Master Thesis

Comparison between the German and the Italian waste management system - a focus on waste pretreatment to achieve landfill stability

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ABSTRACT

This thesis work aims to make a comparison between the German and the Italian waste management system. The waste considered in this study is solely the waste fraction produced in the households, the so called municipal solid waste.

The European Commission provides a specific regulation on waste management and waste disposal. Directive 2008/98/EC and the Landfill Directive 1999/31/EC provide a specific waste hierarchy and impose to reduce the disposal of un-pretreated waste which goes to landfill. Since Germany is one of the European leaders in waste management, this comparison emphasize the differences in the two countries, and is intended as a support for Italy to take note of its weak points in waste management and improve the efficiency of its management system and its compliance with the European directives.

In particular the work analyzes deeply the state of art of the technologies related to waste pretreatment performed in both countries. Waste pretreatments, especially mechanical and biological pretreatments, are the key to reduce the biodegradable fraction in the municipal solid waste, and are so essential for the fulfillment of the Landfill Directive.

In Italy landfilling is the most used final disposal system, while Germany is one of the world leaders in incineration. This different approaches influence the whole waste management system, from the separate collection, the recycling rate, to the pretreatments.

The result of this comparison shows that Italy’s waste management system has to be improved. The main cause of the inefficiency is the lack of a suitable regulation system. Often the regulation is not severe enough, or there is no respect of the existing regulation. Another problem is the low rate of separate collection, especially in the center and in the south. This reduce the efficiency of further waste pretreatment procedures. While the northern part of Italy is implementing well the European directives, the center and the south need to enhance their environmental awareness.

To fulfill the waste hierarchy, a shifting from landfills as final disposal method towards incineration is required. An optimal tool to do this would be the introduction of a landfill ban, along the already existing landfill tax, for untreated municipal solid waste, as Germany did in 2005.

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Abbreviations

AbfAblV	Abfallablagerungsverordnung
AbfG	Abfallbeseitigungsgesetz
ATO	Ambito Territoriale Ottimale
BOD_5	Biochemical Oxygen Demand after 5 days
BTEX	Benzene, Toluene, Ethylbenzene, Xylenes
BUN	Bundesministerium für Umwelt und Naturschutz
COD	Chemical Oxygen Demand
DepV	Deponieverordnung
DK	Deponieklassen
DM	Dry Matter
DOC	Dissolved Organic Carbon
EC	European Community
EEA	European Environment Agency
EPA	Environmental Protection Agency (US)
EPR	Extended Producer Responsibility
EU	European Union
FWS	Former Waste disposal Sites
GDP	Gross Domestic Product
HDPE	High Density Polyethylene
Hhld	Household
IR	Infrared
KrW	Kreislaufwirtschaftsgesetz
LFG	Landfill Gas
LFM	Landfill Mining
LHV	Low Heating Value
L/S	Liquid Solid Ratio
LSR	Landfill Simulation Reactor
MBP	Mechanical Biological Pretreatments
MBT	Mechanical Biological Treatment
MP	Mechanical Pretreatment
MSW	Municipal Solid Waste
MRF	Material Recovery Facility
OECD	Organization for Economic Co-operation and Development
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PA	Polyamide
PE	Polyethylene
PP	Polypropylene

PS	Polystyrene
PVC	Polyvinylchloride
PHS	Petroleum Hydrocarbon Substances
RDF	Refuse Derived Fuel
RI	Respiration Index
RMSW	Raw Municipal Solid Waste
RTO	Regenerative Thermal Oxidation
SB	Stabilized biomass
SF	Solid Fraction
TARES	Tributo Comunale sui Rifiuti e i Servizi
TARI	Tassa sui Rifiuti
TASi	Technische Anleitung Siedlungsabfall
TDS	Total Dissolved Solids
TKN	Total Kjeldal Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TUA	Testo Unico Ambientale
UBA	Umweltbundesamt
UNEP	United Nations Environmental Program
VFA	Volatile Fatty Acids
VKU	Verband Kommunaler Unternehmen
VOC	Volatile Organic Compounds
VS	Volatile Solids
WFD	Waste Framework Directive
WMA	Waste Management Act
WMP	Waste Management Plan
WPP	Waste Prevention Program

1. Introduction

In the past, for almost the entire presence of mankind on earth, the amount of waste generated by humans was insignificant due to low population density and the low level of resource use and technology development. Common waste produced during pre-modern times was mainly ashes and human biodegradable waste, and these were released back into the ground locally, with minimum environmental impact.

With the beginning of industrialization and the sustained urban growth of large population centers, the buildup of waste in the cities caused a rapid deterioration in levels of sanitation and the general quality of urban life. The streets became choked with filth due to the lack of waste clearance regulations.

In the mid-19th century the first legislation about the waste issue emerged. With the economic growth in developed countries in the 60's the waste management concept began to be more important, and different management and disposal techniques have been developed in the years.

Nowadays different waste management systems exist, and in the world different strategies are applied. The choice of system depends mainly on political, economic, social and environmental aspects.

For instance waste management is quite different in developing countries compared to developed countries, but generally the main final treatment methods are three: landfilling, incineration and recycling.

In a developed macro-area like Europe, this three disposal methods are applied in different ways in the different countries.

In some countries like Italy, landfilling is the most used final disposal method for residual MSW, while in other countries like Germany waste incineration is preferred.

The present work aims to compare the pretreatments performed on the waste before it is brought to landfill, in Germany and in Italy. To do this in a proper way, it is necessary to consider different aspects, ranging from the diversities of the area's environment, the culture, the waste composition to economic aspects.

It's important to mention that in Italy more than the half of the total MSW production is finally disposed in landfills, while in Germany the fraction is much lower, since recycling and incineration are more common.

A further main difference is that in Germany the disposal of untreated waste in a landfill is forbidden, while in Italy it is still allowed in certain cases.

All considerations there will be made in the comparison of the German and the Italian waste management system are based only on a fraction of the total amount of waste produced by this countries, the Municipal Solid Waste (MSW).

MSW is the combination of all of an area or a city's produced solid waste. It includes mainly household or domestic waste, but it can also contain fractions of commercial and industrial waste, with the exception of industrial hazardous waste.

There are a number of different ways in which municipalities dispose their waste. One of the oldest and most well-known however, are dump sites, which then developed into modern landfills. These are areas that are specially created so waste can be put into the ground with minimum harm to the natural environment through pollution.

Waste management is nowadays a very important factor for human life. A wrong waste management system can bring to critical and harmful situations for the environment and human life.

An integrated approach to the problem has to be undertaken in order to minimize the negative impacts where a complete avoidance is impossible. This is made conceiving the whole municipal solid waste management system through an integrated approach from the moment of waste generation to and after its final treatment, may it be recycling, incineration or disposal.

It is fundamental to consider case by case in the waste management system planning phase, no situation is like one other, and who does the project has to carefully consider all the aspects that make one situation unique, such for example demography and economy of the area, waste quantity and composition, characteristics of the final disposal site, and so on.

2. Objective and structure of the thesis

2.1 Objective of the work

In this thesis work the main European strategies and regulations about MSW management are discussed, in particular focusing on the German and Italian situation, and their differences in the use of landfills as final disposal.

The *European Landfill Directive 1999/31/EC* prescribe the minimization of biodegradable substances for the waste disposed in landfill, to reduce the potential of biodegradation.

In the German "*Deponieverordnung*", the national landfill regulation, exact indications about the management of a landfill are provided. Furthermore, limits for the organic content, organic pollutants, heavy metals, Benzene-Toluene-Ethylbenzene-Xylene compounds (BTEX), Polychlorinated Biphenyls (PCB), petroleum hydrocarbons, pH and Dissolved Organic Carbon (DOC) were set.

In other countries of the EU like in Italy, the restrictions are not that strong and hence the pre-treatment of MSW to achieve landfill sustainability is different.

To reduce the emissions of leachate and biogas in a landfill, particular pretreatments are performed on the biodegradable substances. This treatments are different in Germany and Italy, and a goal of this thesis is to compare the pretreatment technologies in the two countries, highlighting the possible solutions which can improve the efficiency of them.

To do that, different aspects are considered, like the regulatory framework in the two countries, the diversity of the municipal waste composition and the collection system.

2.2 Structure of the thesis

The first and second chapter regard respectively the introduction and the objective and structure of the thesis-work.

In the third chapter the general waste management principles are presented, showing the hierarchy of measures which have to be taken in a complete management system.

The comparison of the regulatory framework for the disposal of MSW in the two countries is shown in chapter number four. Some regulatory aspects of waste management will be introduced in chapter seven and eight, but in this chapter the European waste directives and the way how they are applied in both countries are explained in detail.

In the fifth chapter, for a better understanding of the waste management system in Germany and in Italy, a brief area description is performed.
The sixth chapter regards the waste characterization. At the beginning of the chapter some data is provided which shows the different amount of waste produced worldwide, showing the difference of waste quantity and quality in rich and poor countries.
Then the waste production and composition in the European Community is described, and finally a waste characterization of Germany and Italy is presented more in detail, dividing the waste in more sub-categories and analyzing them singularly.
In chapter number seven the differences of source segregation and separate collection in Germany and in Italy are described in detail.
The eighth chapter regards the final disposal methods in Europe, and more in detail the German and Italian ways of disposal. The disposal methods considered are three: recycling (which actually is not a final disposal method but a treatment), incineration and landfilling. They are applied in different manner and amount in Europe.
Chapter number nine starts with a general description of the structure of a landfill, and describes then in detail the landfill emissions, leachate and biogas.
The biological waste stability is discussed at the end of the chapter. The biological fraction is the one that dominate the waste degradation process, and is composed from more sub-fractions with different degradation rates. The average composition of the biological waste fraction is represented, and then the relation between biological waste stability and emission potential is discussed.
Chapter 10 can be considered the core of the study, since it concerns the MSW pretreatments and in particular mechanical and biological pretreatments which are necessary to reduce the MSW emission potential. The different treatment options are presented and the state of art in Germany and Italy is described.
The work ends with the conclusions and a summary, which contain a personal advice for the improvement of the Italian waste management system and the pretreatment implementation.

3. General principles of a waste management system

Every waste management system is based on the general concept of sustainability. The Brundtland Report defined sustainability as "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (*G. H. Brundtland, 1987*).

The main criteria on which is based waste management are the waste minimization, waste prevention, waste reuse and recycle, energy recovery, the carbon cycle, the mass balance approach, the life cycle approach and the multi-barrier system for final disposal in landfill. All this concepts aim to have less environmental and human impact as possible.

To implement a proper and efficient waste management, the fundamental aspect is waste hierarchy.

The following hierarchy highlights the relevance of minimization and recovery, that are the first actions to implement when a product become redundant, and when it has no more value for the owner, which wants to dispose it. In **Errore. L'origine riferimento non è stata trovata.** is represented a scheme of this hierarchy.

- The first grade consists of preventing and/or reducing the generation of waste at the source. That means strict avoidance, and involves the complete prevention of waste generation by reducing material or energy in production, internal recycling, product re-use and packaging control. With minimization it is possible to achieve the purpose of reducing the waste impact on the environment, reducing waste quantity by weight, the emissions and improving recyclability
- Material recovery can be summarized by the 3Rs rule: recovery, reuse, recycle and separate collection, which has to be done to reduce the amount of waste which ends to landfill
- Energy recovery can be reached utilizing alternative or renewable energy
- Landfill is the place where residuals are disposed

The second fundamental thing to consider during all the waste management is the mass balance, useful because it can be verified that all generated waste are counted, without any forgotten:

$$\text{Accumulation} = \text{Inlet} - \text{Outlet} - \text{Degradation}$$

The four main steps considered usually in waste management treatment are: waste generation or production, collection and transport, treatment and final disposal. So starting from the amount of raw waste produced by the population, considering the characterization of the area, the information on the population and the main activities, the designer have to take the best decision to obtain a sustainable waste management plan.

