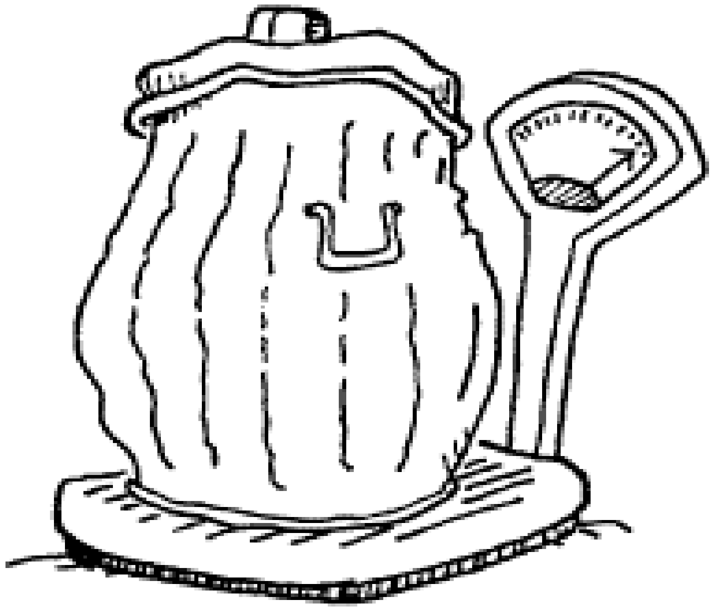
Municipal solid waste treatment in the EU



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Abstract

Waste is an important topic in every developed country. The amount of waste produced has strongly grown in the last decades and continues to do so. Further, the treatment of waste has strong impacts on the environment as well as on the health status of the population. This work wants to study the actual circumstances and the distance to a sustainable waste situation on a national level. This study goes through most of the available techniques related to disposal of waste, as well as the environmental and health impacts created by them. Taking the waste management hierarchy as the starting point for this research, it compares different national situations associated to municipal waste management policies. The only sustainable way for waste management is to reduce its amount through prevention, reuse and recycle of materials. High standards about their disposal have to be applied and regulated.

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List of abbreviations:

BAT - Best Available Technique
CEEC - Central and Eastern European Countries
CFC's - Chlorofluorocarbons
cRDF - coarse Refuse Derive Fuel
FBC - Fluidised Bed Combustion
GHGs - greenhouse gases
HDPE - High Density Polyethylen
LCA - Life Cycle Analysis
MSW - Municipal Solid Waste
MSWM - Municipal Solid Waste Management
MSWI - Municipal Solid Waste Incineration
MBT - Mechanical Biological treatment
OCS - Octachlorostyrene
PAH - Polycylic aromatic hydrocarbons
PCA - Polycylic aromatic compounds
PCBs - Co-planar polychlorinated biphenyls
PCDDs - Polychlorinated dibenzo-p-dioxins
PCDFs - Polychlorinated dibenzofurans (or furans)
POP - Persistent Organic Pollutants
PPP - Polluter Pays Principle
PRN - Packaging Waste Recovery Notes
RDF - Refuse Derived Fuel
3 Rs - Reduce, Re-use, Recycling
TEQ - Toxicity Equivalent
VFPE - Very Flexible Polyethylene

VOC’s - Volatile Organic Compounds

WE - Western Europe

WRAP - Waste and Resources Action Program

1 Introduction

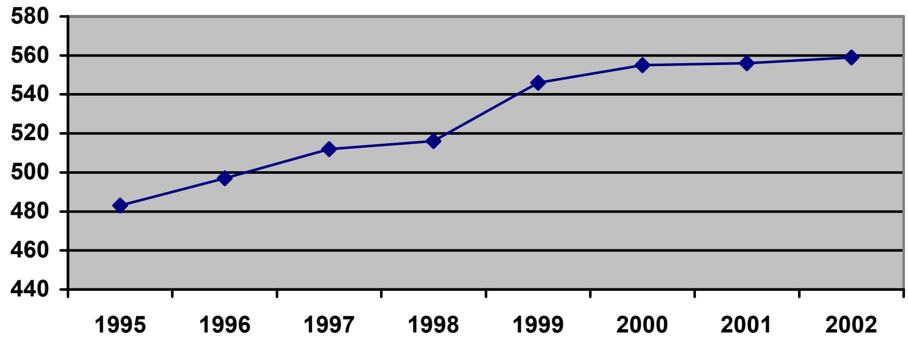

Figure 1-1: Amount of Municipal Solid Waste collected in the EU-15 (kg/capita/year)
Reference: www.europa.eu.int

Waste is an important topic in every developed country. The amount of waste produced has strongly grown in the last decades. The waste mountain has become so big that we cannot look around it anymore. Figure 1-1 illustrates the continuous growth in Municipal Solid Waste Management (MSW).

Waste can be seen as a sign of inefficiency. The less efficiency the more waste. Inefficiency combined with continuous waste growth, means depleting earth's material resources. The resources on earth are limited. In order to preserve them for our next generations they deserve to be used efficiently.

More waste means more treatment. Nearly all waste treatments have emissions. These emissions result in impacts on human health and environment. In heavily populated regions, it becomes steadily more difficult to find space for disposal sites. Landfills are full. The Not In My Backyard syndrome (NIMBY) makes it difficult to find new locations for landfills as well as for incineration plants.

Economic interests increase. Collection and disposal of waste are expensive. Recycling can even be more expensive.

Waste was only recognised as a primary problem in the seventies. Today some countries moved away from inefficient material use. Other countries still have to start the waste transition to a sustainable situation.

What is sustainable waste management? No waste is not possible. Reducing the amount of waste strongly is difficult without reducing the comfort of living. Not limiting the amount of waste can result in serious impacts on health, environment and depletion of resources. Waste is a complex issue. It is not possible to give an easy solution.

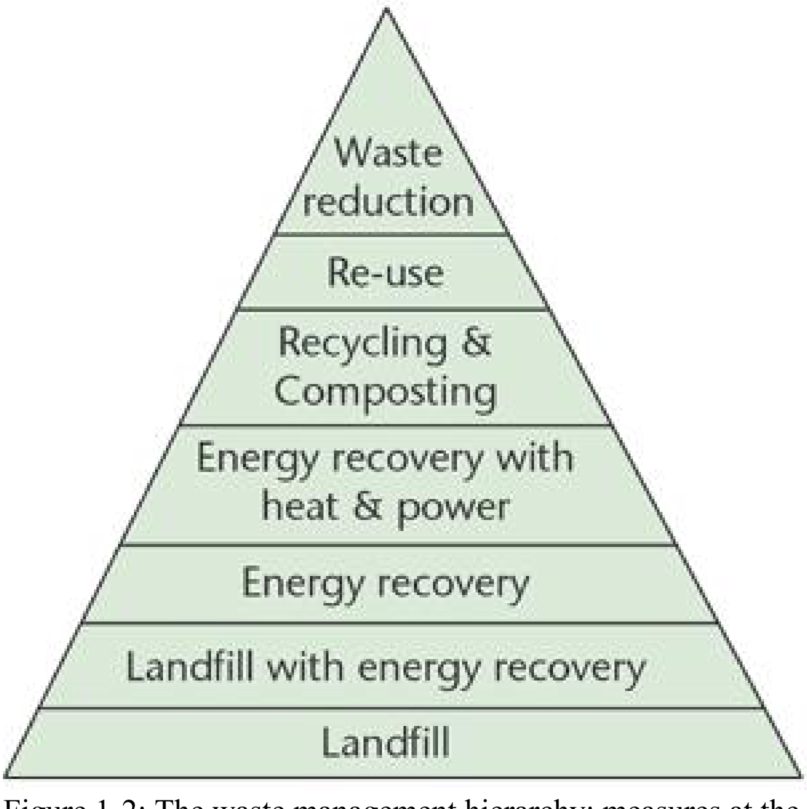

Figure 1-2: The waste management hierarchy: measures at the top of the pyramid get priority
Reference: Jaspers, 2003, pp. 3

This project work formulates a policy line for sustainable waste management. We use the waste management hierarchy as a starting point for our investigations. Numerous questions will be considered in this report. Is the waste management hierarchy a good principle to build up sustainable waste management? Is incinerating always better than landfilling? Are the health impacts of disposal facilities acceptable? Is recycling a good idea? What is the situation in the EU? Do all countries follow a similar strategy? What is the impact of EU-legislation on national waste policies?

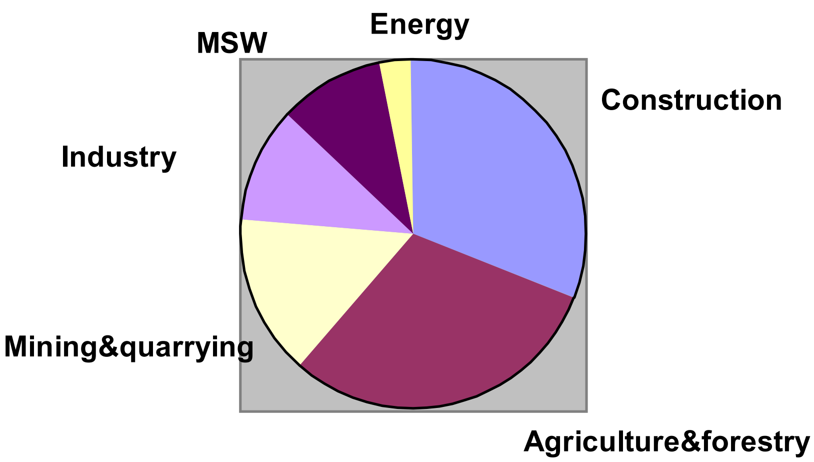

Figure 1-3: Different sorts of waste in WE[1] (average of '98-'01 in % of weight)
Reference: Eurostat, 2003, pp. 8

There is a big difference among the waste of different sectors. Waste of construction or industry cannot be compared to MSW. In order to limit the scope of the study we look at the treatment of MSW. Figure 1-3 depicts the amount of waste per sector. MSW is 10 % of total waste. We look at the non-hazardous part of MSW.

[1] WE=EU-15+Norway, Iceland, Switzerland

It is important to realise that there is a huge diversity between European countries in the definition of MSW, the amount of waste collected, the way of collecting waste and the way waste is treated. This study focuses only on the different ways of treating waste: Recycling, composting, incineration and landfilling. We also mention Prevention and re-use.

In a second chapter we define MSW.

In the third chapter we look at the legislation and minimum standards issued by the EU. The EU is an important player on the waste subject. The chapter describes the background and the reasons why the legislation is issued.

Our fourth chapter discusses the different waste treatment technologies and the impacts on health and environment. What are the different technologies to treat MSW? What are the emissions of the processes to land, water and air? The emissions depend on the technology used. In order to give figures on emissions and the corresponding health impacts, we make a case study on Flanders. How big are the impacts of the waste management in a region with advanced MSW management? Are the impacts acceptable?

Chapter five sums up the advantages and disadvantages of the different technologies. We compare our conclusions with the priority in the waste hierarchy. Does the waste hierarchy prioritises the right technologies?

Chapter six goes deeper into the diversity within Europe. Around Europe, views on waste are different. The diversity has increased with the enlargement of the EU. This chapter chooses Denmark, UK and Poland that each represents a specific attitude towards waste. We compare the situation in the countries and go more in depth in the national problems with waste.

2 Definition

Municipal Solid Waste (MSW) is defined as waste collected by a municipality. It concerns waste from households (82 % of total MSW), small business, office buildings and institutions such as schools, hospitals, government buildings, waste from parks and street cleaning (Eurostat, 2003, pp. 16).

Municipal Solid Waste Management (MSWM) is the generation, separation, collection, transfer, transportation and disposal of waste in a way that takes into account different parameters, such as public health, economics, environment, conservation, aesthetics and is responsive to public demands.

The yearly amount of MSW collected in Western Europe is 210 million tons/year. That is 550 kg/person/year. In comparison, MSW collected in Central and Eastern European Countries (CEEC) adds up to 60 million tons/year or 358 kg/person. Figure 2-1 depicts the composition of MSW.

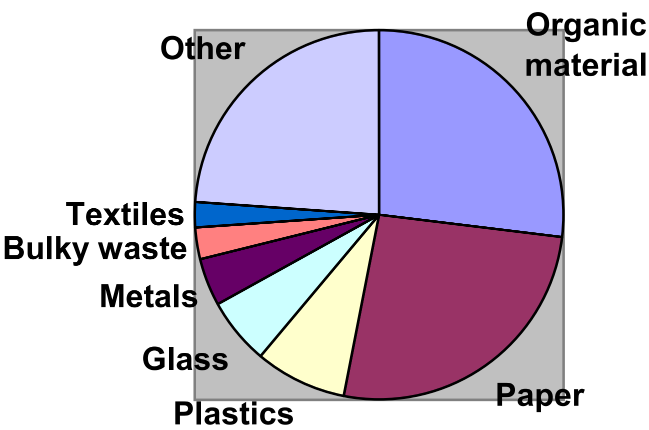

Figure 2-1: Composition of MSW in WE

Reference: Eurostat, 2003, pp. 9

3 EU law

European legislation has strong influence on the national waste policies. New directives are always compromises between front runners who want to have higher standards, and laggards in waste management who prefer to avoid any obligations. The directives that have binding targets are the most debated, but also have the strongest impact. We discuss the directives that are the most relevant for MSW.

3.1 Waste framework directive

Directive 75/442/EEC

Amended by directives 91/156/EEC, 91/692/EEC, 96/350/EC, 96/59/EC

This directive is the framework for management of all waste. MSW is only part of all waste. It forms the basis for all following directives.

