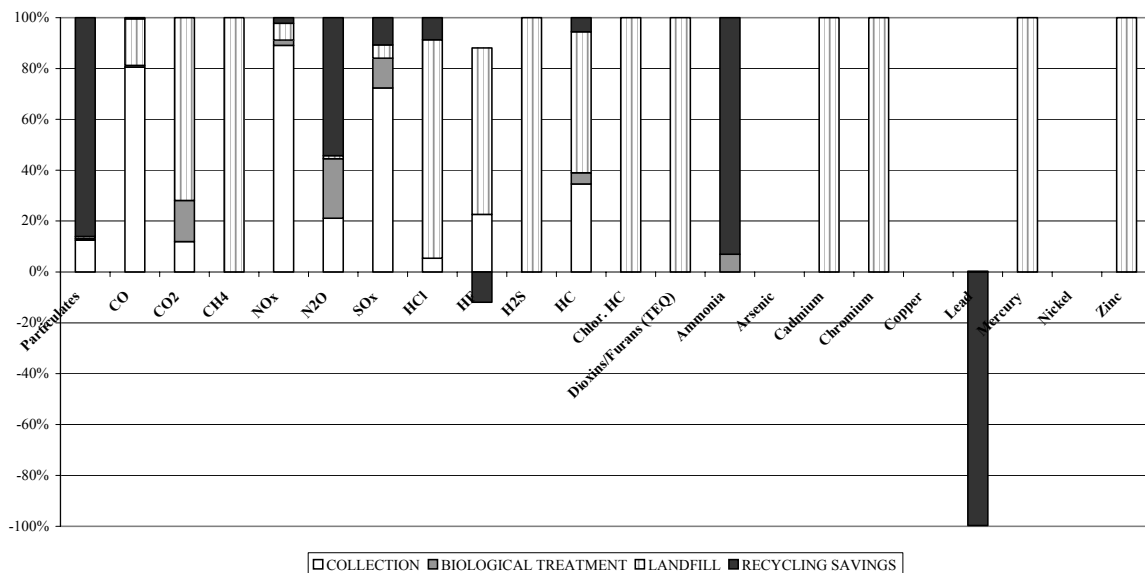


Figure 4. Contribution of MSW management operations to air emissions in 1990 in Porto municipality.

Emissions of HCl, chlorinated HC, HF, Pb, Zn, Cd, Cr, Hg, Cu, Ni and As present meaningful values in 2000, varying from 61.6 kg (Cd, Hg) to 30.7 ton (HCl) but considerably lower than in 1990. For all these pollutants, thermal treatment is the most important or the only source (Cu, Ni, As) in 2000. In 1990 landfill is the major source of HCl and HF emissions with a small contribution from collection and the only source of chlorinated HC. There are no emissions of As, Ni, Cu and Cd, Cr, Hg and Zn are only emitted from the landfill. Note that the low emissions of Pb by the landfill are increased by the contribution of recycling which is the main source of Pb in 1990. This is originated in the glass recycling process that slightly increases the amount of Pb (and HF) emissions when compared with the use of virgin raw materials. From Figure 4, one can see the negative contribution of glass recycling to air emissions in 1990. H₂S emissions were lower in 2000 than in 1990: they are originated by the landfilling process and the decrease in 2000 is also due to savings from paper recycling. Concerning Dioxins/furans, the landfill and the incineration processes are the sources of these emissions with the main contribution from thermal treatment in 2000, representing a total higher emission than in 1990.

Emissions of Ammonia, N₂O and particulates are below zero and so, not represented in Figure 2. In 1990, ammonia is originated by the composting process. Savings from metals recovered in composting and from recycling of glass separately collected, decreased the amount of ammonia leading to a negative value. In 2000, the low ammonia emissions from sorting and biological treatment were exceeded by the avoidance produced by thermal treatment (electricity production from energy recovered from incineration of composting residual waste and from the incineration of mixed waste) as of recycling savings from: metals recovered in the composting, paper, glass and metals from selective collection and also metals from bottom ashes.

Emissions of N₂O were originated in all the processes involved in the waste management system in each year. In 1990 the recycling savings from metals recovered in the composting unit and from glass from selective collection exceeded the emissions from collection and biological treatment, their main sources. In 2000, the electricity produced from energy recovered in the thermal treatment along with the recycling savings from metals recovered from the composting unit, bottom ashes and selective collection lead to a meaningful negative value.