To greatly manage the waste minimization it must to be taken into account who are the main performers of it, like the goods producers, the distributors and the customer.

Also must be thought a minimization program as not on a voluntary agreement but something that must be done from everybody, since one of the fundamental aspects in this field is to have a large support from the actors.

Beginning from this point, it can be highlighted the importance of the communication factor between the competent authority in waste management and the actors. Also, to ensure the success of the process, an according regulation must be provided first of all to producer, using an Extended Producer Responsibility (EPR), which have to manage and treat, at his expense, all the waste produced during the production process (*Cossu et al., 2012*).

4. Waste legislation

Waste is defined by *Directive 2008/98/EC* as "*any substance or object which the holder discards or intends or is required to discard*".

The European Union waste management policies aim to reduce the environmental and health impacts of waste and improve the EU's resource efficiency. This also because potentially waste represents an enormous loss of resource in the form of both materials and energy. In addition, the management and disposal of waste can have serious environmental impacts. Landfills for example take up land space and may cause air, water and soil pollution, while incineration may cause air pollution.

Some aspects about waste regulation will be discussed more accurately in the chapters seven and eight, in particular some data about the application of the landfill directive and the landfill tax are provided in Chapter 8, but here the basics of Germany's and Italy's waste legislation are presented.

4.1 European waste regulation

The most important European directive about waste is the already mentioned *Directive 2008/98/EC*, called also *Waste Framework Directive*.

This directive sets the basic concepts and definitions related to waste management. It explains when the waste ceases to be waste and becomes a secondary raw material. The directive is based on the concept of protection and preservation of human life and the environment. It is also based on the waste hierarchy concept shown in the third chapter.

Two important principles of this directive are the "polluter pays principle" and the "extended producer responsibility", which is a strategy designed to promote the integration of environmental costs associated with goods throughout their life cycles into the market price of the products.

This directive repeals directives *75/439/EEC*, *91/689/EEC* and *2006/12/EC*.

On July 2nd 2014, the European Community adopted a legislative proposal and annex to review recycling and other waste related targets of this directive. The main aim of this proposal is to help turn Europe into a circular economy and to allow a secure access to raw material and create jobs and economic growth.

The main elements of the proposal include among others (*Eurostat, 2014*):

- Recycling and preparing for reuse of municipal waste to be increased to 70% by 2030
- Recycling and preparing for reuse of packaging waste to be increased to 80% by 2030, with material-specific targets set to gradually increase between 2020 and 2030 (to reach 90% for paper by 2025 and 60% for plastics, 80% for wood, 90% of ferrous metal, aluminum and glass by the end of 2030)
- Phasing out landfilling by 2025 for recyclable (including plastics, paper, metals, glass and biowaste) waste in non-hazardous waste landfills - corresponding to a maximum landfilling rate of 25%
- Measures aimed at reducing food waste generation by 30% by 2025
- Promoting the dissemination of best practices in all member states, such as better use of economic instruments (e.g. landfill/incineration taxes, "pay as you throw" schemes, incentives for municipalities) and improved separate collection
- Improving traceability of hazardous waste
- Increasing the cost-effectiveness of "Extended Producer Responsibility schemes" by defining minimum conditions for their operation
- Improving the reliability of key statistics through streamlined calculation of targets
- Improving the overall coherence of waste legislation by aligning definitions and removing obsolete legal requirements

Some other European directives which are currently in use related to MSW management are the following (*Municipal Waste Europe, 2014*):

- *The Lisbon Treaty*: it states that the environment should be regulated by a policy of shared competences between the Union and the member states, and clarifies that one of the Union's objectives is to work for the sustainable development of Europe , based in particular, on high level of protection and improvement of the quality of the environment. Although the idea of sustainable development was included in the previous treaties, the Treaty of Lisbon reinforces and defines this objective better. With this treaty, combating climate change also became a specific objective of EU environmental policy.

- *Commission Communication of February 21st, 2007*: this communication distinguishes between waste and by-products as a non-waste in a production process, and seeks to guide competent authorities in making case by case judgments on whether a given material is a waste or not.

- *Directive 2000/76/EC* of the European Parliament and of the Council of 4 December 2000 on the incineration of municipal waste: the EU imposes strict operating conditions and technical requirements on waste incineration plants, to prevent and reduce air, water and soil pollution caused by the incineration of waste. The directive requires a permit for incineration and co-incineration plants. Emission limits are introduced for certain pollutants released to air or to water.
- *Council Directive 1999/31/EC* of April 26th, 1999 on the landfilling of waste**.** This directive will be discussed more in detail in the next lines (and also in chapters seven and eight), and is the most relevant for the development of the core topic of this thesis.
  The directive has the goal to prevent and reduce the adverse effects of the landfilling of waste on the environment and human health. Reducing the biodegradable content in the landfilled waste will reduce the production of biogas and leachate.
  Its main focus is to achieve common standards for the design, operation and aftercare of landfill sites.
  It defines the different categories of waste (municipal waste, hazardous waste, non-hazardous waste and inert waste) and applies to all landfills.
  The Directive obliges Member States to minimize biodegradable waste to landfills to:
    - 75% by 2006
    - 50% by 2009
    - 35% by 2016

    and to treat it before disposal (the reduction is referred to values of the year 1995 in the respective countries).
    The Directive also defines waste which has not to be accepted in any landfill and sets up a system of operating permits for landfill sites. The directive come fully into force on August 16th, 2009.

4.2 Implementation of European waste directives in Germany

The basis of the German waste legal framework is the European *Waste Framework Directive 2008/98/EC*, which defines the main waste-related terms, lays down a five step waste hierarchy, and contains key provisions for German waste disposal law.

Responsibility for waste management in Germany is shared between the national Government, the Federal States (Bundesländer) and local authorities.

The National Ministry of Environment sets priorities, participates in the enactment of laws, oversees public relations and defines requirements for waste facilities.

Each Federal State adopts his own waste management act, which contain supplementary regulation to the national law, e.g. concerning regional waste management concepts and rules on requirements for disposal. There is no national waste management planning in Germany, but each State develops a waste management plan for its area.

For the household waste, the Recycling Management and Waste Act assigns responsibility to the local public waste disposal authorities (in most Federal States these are districts and towns). Their responsibility covers the collection and the transport of waste, measures to promote waste prevention and recovery and the planning, constructing and operating of waste disposal facilities.

The municipalities have more practical tasks usually, like providing sites for waste collection (*EEA, 2009*).

Germany's first uniform national waste disposal act, the "*Abfallbeseitigungsgesetz (AbfG)*", was adopted in 1972. *The Kreislaufwirschaftsgesetz (KrWG)* is today Germany's main waste disposal statute, and incorporates the main structural elements of the "*Kreislaufwirtschafts - und Abfallgesetz (KrW-/AbfG)*". It entered on force on October 6th, 1996, and was modified lastly on May the 1st, 2014.

The disposal of specific types of waste (end-of-life vehicles, used batteries and end-of-life electronic and electrical devices) is governed by special regulations.

The *Waste Management Act (WMA)* is further differentiated by the waste management acts of the Federal States. Under the German Constitution, the federal government is charged with regulating waste disposal related matters, while the regional states only have jurisdiction over those aspects of waste disposal that are not already regulated by the federal law.

Legal prescriptions in the regional laws tend to address implementation related matters such as the following: determining which entities are subject to waste disposal obligations, the authorizing bodies for waste disposal matters and municipal waste disposal ordinances.

The collection and recovery of MSW at the municipal level are governed by municipal ordinances concerning matters such as usage and integration into the public system, as well as municipal garbage collection charges.

The *Waste Management Act* entered into force on June 2012. The WMA was enacted as *Article 1* of the law titled "*Gesetz zur Neuordnung des Kreislaufwirtschafts- und Abfallrechts*", and supersedes the law titled *"Kreislaufwirtschaftsgesetz (KrWG)"*, and transposes *Directive 2008/98/EC* into German law.

The act adopts the definition of waste from the *European Waste Framework Directive*, whereby the restrictive wording "*moveable property which the holder discards or intends or is required to discard*" is replaced by "*all substances or objects*".

One of the core provisions of the WMA is the waste hierarchy presented in Chapter 3.

Based on this hierarchy, the waste management measures are to be used to best protect human health and the environment, in light of the relevant technical, economic and social factors.

Since January 1st, 2015, separate collection is mandatory for organic waste, as well as for paper, metal and glass. With a view to promoting recycling, *Article 14* of the WMA sets so called recovery rates that will become mandatory in 2020.

Article 17(1) of the act states that waste from households has to be handed over to public sector garbage collection companies, whereby the private households are exempted from this requirement, insofar as the waste in question "*is used on a piece of property that is used for purposes of leading a normal life*."

According to *Article 33* of the Waste Management Act, by December 12th 2013 the administration and the Federal States are to have jointly elaborated the first waste prevention program, which is to define waste prevention objectives and measures. *Articles 53 and 54* enact a new regulation for companies that collect, transport, deal in, or act as middlemen in connection with waste.

These articles eliminate the distinction between waste destined for disposal and waste destined for recycling, replacing these criteria with the potential hazards entailed by the waste in question.

All transport operations involving non-hazardous waste are to be notified, and a permit is to be obtained for the transport of hazardous waste.

In accordance with *Article 72(5),* notification and permit requirements took effect on June 1st, 2014, for companies that are not specialized in waste collection and transporting.

This Waste Management Act is supplemented by other regulations such as the "*Abfallverzeichnis-Verordnung*", a regulation which lists the types of waste that are classified as hazardous and non-hazardous (*UBA, 2014*).

4.2.1 German regulation on landfills

At the end of the 80's in Germany the concept of modern landfill started to develop, because people noticed that the dump sites used at the time were really polluting the environment, with the leaking of leachate and biogas emissions. Incinerators were not so developed as today, and the public opinion was against the implementation of them, scared from the possible emission of dioxins, heavy metals and other air pollutants.

Although landfills were less polluting than dump sites, it was still impossible to ensure total certainty that there will be no leaking over time. A landfill can emit leachate and gas for a hundred years, and it can happen that after some years the materials of the bottom layers and the top cover can break and leaking, or emissions can occur.

The only way to avoid or at least strongly reduce this risk is to pretreat the waste before it is disposed in landfill. Based on this consideration, in the 90's the German waste disposal regulation changed.

In 1993 the "*Technische Anleitung Siedlungsabfall*" (TASi) comes into force, which is based on the concept of a sustainable way for disposing waste in landfills. It introduced also the multi-barrier concept in favor of the prevention of leakage, which will be presented in the next chapters. This regulation promoted the use of mechanical and biological pretreatments of the waste, before the final disposal.

Meanwhile also the regulation about waste incinerators had become more severe and the emission limit values reduced. New technologies allow to emit less waste gasses in the combustion. This facts brought the German waste policy to consider waste incinerators more sustainable as landfills for the final waste disposal.

In 2001, with the "Abfallablagerungsverordnung" (AbfAblV) , the principles of the TASi have been implemented further.