The framework directive prescribes central principles:

- The waste management hierarchy: Prevention, re-use, recycling and recuperation of energy and materials get priority.
- Principle of Best Available Technology (BAT): disposal facilities must be equipped with the best available technology. The BAT is selected on technological, environmental and economical criteria.
- Principle of proximity: Waste must bet treated as close as possible to the place of production or collection.
- Principle of Self-sufficiency: Every member state, every community is responsible of its own waste.

- Polluter Pays Principle (PPP): Waste disposal facilities must not be paid by tax payer's money, but by the polluter.

The directive also puts specific obligations on the member states to ensure corporate governance. Every state must make a waste management plan which integrates local, regional and national needs. The Member state is responsible for control on the disposal facilities. A system of licenses has to be introduced. Members states must install a monitoring and reporting systems in accordance with the European guidelines (Eurostat, 2003, p85; www.europa.eu.int).

3.2 Non-tariff barriers: Ruling of Court of Justice: 20/11/1988

In the 1960's Denmark installed a deposit refund scheme for bottles. Metal cans were forbidden and producers were obliged to use refillable packaging. Local producers as Carlsberg and Tuborg adapted easily. Locally, they sold refillable bottles and for export they used non-refillable packaging.

For foreign firms the refillable requirement worked out differently. They did not want to adapt their internationally accepted non-refillable products to the Danish market. Foreign firms claimed that the deposit refund system formed a non-tariff barrier[2] and blocked the free European market. A system based on environmental concerns became an industrial battlefield.

The Court of Justice ruled in 1988 that a deposit refund system is allowed if:

- No specific European legislation is applicable
- It is in the general interest of the public

This ruling had an important consequence: protection of environment is imperative and can overrule free trade.

A critical remark can be made on the ruling. Refillable materials are not necessarily more environmentally friendly. Industrial competitors such as Sweden, Germany and the Netherlands have tried to prove this regularly to push the Danish government to a more open system. (Buclet, 2002, pp. 28)

3.3 Packaging and packaging waste directive

Directive 94/62/EEC

In 1991 the Töpfer law was introduced in Germany. The law prescribes high recycling rates and high standards for disposal facilities. The law introduces the Extended Producer Responsibility principle. It is the producer, the industry, that is responsible for monitoring and achieving the targets.

The German industry organised an alternative collection scheme: The green dot. A company pays a fee dependent on the packaging delivered to the market and may put the green dot label on its product. Green dot labelled products are free from Producer Responsibility.

High standards obliged expensive flue gas cleaning and good landfill isolation. Prices soared. A ton of waste incinerated in Germany costed 166 EUR/ton. In France the same waste incinerated costed 53 EUR/ton. This situation stimulated exports of waste to the rest of Europe. European landfills and incineration units

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[2] The market within the EU is free. Countries cannot put up barriers against foreign firms entering local markets. With a non-tariff barrier countries try to give local firms a competitive advantage

were flooded with German waste. German legislation obliged recycling. The high quality recycling products were sold all over Europe. Immature recycling efforts in other countries were killed by oversupply of recycled goods (Curzio, 1994, pp. 156; Buclet, 2002, pp. 81, pp. 116).

In order to harmonise packaging systems in Europe and in order to ensure functioning of the free market the Packaging directive was negotiated. The directive installed minimum standards:

- Every member state has to set up a system of return and collection of used packaging
- In line with the waste hierarchy the directive sets 5 year targets for recovery of energy and material and recycling of materials:
    - Recovery: 50-65 % (min-max)
    - Recycling: 25-45 % (min-max)
    - Minimum 15 % recycling for every packaging material
    - Portugal, Greece and Ireland get 5 years extra
- Member states must encourage use from recycled packaging waste

The directive is so important because it contains quantitative targets. In 2001 the European Commission did a proposal for higher recovery and recycling rates for 2006. Recovery should be between 60-75 % and recycling between 55-70 %. The minimum targets for glass, paper, metals and plastics will be reinforced up to respectively, 60, 55, 50 and 20 % (Eurostat, 2003, pp. 86;www.europa.eu.int).

without calling it a barrier. This is of course forbidden.

3.4 Landfill directive

Directive 99/31/EEC

The aim of the directive is to prevent or reduce negative impacts of landfilling on the environment and health risks.

This directive is a difficult compromise between nations. The first proposal of the Commission started the discussion in 1990. The final directive was approved in 1999. Many countries in the EU rely heavily on landfilling. Prescribing high standards raises the price of waste management.

Especially UK delayed the approval of the directive. The UK has a tradition of co-disposal. That means that in one landfill hazardous and non-hazardous waste are mixed. This is a cheap form of storing hazardous waste. As English companies had a strong expertise, UK wanted to introduce this technique in whole Europe to open new markets. The rest of Europe wanted to ban this technique in UK (Buclet, 2002, pp. 95, pp. 99).

The directive prescribes following measures:

- Treating waste before landfilling
- Phasing out co-disposal
- Supervising closure and aftercare: it is not enough anymore to simply dump soil on an old landfill to put it out of sight.
- In the line with the PPP a min price for landfilling is defined. Pre-treatment costs, Investment costs, operating costs, cost of closure, after care, financial provisions have to be included in the price.

- Targets are set to reduce the amount of biodegradable waste sent to landfills. The base is the amount of municipal biodegradable waste in 1995.

  2006: 75 % of biodegradable waste sent to landfill

  2009: 50 % of biodegradable waste sent to landfill

  2016: 35 % of biodegradable waste sent to landfill

  Countries that rely highly on landfilling get a 4-year derogation. Again, the quantitative targets have the strongest impact on national strategies. This will be illustrated in the chapter on UK policies. (www.europa.eu.int; Strategy Unit UK, 2002)

3.5 Incineration directive

Directive 2000/76/EU

The aim is to prevent and reduce pollution of air, water, soil and damage to human health by incineration.

The directive prescribes technical standards for incineration facilities. Emissions of CO, HCl, Total Organic Carbon (TOC), HF, SO2, NO, NO2, dioxins, … are limited (www.europa.eu.int).

3.6 Waste transport directive

Directive EEC/259/93 and 94/721/EEC

The aim is to regulate imports and exports of waste inside and outside the EU.

A reason for the transport directive is a conflict of principles. Based on the Extended Producer Liability and the Waste Hierarchy, the producer tries to recycle his waste in the cheapest way and tries to sell his recycled waste at the best price. However, this can form a conflict with the principle of Proximity and Self-sufficiency. The producer should recycle his waste as close as possible and sell it to the nearest producer.

The case of Belgium illustrates this conflict. Belgium recycles its paper. There is, however, no industry that uses recycled paper. Belgium exports/sells its recycled paper to French paper producers. This is sound economic and environmental policy. However, this is in conflict with the principle of Proximity and Self-sufficiency (Buclet, 2002, pp. 17, pp. 39, pp. 118).

The transport directive divides the waste in three lists and sets priorities for each list:

- Green List: Free transport (just notification to government)
  e.g.: sorted MSW
- Orange List: Limited transport e.g.: unsorted MSW
- Red List: Transport restricted strongly: e.g.: hazardous waste

Products on the Green List can be traded freely. Products on the Orange and Red List are restricted and fall under the principles of Proximity and Self-sufficiency.

Exports out of and imports into the EU are forbidden except for specific situations (www.eea.eu.int; Jaspers, 2003, pp. 2).

3.7 European impact

The directives of the European Union introduced sound minimum policies for all member states. The European policies ended complete negligence of the waste problem. Dumping in a random pit without any environmental protection, burning waste without any flue gas cleaning and exporting to third world countries were forbidden.

The directives also put forward a clear vision with priority to prevention, recycling and recovery. The targets will be strengthened in the future. This will have a strong impact on waste management in whole Europe and especially on laggards as UK and Greece.

The role of front-runners as Germany, the Netherlands or Denmark cannot be underestimated. They proved the liveability of sustainable waste management. In those countries industrial interests could build up in order to spread around Europe and form the pressure necessary in negotiating EU directives.

4 Technology and environment

While waste cannot be eliminated, we can reduce its environmental impact by preventing waste wherever possible, and making more sustainable use of the waste that is produced. This is known as the "waste management hierarchy": we should aim to reduce, re-use or recycle waste (3Rs) as the preferred options to other waste treatment methods (e.g. landfill or incineration). Prevention has the highest priority. Where possible, prevention has the highest positive impacts on the waste cycle. Prevention is difficult to measure and the possible measures are numerous.

By using 3Rs management practices we can minimise operational costs and environmental harm. This fact puts them as the most desirable options in the waste management hierarchy. However, they are still not the most common ones. This is mainly because it will take too many socio- economical aspects to make those methods fully attractive for society. That is why we will have a closer look at such technologies as incineration and landfilling that are still used most often. After the technological description of those methods, their costs and impact to the environment and health, we will conclude by summing up the advantages and the impacts on the environment.

4.1 Prevention: reduce and reuse

Waste prevention is the first priority among waste management options because it has no negative effect to the environment, conserves energy and resources, and does not require new facilities. It is also called source reduction because it reduces or eliminates pollution at the sources.

It involves changes in the design, manufacture, purchase or use of products and materials to reduce the amount and toxicity of what gets thrown away (E.Smith, 2004, pp.427). Reducing the amount of waste generated is a practical way to reduce disposal and production costs as well as environmental impacts. There are several examples of waste prevention:

- Using of minimal or reusable packaging
- Using and maintaininig durable equipment and supplies
- Reusing products and supplies
- Using supplies and materials more efficiently
- Reducing the use of hazardous consistants - if difficult to handle or hazardous materials which can be substituted by easy recyclable or recoverable materials, negative impacts would be minimised (www.epa.gov/epaoswer).

Reusing also reduces waste. It is preferable to recycling, as the item does not need to be reprocessed before it can be used again.

4.2 Recycling and composting

4.2.1 Recycling

Recycling turns materials that would otherwise become waste into valuable resources and generates a host of environmental, financial, and social benefits. It prevents the emission of many greenhouse gases and water pollutants. Recycling decreases the need to extract and process virgin material, which pollute air, soil and water with toxic material. It saves energy necessary to produce new materials. It can save from 1.5 to 5 times more energy than is generated by incineration (Association of Cities and Regions for Recycling - ACRR, 2004).

After collection, materials such as: glass, aluminium, steel, plastics, and paper are separated and sent to facilities that can process them into new materials or products (Smith, 2004, pp. 427).

Paper and aluminium offer the best returns from recycling per ton of MSW. Glass provides the least benefit (ACRR, 2004).

Aluminium is used in many packaging applications: beverage cans, laminates and foils.It has a high value as a scrap metal and can be economically recycled. Aluminium recycling uses 95% less energy than it is made from raw ore. It also creates approximately 95% less water and air pollution (ACRR, 2004).

It is more environmentally friendly to recycle waste paper for new paper production than it is to burn waste paper for energy production. One ton of paper used for recycling saves 40% of the energy used to make paper from virgin material (ACRR, 2004).

Glass recycling saves 4-32% of the energy necessary to produce glass from virgin material. It leads to 20% less air pollution and 50% less water pollution.

Using recycled material to produce new plastics uses 2/3 of the energy required to manufacture it from raw materials. However there are some problems with plastic recycling. Those problems are mainly due to technical issues. There are different kinds of plastic polymers that cannot be treated together. Prior to the recycling, separation is required.

We should also be aware that the market for recycled materials is volatile. When prices are too low for particular materials, it costs communities more to collect, separate and sell them than to landfill them (de Betlencourt, 2000, pp. 157).

4.2.2 Composting

Composting is another form of recycling. There are different methods of treating biodegradable materials. However, in this project we will focus only on composting as this is the principal alternative treatment for biodegradable waste. In view of the EU Landfill directive, in order to reduce dependence on landfills, a substantial increase in composting can be expected (www.europa.eu.int).

Composting is nature's way of recycling organic wastes. It is an aerobic process in which biologically degradable wastes are broken down to form a stable, granular material, through self-heating. The process is a complex interaction between the waste and the micro-organisms within the waste. The micro-organisms that carry out this process fall into three groups: bacteria, fungi and actinomycetes. Actinomycetes is a form of fungi – like bacteria microscopic organisms that break down organic matter. The first stage of the biological activity is the consumption of easily available sugars by bacteria, which causes a fast rise in temperature. The second stage involves bacteria and actinomycetes that cause cellulose breakdown. As the compost cools there is the last stage which concerns the breakdown of the tougher lignins by fungi (Eumnomia research, 2003, pp.23).

The suitable conditions for efficiently biological activity has to cover the following critical factors: **carbon to nitrogen ratio**, the ideal carbon to nitrogen (C:N) ratio, by weight is 30 parts carbon to 1 part nitrogen; **particle size,** an optimal size for compost material is approximately two inches (~5cm) ;

aeration, compost pile should be aerated at least once or twice a month to sustain oxygen levels and prevent anaerobic conditions, which produces odours and other harmful by-products; **moisture,** an optimal moisture content by weight is 40 or 60 percent; **temperature**, temperature around 65^{0}C guaranties the destruction of harmful pathogens (Jørgensen, 1981, pp. 358).

Composting provides the humus and nutrients essential for a healthy soil. By returning compost to the soil, the soil is rebuilt and maintained for sustainable production.

There are various methods and equipment available for the composting process depending on the kind of material and the time needed for composting process. The general experience in composting is that oxygen supply is the most important factor, and therefore equipment design tends to concentrate on the efficient transfer of oxygen to all parts of the composting material (Jørgensen, 1981, pp. 358).