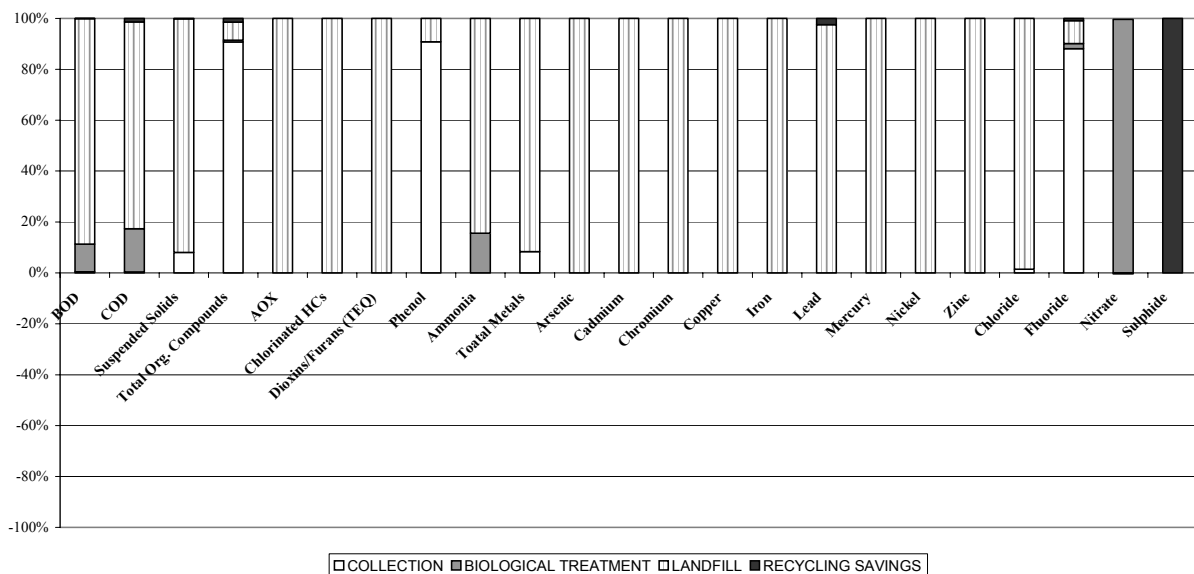


Figure 5. Contribution of MSW management operations to water emissions in 1990 in Porto municipality.

Emissions of particulates are also not represented due to the negative values for both years. Besides the contribution of all the processes involved in the waste management system, the dominance is for collection in 1990 and thermal treatment in 2000. However, the recycling savings exceeded these emissions: in 1990 the recycling of metals from the composting unit and from the glass recovered from selective collection and in 2000, the recovery of metals from composting, metals from bottom ashes and paper, metals, plastics and glass from selective collection.

Results in Figure 3 show that emissions for water are higher in 1990 than in 2000 for all pollutants except for phenol that is higher in 2000. The main water pollutants are in 2000 COD, BOD and chloride and in 1990 TOC, ammonia and suspended solids. Note that COD and BOD emissions in 2000 have negative values. The main sources of BOD emissions were the landfill in 1990 and composting in 2000, but the amount emitted from composting is similar in both years (1.03 ton in 1990 and 1.20 ton in 2000). All the waste management operations contribute to this pollutant in both years. Also COD emissions have a contribution from all the operations with the major sources being the landfill in 1990 and composting in 2000. However, in 2000, the recycling savings from recovered materials exceeded the emitted values of BOD and COD leading to negative overall values. Recovered materials contributing to the decrease in BOD emissions are ferrous metals from composting, bottom ashes and selective collection and paper from selective collection. Recovered materials contributing to the decrease in COD emissions are paper and glass from selective collection. For chloride, also landfilling was the main source followed by collection – all the operations have a small contribution, however, the recycling savings (from paper and plastic from selective collection) in 2000 decreased the total amount of this pollutant. Ammonia is originated in all operations except collection.

The main contributor to ammonia emissions is the landfill followed by composting in 1990 and composting in 2000, where thermal treatment and recycling savings (from ferrous metals from composting, bottom ashes and selective collection and paper from selective collection) reduced the total amount.