The real big change in the German waste disposal system was in 2005, where a regulation prohibit the waste disposal in landfills of untreated MSW. This regulation called "*Bericht Siedlungsabfallentsorgung*" entered into force at June the 1st, 2005 (*BUN, 2005*). This facts brought to a big reduction in the numbers of landfills in Germany. This is represented in Figure 4.1. Today there are only 140 MSW landfills in Germany (*Statista, 2014*).

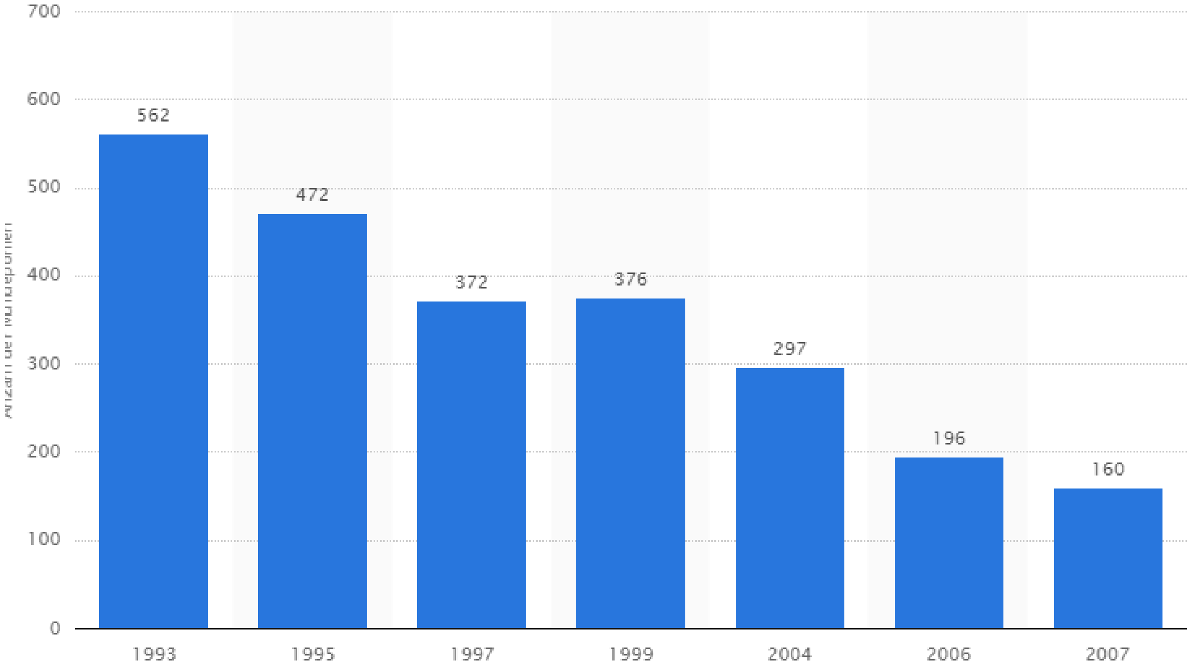


Figure 4.1: *Number of MSW landfills in Germany, from 1993 to 2007 (UBA, Statista, 2015)*

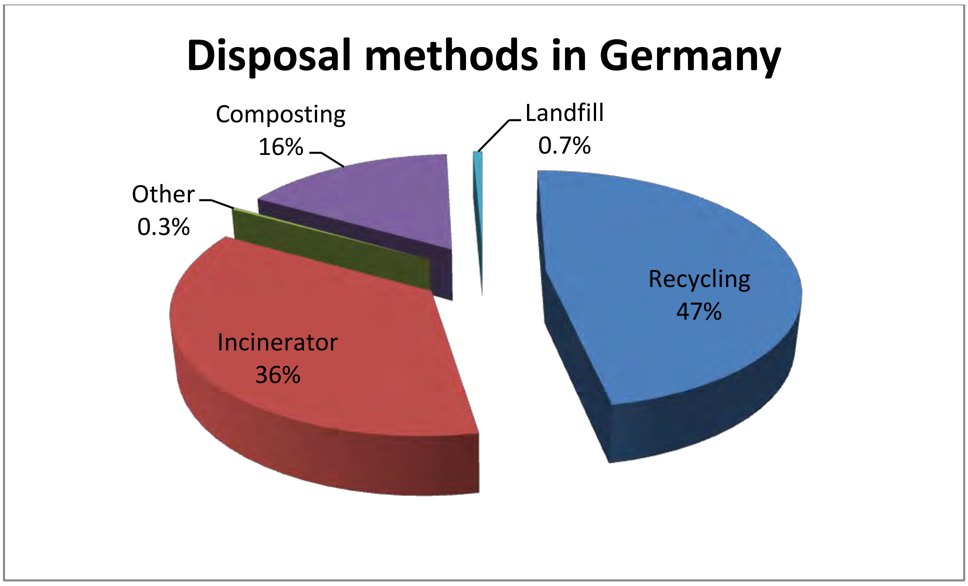


Figure 4.2: *Percentage of final disposal methods in Germany in the year 2014 (Eurostat, 2014)*

Figure 4.2 shows in which percentage the MSW is finally disposed or treated. In Chapter Eight this percentages are discussed and values for other European Countries are provided. Moreover it is noteworthy to mention that although Germany has a landfill ban for untreated waste, no landfill tax exist in the German regulation, despite a lot of other EU Member States use a tax.

All this regulations brought to the developing of the German “*Deponieverordnung*” which is in force nowadays.

4.2.2 The German “Deponieverordnung”

In Germany all the regulation about the creation and management of a landfill is defined by the “*Deponieverordnung (DepV)*” of April 19th, 2009, entered in to force on July 16th, 2009, and modified lately on May the 2nd, 2013. The regulation is divided in six parts, and has many appendices.

1. General provisions
2. Construction, operation, closure and aftercare of landfills
3. Utilization of landfill replacement construction materials
4. Other regulations
5. Long-term storage
6. Final provisions

The regulation is valid for the creation, the management, the aftercare and the closure phase of landfills. The regulation is not valid for landfills which started the closure phase before January the 1st, 1997 and for landfills which has been closed before July 16th, 2009.

It states that all the waste which contains more than 5% of biodegradable matter (of the total organic carbon) has to be treated before its disposal in landfill.

The regulation organizes the landfills in five different classes, in which are disposed different types of waste. The classes are named “Deponieklassen (DK)”, and are numbered in the regulation from zero to four:

- DK 0: landfills in which are disposed inert materials, construction materials and soil waste. This kind of landfills must have at least a clay bottom barrier of one meter thickness, and a leachate drainage system with pipes with diameter of at least 0.3 m.
- DK I and DK II: landfills for non-hazardous waste, like treated MSW, industrial waste and intercalation materials. DK I regards above-ground landfills which contain waste with a very low rate of biodegradable matter, and which produce a reduced amount of leachate and biogas. Landfills classified as DK II are MSW landfills, on which is disposed waste with a higher biodegradable material content as waste in DK I landfills. In this type of landfills the clay layer must have at least 0.5 m of thickness for DK I and 1 m for DK II.

The leachate drainage system is made of pipes with a diameter of at least 0.5 m. Also an High Density Polyethylene (HDPE) layer under the gravel layer has to be provided (usually 1-2 cm).

- DK III: this class regards landfills for hazardous waste disposal (corrosive, toxic, carcinogenic and other harmful materials). The geologic barrier must be of at least 5 m, and a seal control system must be installed.
- DK IV: landfills for hazardous waste, located in a mine or a cavern with a very thick artificial or a natural barrier of clay and rocks.

The regulation requires from the landfill operator that the staff which works on the landfill is qualified and work in a proper way, minimizing every risk and accident probability.

The waste can only be disposed if at the moment of the arrival of it in the landfill side, it already fulfill all required criteria, i.e. it was subjected to specific mechanical-biological pretreatments if necessary.

The producer of the waste (or in case of separate collection the company responsible for the collection) has to characterize the waste when its brought to landfill, from a physical and chemical point of view. The producer has to perform periodically some tests on waste samples, to check if the waste he brings to landfill fulfill the regulation.

Also the landfill operator has to perform an acceptance control for each waste arrival, which regards physical and chemical properties.

The operator has to take care of all phases of a landfill, from the waste disposal phase to the aftercare and closure phase. He has also to check periodically if there is the presence of accidental leachate or biogas emissions in the soil or groundwater. Each year the operator has to deliver a report to the competent authority which explains in detail the management of the landfill.

The regulation requires that the location for the creation of a new landfill fulfill some criteria: there must be at least 1 m soil between the basement of the landfill and the groundwater level. In particular drinking water, water springs and conservation areas must be protected. Particular natural events like floods, earthquakes and avalanches must be taken in consideration if the area is at risk.

The soil layer under the landfill must be able to take care of loads of the landfill, and the weight of the waste should not damage the leachate drainage system.

The improvement of the geologic barrier and the technical measures which eventually substitute the geological barrier, the materials, the cover layers and all components must be effective for a period of at least 100 years.

Table 4.1 shows the minimum values that the different basement layers must have, where k is the hydraulic conductivity and d is the thickness of the layer.

Nr.	Systemcomponent	DK 0	DK I	DK II	DK III
1	Geologic barrier	$k \leq 1x10^{-7}$ m/s $d \geq 1,00$ m	$k \leq 1x10^{-9}$ m/s $d \geq 1,00$ m	$k \leq 1x10^{-9}$ m/s $d \geq 1,00$ m	$k \leq 1x10^{-9}$ m/s $d \geq 5,00$ m
2	First layer	non mandatory	mandatory	mandatory	mandatory
3	Second layer	non mandatory	non mandatory	mandatory	mandatory
4	Mineral drainage layer	$d \geq 0,30$ m	$d \geq 0,50$ m	$d \geq 0,50$ m	$d \geq 0,50$ m

Table 4.1: *Minimum values of hydraulic conductivity and thickness of the different landfill layers, in all landfill categories (DepV, 2009)*

Table 4.2 shows the characteristics that the surface sealing system should have, according the "*Deponieverordnung*".

Nr.	Systemcomponent	DK 0	DK I[5)]	DK II[6)]	DK III
1	Balancing layer	non mandatory	in some cases mandatory	in some cases mandatory	in some cases mandatory
2	Gas drainage layer	non mandatory	non mandatory	in some cases mandatory	in some cases mandatory
3	First sealing component	non mandatory	mandatory	mandatory	mandatory
4	Second sealing component	non mandatory	non mandatory	mandatory	mandatory
5	Seal control system	non mandatory	non mandatory	non mandatory	mandatory
6	Water drainage layer $d \geq 0,30$ m, $k \geq 1x10^{-3}$ m/s, Gradient > 5 %	non mandatory	mandatory	mandatory	mandatory
7	Recultivation layer	mandatory	mandatory	mandatory	mandatory

Table 4.2: *Different characteristics that a surface sealing system must have, for four different types of landfills (DepV, 2009)*

The regulation provides also specific requirements for the location, and the following aspects are particularly important and have to be taken in consideration:

- Natural geologic barrier
- Geotechnical aspects
- Soil type
- Safety of the area
- Groundwater streams

The landfill operator has to perform tests on the disposed waste, which regards the parameter expressed in the following Table 4.3. This table shows all the parameters, elements and compounds which have special limitations in the German *DepV*.