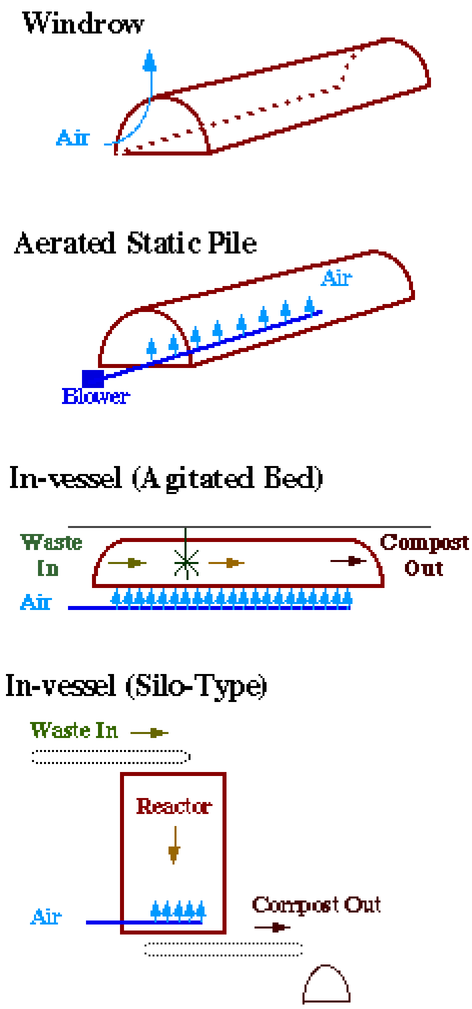


Figure 1. Typical Composting Systems

Figure 4-1: Composting systems

References: Cornell University

4.2.2.1 Windrows

Windrows system is a low technology system which requires minimum investment in terms of equipment and finance (see Figure 4-1).

Windrows are a traditional form of composting in which the material is placed into long piles or rows (windrows), usually between 2-3m high and 3-4m wide.

Optimum moisture content is around 50%. When the material is dry it needs water adding prior to composting. If different materials are to be decomposed, they need to be mixed before composing.

Aeration of the windrow is achieved by turning the material. To turn the piles, tractors with front end loaders or different kinds of machinery are used. The composting process occurs faster inside the windrow where the temperatures are higher. Therefore, by exchanging material from the inside to the outside, greater uniformity in the final material is achieved. Compost in windrow is usually ready within 10 months. After this period, the compost is moved to curing and storage piles for another 40 days (Cornell University, Composting trends and technologies).

4.2.2.2 Aerated piles

There is a wide range of improved mechanical composting systems, which all aim to improve the method of aeration so as to maintain optimum conditions within a decomposting system.

Aerated piles are used to move air through the pile. When temperature in the material exceeds the optimum, a thermostatically controlled blower pushes or pulls air through the pile for aeration. In the same time it is cooling the pile and supplying the necessary oxygen.

Because there is no mechanism for remixing during the composting process aerated static piles are most commonly used for homogeneous materials such as sludges. When those materials are mixed with a dry porous substrate like woodchips they form a thin liquid film in which decomposition can occur (Cornell University, Composting trends and technologies).

4.2.2.3 Enclossed vessels (invessels)

The third technology is enclossed vessels composting. The vessel or container can be anything from a silo to a concrete-lined trench. Within these systems it is possible to collect and treat odours from such materials as sludge or MSW. In-vessel systems usually use forced aeration, similar to an aerated static pile.

Differently silo-type systems which rely on gravity to move material through the vessel. Because there is a lack of internal mixing, it limits the silos to homogeneous materials like sludge.

Agitated bed is another enclosed vessel systems. It includes internal mixing that physically moves materials through the vessel, combining the advantages of the windrow and aerated static pile methods. In general composting process in this method can be very rapid (few days).

The differences between these compost processing technologies largely revolve around how they manage the critical factors. Since no one system is consistently the best, evaluating the trade-offs for a particular situation is a large part of developing a successful composting program (Cornell University, Composting trends and technologies).

4.2.3 Costs

Composting costs include site acquisition and development, regulatory compliance, facility operations and marketing of the finished product. The facility must be approved by the local health department. Additional requirements may include land for buffers around the compost facility, site preparation, and handling equipment such as shredders, screens, conveyers and turners. Facilities and practise to control odours, leachate and run off are a critical part of any compost operation.

The cost of constructing and operating a windrow composting facility will vary from one location to another. The operating costs depend on the volume of material processed. The use of additional feed materials, such as paper and mixed municipal solid waste, which will require additional capital investment and materials processing labour.

The capital costs of windrow or aerated piles is lower than in-vessel composting configuration. However, costs increase markedly when cover is required to control odours. In general costs of windrow systems are the lowest compered to the other two techniques.

In-vessel system is more costly than other methods, mainly with respect to capital expenditures. Also, because it is more mechanised and more equipment maintenance is necessary, however the labour intensive tend to be less (EPA, Biosolids Technology fact Sheet, 1994, pp. 7).

4.2.4 Environmental and health impacts

Composting can be used as fertiliser for agricultural soils. This practice can be extremely important in order to decrease the amounts of chemical fertilisers used. Composting practices emit into the atmosphere different gases: greenhouse gases (GHGs), volatile organic compounds (VOCs) and odours. In soils and water systems the major concerns are due to deposition of salts and heavy metals.

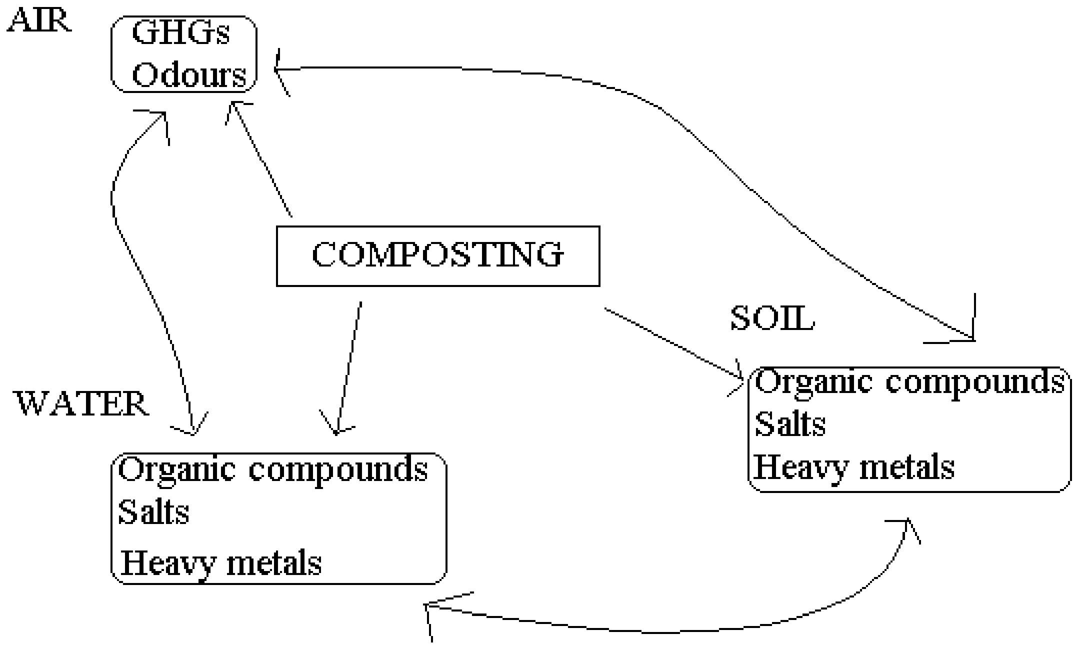


Figure 4-2: Principal emissions from composting

4.2.4.1 Air pollution

The main issues are releases of different GHGs (VOCs, CO_2 and CH_4) and odours (NH_3, H_2S) (Peigne & Girardin 2004, pp. 45-68). VOCs increase the level of smog (tropospheric ozone), which can modify the temperature structure of the atmosphere, leading to climate changes. The emissions of VOCs depend on the temperature, aeration and biological activity in the compost. The greenhouse gases CO2 and CH4 trap thermal energy that comes to the atmosphere, rising the global temperature of the Earth (Gardner et al. 1993, pp. 165-174). The contribution of GHGs from composting to global warming is low because this practice is not yet widespread. Enclosed composting facilities have biofilters that remove odour emissions (Tsiliyannis 1999, pp. 231-241).

4.2.4.2 Soil pollution

Pollution of soils is mainly due to the addition of salts, heavy metals and different organic compounds. They change the properties of the soil and can be toxic for the vegetation. Some metals are present in composted soils in higher concentrations than in agricultural soil, e.g. lead, zinc and copper, which can lead to the impairment of crops. If the bioavailability is high, these compounds can cause contamination in the whole food chain. The form in which the metal is found, determines the bioavailability. Some of them being much easier to mobilise by water or plants than others. Application of compost as fertilisers has effects in the soil's physical, chemical and microbiological characteristics such as:

- Physical characteristics: organic matter added to soils from compost improves the stability. It increases the water holding capacity and the porosity, which is beneficial for agricultural purposes.
- Chemical characteristics: the main positive effects are remarkable augmentation in the content of organic matter and an increase in pH in acidic soils. Both changes are also extremely beneficial for agricultural purposes. However, if the compost is contaminated, the levels of organic contaminants may increase. Also, the levels of some other pollutants, e.g. PAHs, PCBs, phenols and heavy metals may increase. The conductivity of the soil can

change due to a higher concentration of salts, which affects negatively the uptake of nutrients from the plants.

- Microbiological characteristics: changes in the physical and chemical characteristics of the soil induce changes in its microfauna. Redistribution of organisms, changes in abundance and biodiversity and/or interferences with some of their metabolic activities might happen. This will affect the surrounding vegetation.

Some soils are much more susceptible to contamination than others (He at al. 1992, pp. 318-329). The biodegradable waste used for composting must be free of contamination. If not, the end product will also be contaminated. The contamination will be passed on to the soil whereto the compost is added.

4.2.4.3 Water pollution

The main pollutants of the water systems are caused by washout processes of soils treated with compost. Therefore, the contamination of water systems includes heavy metals, different organic compounds, e.g. phenols, PAHs, PCBs, etc., and salts, e.g. NO_3^-, NH_4^+, etc. (He at al. 1992, pp. 318-329; Peigne & Girardin 2004, pp. 45-68).

4.3 Incineration

The reduction in available land for landfill and the growing amount of garbage have become a major problem for many municipalities (Rowat 1999, pp. 389-396). Therefore incineration has become a solution for this problem, reducing significantly the volume of waste. Despite this advantage, Municipal Waste

Incineration has many environmental problems that need to be overcome before using incineration processes as the major waste management option.

4.3.1 Main techniques

Incineration is a controlled burning process. It has been used for dealing with waste over the last century, during which time technologies, particularly for treatment of emissions have vastly improved.

There is a clear distinction between incineration and RDF (Refuse Derived Fuel) plants. Incineration plants may or may not recover heat generated by combustion, while RDF plants (such as cement kilns, steel or power plants) main purpose is energy generation or the production of material products (www.europa.eu.int).

The incineration of waste is a subject of considerable public concern. In the absence of effective controls, harmful pollutants may be emitted into the air, land and water where they may influence human health and environment impacts, e.g. acidification. It is widely recognised that whilst incineration of waste, preferably with energy recovery, can form an important part of an integrated waste management system, strict controls are required to prevent adverse environmental impacts.

Thermal treatment is a broad term used to describe a range of heating or combustion technologies used for the treatment of waste. Various technologies have been developed which differ significantly depending on process temperature, amount of oxygen and the specific waste catered for, but all produce large quantities of heat which can be recovered as process heat, steam/hot water for district heating or for the production of electricity (Eunomia research, 2003, pp. 13). The most common types are mass burn, Fluidised Bed Combustion (FBC), pyrolysis and gasification.

4.3.1.1 Mass burn

Mass burn is the simplest and the most common form of incineration. The following figure 4-3 shows Dudley plant in the West Midlands (1998):

Figure 4-3: Dudley waste incineration plant
References: Cardiff University, MSW combustion

At first the incinerator has to be brought up to the running temperature of about 740^{0} C before it is operational. Waste arrives in a dustcart and is tipped into the holding area (1) where it is picked up by the grabs (2) and dropped into the feed hoppers (3). The waste is then mechanically pushed by a hydraulic ram (5) onto the moving grate within the incinerator (4). This will allow the refuse to gradually pass through the incinerator for about two and a half hours. Air is drawn to the combustion chamber from the holding chamber (6) to avoid the escape of malodours to the surrounding community. The ash is quenched (7) and its recycling can be carried out by extracting the metal content using an electromagnet. The heat from the combustion chamber is utilised in a multi-pass boiler (8). The flue gas will then need to go through a clean up operation before they can be discharged to the air. Dry urea is injected directly into the combustion chamber to limit the production of nitrous oxides (NO_x), which is a green gas causing acid rain. The gases will then go to the scrubber reactor (9) which sprays lime milk in order to treat acid pollutants (SO_2 and HCl) and injects active carbon to remove residual organic compounds such as dioxins. Further they will pass through a bag house filter which removes particulate matter and take out the heavy metals. In this way a big amount of poisonous and environmentally damaging components are removed from the flue gases and the remainder (mostly carbon dioxide and water vapour) can be discharged through the chimney stack.

The efficiency of electricity recovery is about 21%. The waste is reduced to 24% of its original weight and only 10% of the original volume (Cardiff University, MSW combustion). 75% of this is bottom ash which is inert, 12.5% more is recovered as ferrous metals. 12.5% of fly ash is collected. This is a special kind of waste because lime that is used to neutralise the acidic gases gives it an irritant property. The bottom ash is disposed of in regular municipal landfills or it can be used as a substitute raw material in road construction. However the fly ash has to be sent to a specific landfill waste that is potentially hazardous. Therefore the landfill needs effective leachate controls to reduce the risk of polluting local groundwater systems (Cardiff University, MSW combustion).