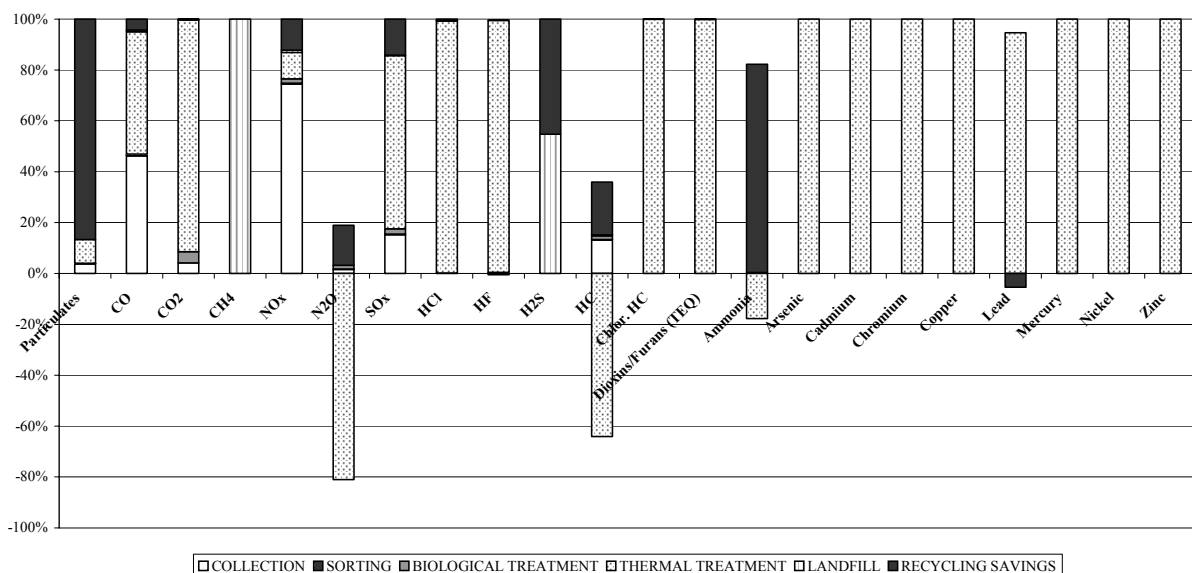


Figure 6. Contribution of MSW management operations to air emissions in 2000 in Porto municipality.

All operations also have a contribution to suspended solids emissions: the landfill and collection are the main sources in 1990 with an increase of the contribution of collection in 2000 where recycling savings (from ferrous metals recovered from composting, bottom ashes and selective collection) and thermal treatment, decrease the overall value of this emission. Also landfilling and collection are the main sources of Total metals (that has the contribution of all the operations) with the predominance of landfilling in 1990 and of collection in 2000. Collection is the main source for TOC emissions (among all the other operations) with a meaningful contribution to its decrease from thermal treatment in 2000 and from recycling savings in both years, but higher in 2000 due to glass from selective collection and metals from composting in 1990 and from paper and glass from selective collection in 2000. All the operations except collection contribute to Fe emissions and landfilling is its main source with a small negative contribution from thermal treatment in 2000. Also for Fluoride, all the operations contributed to its emissions but collection is the main source in both years with a decrease caused by recycling savings in 1990 (metals from composting) and by thermal treatment and also recycling savings in 2000 (metals from composting, bottom ashes and selective collection and paper from selective collection), leading to a negative value in 2000. AOX is only produced in landfills and its emissions in 2000 were exceeded by the recycling savings of paper from selective collection. Landfill is also the unique source of chlorinated HC, Zn, Ni, Cr, Cu, As, Cd, Hg and Dioxins/furans in both years. Also Pb is only emitted by the landfill but this emission is exceeded by recycling savings of metals from selective collection in 2000. Nitrate emissions are originated in the composting process in 1990 but in 2000 there was also a small contribution from sorting. However, on that year, the recovery of energy from thermal treatment reduced them to a negative value. In 2000, recycling savings (from ferrous metals recovered from composting, from bottom ashes and from selective collection) have a negative contribution to nitrate emissions slightly increasing the total overall emissions. For sulphide, emissions are negative in both years: the only contribution came from recycling savings from metals recovered from composting in both years and also from bottom ashes and selective collection along with paper in 2000.