1 Nr.	2 Parameter	3 Unit of measurement	4 Geologic barrier	5 DK 0	6 DK I	DK II	8 DK III	9 recultivation layer
1	**Organic content of the dry residue of the original substance**							
1.01	Loss on ignition	mass %	≤ 3	≤ 3	≤ 3	≤ 5	≤ 10	
1.02	TOC	mass %	≤ 1	≤ 1	≤ 1	≤ 3	≤ 6	
2	**Solid criteria**							
2.01	BTEX	mg/kg DM	≤1	≤ 6				
2.02	PCB 7 PCB-congeners, PCB-28, -52, -101, -118, -138, -153, -180	mg/kg DM	≤ 0,02	≤ 1				≤ 0,1
2.03	PHS (C10 to C40)	mg/kg DM	≤ 100	≤ 500				
2.04	PAH sum (according EPA)	mg/kg DM	≤ 1	≤ 30				≤ 5
2.05	Benzo pyrene (a)	mg/kg DM						≤ 0,6
2.06	Acidic neutralization capacity	mmol/kg			must be identified for hazardous waste	must be identified for hazardous waste	must be identified	
2.07	Extracted lipophilic compunds in the original substance	mass %		≤ 0,1	≤ 0,4	≤ 0,8	≤ 4	

Table 4.3 - part 1: *Legal concentration limits of different indicators and compounds for the different landfill types (DepV, 2009)*

1 Nr.	2 Parameter	3 Unit of measurement	4 Geologic barrier	5 DK 0	6 DK I	DK II	8 DK III	9 recultivation layer
2.08	Lead	mg/kg DM						≤ 140
2.09	Cadmium	mg/kg DM						≤ 1,0
2.10	Chrome	mg/kg DM						≤ 120
2.11	Copper	mg/kg DM						≤ 80
2.12	Nickel	mg/kg DM						≤ 100
2.13	Mercuy	mg/kg DM						≤ 1,0
2.14	Zinc	mg/kg DM						≤ 300
3	**Eluate criteria**							
3.01	pH value		6,5-9	5,5-13	5,5-13	5,5-13	4-13	6,5-9
3.02	DOC	mg/l		≤ 50	≤ 50	≤ 80	≤ 100	
3.03	Phenols	mg/l	≤ 0,05	≤ 0,1	≤ 0,2	≤ 50	≤ 100	
3.04	Arsenic	mg/l	≤ 0,01	≤ 0,05	≤ 0,2	≤ 0,2	≤ 2,5	≤ 0,01
3.05	Lead	mg/l	≤ 0,02	≤ 0,05	≤ 0,2	≤ 1	≤ 5	≤ 0,04
3.06	Cadmium	mg/l	≤ 0,002	≤ 0,004	≤ 0,05	≤ 0,1	≤ 0,5	≤ 0,002
3.07	Copper	mg/l	≤ 0,05	≤ 0,2	≤ 1	≤ 5	≤ 10	≤ 0,05
3.08	Nickel	mg/l	≤ 0,04	≤ 0,04	≤ 0,2	≤ 1	≤ 4	≤ 0,05
3.09	Mercuy	mg/l	≤ 0,0002	≤ 0,001	≤ 0,005	≤ 0,02	≤ 0,2	≤ 0,0002
3.10	Zinc	mg/l	≤ 0,1	≤ 0,4	≤ 2	≤ 5	≤ 20	≤ 0,1
3.11	Chloride	mg/l	≤ 10	≤ 80	≤ 1 500	≤ 1 500	≤ 2 500	≤ 10
3.12	Sulfate	mg/l	≤ 50	≤ 100	≤ 2 000	≤ 2 000	≤ 5 000	≤ 50
3.13	Cyanide	mg/l	≤ 0,01	≤ 0,01	≤ 0,1	≤ 0,5	≤ 1	
3.14	Fluoride	mg/l		≤ 1	≤ 5	≤ 15	≤ 50	
3.15	Barium	mg/l		≤ 2	≤ 5	≤ 10	≤ 30	
3.16	Total Chrome	mg/l		≤ 0,05	≤ 0,3	≤ 1	≤ 7	≤ 0,03
3.17	Molybdenum	mg/l		≤ 0,05	≤ 0,3	≤ 1	≤ 3	
3.18a	Antimony	mg/l		≤ 0,006	≤ 0,03	≤ 0,07	≤ 0,5	
3.18b	Antomony - Co value	mg/l		≤ 0,1	≤ 0,12	≤ 0,15	≤ 1,0	
3.19	Selenium	mg/l		≤ 0,01	≤ 0,03	≤ 0,05	≤ 0,7	
3.20	Total content of dissolved solids	mg/l	≤400	≤400	≤3 000	≤6 000	≤10 000	
3.21	Electrical conductivity	µS/cm						≤ 500

Table 4.3 - part 2: *Legal concentration limits of different indicators and compounds for the different landfill types (DepV, 2009)*

4.3 Implementation of European waste directives in Italy

In Italy the first regulation concerning the integrated waste management was the "*decreto legislativo 5 febbraio 1997, n.22*", the so called "*decreto Ronchi*". This decree was the implementation of the European directives *91/156/CEE*, *91/689/CEE* and *94/62/CE*.

It defined the responsibilities among the actors of the national waste management system. In particular, regions hold the responsibility for drawing up waste management plans to promote waste reduction (with regard both to hazardousness and quantity), and municipalities within optimal management areas (Ambito Territoriale Ottimale - ATO, which are generally represented by provinces) organize municipal waste collection and management. It set the following targets for separate collection of municipal waste to be achieved at ATO level (percentages are related to municipal waste generation):

- 15% by 1999
- 25% by 2001
- 35% by 2003

This issues are nowadays present in the "*d. lgs. 3 aprile 2006, n. 152*", also called "*Testo Unico Ambientale*", the Italian Environmental Code. This legislative decree contains almost the whole national environmental legislation, and is so the most important national law source about environmental issues. It is based on the waste management hierarchy imposed by the European directives.

The *Directive 2008/98/EC* of the European Parliament and of the Council of 19 November 2008, which sets down the fundamental principles and rules for definition and management of waste, was also incorporated into "*Testo Unico Ambientale*".

The provisions set down in the Environmental Code can be divided into two sections: a general section containing about forty articles (*Articles 177-216*), relating to the sphere of application of the associated provisions and corresponding exclusions, principles, prevention of wastes, definitions, the liability of the producer, by-products, so-called end of-waste materials, classification of wastes, powers and jurisdiction, and the associated department and authorizations.

The second section contains about twenty articles (*Articles 217-238*), dedicated to coverage of specific types of wastes (packaging materials, electrical and electronic equipment, tires, end-of-life vehicles, the various waste consortia, etc.) (*www.ius-publicum.com*).

In Italy the citizens have to pay a waste fee for the management of MSW, which regards procedures from waste collection to disposal.

Until December 31st, 2013, this fee was called "*tributo comunale sui rifiuti e sui servizi*" (TARES). This has been introduced with the legislative decree "*decreto-legge 6 dicembre 2011, n. 201*", the so called "*decreto salva Italia*", and became a law after (*legge 22 dicembre 2011, n.214*).

At January 1st, 2014, this fee was substituted by the "*Tassa sui rifiuti*" (TARI), introduced with law "*legge n. 147 del 27 dicembre 2013*", which is the current waste fee. This fee depends from the amount of family members and varies usually between the 100 and 300 EUR/y.

In the following lines are listed the main most recent Italian laws related to waste management:

- *D.lgs. 03 dicembre 2010, n. 205*: Implementation of *Directive 2008/98/EC* of the European Parliament
- *D.Lgs. 29 giugno 2010, n.128*: Updating of the Environmental Code 152/2006
- *DPCM del 27 aprile 2010*: change of the "*modello unico di dichiarazione ambientale (MUD)*"
  (G.U. 28 aprile 2010, n.98)
- *Delibera 20 luglio 2009*: Criteria and requirements for the enrollment in the first category for the performance of digestion activity in waste collection centers
  (*G.U. 5 agosto 2009, n. 180*)
- *D.M. 13 maggio 2009*: Changing of *decreto dell'otto aprile 2008* laying down the rules of the collection centers of MSW, as required by Article 183, paragraph 1, letter cc, of *TUA*
  (*G.U. 18 luglio 2009, n. 165*)
- *D.M. 22 ottobre 2008*: Simplification of administrative procedures referred to in Article 195, paragraph 2, letter s-bis) of *Legislative Decree no. 152/2006*, regarding the collection and transport of specific types of waste
  (*G.U. 12 novembre 2008 n. 265*)
- *D.M. 8 aprile 2008*: Discipline of collection points of MSW collected separately, as required by Article 183, paragraph 1, letter cc) of *TUA*
  (*G.U. 28 aprile 2008, n. 99*)

About the Italian regulation which concerns landfill and incinerators, the following decrees are the most relevant ones (*Novambiente, 2015*):

- *Allegato DGRV n. 2155 del 13 dicembre 2011*: Regional Program for the reduction of the amount of biodegradable waste going to landfill
- *D.M. 27 settembre 2010*: Definition of the criteria for the acceptance of waste in landfills, replacing those contained in the Decree of the Minister of Environment of August 3, 2005
  (*G.U. 281 del 1-12-2010*)
- *D.M. 3 agosto 2005*: Definition of the criteria for the acceptance of waste in landfills
  (*GU n. 201 del 30 agosto 2005*)
- *D.Lgs. 11 maggio 2005, n. 133*: Execution of directive 2000/76/EC - waste incineration
  (*G.U. 15 luglio 2005, n. 163 - S.O. n. 122)*
- *D.Lgs. 13 gennaio 2003, n. 36*: Execution of directive 1999/31/CE - MSW landfills
  (*G.U. 12 marzo 2003 n. 59*)

The Environmental Code sets the different responsibilities at national, regional and municipal level (*d. lgs. 3 aprile 2006, n. 152*):

National tasks (Environmental Code Art. 195):

- Identification of the disposal, reuse and recycling plants
- Creation of a national environmental law regulation
- Instructions for the citizens about how to perform waste separation, collection and disposal
- Creation of economic actions which support and promote reuse and recycling of waste
- Creation of national guidelines for the waste management
- Decision about the location of waste disposal plants
- General criteria for source segregation and waste collection

Regional tasks (Environmental Code Art. 196):

- Creation of a regional waste management plan
- Specific regulation about source segregation and waste collection
- Regulation about the soil remediation
- Emit authorizations for waste disposal and recycling plants

Provincial tasks (Environmental Code Art. 197):

- Control over soil remediation procedures
- Periodical control of all waste management procedures, waste trade procedures, and the fulfillment of the waste regulation by all citizens and companies
- Identification of the zones for the building of waste disposal and recycling plants

Municipal tasks (Environmental Code Art. 198):

- Ensure the safety in all processes of waste management
- Way of source segregation and waste collection
- Waste transport system

The landfill regulation in Italy is provided by the decree "*D. Lgs. 13 gennaio 2003, n. 36*", which transposes the previously mentioned *Council Directive 1999/31/EC of 26 April 1999* on the landfilling of waste.

The contents and aims of this decree can be compared with the German "*Deponieverordung*". It provides all the necessary information for an adequate landfill management. The goals of this decree are expressed by *Article 1*: minimizing the biogas and leachate emission risks and also reduce the amount of waste which goes to landfill, due recycling , anaerobic digestion and composting.