4.3.1.2 Fluidised bed combustion

Fluidised bed incinerators operate with a bed of hot sand. Before the waste is incinerated, non-combustible components are removed. Then the wastes are shredded to produce coarse Refuse Derive Fuel (cRDF). cRDF has a higher calorific value than waste that was not treated. The further process is based on feding cRDF into a bed made up of a mixture of sand and dolomite (sulphur-absorbing chemical). In this process small particles of waste material and inert sand bed material are fluidised by injection of air underneath with sufficient velocity to keep the particles in the bed in a constant state of turbulent motion, providing good mixing. The bed consists of an expanded formation of waste and bed particles which resemble a bubbling liquid and provides good mixing and turbulence, combined with long residence time, promoting good burnout of the waste. Secondary air is injected above the bed in the freeboard, where combustion of volatile compounds takes place. Temperatures generally remain below 1000^0 C, minimising the levels of NO_x produced in the combustion process (Zscherning).

There are two variations: bubbling fluidised beds and circulating fluidised beds. In a bubbling fluidised bed the combustion air velocity is set so that the expanded bed formation remains stable, with most of the reactions and heat transfer taking place either in the bed or just above it. With circulating fluidised beds, higher velocities are used so that the solid particles are transported with the flue gases. Heat recovery is possible on the recirculated solids. If we compared, the whole process is between 25-35% slower than mass burn technology (Zscherning).

4.3.1.3 Pyrolysis and gasification

Pyrolysis and gasification are quite new methods for treatments of municipal solid waste and remain relatively unproven in European usage compared with classical methods. Despite the fact that these technologies are widely used and well established as industrial processes for energy recovery from hydrocarbons feedstock, their use as process for dealing with mixed municipal waste streams is at an early stage of development.

Both pyrolysis and gasification turn wastes into energy rich fuels by heating the waste under controlled conditions. In contrast to incineration, which fully converts the input waste into energy and ash, these processes deliberately limit the conversion so that combustion does not take place directly. Instead, they convert the waste into valuable intermediates that can be further processed for materials recycling or energy recovery e.g. syngas (a mixture of carbon monoxide and hydrogen), oils and char (Eunomia research, 2003, pp. 16).

Pyrolysis is a thermal decomposition of fuel in the absence of air. Solid waste is converted to a gas and/or liquid, which is then converted to electricity by combustion in a gas turbine or diesel engine. Some solid residue generally remains. Heat has to be provided to the fuel for decomposition to occur and this is normally integrated into the overall process scheme.

One advantage of the pyrolysis technique is that some liquid fuel can be produced, which is versatile, easily transportable and could be used, for example, as a transport fuel in an international combustion engine. Because much of the fuel produced in the pyrolysis process is consumed within the operation, pyrolyis tends not to be an efficient conversion technology (Zschernig).

Gasification is a reaction between the fuel and oxidant (steam and oxygen) carried out in a restricted supply of oxygen so that complete combustion of the fuel does not take place. Instead the volatile gas comprising combustible components, such as hydrogen, carbon monoxide, methane and higher hydrocarbons is produced, which is subsequently burned to generate electricity, normally in a gas turbine. Gasification reactions include partial oxidation of the fuel and the water gas reaction and so are generally autothermic, not requiring heat to be supplied from elsewhere in the process. Therefore, thermochemical conversion of the fuel to electricity effectively takes place in two stages. The advantage of this is that pollutants can be removed from the small fuel gas stream. Also, the second stage is often in a gas turbine or diesel engine. Consequently a higher overall plant efficiency can be achieved through the use of combined cycles with the potential for further increase as gas turbine firing temperatures are increased (Zschernig).

Gasification is an energy efficient technique for minimising the solid waste volume and for recovering energy. It generates 500-600 kWh useable energy per ton of waste. This technology has been used more widely than pyrolysis because it doesn't have problems with heat transfer and is a more efficient process that produces a single gaseous product (Cardfiff University, 'Gasification').

4.3.2 Costs

Incineration costs vary depending on an applied incineration technique. Mass burn incineration as the lowest technology system seams to be the cheapest whereas pyrolysis and gasification are more advanced technologies and are still in development stage.

In general, as with landfilling, variations of incineration costs are associated with the degree to which emissions are regulated. Countries have different emission standards. The tighter the standards, the bigger are the requirements for additional capital investment.

Another important aspect of an incineration plant is energy recovery. Those countries that have incinerators attached to the district heating schemes can benefit from sales of heat energy and electricity. In some countries energy purchases are subsidised as the energy gained from waste is considered to be renewable. Those subsidies reduce incineration gate fees (unit prices paid by the consumer for the service provided). However, there are also countries that tax incineration as well as landfilling. When considering costs of incineration the approach taken to deal with residues is also very important. In some countries bottom ash and fly ash are recycled, e.g. in construction facilities. In most cases the ashes are still landfilled which causes further cost escalation (Eunomia research, 2003, pp.119).

4.3.3 Environmental and health impacts

Problems related to incineration practices are incomplete burning of some materials, inadequate functioning of the pollution control equipment and lack of pollution monitoring in the incineration plants. Emissions have strong health and environment impacts, due to the high toxicity of the released compounds and because of their capacity to spread over long distances (Anon. DETR 1999). Small incineration plants lack the adequate filters to prevent releases of toxic compounds to the environment, and in many of the larger ones they do not always work, or at least not properly (Låg 1985, pp. 356; Lisk 1988, pp. 39-66).

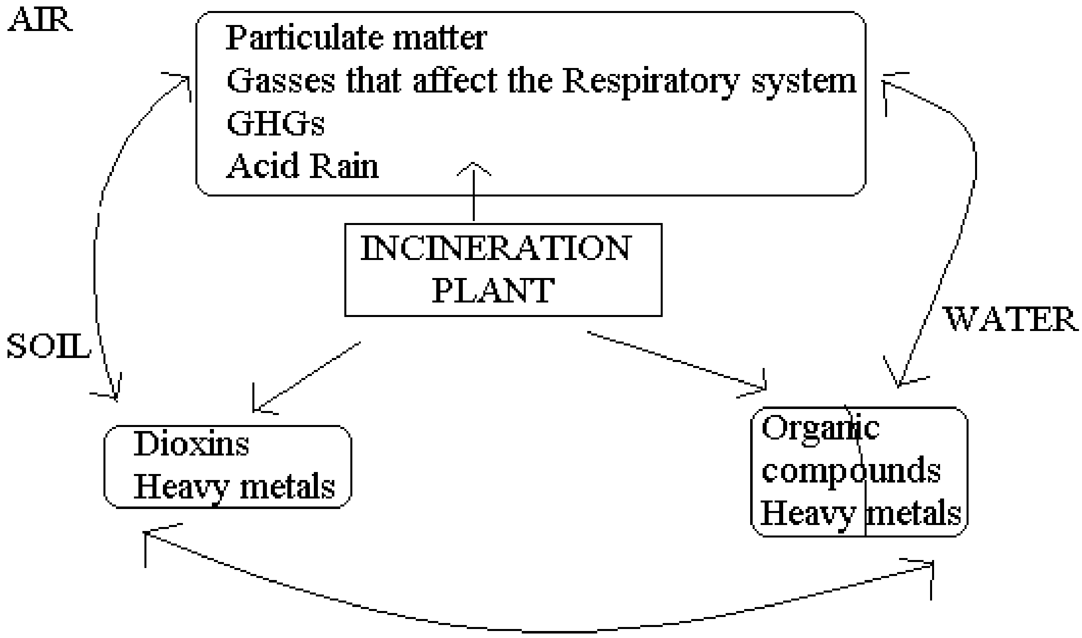


Figure 4-4: Principal emissions from an incineration plant

Releases of dioxins, heavy metals and other compounds (OCS, PCBs, HCBs) afterwards settle down on terrestrial and water systems systems (Chu et al. 2003, pp. 619-625). The impacts of the emissions are much more important in soil and water systems (see soil and water sections) than in the atmosphere. Although the releases of dioxins by MSWI facilities have diminished thanks to new EU legislation (Domingo et al. 2002, pp. 461-465), MSWI is still one of the major source of emissions of these substances (Cohen et al. 2002, pp. 4831-4845).

The amount and kind of toxins released through the chimney is influenced by:

- Oven Temperature.
- Climate.
- Moisture conditions.
- Waste composition.

- Performance of the air pollution control equipment.

There are different recovery techniques that decrease the amount released, but the data are not always reliable because of the non-continuous sampling methods (Connett & Connett 1994, pp.14-20).

4.3.3.1 Air pollution

It is one of the major distresses regarding incineration activities. Depending on the temperature the facility is working at, the releases of pollutants change. At high temperatures heavy metals escape, but, on the other hand, at lower temperatures, there is production of dioxins and other organic compounds that would be eliminated if the facility was working at high temperatures. At the start up of the incineration plant, with cold temperatures, most of the toxic organic compounds are formed. The technologies, e.g. creation of biofilters, addition of active carbon, etc., diminish the quantity and toxicity of some pollutants. The toxic compounds are concentrated in the ashes. After combustion, those residues are generally landfilled. This can lead to toxic releases onto soils.

The principal emissions from a MSWI facility are particulate matter, gases contributing to the greenhouse effect and causing acid rain (SOx, H_2S, CO, Volatile Organic Compounds (VOCs, including CFCs) and NOx), polycyclic aromatic hydrocarbons (PAHs), gases that affect the respiratory system (Aldehydes, HCl and polycyclic aromatic compounds (PCAs)), dioxins, octachlorostyrene (OCS), heavy metals and a multitude of other organic compounds (Rowat 1999, pp. 389-396; anon. Saskatchewan Environment 2003). PAHs, dioxins, OCS, heavy metals and other organic compounds affect mainly the aquatic and terrestrial systems when they settle down from the atmosphere.

PARTICULATE MATTER

Particulate matter is a general term used for dust and soot that includes particles composed of organic matter and other. They can cause health problems because they can affect the pulmonary function of humans (Hu et al. 2001, pp. 1185-1194). The most common effects are chronic bronchitis, aggravating asthma and premature deaths (anon. CCME 2004). Similar effects have been observed with animals (anon. Saskatchewan Environment 2003).

GASES THAT AFFECT THE RESPIRATORY SYSTEM

The main ones are Hidrochloric acid, Aldehydes and Polycyclic aromatic compounds (PCAs). The first two compounds cause irritation of the respiratory tract and in addition they can contaminate soil and water. Aldehydes are animal carcinogens as well (anon. Saskatchewan Environment 2003). PCAs such as naphthalene, benzo(a)pyrene, anthracene, fluoranthene, pyrene and phenantherene among others, are found both in the gaseous emissions and in the fly ash. Some of them are proved to be carcinogens, affecting preferentially the respiratory system (Rowat 1999, pp. 389-396).

GLOBAL WARMING AND ACID RAIN

Some of the gases produced in the incineration process are GHGs, like CO, volatile organic compounds (VOCs) and NOx, and gases that contribute to acid rain, like SOx, H_2S and again NOx (anon. Saskatchewan Environment 2003).

CO is oxidized in the atmosphere, becoming CO_2, one of the most important GHGs due to its highly increasing levels in the atmosphere. VOCs, which are released during incomplete incineration of basically any kind of organic, increase the level of smog (tropospheric ozone) (Gardner et al. 1993, pp. 165-

174). High ozone levels on the tropospheric layer are also known to affect human health, causing chronic lung diseases. It damages crops as well, and increases in some tree species their vulnerability to some diseases (anon. CCME 2004). Another kind of VOCs, the chlorofluorocarbons (CFCs) cause depletion of the stratospheric ozone, also contributing to global warming. NOx intensifies the formation of smog and acid rain. In a lesser extent NOx participates in the depletion of the stratospheric ozone layer. It can also cause several respiratory illnesses, e.g. significant increase in bronchitis in children exposed to high levels of nitrogen dioxide (anon. Saskatchewan Environment, 2003; Rowat, 1999, pp. 389-396).

4.3.3.2 Soil pollution

Pollution of soils is basically due to deposition of particles released to the atmosphere that settle down at some point (which can be far away from the incinerator), and in a lesser extent, due to landfilling of ashes from incineration facilities. The deposition of particles from aerial systems depends on their weight. The heavier ones settle down closer to the incinerator than the light ones, that can travel over long distances, causing global problems (Cohen et al. 2002, pp. 4831-4845). The landfilling of Incineration Bottom Ash is another source of soil pollution from incineration. There have been many attempts to use it as fertiliser and in the construction industry, e.g. asphalt for roads and concrete for buildings. However, if the ashes are not treated in a good way before reuse, there are major regards due to its toxicity.

DIOXINS

The term dioxin is used for a high number of potential carcinogens and endocrine disrupters (Cohen et al. 2002, pp. 4831-4845). Dioxins are persistent organic pollutants (POPs) (Anon. 1999b). They are known to be extremely toxic even at low concentration levels (Anon. 2004b). There are around 700 different compounds, all of them members of the following chemical families:

- Polychlorinated dibenzo-p-dioxins (PCDDs)
- Polychlorinated dibenzofurans (PCDFs or furans)
- Co-planar polychlorinated biphenyls (PCBs) (Anon. 2003a)

The most toxic of all is 2,3,7,8-tetrachlorodibenzo-p-dioxin or TCDD (Anon. 2003a). TCDD has been categorised as a known human carcinogen by the International Agency for Research on Cancer (IARC) in 1997. Dioxins are bioaccumulated in the environment through the food chain, especially in fat tissues. They are widespread in all environments, but they concentrate in sediments and animals. Dioxins settle down from the atmosphere onto soils and water surfaces deposition (Cohen et al. 2002, pp. 4831-4845; Vassileva et al. 2000, pp. 159-173). The vegetation accumulates these compounds and some plants can be used as bioindicators (Loppi et al. 2000; Domingo et al. 2001, pp. 517-524).