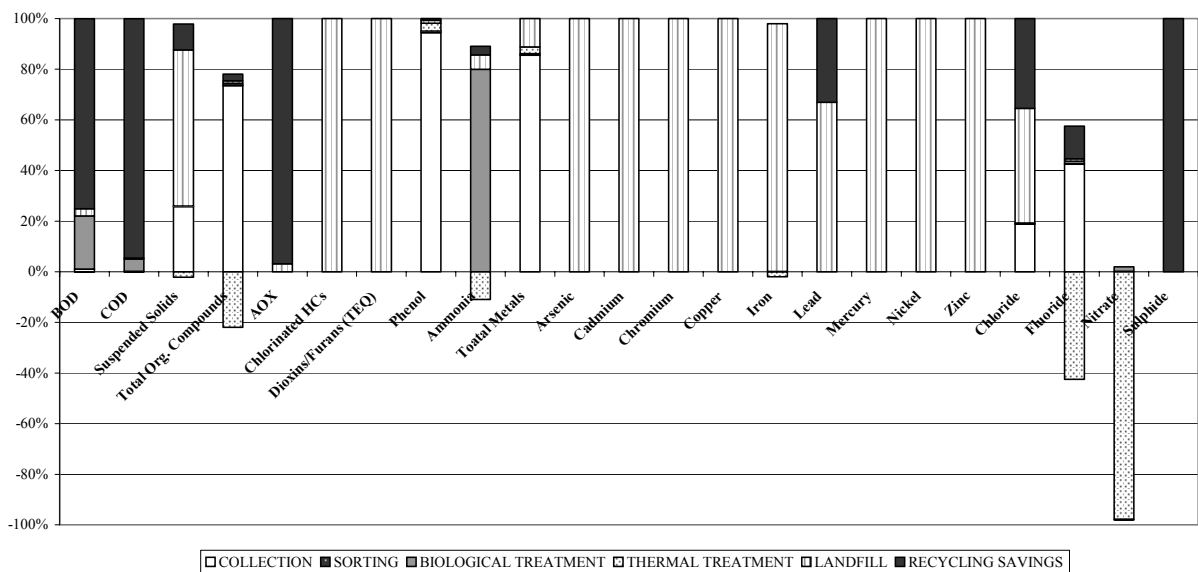


Figure 7. Contribution of MSW operations to water emissions in 2000 in Porto municipality.

4. CONCLUSIONS

Along with changes in collection schemes and treatment/disposal options in the MSW management in Porto city between 1990 and 2000, also environmental burdens changed both in terms of pollutants and their amount. The most important source for each pollutant among the operations involved in the waste management system in each year is also different. The main conclusions from the study are:

- air emissions of CO₂, NO_x, CO, SO_x, HCl, Chlorinated HC, HF, Pb, Zn, Cd, Cr, Hg, Dioxins/furans, Cu, Ni and As, were higher in 2000 than in 1990;
- all emissions to water, except phenol and total organic compounds, were higher in 1990 than in 2000
- the main pollutants to air in 1990 were CO₂, CH₄, NO_x and CO;
- the main pollutants to air in 2000 were CO₂, CO, SO_x, CH₄ and NO_x;
- the main pollutants to water in 1990 were COD, BOD, chloride and ammonia;
- the main pollutants to water in 2000 were TOC, ammonia and suspended solids;
- landfilling was the main source of air and water pollutants in 1990 followed by collection;
- in 1990 landfilling was: (i) the single source of AOX, chlorinated HC, Dioxins/furans, As, Cd, Cr, Cu, Fe, Pb, Hg, Ni and Zn; (ii) the main contributor for BOD, COD, and ammonia along with a small contribution from composting and (iii) the main contributor for SS, total metals and Cl with a small contribution from collection;
- in 2000, thermal treatment was the main source of air pollutants and the landfill the main source of water pollutants;
- collection was the main source for CO, NO_x and SO_x in air emissions in 1990 and for NO_x in 2000;
- collection was the main source for TOC, phenol and fluoride in water emissions in 1990 and for TOC, phenol, total metals and fluoride in 2000;
- biological treatment was the main source for N₂O and ammonia in air emissions in 1990;
- biological treatment was the only source for nitrate in water emissions in 1990 and the main source in 2000 for BOD, COD and ammonia;
- recycling savings contribute to decrease the following emissions:
 - to air in 1990: particulates, CO, NO_x, N₂O, SO_x, HCl, HC and Ammonia,
 - to water in 1990: BOD, COD, suspended solids, TOC, phenol, ammonia, Pb, fluoride and sulphide,
 - to air in 2000: particulates, CO, CO₂, NO_x, N₂O, SO_x, HCl, H₂S, HC, Ammonia and Hg,
 - to water in 2000: BOD, COD, suspended solids, TOC, AOX, phenol, ammonia, Pb, chloride, fluoride and sulphide;
- recycling savings have a negative contribution to the following emissions:
 - HF and Pb to air in 1990 and in 2000,
 - nitrate to water in 1990 and in 2000,
- thermal treatment in 2000, due to recovery of energy, contributes to decrease the following emissions:
 - to air: N₂O, HC and ammonia,
 - to water: BOD, COD, suspended solids, TOC, ammonia, Iron, fluoride and nitrate.

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