Article 2 contains specific definitions to all involved parts. The third and fourth article divide the landfills in different classes:

- Inert waste landfills
- Non-hazardous waste landfills
- Hazardous waste landfills

Article 5 states that within a year since the entry in force of the decree all the regions have to develop a plan for the reduction of disposal of biodegradable waste in landfills. The decree impose to:

- Reduce the amount of biodegradable waste to 173 kg/inhabitant/y by 2008
- Reduce the amount of biodegradable waste to 115 kg/inhabitant/y by 2011
- Reduce the amount of biodegradable waste to 81 kg/inhabitant/y by 2018

Article 6 and 7 state which waste-types are not allowed in a landfill. Article 8 and 9 contains information related to the authorization required for the opening and the management of a landfill side.

Article 11 list the admission procedures. *Article 12 and 13* regard rules about the closure and the aftercare phase. *Article 14 and 15* regard the financial and economic aspects of the landfill management, while *Article 16* contains the sanctions in case of violation of the regulation.
The last Article, number 17, states that all landfills which already have an authorization can still dispose waste until July 16th, 2005 without considering this decree, while new ones have to consider this decree since their opening.
Annex 1 gives particular criteria about the location of a new inert waste landfill, and defines the features of the geologic barrier. The basement of the geologic barrier must be a natural clay layer with thickness > 1 m and a permeability $k < 1 \cdot 10^{-7}$.
Also the top-cover needs to have specific features, and they are identical to that required by the German "DepV".
For non-hazardous and hazardous waste landfills the features are different and more precautionary.
Annex 2 contains specific regulation about the aftercare phase. About the concentration of specific chemical compounds and indicators, this directive is not that strict as the German "DepV". There is a list (Table 4.4) which indicates the parameters and compounds which have to be monitored in the groundwater, but no specific concentration levels which have to be respected are provided by the directive. This was until 2005.

pH
Temperature
Electric conductivity
Oxidizing power
BOD5
TOC
Ca, Na, K
Chlorides
Sulfates
Fluorides
Fe, Mn
As, Cu, Cd, Cr, Hg, Ni, Pb, Mg, Zn
Cyanides
Nitrogen
Phenols
Pesticides
Organic solvents

Table 4.4: *Parameters which have to be periodically measured in the groundwater, and in the leachate according to "D. Lgs. 13 gennaio 2003, n . 36"*

Also some tests on the waste have to be performed, in particular on the biogas and the leachate, but no particular limits are provided.

With the decree "*D.M. 3 agosto 2005*", specific values for the different parameters have been introduced.

For non-hazardous waste landfills the legal limits set in this decree are shown in Table 4.5.

Component	mg/l
As	0.2
Ba	10
Cd	0.02
Cr	1
Cu	5
Hg	0.005
Mo	1
Ni	1
Pb	1
Sb	0.07
Se	0.05
Zn	5
Chlorides	1500
Fluorides	15
Cyanides	0.5
Aromatic organic solvents	0.4
Chlorinated organic solvents	2
Nitrogenous organic solvents	0.2
Pesticides	0.1
Sulfates	2000
DOC	80
TDS	6000

Table 4.5: *Concentration limits of different components in the waste in non-hazardous landfills, considering 1 kg of waste and a L/S = 10 (i.e. MSW landfills), according to "D.M. 3 agosto 2005"*

Also the decree "*D.M. 27 settembre 2010*" aims to define more precisely the admission criteria for waste in landfills, and other limits have been introduced, for example for BTEX.

In this decrees also the definition of a landfill tax is provided. For the leachate itself specific legal limits have been set.

The landfill tax in Italy was introduced firstly in 1996, based on *Law 549/1995* and following amendments intended to reduce waste production and promote material and energy recovery. The Law defines the upper and the lower level of the tax (currently EUR 0.001-0.01/kg for inert waste and EUR 0.00517- 0.02582/kg for hazardous and non-hazardous waste), which is applied at a regional level. According to the Law, the tax is based on the amount of solid waste landfilled. The tax is additional to the gate fee, and needs to be paid from each citizen.

4.4 Differences in the waste legislation of the two countries

Comparing the two legal frameworks it is possible to notice a difference in the EU directives implementation. Although both legislation systems are based on the same EU directives, the way they are applied in each country is different.

In 2012 the European Commission performed a screening of the waste management in the different Member States (*Bipro, 2012*). The result of the screening procedure divides the European countries in three groups: Germany is in the first group, which is the group of countries with a very well implemented waste management, while Italy is in the last group, which represents countries with large implementation gaps in waste management (for the complete screening results of all Member States, see Annex 1). The ranking was performed giving a certain score to each country, based on different aspects.

Italy reached average or good scores for half of the criteria (nine criteria). Deficits in waste management performance were identified and related to all criteria on waste management planning, non-compliant landfills for non-hazardous waste and decrease of municipal waste recycling in the last years.

The situation is mirrored by the highest number of infringement procedures regarding the WFD and Landfill Directives which were all brought to court. However, Italy is performing average in several aspects (e.g. energy recovery and recycling, adoption of restriction for landfilling of municipal waste and average ratio of biodegradable waste going to landfills).

The full score was applied for the total typical charge for landfilling municipal waste which is above the EU average, for the fulfilment of the reduction target on biodegradable waste going to landfills and for a reported full coverage of collection of waste from households.

It has to be noted that there are large divergences between the northern and the southern part of Italy. As the northern part is well performing in several issues, the south has large problems, including problems of waste collection and high dependency on landfilling.
What emerges from this screening is that the Italian waste management system is not well implemented, and this also due to the lack of proper legislation.
Focusing only on landfill management, Italian situation is in the European average. The European waste directives about landfill management have been implemented with positive results, and the national landfill regulation is working properly. It is true that compared to other European countries like Germany, Italy is still relying too much on landfills as final disposal method (especially in the southern part), but there exist good prospects for the future that Italy will reduce its amount of disposed waste due recycling, incineration and composting.

5. Area description

5.1 Germany

The area of Germany is more or less 357.020 km^2.

It is consisting of 16 Federal States, which retain limited sovereignty.

With 80 million inhabitants, it is the most populous Member State in Europe. Germany is a major economic and political power of the European continent and a historic leader in many cultural, theoretical and technical fields.

After the United States, Germany is the second most popular migration destination in the world.

As a global leader in several industrial and technological sectors, it is both the world's third-largest exporter and third largest importer of goods.

Germany is a developed country with a very high standard of living, featuring comprehensive social security that includes the world's oldest universal health care system (*Destatis, 2015*).

Figure 5.1*: Geographical position of Germany (Google, 2015)*

Geography and environment:

The altitude ranges from the mountains of the Alps in the south to the shores of the North Sea in the northwest and the Baltic Sea in the northeast. The forested uplands of central Germany and the lowlands of northern Germany are traversed by such major rivers as the Rhine, Danube and Elbe. Glaciers are found in the Alpine region. Significant natural resources are iron, ore, coal, potash, timber, lignite, uranium, copper, natural gas, salt, nickel, arable land and water.

Climate:

Germany has a temperate seasonal climate in which humid winds predominate. The country is situated in between the oceanic Western European and the continental Eastern European climate. The climate is moderated by the North Atlantic Drift, the northern extension of the Gulf Stream. This warmer water affects the areas bordering the North Sea, consequently in the northwest and the north the climate is oceanic. Germany gets an average of 789 mm precipitation per year. Rainfall occurs year-round, with no obligatory dry season. Winters are mild and summers tend to be warm, temperatures can exceed 30 °C (*Dwd, 2015*).

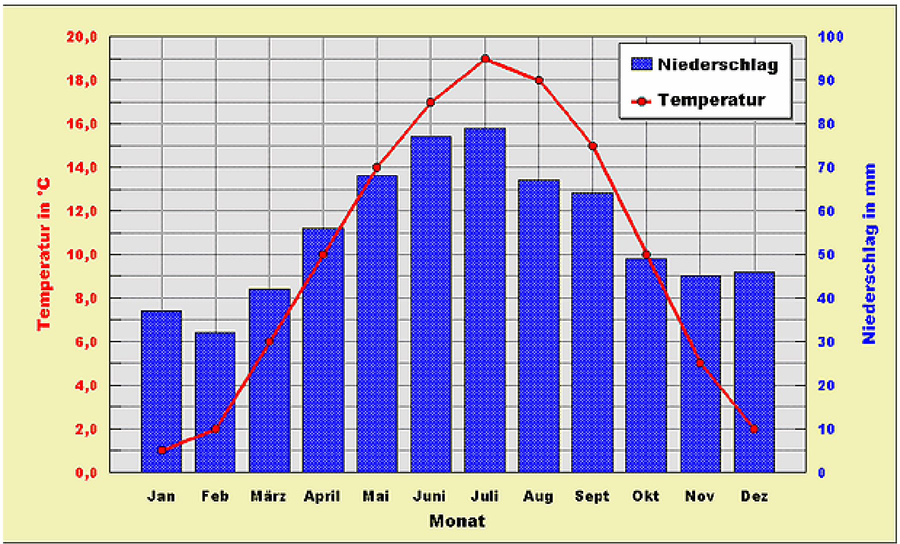


Figure 5.2*: Average monthly temperature and rain (in mm) in Germany in 2012 (Stgt, 2012)*

5.2 Italy

Italy covers an area of 301.330 km^2. With 61 million inhabitants, it is the 5th most populous country in Europe. Among the world's most developed countries, Italy has the 4th-largest economy in the European Union and 8th in the world by GDP. Italy is located in Southern Europe and comprises the boot-shaped Italian Peninsula and a number of islands (*Istat, 2013).*

Figure 5.3*: Geographical position of Italy*
Google, 2015

Geography and environment:

Italy has a coastline of 7.600 km on the Adriatic, Ionian and Tyrrhenian seas.

The Apennine Mountains form the peninsula's backbone and the Alps form most of its northern boundary.

The Pò, Italy's longest river, flows from the Alps on the western border with France and crosses the Padan plain on its way to the Adriatic Sea.

The Mont Blanc is the highest point in Italy and the European Union.

The country is situated at the meeting point of the Eurasian Plate and the African Plate, leading to considerable seismic and volcanic activity.

Climate:

Thanks to the great longitudinal extension of the peninsula and the mostly mountainous internal conformation, the climate of Italy is highly diverse. In most of the inland northern and central regions, the climate ranges from humid subtropical to humid continental and oceanic. In particular, the climate of the Pò valley geographical region is mostly continental, with harsh winters and hot summers.

The coastal areas of Liguria, Tuscany and most of the South generally fit the Mediterranean climate stereotype.

Temperature and rainfall are quite different from the north to the south and on the islands.