60 % of the accumulation on fruits and vegetables come from air-to-leaf transfer, 33% from deposition of particulate matter and 8% from absorption by the root. They enter the food chain when animals eat contaminated plants and sediments (Anon. 2003a). The oral bioaccesibility of dioxins for cattle in contaminated soils is between 19-34% (Ruby et al. 2002, pp. 4905-4911). Species high in the food chain, e.g. predators and scavengers, are affected by hormonal, reproductive and developmental impairments due to the high accumulation of dioxins in their tissues. To humans, dioxin exposure comes mainly via the food chain, especially in aliments with a high content in fat (Anon. 2004b). The estimated half-life in a human body is of 7 to 20 years,

depending on the source fat (Rowat 1999, pp. 389-396). Foetuses, new-borns and populations with a high exposure because of their diet, e.g. high consumers of fish and diary products, are the most vulnerable groups. Its main effects on humans are skin lesions and altered liver function when short-term exposure. Long term exposure might cause cardiovascular disorders, sensory impairments, depressive syndromes, disorders in the metabolism of fat, in the urinary tract and in pancreatic functions (Rowat 1999, pp. 389-396), impairment of the immune, nervous and endocrine systems, reproductive functions (Anon. 1999b), variation in serum lipid level, microsomal enzyme induction, gastrointestinal alterations and some types of. In foetuses and lactants they also affect the hypothalamic-pituitary-thyroid system (Anon. 2004b) which leads to a hormonal impairment that alters the normal development of the child.

HEAVY METALS

The main concerns regarding heavy metals are lead and cadmium contamination. Child exposition to lead via dust and atmospheric deposition on soils is critical in contaminated areas. It affects the nervous system, slowing down the nerval response (Anon. 2002b). High exposures might affect haemoglobin synthesis, kidneys, the gastrointestinal tract and the reproductive system (Anon 2004c).

The main intake pathway of cadmium is vegetables and corn products. The uptake of this heavy metal is mainly in acidic soils. Plants, especially epiphytic lichens, are good bioindicators of heavy metals contamination because they retain concentrations of cadmium similar to the surrounding environment (Loppi et al. 2000, pp. 361-371). Cadmium mainly accumulates in the kidney of animals and humans, damaging the filtering mechanisms. Even though heavy metals are eventually excreted, they remain in the body for a long time, several decades for humans. A long-term exposure can cause lung cancer and bone defects (osteomalacia, osteoporosis, etc.) (Anon 2004c). It is extremely toxic to soil organisms, e.g. earthworms, which can die at even low concentrations (Anon 2003c) and microorganisms, which will change the rate of leaf and litter decomposition response. Another heavy metal of concern for the microfauna of the European boreal forests is mercury response (Anon. 2002b).

4.3.3.3 Water pollution

Like in soil pollution, water pollution is mainly due to deposition of particles released into the atmosphere, but also due to washout processes in contaminated soils. These soils are contaminated either because of atmospheric deposition or due to dumping of ashes or other residues from the incinerators. The main pollutants are heavy metals and chlorinated compounds, e.g. OCS.

OCTACHLOROSTYRENE (OCS)

OCS has never been used as a commercial product, but it is a by-product formed in the partial incineration of chlorinated compounds at 600-800C (Chu et al. 2003, pp.619-625). Occasionally measured in soil and sediments it is quite abundant in aquatic fauna, especially marine species. It bioaccumulates through the food chain, being in low concentration at the bottom of the trophic chain (e.g. benthic fauna) and in much higher concentrations at the species at the top of the trophic chain (e.g. fish and marine mammals). It has also been found in bird samples. In human blood the measured levels are lower than expected for a species at the top of the food chain. However, 4-HO-Heptachlorostyrene, the main by-product of its metabolization, is found in high concentrations, which leads to the conclusion that we are able to metabolise OCS. Since this also happens to another predator species, namely the polar bear, we might underestimate its importance on the environment (Chu et al. 2003, pp.619-625).

HEAVY METALS

One of the main problems comes from mercury contamination, especially in the form of methyl-mercury. In acid conditions, pH between 5-7, surface water can mobilise ground mercury, which leads to higher concentrations of this heavy metal at lakes, groundwater systems, seas, etc. Fishes accumulate this metal in high concentrations. Other animals like humans are exposed through the food chain. Mercury mainly affects brain functions and if the contamination occurs early in the development, it causes persistent effects on the nervous system (Anon. 2002b). In humans it also causes DNA and chromosomal damages, birth defects, sperm damage, allergic reactions, headaches, etc. (Anon 2004c).

Both cadmium and lead also accumulate in aquatic systems. Cadmium is bioaccumulated especially in freshwater systems, while lead is of great concern in phytoplankton communities. Phytoplankton is of extremely high importance for the global equilibrium of the oceans (Anon 2004c).

4.4 Landfilling

Historically landfilling has been the major practice for municipal solid waste disposal. Nowadays municipalities are forced to find new methods for waste disposal due to critical environmental problems from old landfills and a lack of land availability caused by a fast growing population and a higher rate of waste-production. Landfilling solid waste is a permanent disposal process by which we spread, compact, and cover (seal) waste with either ash from the Waste-to-Energy facility or soil. It is still the most common form of disposal in the vast majority of cases.

Landfill sites have to be well designed to prevent surface water and groundwater pollution, to minimise all impacts from operations and to facilitate site closure, and post-closure care. Landfill system design report must contain: the suggested site boundaries, buffer area, waste fill area and contours, surface water control works, on site roads and structures, final cover design, design of liner and leachate collection system and landfill gas control works, monitoring facilities for groundwater, leachate and surface water, site closure and post-closure care facilities (Botlin, 1995, pp. 558). When designing landfill site the following characteristics must be considered: the geology, hydrogeology, topography, drainage, and permafrost of the site and transport facilities.

4.4.1 Configurations of sanitary landfilling

Sanitary landfill is an engineered facility that needs detailed planning, careful design and efficient operation as to minimise potential environmentl problems. There are three configurations of sanitary landfilling, depending on the landfill site topography: the area, the ramp and the trench method.

In the **area method** waste is spread on the ground and then compacted to 2 meters. Waste can be stacked into different layers with this method. To cover compacted waste soil or synthetic material is used. It is usually put after each operation day or more often. The **ramp method** is a kind of the area method. It is mainly used for sloping land. Wastes are spread and compacted on a slope. The **trench method** is the preferred method for disposing waste by landfilling. It is the most economical and manageable plan. It is used for flat or gently sloping land. In the trench design trenches are dug twice as wide as the tractors. The waste is then placed in and then soil is added to cover it. When selecting the waste to put in the trench it is important to separate wet wastes from dry waste (Council of European Professional Information Societies - CEPIS, 1998).

4.4.2 Mechanical Biological treatment

Prior to landfilling sometimes Mechanical Biological Treatment (MBT) is undertaken. Such pre-treatment can lead to the material to be landfilled being relatively benign to the environment. There are four stages of this process: waste input and control, mechanical conditioning, biological treatment and emplacement of treated waste at a landfill. The mechanical stage is to sort out the non-biodegradables and any recyclables. Next, the residual waste is prepared for biological treatment by comminution, mixing and, if necessary, moistening. The biological stage effects extensive biological stabilization of the waste. The waste is exposed to atmospheric oxygen to induce aerobic decomposition, or by breaking it down in the absence of atmospheric oxygen in anaerobic fermentation process. The last step is deposition of the treated material.

There are several advantages of MBT: reduction of the waste volume, lengthening the useful life of the landfill, while reducing the rate of gas formation, hence reducing the danger of landfill fires and reducing the leachate load (The Deutsche Gesellscheft fur Technische Zusammenarbeit - GTZ).

4.4.3 Landfill system

Nowadays solid waste landfills are of a ‘dry tomb’ design. The waste is isolated from water that can generate leachate from solid waste, which may cause groundwater pollution. The main concept of dry tomb is to isolate waste from the environment in a compacted soil and plastic sheeting tomb. Plastic sheeting is a thin layer of HDPE (high –density polyethylene). It is combined with a compacted soil-clay layer to form composite liner. A typical double composite liner landfill containment system is shown in figure 4-5 (Fred Lee, 2004, pp.1).

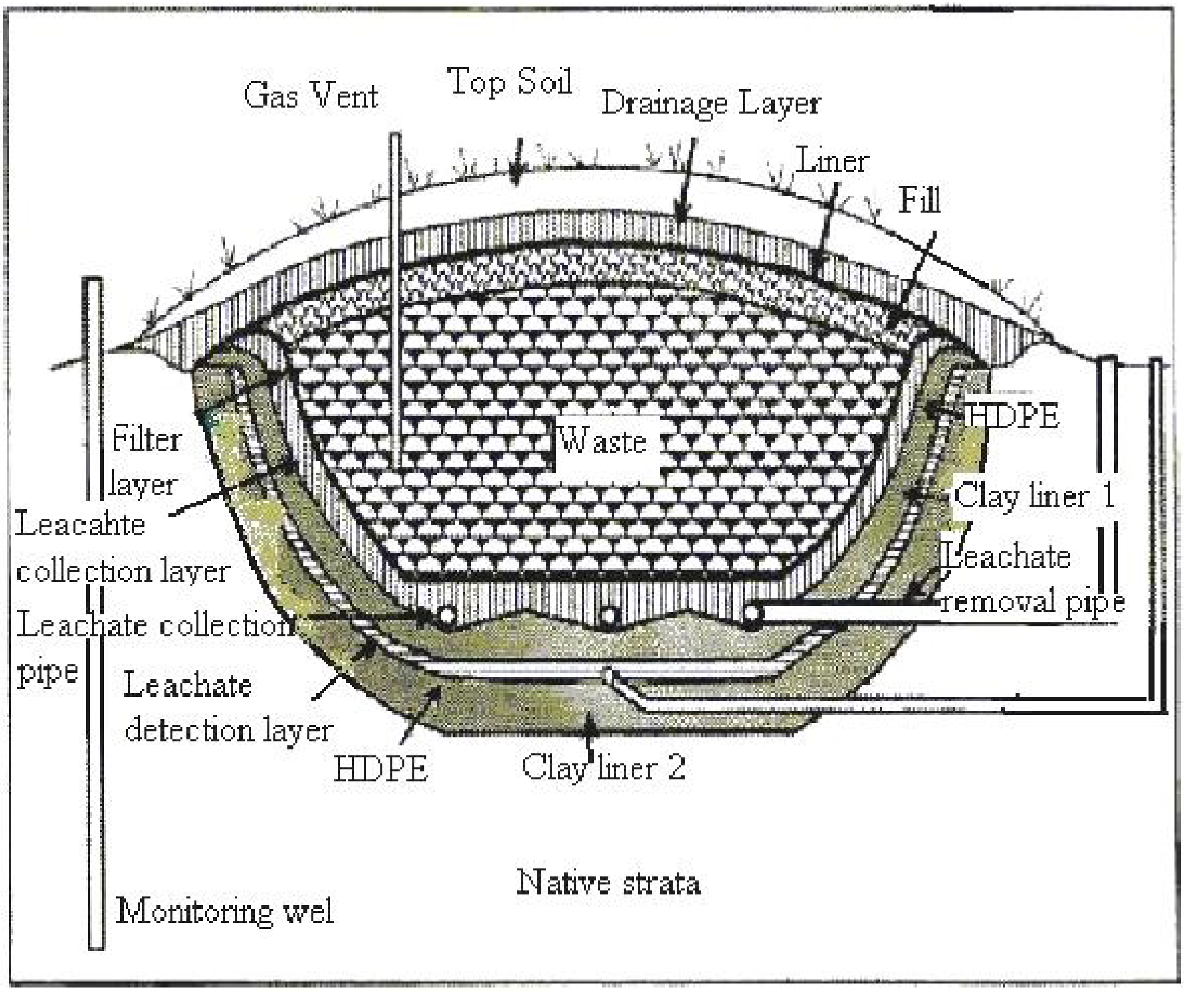


Figure 4-5: A double composite liner landfill system

References: Fred lee, 2004, pp.1

4.4.3.1 Leachate collection and removal system

Leachate is a noxious, mineralized liquid capable of transporting bacterial pollutants produced when water moves through the refuse (Botlin, 1995, pp.557). Leachate generated in the solid waste passes through a filter layer which underlines the waste. It is supposed to keep the solid waste from infiltrating to leachate collection system. This system usually consists of gravel. It allows leachate to flow across the top of the liner to the top of the HDPE liner. Then it flows across to the top of the liner to a collection pipe and is transported to a container, where the leachate can be pumped from the landfill. Lower composite liner represents a leak detection system for the upper liner. It is located between the two composite clay liners. It is suggested that geosynthetic liners should be used as an add-on to the regular clay liner. Geosynthetic liners are thin layers of bentonite clay which is encased in a woven material. Together with clay liners they minimise leachate formation through infiltration or ground water intrusion (Fred Lee, 2004, pp.7).

4.4.3.2 Landfill cover

The landfill cover is designed with a sloping surface as to enhance surface runoff. Runoff is then collected by drainage channels constructed at the surrounding edge of the landfill. Materials (geomembranes) usually used for waste cover are: low-permeability plastic sheeting layer, HDPE, very flexible polyethylene (VFPE), or polyvinyl chloride (PVC) (Zanzinger, 1999, pp. 2-3). Above the layer there is a drainage layer. Above there is topsoil that serves as vegetation layer. It is designed to promote the growth of vegetation that will reduce the erosion of the landfill cover. Landfill covers should be monitored as to detect when moisture leachate through the cover occurs. Usually it is a visual inspection of the vegetative soil layer. All the cracks and depressions that are observed are then filled with soil (Fred Lee, 2004, pp.5).