In Figure 5.4 and Figure 5.5 the national monthly average trend of this values is shown (*Codima, 2014).*

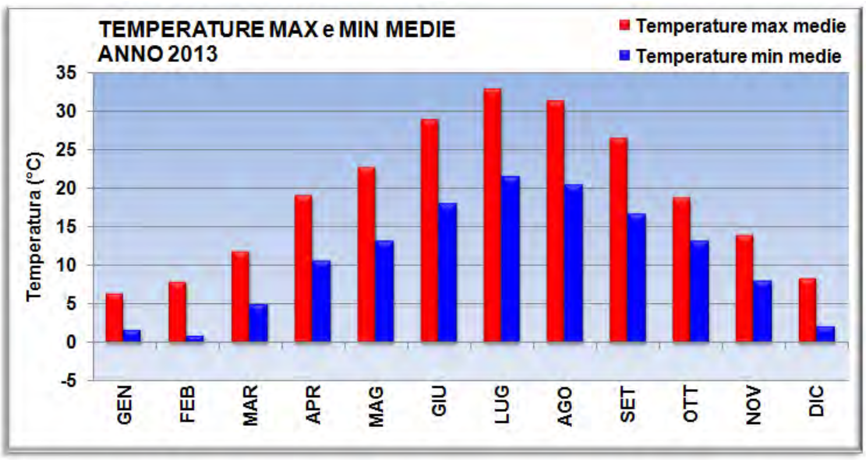


***Figure 5.4**: Average monthly temperature in Italy in 2013 (Codima, 2014)*

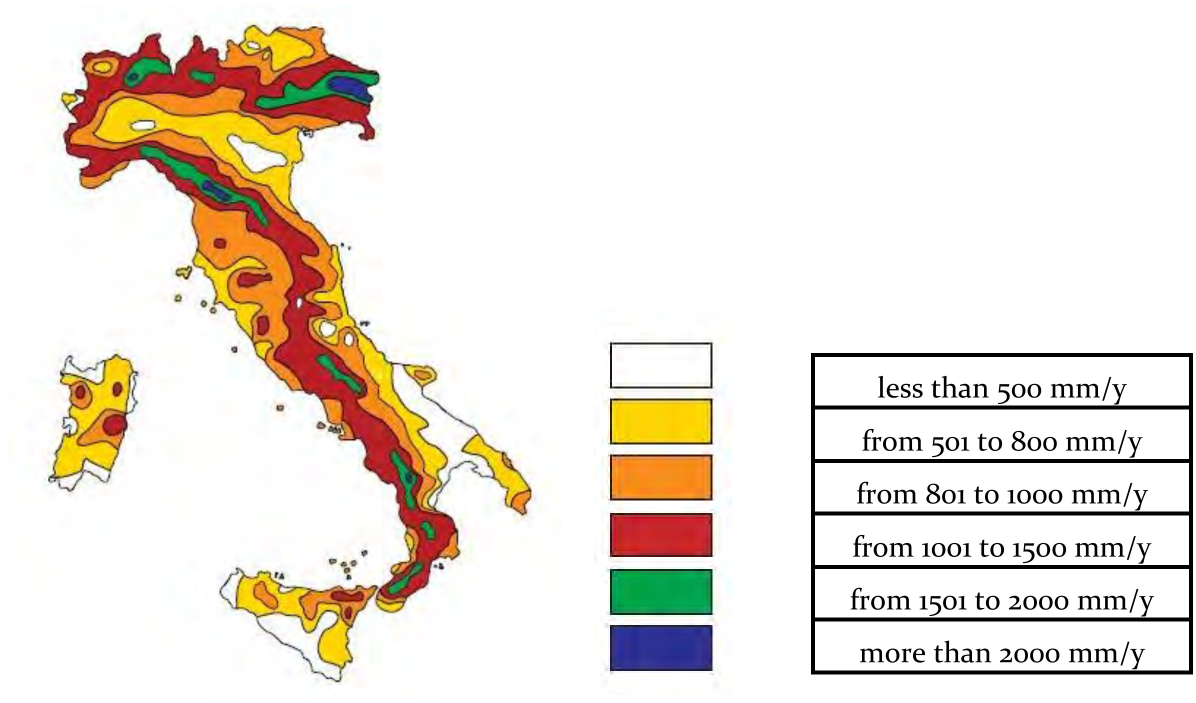


Figure 5.5*: Average yearly rainfall in mm in Italy - 2013 (Il Meteo, 2014)*

6. Waste characterization

Waste characterization is the process by which the composition of different waste streams is analyzed. It is performed separating the waste in different categories, similar in physical properties, and define the amount of waste for each category. In this study, the categories considered are:

- Cellulosic material
- Plastic material
- Metals
- Putrescible waste
- Glass and inert waste
- Hazardous waste
- Composite waste and other types of waste

Developers of new waste treatment technologies must take into account in what exactly waste streams consist of in order to fully treat the waste.

6.1 Waste characterization in the World

Worldwide, developed countries produce more waste per capita because they have higher levels of consumption. There are higher proportions of plastics, metals, and paper in the municipal solid waste stream and there are higher costs of the work. As countries continue developing, there is a reduction in biological solid waste and ash percentage in the waste. Per capita waste generation in OECD countries has increased by 14% since 1990, and 35% since 1980. Waste generation generally grows at a rate slightly lower than GDP in these countries. Developed countries consume more than 60% of the world industrial raw materials and only comprise 22% of the world's population (*Hoornweg et al., 2012).*

Developing countries produce lower levels of waste per capita with a higher proportion of organic material in the municipal solid waste stream. If measured by weight, organic (biodegradable) residue constitutes at least 50% of waste in developing countries. Labor costs are relatively low but waste management is generally a higher proportion of municipal expenditure. Figure 6.1 is a graphical representation of the average daily amount in kg of MSW produced per person, all over the world. Figure 6.2 shows the average amount in kg of MSW per capita produced in a year in the different countries of Europe.

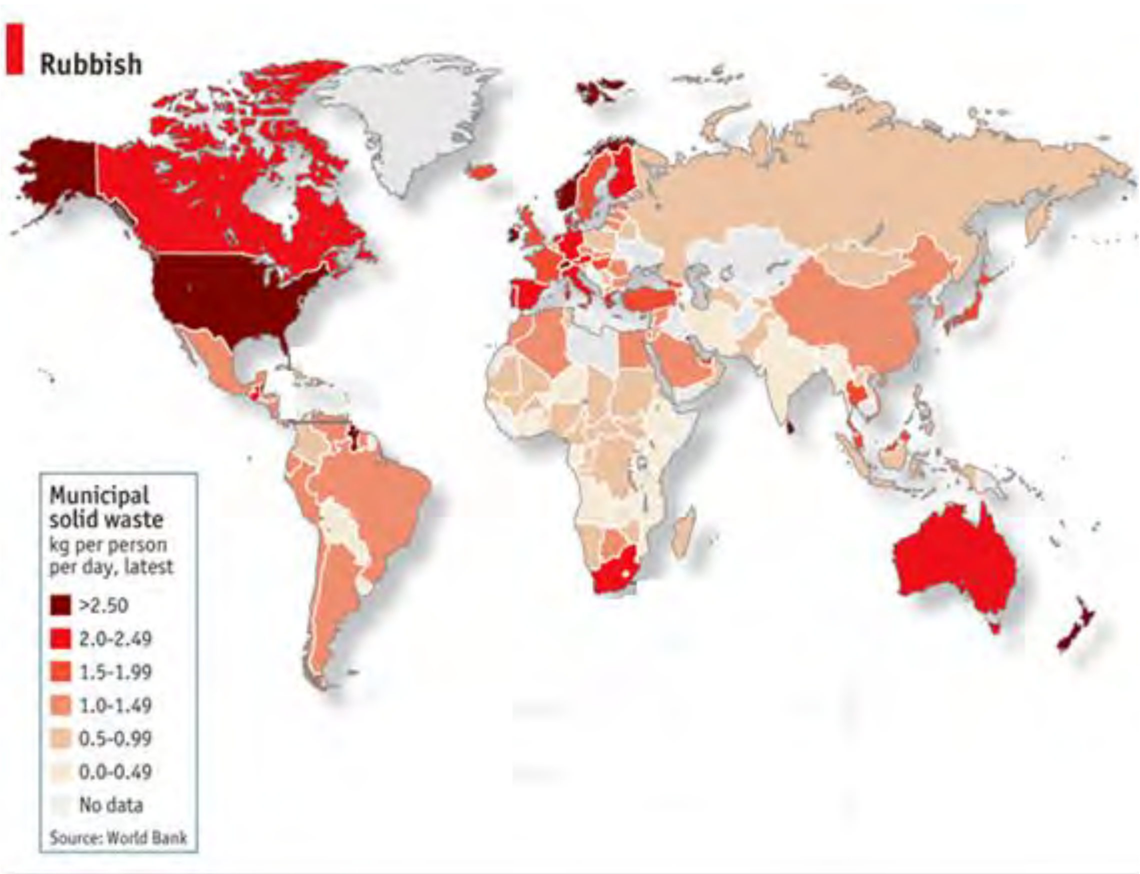


Figure 6.1: *Average amount of MSW produced per person per day, in kg, in different countries (Statista, 2014)*

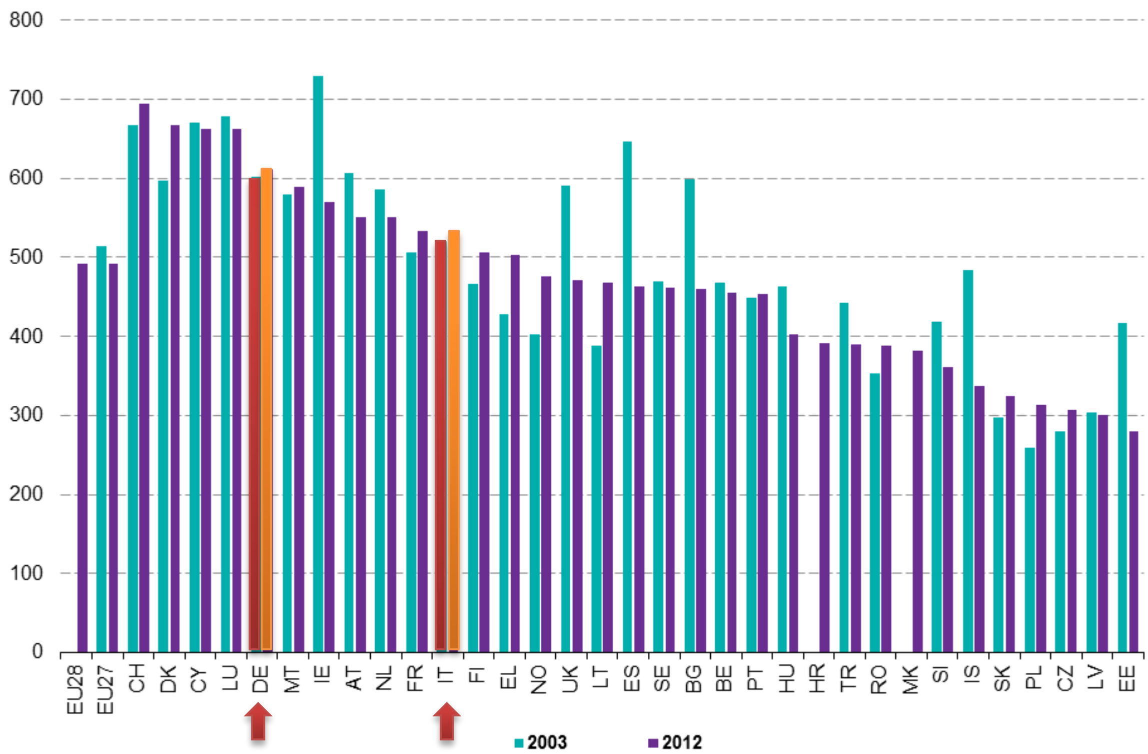
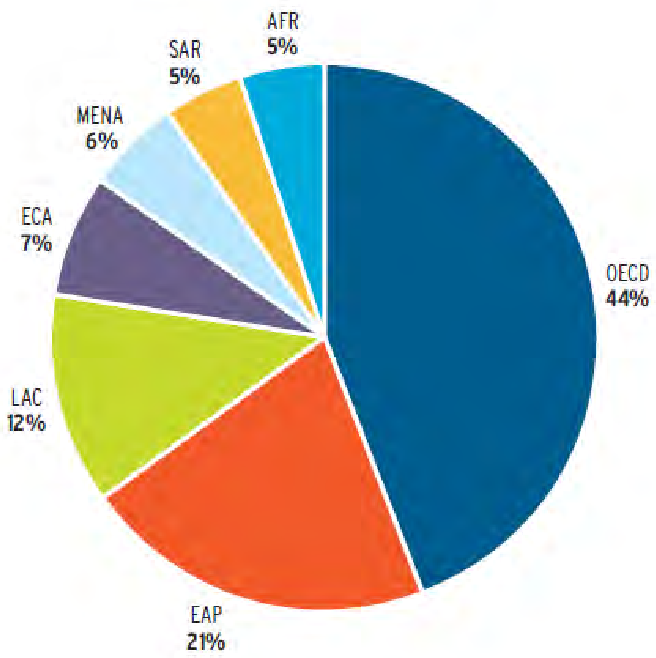


Figure 6.2: *Average amount of MSW produced per person per year, in kg, in different countries in Europe (Eurostat, 2014)*

Nowadays global MSW generation levels are more or less 1.3 billion tons per year, and are expected to increase to approximately 2.2 billion tons per year in 2025.

This represents a significant increase in per capita MSW waste generation rates, from 1.2 to 1.45 kg per person per day, in the next 15 years (*Hoornweg et al., 2012).*

MSW generation rates are influenced by economic development, the degree of industrialization, public habits and local climate. Income level and urbanization are highly correlated, and as the standard of living increase, consumption of goods increase, and consequently also the production of waste.



AFR	Sub - Saharan Africa
EAP	East Asia and Pacific Region
ECA	Eastern and Central Asia
LAC	Latin America and Caribbean
MENA	Middle East and North Africa
OECD	OECD Countries
SAR	South Asia Region

Figure 6.3*: Waste generation by region (Hoornweg et al., 2012)*

Region	Current Available Data			Projections for 2025			
	Total Urban Population (millions)	Urban Waste Generation		Projected Population		Projected Urban Waste	
		Per Capita (kg/capita/day)	Total (tons/day)	Total Population (millions)	Urban Population (millions)	Per Capita (kg/capita/day)	Total (tons/day)
AFR	260	0.65	169,119	1,152	518	0.85	441,840
EAP	777	0.95	738,958	2,124	1,229	1.5	1,865,379
ECA	227	1.1	254,389	339	239	1.5	354.810
LCR	399	1.1	437,545	681	466	1.6	728,392
MENA	162	1.1	173,545	379	257	1.43	369,320
OECD	729	2.2	1,566,286	1,031	842	2.1	1,742,417
SAR	426	0.45	192,410	1,938	734	0.77	567,545
Total	2,980	1.2	3,532,252	7,644	4,285	1.4	6,069,703

Table 6.1*: Waste generation projections for 2025 by region (Hoornweg et al., 2012)*

The previous figure and the related table show clearly how high the amount of waste produced by the OECD countries, Japan and the Pacific Region is. This countries produce more than the half of the global waste production. Africa, South-and Central America, Central Asia and the Middle East are the most populated regions of the World, but there waste production is far lower. This is related to the welfare. The projections for the year 2025 show how the waste production in this countries will increase, while the only group which will decrease its waste production (from 2.2 to 2.1 kg/capita/day) is the OECD group. This can be explained due to the fact that the globalization and the continuously developing of countries like China, India, Brazil and other developing countries will bring to a higher economic welfare in this countries, which bring in turn to a higher rate of waste generation.

The OECD countries instead will probably have a constant or slightly growing economic situation, and develop maybe further waste minimization and prevention strategies, and for this reason their waste generation will not rise.

Previously, talking about developed and developing countries, the different waste composition was mentioned. As a country develops and becomes wealthier, the composition of waste typically becomes more varied and complex. The waste composition related to the income of the country is shown in Figure 6.4, while Figure 6.5 shows the relationship between GDP per capita and the MSW production.

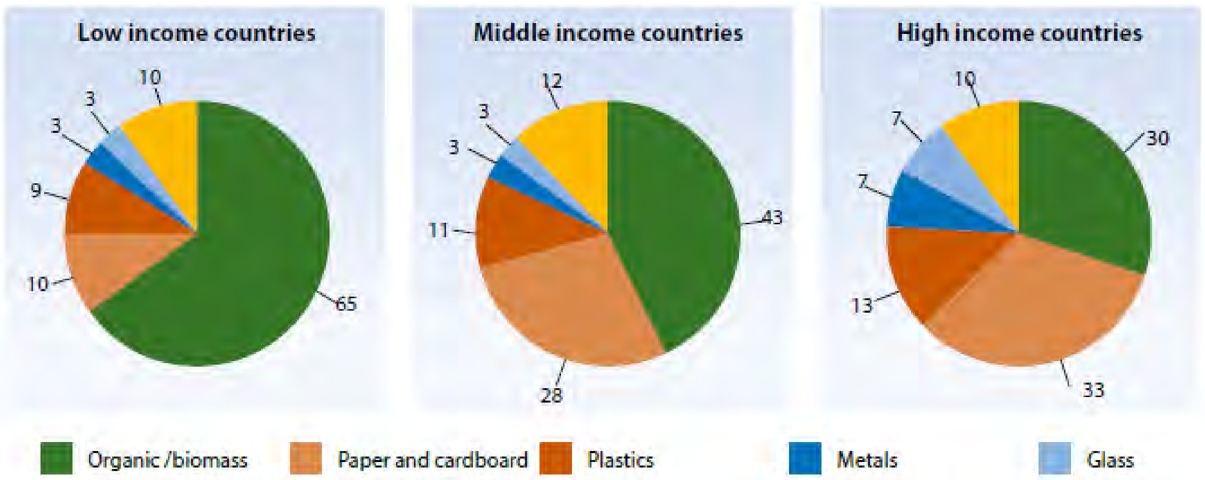


***Figure 6.4**: Composition (in %) of MSW by national income (UNEP, 2011)*

In developing countries the rate of the organic fraction is higher in MSW, because the economy in this countries is mostly based on the trade of goods of first use, as food.

In developed countries the industry is performing production processes using more products as plastic, metals and paper, and for this reason they will be present in a higher amount in the waste.

***Figure 6.5**: Relationship between GDP and MSW production (UNEP, 2011)*

This graph shows how citizens of richer countries with a higher average income, have a greater purchasing power and buy more products, and produce so more waste.

Another consideration is that developed countries with a western mentality are more marked by a consumeristic way of thinking, and often resources (like food, clothes and electric devices for example) are not totally used, but partly wasted. In developing countries where people have a lower standard of living there is the tendency to maximize the use efficiency of each product, and as a result to reduce the waste production.

One of the main problems facing policy makers in the waste management sector is how to predict the amount and the composition of MSW that is likely to be generated in the near future, in order to devise the most appropriate treatment and disposal strategy.

A study *(Daskalopoulos et al., 1998*) revealed that it is possible to predict the waste amount knowing the GDP trend over time. The research team of this study created a model which can predict the waste amount of the different waste categories, in relation to the GDP.

So GPD can be used as prediction and in waste policy to define the best treatment and disposal solutions.

For a more complete vision of the relation between GDP and waste production see Annex 2.

6.2 Waste characterization in the European Community

It's important to remind that MSW accounts more or less only 9-14% of the total waste generated (like Figure 6.6 and 6.7 show in detail). However, it has a very high political profile because of its complex character, due to its composition, its link to consumption patterns and the risk it can cause to human health and the environment. Figure 6.6 shows the General waste composition in Germany. In Italy the waste from production and industry is less, but the other waste categories are almost the same.

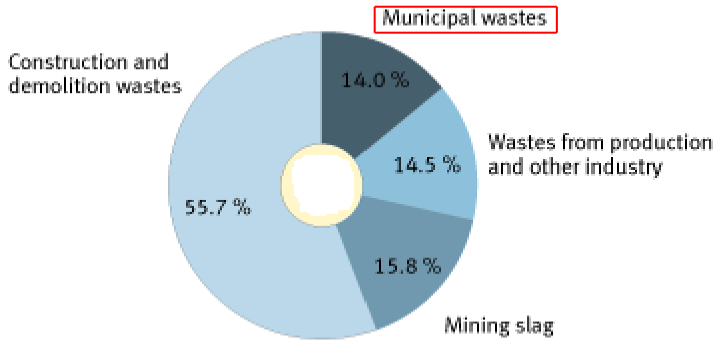


***Figure 6.6**: General waste composition in Germany (Destatis, 2014)*

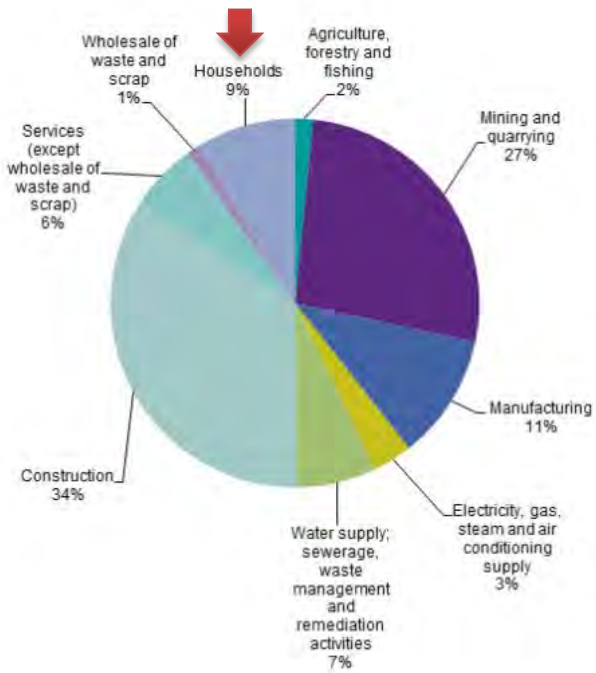


***Figure 6.7**: General waste composition in the EU-28, in 2012 (Eurostat, 2014)*

In the year 2010, the total generation of waste from economic activities and households in the European Community amounted to 2.5 billion tons.

Eurostat has collected and published data on municipal waste since 1995. These data are widely used for comparing municipal waste generation and treatment in different countries, and indicators on municipal waste are used to monitor European waste policies. The data on municipal waste expressed in kilograms per capita are part of a set of indicators compiled annually to monitor the EU's sustainable development strategy.