4.4.3.3 Landfill gas

The anaerobic decomposition of organic materials in a municipal solid waste landfill will generate a combination of gases, mainly methane and carbon dioxide. The migration of landfill gas under ground can pose safety risk for landfill construction. In smaller landfills the gas venting layer provides the effective collection and dispersion of landfill gas. The gas is passively released through vents installed in a landfills cover system. The gas venting layer in larger landfills is eliminated and the gas is actively collected via horizontal trenches and collection wells then burned in flares or utilised in projects that make use of the energy value of the methane component of the landfill gas. Landfill gas collection system should be installed. It should be designed to have at least 95% probability of collection all landfill gas generated at the landfill (Fred Lee, 2004, pp. 10).

4.4.4 Bioreactor landfill

A bioreactor landfill is a sanitary landfill that uses microbiological processes to transform and stabilise the decomposable organic waste within 5 to 10 years of implementation, compared to 30 to 100 years for dry Subtitle D landfills (those that accept MSW and so-called nonhazardous industrial waste). To promote waste stabilisation, moisture (usually leachate) is added. Stabilisation means that waste does not produce landfill gas any more through the biochemical reactions of bacteria utilising some of the organic components in wastes as a source of energy (Fred Lee, 2004, pp.12).

There are three different types of bioreactor landfill configurations: **aerobic-** leachate is re-circulated into the landfill and air is injected, **anaerobic-** leachate is also re-circulated into the landfill but biodegradation occurs in the absence of oxygen, **hybrid** - aerobic-anaerobic treatment to degrade organics in the upper part of the landfill and collect gas from lower part (EPA, 2003).

4.4.5 Costs

The costs of landfilling are determined by the extent to which waste is accepted and the regulatory regimes in different countries. Concerning landfilling costs we should take into account: the costs of engineering, operating costs such as monitoring and leachate treatment; site acquisition and any installations put in place to collect and generate energy from landfill gas. Engineering costs will be affected by geological characteristics of the potential landfill site and the size of the landfill will determine the contribution to unit prices charged for landfill disposal.

The future estimation is that landfill costs are likely to rise in those countries where gate fees are currently low. This rise will depend on many features such as the way in which different countries implement various aspects of the EU landfill directive (Eunomia research, 2003, pp.115).

4.4.6 Environmental and health impacts

The major concern regarding landfilling sites is the release of gases and leachates. The pollution of the aerial systems occurs through release of gas. The contamination of terrestrial and aquatic systems comes through leachates and landfill gases (El-Fadel et al. 1997, pp. 1-25; Tsiliyannis 1999, pp. 231-241).

The quantity of gases released from landfills has decreased due to the installation of covers. These covers not only stop the gases from spreading into the atmosphere, but can also recover and use them in energy recovery systems, e.g. methane that can be burned and produce energy.

The properties of the leachates vary greatly depending upon the different abiotic factors like temperature, moisture, aeration conditions and diversity of waste, etc. We will go through the main pollutants generated in leachates.

The impermeable layer of a landfill has a lifetime of 30 - 40 years. Even if state of the art technology is used the lifetime of a landfill cover is limited. The majority of the toxic emissions will be released during the lifetime of the covers. However, the toxic substances stored will not disappear. The toxic emissions won't stop completely. Will all the waste be dug up after the regular lifetime of the landfill and put in a new landfill? What will be done if leaks are detected? Landfills have an unavoidable long-term risk of toxic emissions (Ludwig et al., 2003, pp.365).

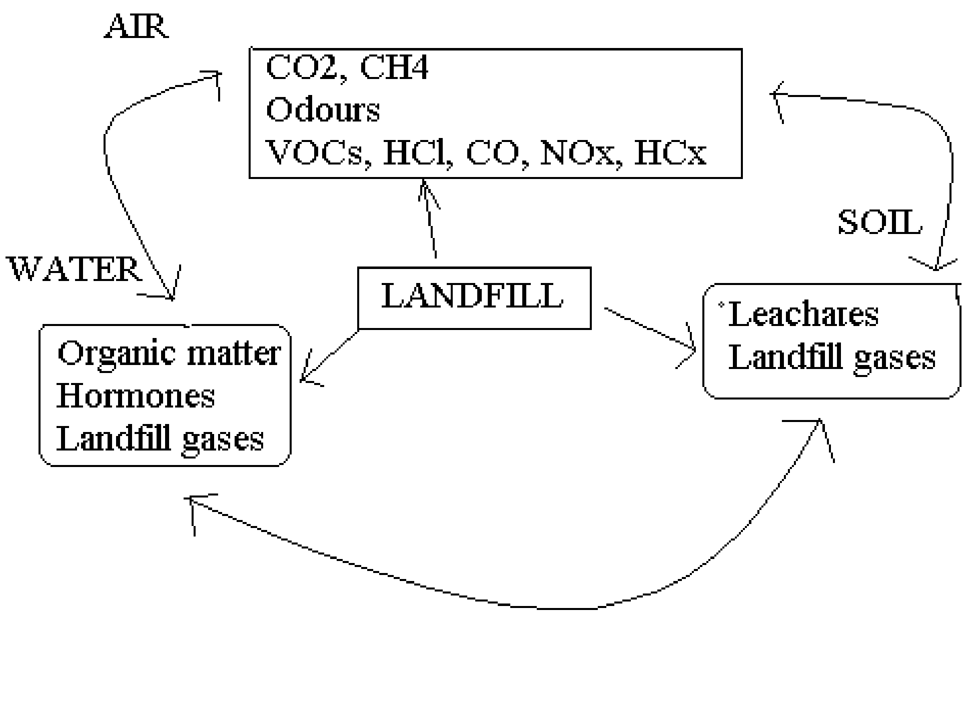


Figure 4-6: Emissions from landfills

4.4.6.1 Air pollution

Landfill gases cause global warming and unpleasant odours (El-Fadel et al. 1997, pp. 1-25; Tsiliyannis 1999, pp. 231-241). The air contamination decreases significantly with the new technologies imposed by the new EU legislation, e.g. covers and recovery of gases. Still the functioning of these techniques is not completely successful and problems regarding the maintenance and proper working of the covers are of major interest nowadays.

GLOBAL WARMING

Landfilling releases Carbon dioxide (CO_2) and methane (CH_4), which are greenhouse gases (GHGs), in large amounts. The theoretical gas emission from an average landfill is 200m^3/ton MSW, but the practical is around half (Tsiliyannis 1999, pp. 231-241). The emissions of methane from landfills per year are between 40-75 million tons, which is around one tenth of the global emissions of this gas. Methane accounts for 18% of the GHGs per year. CO_2 accounts for 56%. However, methane is of greater concern than CO_2 since its greenhouse effects are around 25 times higher. This is due to its effectiveness in trapping infrared radiation and because it is much more persistent in the atmosphere (El-Fadel et al. 1997, pp. 1-25).

UNPLEASANT ODOURS

Unpleasant odours are mainly caused by esters, hydrogen sulphide, organosulphurs, alkylbenzenes, limonene and other hydrocarbons that are released in landfills. Although some of their trace elements can be toxic, the main concern is an environmental nuisance. (El-Fadel et al. 1997, pp. 1-25).

GENERAL GAS EMISSIONS

Landfilling generates to a lesser extent, other constituents that can have environmental and health effects. More than 100 different compounds have been identified, most of them potentially toxic or carcinogenic, e.g. volatile organic compounds (VOCs) that are potential carcinogens or can influence the bacterial communities, CO, HCl, NOx, HCx, etc. (Tsiliyannis 1999, pp. 231-241)

4.4.6.2 Soil pollution

Pollution of soils is due to leachates and gases. Leachates are composed by a high variety of substances depending on the kind of waste landfilled, the climatic characteristics (e.g. at some temperatures some processes are favoured instead of others) and the aeration systems. All these factors determine the properties of the resulting leachate. The common compounds present in leachates are different organic compounds, heavy metals, salts and gases.

Landfill gases can escape through weakness or breaks in the insulation walls of landfills. Then, they move through the different layers of the soil until they find their way to the surface. Depending on the properties of the soil, this can be quite far from the landfill site. During their travel, they contaminate the soil (and also the water currents – see water pollution section) with the particulate materials suspended on them. Once they get to the surface they can cause fires and explosions (El-Fadel et al. 1997, pp. 1-25; Tsiliyannis 1999, pp. 231-241).

LEACHATES

Leachates in soils cause short-term changes in bacteria, which might modify the availability of nutrients. This is due to the toxicity of different organic compounds and salts, which either kill or favour different bacterial populations.

Leakage of heavy metals and salts change the properties of the ground and therefore on the vegetation (Poly et al. 2002, pp. 4729-4734).

LANDFILL GASES

The flora is also affected by the release of gases that move through the soil (in majority methane) in different ways: (i) landfill gas displaces oxygen, causing asphyxia in the roots. (ii) methane is oxidised by bacteria (methanotrophs) near the surface. This reaction depletes oxygen (asphyxia of the plants) and releases heat, and finally, (iii) this heat increases soil temperature again leading to asphyxia of the surrounding vegetation (El-Fadel et al. 1997, pp. 1-25). The presence of landfill gases also causes differences in the normal growth of the roots (Gilman et al. 1982, pp. 3-10). The content in nitrogen and ammonia is quite high (Barlaz & Reinhart 2003, pp. 557-559). That affects the surrounding vegetation due to a change in the competition abilities of the plants.

The gases can also explode once they get to the surface, provoking sudden fires in places sometimes far away from the landfill site.

4.4.6.3 Water Pollution

Landfills can cause pollution from discharges, insufficient bottom sealing and washout processes. The main pollutants of the aquatic systems are organic materials, different kinds of hormones and landfill gases that have a high solubility in the water currents. If the landfill has an insufficient bottom sealing, as it happened with the old ones, there is groundwater pollution (Schwarzbauer et al. 2002, pp. 2275-2287).

ORGANIC MATTER

Leachates from landfills change the biological properties of the aquatic systems. Due to a high input of organic matter, the growth of bacteria is stimulated. This excess of bacteria causes a rise in the biological oxygen demand (BOD), which may end up in a depletion of oxygen in the water system. The depletion of oxygen causes asphyxia to the rest of the aquatic organisms, e.g. fish. Compounds with elements such as nitrogen and phosphorus also affect the environment. Their presence may lead to eutrophication of these ecosystems. Typical contents of a leachate are liphophilic organic substances. 180 different organic compounds in a leachate have been identified (Schwarzbauer et al. 2002, pp. 2275-2287).

HORMONES

The leachate also contains xenoestrogens, e.g. bysphenol A, and other hormones. Hormones affect the physiological characteristics of the fauna of the aquatic systems it pollutes. They come from chlorinated plastics or medicaments. They can cause feminisation of aquatic biota like fish and frogs (Anon. Danish EPA 2002; Windham 2004). The estrogenic activity of the leachate can be avoided by a pre-treatment with activated carbon. However, not all the landfills have this system (Coors et al. 2003, pp. 3430-3434)

LANDFILL GAS

Landfill gas can also pollute the groundwater. It has a high concentration of CO_2, which due to its high solubility can be an important pollutant. It also has some potentially toxic trace elements, e.g. vinyl chloride and other volatile hydrocarbons. Unless the leachate is treated before its disposal, ammonia and nitrogen are present in such high concentrations that they become toxic in the aquatic ecosystem. (Barlaz & Reinhart 2003, pp. 557-559) The gases can cause health damages to flora and fauna populations even far away from the landfill.

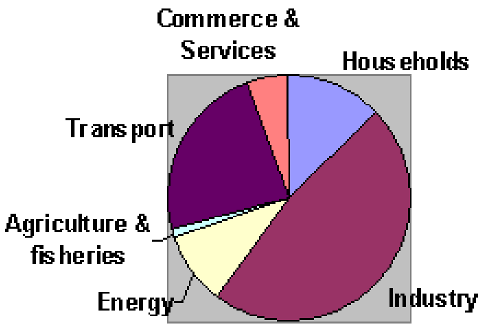
4.5 Environment and health impacts in figures: a case study on Flanders

This case study presents figures on emissions and their corresponding health impacts. How important are the emissions of waste management? Are the emissions acceptable? We compare the contribution of the waste treatment structure to total emissions and to the contributions of the other sectors.

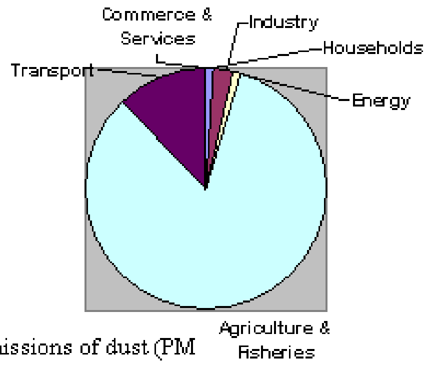
Flanders is a region in the north of Belgium with 6 million inhabitants. It is an industrialized and highly populated region. It has a tradition of incineration. In the last decade it has made a strong progress in sustainable waste development. It can now be counted among the leaders in waste treatment. The figures shown here cannot be generalised over whole Europe. Flanders has strong regulations to minimise emissions. The emissions would be much higher in a less strictly controlled structure.

Flanders reports on the emissions per sector. The emissions and health impacts of the waste collection and treatment, are included in the sector Commerce & Services. Other subsectors of Commerce & Services are commerce, hotels and restaurants, administration, education, health care and other community services. The waste sector is not responsible for all emissions in the Commerce & Services sector but will be the major contributor in the emissions discussed below (VMM, 2003, pp. 137-290).

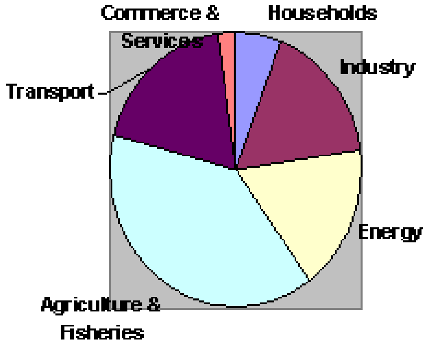
The waste collection and treatment structure contains here all waste, not only MSW. It concerns yearly 32 million tons of non – hazardous waste and 1 ton of hazardous waste (Eurostat, 2003, pp. 46-50).



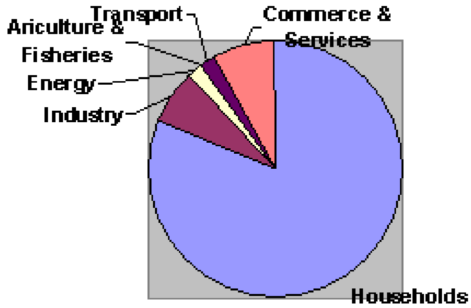
Graph: The emissions of NMVOC in 2002 (Non-Methane Volatile Compounds)



Graph: The emissions of dust (PM 10; PM 2,5; PM 0,1)



Graph: Acidifying emissions (SO2, NOx, NH3) in 2002



Graph: The emissions of dioxins in 2002

Figure 4-7 Emissions per sector in 2002

Reference: VMM, 2003, pp. 139, 150, 184, 253

In the figure 4-7 we can see that the waste management structure is responsible for 5 % of VOCs, 8 % of dioxins, 0,1 % of dust (PM 10; PM 2,5; PM 0,1) and 2 % of acidifying emissions.

After 1994 the contribution of the Commerce & Services was strongly reduced. Strict norms for incinerations plants were issued. The households are responsible for most dioxin production. This is mainly due to uncontrolled incineration of household waste in the back of the garden and heating buildings in open fires with solid fuels.

Belgium is a leader in dioxin measuring and cleaning. In 1999 Belgium had a dioxin food crisis that shocked the public and caused a change in political power. The public is still highly sensitive to dioxin emissions.

Because of the strict policies introduced in 1994 the emissions of dust from waste incineration have decreased strongly.

Acidifying emissions of waste incineration processes concern mainly NOx. The acidifying emissions of Commerce & Services are not only due to waste treatment. The heating of buildings also contributes a large part of the emissions.

Metal	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
%	8	5	2	0	4	0	0	0

Table 4-1: Emissions of heavy metals of Commerce & Services in % of total emissions

Reference: VMM, 2003, pp. 160

The Industry and Energy sector are the main contributors to emissions of heavy metals. Household waste contributes little. The emissions of heavy metals are nearly fully due to industrial waste. The emissions of heavy metals are not zero. The percentage of emissions of the waste structure is, however, below 0,5 %.

For GHGs, the amount of GHGs emitted by the waste treatments, is under 5 % of total emissions. The contributions in CO2 emissions are not so important. If energy can be recuperated CO2 can even be avoided. The waste treatment is, however, responsible for 18 % of CH4 emissions. The methane emissions are due to landfills. Flanders will strengthen the waste management hierarchy. With less waste landfilled the CH4 emissions will decrease. However, extra CH4 emissions by an increase in the amount of biodegradable waste composted can partially compensate this decrease (VMM, 2003, 288-290).

	VOC (ton)	Dioxins (g)	As (kg)	Cd (kg)	Cr (kg)	Cu (kg)	Hg (kg)	Ni (kg)	Pb (kg)	Zn (kg)
‘95	11352	112[3]	47	294	577	1031	251	299	12239	<0,5
‘02	8864	7	75	25	59	53	62	14	140	<0,5

Table 4-2: Emissions of waste management in Flanders

Reference: VMM, 2003, pp. 160

The importance of the emissions of the waste structure are the largest in VOCs, dioxines and heavy metals. The other emissions are all less than 2 % of total emissions in Flanders. We illustrate the improvements achieved in the most relevant emissions since 1995 in table 6.2. Only the emissions of As could not be reduced. (VMM, 2003, pp. 446)

This case study proves that it is possible to build up a waste management structure with acceptable health and environmental impacts. The waste management structure contributes less than 8 % of total emissions in all discussed compounds. Based on the improvements in the last decade and the low contribution to total toxic emissions, priorities to decrease the damaging impacts of total emissions have to be put on other sectors.

The build-up of the low emissions required, however, efforts. It took Belgium ten years and expensive investments to achieve the actual situation. Not all countries are capable or willing to make these efforts. We can also see that contributions are not zero. Continual improvements and stricter standards have to be implemented to further minimise emissions.

[3] Strong reductions were already made before ’95. In 1990 the emissions of VOC’s and dioxins were respectively 11352 ton and 261 g.

5 Summing up

5.1 Costs

The financial cost estimation and comparison exhibits considerable variation in different countries. Within each waste management method there are several techniques, from low to very advanced technology facilities. The price of the management technique depends on the national regulations and licensing regimes. Incineration and landfill taxes strongly influence the price.

Recycling is often the cheapest solution for easy collectable materials. However, separate collection can be expensive. The collection scheme must be paid by the community. In addition to the regular garbage pick up the community provides; new trucks, employees and other expenses have to be provided for the recycling cycle. This is an added expense to the community budget. We should also be aware that market for recycled materials is volatile. When prices are too low for particular materials, it costs communities more to collect, separate and sell them than to put them in a landfill (de Betlencourt, 2000, pp. 157). However, recycling and composting operating systems cost far less to built and operate than incinerators or landfills (www.greenpeace.org.).

Costs of landfilling and incineration have a tendency to rise. This is due to stricter regulations on pollution. In general incinerators are the most costly waste management option. They require large capital investment and high operating costs. Incineration usually costs 5 to 10 times more than landfilling. However it still does not eliminate the need for landfilling because of the ash residues.

Taken together, costs of MSW treatment exhibits a lot of variation across countries where the regulatory regime is a key determinant for those costs, both operational and engineering. It is significant to mention that above estimation of costs do not cover the environmental and health costs of each waste management method.

5.2 Advantages and disadvantages of different techniques

TECHNIQUE	ADVANTAGES	DISADVANTAGES
RECYCLING	• conserves natural resources • reduces the amount of waste that requires disposal and saves on the associated costs • provides a raw material for new industries	• costs and the energy used for collecting, transporting and reprocessing of recyclables are high • fluctuations in the prices paid for collected recyclables • unless there is a suitable market for them, some compounds are not recycled
COMPOSTING	• removes organic waste from landfill providing organic materials on the soils and reducing methane emissions • provides a useful compost which improves soil properties for agriculture. It replaces other soil improvers and conditioners and protects against erosion	• can produce unpleasant odours, spores and fungi and possibly polluting liquid effluence if not properly processed • problems with contamination of the final product can arise in large-scale composition operations • large-scale composting requires a good quality feedstock, therefore, separation costs can be high

INCINERATION	• energy production from waste reduces the use of fossil fuels such as oil and coal • reduces the weight of waste requiring disposal to landfill by 70% • reduces the volume up to 90% • energy generated is 5 times more effective than from landfill • Over 80 % of ashes can be recycled	• costs are much higher than landfill • emissions contain persistent pollutants which must be controlled to minimise harm to health • the remaining ash still requires disposal. The toxins in the waste are concentrated in the fly ash. This material requires very careful disposal • Incineration sites are difficult to find (NIMBY)
LANDFILLING	• relatively low costs • suitable for the reclamation of land for agriculture, wildlife or leisure uses • landfill gas is a suitable fuel for heat and power generation • suitable for disposing a wide variety of wastes	• emits greenhouse gases: especially the emissions of methane are important • Unavoidable long term emission risks • Landfill sites are difficult to find (NIMBY) • Landfill without energy recovery is the least sustainable disposal option

Table 5-1: Summing up of waste management techniques

6 Waste management: Diversity in Europe

Waste management in Europe is highly diverse. Main disposal technologies and recycling and recovery rates are different.

France, the Netherlands, Germany, Denmark, Belgium, Luxembourg and Sweden traditionally rely on incineration for waste management. UK, Portugal, Spain and Greece landfill nearly all their MSW. Most newcomers in the EU also landfill their MSW. In the Central and Eastern European Countries however, the amount and the kind of MSW collected are different because of their different economic situation.

Concerning prevention and recycling rates, Denmark, Belgium, Austria, Sweden, the Netherlands and Germany are generally seen as frontrunners. UK, Spain, Portugal, Ireland and above all Greece are laggards (Curzio, 1994, pp. 15, pp. 35).

In order to show the diversity in Europe in a surveyable way we compare three countries: Denmark, UK and Poland. Afterwards we go deeper into the national situations.

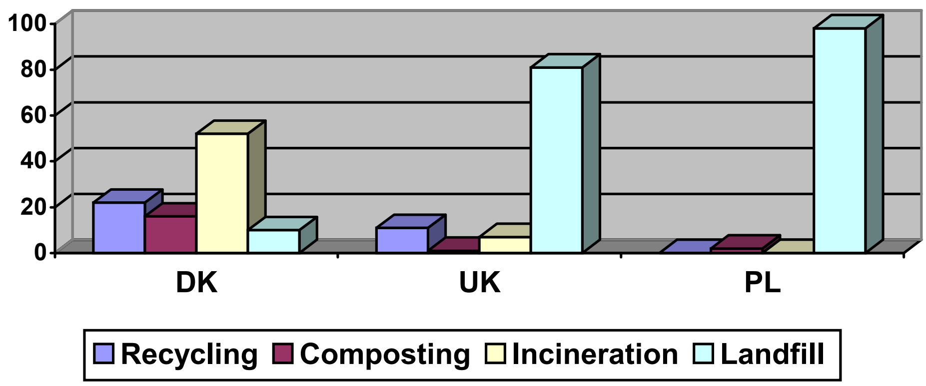


Figure 6-1: Treatment of MSW in % of total amount treated

Reference: Eurostat, 2003, pp. 23

Denmark is an example of a front-runner in waste management with high recycling and recovery percentages. The UK stands for a group that relies heavily on landfilling and has low standards and little attention for waste management. Poland represents the newcomers in the EU. Nearly all the waste is landfilled. Recycling is nearly non-existent. Collection schemes are not country-wide present. Figure 6.1 illustrates the situation.[4] Denmark clearly implemented the waste management hierarchy the most successful.

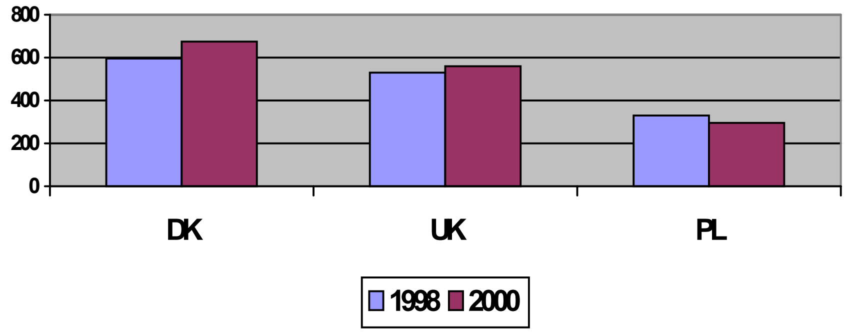


Figure 6-2: Kg MSW/Capita

Reference: Eurostat, 2003, pp. 18

In graph 6.2 we can see that in general the amount of waste collected in developed countries still rises. The amount of waste produced in the new accession countries will catch up. The amount of MSW in Poland is expected to grow 30 % by 2010. This evolution shows the importance of prevention. Improvement of treatment policies is not enough to slow down waste production. More prevention is necessary for sustainable development (www.compostnetwork.info).

6.1 Denmark

Denmark started its sustainable waste policy already in the seventies. There was a strong public and political consensus on respect for the environment. This resulted in a search for reduction of virgin materials and a reduction of landfilling.

	2001	2004	2008
Recycling	29	/	33
Incineration	61	/	60
Landfilling	8	/[5]	7

Table 6-1: Waste treatment (%)

Reference: Danish government, 2003, pp. 45

The waste policy is based on the idea of the waste hierarchy. Table 8-1 gives the actual situation and the targets for 2008 for household waste[6].

	2001	2004	2008
Recycling	88	70	85
Landfilling	12	30	15

Table 6-2: Treatment of incineration ashes (%)

Reference: Danish government, 2003, pp. 33

The importance of recycling is also shown by table 8-2. More than 85 % of the ashes of the incineration plants are recycled. The targets for 2004 and 2008 were already achieved in 2001.

[4] It is a simplification to have one country represent a group. The diversity within the three groups is high.

[5] The targets for 2004 were divided for the subsectors of household waste: Domestic waste, Bulky waste, Garden waste.

[6] Households are in Denmark responsible of 86 % of the MSW. (Eurostat, 2003, pp. 17)

Denmark reached this oustanding waste performance through a portfolio of measures. Government bans are widely used. In 1997 a ban was introduced on landfilling combustible waste. This was a very effective measure to shift waste from landfilling to incineration.

The government issued a number of obligations to firms and municipalities. E.g.: Every 4 years all municipalities have to make a short term (4 years) and a long term (12 years) waste management plan. It is the responsibility of the municipality to include the interests of the public, firms and governments.

The Danish deposit refund system plays an important role in prevention and recycling of waste. Around 390000 tons of waste is prevented yearly. That is more than 12 % of the household waste production (Danish EPA, 1999).

The Danish government also installed more flexible, economic incentives. A weight-based packaging tax must be paid. The height of the tax is based on a Life Cycle Analysis of the material used. For easily recyclable glass the tax in 2000 was only 0,7 DKK/kg. For Aluminium, that can cause environmental and health hazards if not collected properly, a tax of 10,5 DKK/kg was to be paid.

A waste tax was introduced in order to strengthen the waste hierarchy in 1987. In 1999 recycling waste was free. Incineration of waste with energy recuperation costed 330 DKK/ton and landfilling costed 375 DKK/ton.

These taxes have a double goal. First they strengthen government priorities. Secondly, they cause a shift in taxation. Not labour, but negative things as pollution are penalized by high taxes (Danish EPA, 1999, pp. 40-45; www.mst.dk).

Even with an outstanding waste record, improvements are necessary. There are two large challenges:

- Disconnect economy growth and waste growth. The information to the public and the producers is essential.
- More environment for money. The efficiency has to be maximised and the costs minimised. The burden for producers and municipalities cannot rise anymore. Further progression will have to be made there where it is easy and cheap.

The government has also identified a number of specific problems. The MSWM is too bureaucratic. Producers have problems coping with the growing amount of rules. The system loses its transparency. Also, there is too little private initiative. Nearly all disposal facilities are managed by public institutions. Private initiative and competition can boost efficiency. The government installed a work group. The conclusions will be presented in 2004. Laws and organisations will be restructured and more transparent.

Firms need clear signals. They can adapt to less damaging materials. The Danish already introduced a list of unwanted materials. E.g.: The use of PVC will be discouraged.

New technologies are spread too slowly. A knowledge centre has been founded to stimulate implementation of new technologies and spread information.

The waste management hierarchy is a too blunt instrument to determine the impact of specific materials. Material indicators based on LCA will be

composed. These indicators will e.g. determine the height of the environmental tax on a material.
Information to citizens will be improved. Municipal workers will be educated to better spread information. Labelling of products also helps the consumers.

In general citizens pay yearly a flat fee for waste management. There is no incentive to reduce waste. This is not in line with the PPP. Municipalities are encouraged to introduce a weight-based waste collection scheme. Bigger polluters pay more.

Finally, when dealing with waste problems,the interaction with the EU stays strong. Denmark will continue to push negotiations for higher standards. On the other hand, EU policies stimulate Danish waste policies. The packaging directive resulted in obligations for Danish municipalities to have a separate collection for plastics. (Danish government, 2003, pp. 53-57; Danish EPA, 1999, pp. 26-29)

6.2 UK

The UK is an example of a country that used to have little focus on waste management. Nearly all waste is landfilled. Source separation schemes are only partially developed. UK recycles 11 % of its MSW. what is clearly less than Belgium, Germany, Austria and Denmark who recycle between 35 and 60 %. Standards for waste disposal facilities are low. One quarter of methane emissions in the UK is a consequence of badly isolated landfills.

England's reliance on landfilling reflects open space and history of extraction industry. Suitable landfill sites were abundant and landfilling has always been

cheap. This combined with a strong public opposition against incineration plants and in general low public awareness resulted in the actual situation.
However, UK is forced to shift its current waste policy because:

- MSW is predicted to grow yearly 3 %. without any change the cost of the waste management will double by 2020.
- Highly populated areas such as the Southeast are running out of potential landfills.
- European legislation. Two directives put actual targets on UK
    - The packaging directive forces UK to recover electricity or materials with min 50 % of the waste and recycle min 25 % of packaging.
    - The landfill directive sets out targets to reduce the amount of biodegradable waste landfilled. UK has to reduce its biodegradable waste in 2010 to 75 % of 1995 level and to 35 % in 2020.

In 'Waste not, Want not' (2002) the English government describes its future policy. The waste treatment must be pushed up the waste hierarchy. Priority to prevention (e.g. better product design), recycling ,re-use and energy recovery. In 2000 UK has installed the Waste and Resources Action Program (WRAP) to support recycling efforts. WRAP creates stable markets for R&D, capital investments and price stabilisation mechanisms.

The standards of disposal facilities will be strengthened according to EU directives. The prices for landfilling will rise. In line with the PPP all monetary and external costs will be accounted to the polluter. In 1996 UK introduced a landfill tax to internalise external costs to discourage landfilling. In 2002 the tax was 13 GBP/ton (=143 DKK/ton)[7]. That is too low to discourage landfilling. In Denmark the landfilling tax was 375 DKK/ton in 1999.

At this point, the costs of household waste collection and treatment to households are almost fully financed by general budgets of local governments. According to the PPP the costs must be allocated to the households in proportion to their waste production.

Nowadays waste management is a fragmented authority, divided by counties and districts. A structural reform is necessary.

The UK also introduced promising market mechanisms. Market mechanisms are usually more cost efficient. Every participant can minimise his own costs. When the market mechanisms work in UK they can be exported to the whole continent.

In order to meet the EU targets for recovery of packaging a tradable certificate system is installed. Following the Extended Producer Responsibility the producers become responsible for the targets. The reprocessors give out Packaging Waste Recovery Notes (PRN). The producers need an amount of PRN corresponding to the amount of Packaging waste produced. These PRN can be freely traded. Producers who make their packaging waste better recoverable can sell excessive PRN.

To reach the targets for biodegradable waste a trade mechanism is proposed where the municipalities are the traders. The municipalities would get a free amount of waste certificates corresponding to the number of inhabitants.

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[7] 1 GBP = 11 DKK on 19/05/2004

Certificates that are not used can be sold. This would form a strong incentive for the municipalities to reduce generation and increase recovery of MSW.

The UK policy is based on the idea that transition to a durable waste management system takes between 10 and 15 years. That was the time needed for Belgium, the Netherlands and Denmark too.
The UK policy seems promising. However, UK has a tradition of not meeting its waste objectives:

- 1990: The environment white paper: a target of 25 % recycling in 2000
- 1995: Making waste work: same objective
- 2000: Waste strategy 2000: targets of recycling and composting at 17 % by 2004 and of 25 in 2006.

At this point UK recycles barely 12 % of its MSW with nearly no composting at all.

The UK still has little focus on waste treatment. E.g. landfilling without the internalisation of external costs, is still too cheap to stimulate the waste hierarchy. This lack of interest can also this time lead to not meeting targets. However, this time there is the pressure of the European deadlines. Secondly, the rising awareness of the public can push the situation towards a fast evolution in the good direction. (Slater, Frederiksson, Resource conversation & recycling, 32/2001, pp. 359-374; Strategy Unit UK, 2002; OECD, 2002, pp. 86-105)

6.3 Poland

In the beginning of the 1990's Polish waste management was at a very low technical level with no or little attention to environment or health hazards.

Waste management was seen as a luxury product that Poland could not afford during a difficult transition.

The pressure from the EU pushed Poland towards more sustainable management. The Acquis Communautaire, the European legislation that Poland has to implement, obliged Poland to adopt European minimum standards. It is no coincidence that nearly all Polish waste laws were approved in the period 1997-2001. The changes in legislation were necessary to join the EU.

Poland caught up strongly in the last decade. At national level EU-laws have been introduced. However, there is still a long way to go. The Polish economy is not focused on waste. The amount of waste is high compared to the productivity. Poland produces 1897 kg waste/ EUR 1000 value added compared to Denmark's 123 kg/1000 EUR value added (Eurostat, 2003, pp. 11).

Only 30 % of the landfills are in line with the current EU standards.

Poland has no reliable waste statistics. Poland does not know how many people in the countryside are not covered by a municipal collection scheme.

Only 25 % of the municipalities comply with national regulations to have a local waste management plan. Only 30 % of the municipalities collect separated fraction of MSW. In general the administrative capacity of the municipalities is too weak.

Finally, the Polish population is unaware of the waste problem. Only 22 % of the adults see waste management as a primary problem. The education does not focus on waste either.

The change towards sustainable waste management started with the adoption of the Acquis Communautaire half way the nineties. Poland estimates that it will reach a sustainable waste situation in 2025. Poland currently landfills 98 % of all its MSW. In the future measures will be taken to adopt the waste management hierarchy.

Poland has set targets in the short term. The monitoring system has to be improved. Knowing how much waste and what kind of waste there is, is essential to come to a decent waste policy. The administrative capacity of the municipalities must be boosted. This is not only the case in waste or environment matters. They must catch up with current legislation.

In the medium term, Poland wants to comply with EU legislation. For MSW special attention will go to packaging waste, biodegradable waste and disposal facilities. Public knowledge and education on waste have to be boosted.

Poland gives priority to flexible, economic measures. Polish communities cannot cope with a high financial burden. The waste management will have to be highly cost efficient. It is also an explicit policy to shape the waste management so that the maximal support from the EU is gathered (Eurostat, 2002, pp. 25-28, 53-63, 71-78; Eurostat, 2003, pp. 11; Polish ministry of environment, 2001, pp. 36-39; www.compostnetwork.info).

7 Conclusions and recommendations

Our conclusions support the priority order in the waste management hierarchy. It is a guideline for sustainable waste management. The hierarchy should be the policy line at EU and national level.

Waste prevention is the highest priority in MSWM. Prevention means a decrease in the amount of waste produced, as well as the use of easier recyclable materials. If we look at the actual situation in the EU, we can see that MSW still grows. Prevention must be supported.

Recycling should be strengthened. It recuperates valuable resources and closes material loops. Composting is a way of minimising the biodegradable waste going to landfills while creating a useful end product. However, recycling and composting still are end-of-pipe solutions. It does not tackle the amount of waste produced.

There is a general tendency in Europe to increase recycling. It concerns mainly the easily collectable and recyclable materials: Paper, plastics, glass and metals. The EU directive for packaging waste plays a crucial role. The binding targets force all member states to improve their MSWM. Stronger targets have to be fixed.

The price paid for the recycled materials is important for the competitiveness of recycling initiatives. At this moment the prices are volatile. Measures have to be taken to enhance the price stability and the profitability of recycled materials.

Organic waste will also be recycled in the future. The EU landfill directive plays a crucial role. The directive issues binding targets to reduce biodegradable waste in landfills. Composting is the most attractive alternative.

For recycling and composting the efficiency of the process depends on the purity of the waste. Separation at source should be strengthened. For a good separation of MSW the citizens have to cooperate. Denmark, UK and Poland put a high priority on information and education to the public.

Separate collection schemes have to be organised on a community level. In Poland the local administrative capacities are low. A further general transition has to be finished before a better local MSWM can be expected.

For disposal, by implementing high standards for landfilling and extensive cleaning of incineration gases, emissions and health impacts can be minimised. The advantage of incineration compared to landfilling is that energy is recovered and materials are recuperated. For a safe recuperation of materials the incineration plant has to work in optimal conditions. With incineration special attention should go to measuring and minimising the impacts of POPs and other potential emissions. POPs are of global concern because of their capacity to persist in the environment and their toxicity. Another advantage of incineration is the smaller amount of land needed.

Incineration with material and energy recovery is strong in Denmark. Other EU countries, however, will not necessarily go so far in incineration, e.g. public opposition makes it difficult in the UK to switch from landfilling to incineration.

The EU incineration directive is important for the environmental impact of incineration. The directive obliges strict flue gas cleaning. This minimises and regulates the emissions of toxic persistent matter. The high standards entail high costs. Incineration is an expensive disposal technique. The case study of Flanders proves that acceptable levels of emissions can be attained if strict regulations are applicated and if extensive cleaning works optimally.

For landfilling, there is a general tendency in Europe to reduce the amount of waste landfilled. The landfill directive plays a crucial role. The directive issues targets for diminishing the amount of biodegradable waste landfilled.

The directive is important for the environmental impact of landfilling. By obliging high standards the big historical pollution by landfills will be avoided in the future. Also, minimum prices have been installed according to the Polluter Pays Principle. These rising prices combined with landfill taxes already reduced landfilling in Denmark. A similar evolution is expected in the rest of Europe. The rising prices of landfilling will have an important impact on countries as UK and Poland that rely heavily on landfilling for waste management.

Both landfilling and incinerating form inevitably a minimal health and environment hazard. The only way to avoid the corresponding emissions of the disposal techniques, is going up the waste hierarchy.

The hierarchy should be stimulated by a combination of measures. Flexible market mechanisms have a high potential thanks to their efficiency. Market mechanisms that are implemented successfully in one country must be considered at European level.

In many countries the landfill and incineration taxes are low and don't form an incentive to avoid disposal. Disposal taxes should rise and environmental costs should be included. As landfilling is lower in the waste management hierarchy it should get a higher tax than incineration with energy and material recuperation. Recycling should be encouraged. The recycling tax should be low or even zero.

The most used measure is banning. A ban on landfilling biowaste has been implemented on EU-level. A ban on landfilling combustible waste should be introduced.

Finally, information to households and industry is an efficient measure. Simple and clear info makes the industry aware and helps the industry to prevent waste. Through information the consumer becomes aware of the problem and learns how to prevent and recycle waste.

The waste cycle must be minimised. However, it will never be possible to avoid waste. Not all waste can be prevented. For some waste it will not be opportune to recycle because of environmental and economical interests. Even when we incinerate all our waste and recycle our ashes up to the maximum, a percentage of the ashes will be landfilled. On the complex waste question, it is not possible to give an easy answer. Every waste system will have a cascade of treatment techniques. This cascade has to be based on the waste management hierarchy.

This study does not go into a cost comparison for local projects because we focus on a European or national level. The situations locally are very different. It is however, our opinion that locally, costs should be one of the decisive components for choosing a waste management. In the cost section, not only operating cost, but also external costs, e.g. environmental and health costs, should be introduced.

In general, European countries put a lot of stress on the efficiency of the waste system. The costs of the system must be minimised. Economic instruments are a possible way boosting the efficiency in the waste system.

Finally, the situation in Europe is highly diverse. The EU legislation harmonises the situations up to a certain degree. Minimum standards will be implemented everywhere. However, a wide array of policies and visions is still possible. National differences influence the waste structure. Different answers are formulated on the complex waste question. A diverse European waste situation can also be expected in the future.

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