	Total waste from economic activies and households	Mining and quarrying	Manufacturing	Energy	Construction & demolition	Other economic activities	Households
EU-28	2 505 660	671 830	275 960	86 040	859 870	392 360	219 600
Belgium	62 537	1 701	14 543	1 210	18 165	22 239	4 679
Bulgaria	167 396	150 214	3 306	8 032	79	2 235	3 529
Czech Republic	23 758	115	4 202	1 540	9 354	5 212	3 334
Denmark	20 965	41	1 919	517	3 176	12 877	2 436
Germany	363 545	24 493	48 981	9 087	190 990	53 682	36 312
Estonia	19 000	6 453	3 716	6 534	436	1 430	430
Ireland	19 808	2 196	3 259	334	1 610	10 679	1 730
Greece	70 433	44 793	4 941	11 029	2 086	2 387	5 198
Spain	137 519	31 732	16 480	2 339	37 947	25 823	23 198
France	355 081	1 053	20 382	993	260 226	43 121	29 307
Croatia	3 158	29	634	108	8	2 379	0
Italy	158 628	706	35 928	2 660	59 340	27 515	32 479
Cyprus	2 373	382	132	3	1 068	327	461
Latvia	1 498	1	375	25	22	382	694
Lithuania	5 583	7	2 653	68	357	1 238	1 261
Luxembourg	10 441	18	867	2	8 867	437	250
Hungary	15 735	87	3 134	2 718	3 072	3 859	2 865
Malta	1 353	57	9	0	988	150	150
Netherlands	119 255	184	14 094	1 156	78 064	16 685	9 072
Austria	34 883	269	2 958	453	9 010	17 569	4 623
Poland	159 458	61 547	28 618	20 291	20 818	19 294	8 890
Portugal	38 347	1 206	9 766	456	11 071	10 386	5 464
Romania	219 310	177 404	7 862	5 888	238	21 791	6 127
Slovenia	5 159	12	1 517	558	1 509	835	728
Slovakia	9 384	166	2 669	878	1 786	2 167	1 719
Finland	104 337	54 851	15 211	1 445	24 645	6 504	1 681
Sweden	117 645	89 026	7 823	1 479	9 381	5 898	4 038
United Kingdom	259 068	23 092	19 970	6 239	105 560	75 258	28 949
Liechtenstein	312	12	32	0	0	268	0
Norway	9 433	366	2 687	28	1 543	2 580	2 229
FYR of Macedonia	2 328	855	1 017	4	0	0	451
Serbia	33 623	26 458	1 146	6 019	0	0	0
Turkey	783 423	723 791	11 406	18 578	0	60	29 587

Table 6.2*: Waste generation by economic activity and household in the EU-28, 2010 (Eurostat)*

Table 6.2 shows an analysis of the total waste generated by various economic activities. There were considerable variations across the EU-28 Member States in 2010, both in the amount of waste generated and the activities that contributed considerably to waste generation.

The total amount of waste generated in 2010 ranged from 1,3 million tons in Malta to 363,5 million tons in Germany.

The highest shares of the EU-28 total being accounted for by Germany (14.5%), France (14.2%) and the United Kingdom (10.3%), which made up 39.0% share of total EU-28 waste generation.

Regarding waste generation by activity, construction accounted for the largest share of generated waste in eleven EU Member States, ranging from 27.6% in Spain to 84.9% in Luxembourg. The manufacturing industry accounted for the largest share of generated waste in Lithuania (47.5%), Slovenia (29.4%) and Slovakia (28.4%). Mining and quarrying accounted for the largest share in Bulgaria (89.7%), Romania (80.9%), Sweden (75.7%), Greece (63.6%), Finland (52.6%) and Poland (38.6%). In Estonia, energy (electricity, gas, steam and air conditioning supply) made up the largest share (34.4%), while in Latvia, it was households (46.3%) (*Eurostat, 2014*).

For 2012, municipal waste generation totals vary considerably, ranging from 668 kg per capita in Denmark to 279 kg per capita in Estonia. The variations reflect differences in consumption patterns and economic wealth, but also depend greatly on how municipal waste is collected and managed. There are pronounced differences between countries regarding the degree to which waste from commerce, trade and administration is collected and managed together with waste from households. Households generate between 60% and 90% of municipal waste while the remainder can be attributed to commercial sources and administration (*Eurostat, 2014*).

Some of the large variations between countries may be linked to the differences in economic structures. For example, the high level of waste generated in Bulgaria, Finland, Estonia, Sweden and Romania was strongly influenced by large quantities of mineral wastes from mining and quarrying activities, whereas in Luxembourg, mineral waste from construction was largely responsible for the high amount of waste generated.

6.3 Waste characterization in Germany

In the year 2001 in Germany the average MSW production per capita was 628 kg. There has been a decrease to 564 kg in 2006 (that means 1.54 kg per day). From 2006 to 2010 there has been a slight increase, but the level is quite constant, as Figure 6.8 shows.

The total German generation of MSW decreased from 52.1 million tons in 2001 to 46.4 million tons in 2006. In 2010 the amount was of 47.7 million tons. In the years from 2011 to 2013 the waste amount remained more or less stable.

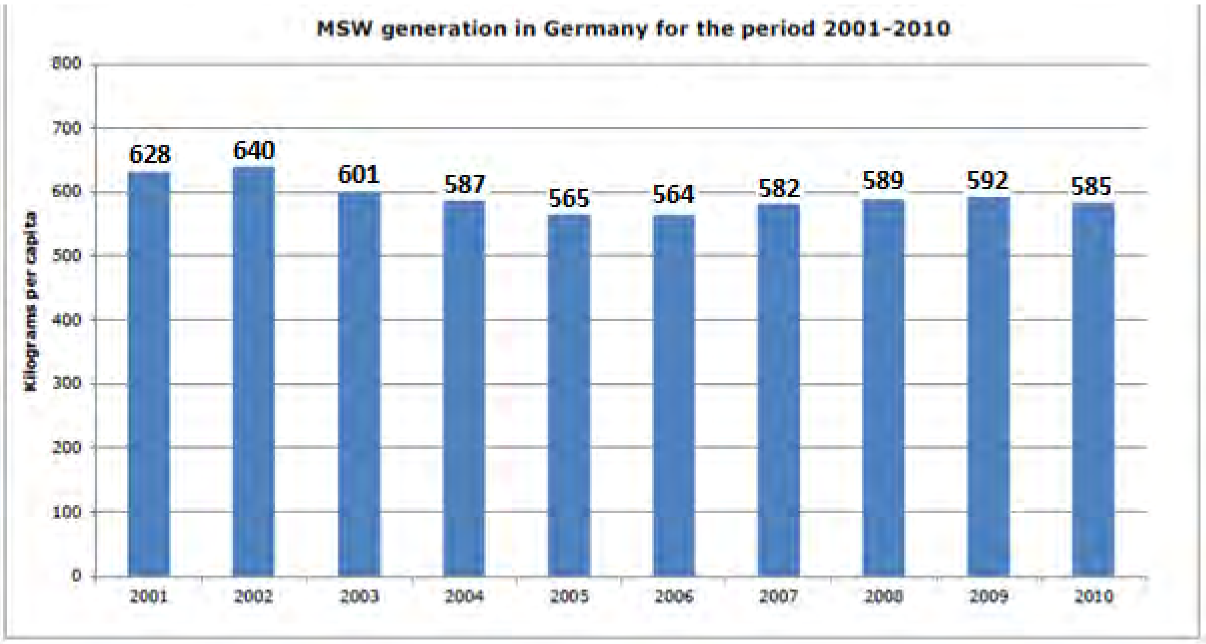


Figure 6.8*: MSW generation in Germany from 2001 to 2010 (EEA, 2013.)*

The MSW composition in the Federal States in Germany is slightly different in each of them. This is caused by several factors, like different collection and separation methods, consumption habits, economic activities, industrial activities and so on.

Since data about the MSW composition is available in greatest part for single Federal States, to have adequate representative values for the whole country, an average data has been created. This data is the result of the average of the data of more Federal States.

The data considered to build this representative MSW composition was taken from various documents, Waste Management Plants, Articles and online reliable sources, related to several Federal States in the years 2010-2013.

The following sources contain the data used for the creation of the German average waste composition data used in this Thesis (information retrieved between 12/18/2014 and 12/21/2014):

- Berlin – Senatsverwaltung für Stadtentwicklung und Umwelt, 2013. *Abfallbilanz des Landes Berlin 2013.*
- Baden-Württemberg - *https://www.statistik-bw.de/UmweltVerkehr/Landesdaten/*
- Bayern - *www.statistik.bayern.de/presse/archiv/2012/142_2012.php.*
- Nordrhein-Westfalen - Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen, 2011. *Abfallbilanz Nordrhein-Westfalen für Siedlungsabfälle 2010/2011.*

- Sachsen - *http://www.statistik.sachsen.de/html/834.htm*

Other links containing data of other Federal States used for the calculation:

- *http://www.eaw-rheingau-taunus.de/files/Hausmuellanalyse_2012homepage_IIx.pdf*
- *http://www.biellerhoop.de/*
- *http://ww.statistik-portal.de/statistik-portal/de_jb10_jahrtabu4.asp*

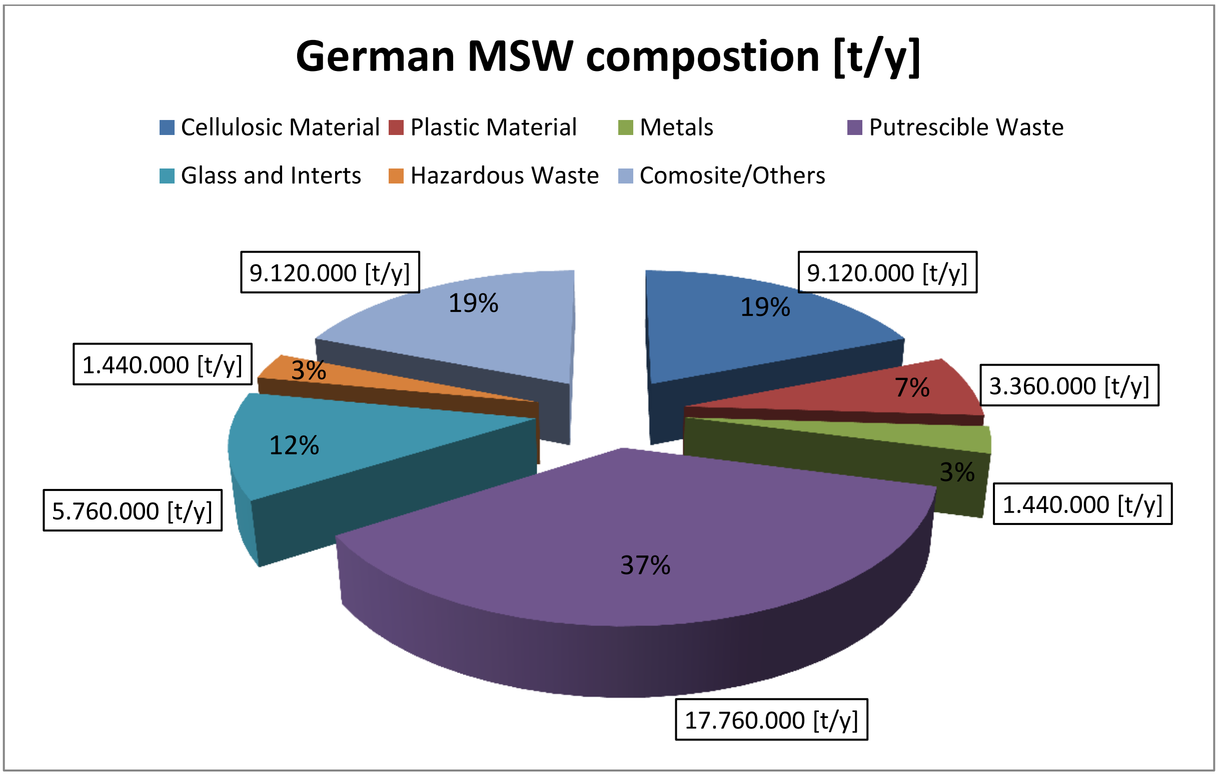


Figure 6.9*: Average MSW composition in Germany in one year, subdivided in different categories*

This figure show the average German MSW composition, based on the data provided by the different Federal States and listed in the previous links.

This data is not referred to a particular year, since it contains data of the period 2010-2013, but it is still a good representation of the typical MSW composition in Germany in the last period. The total amount of waste considering all the categories is 48 million [t/y].

In Annex 3 are provided the values of the single subcategories, for a more thorough vision. The same data representation as in Figure 6.9 is expressed for all the different waste categories, for Germany and for Italy.

6.4 Waste characterization in Italy

In 2013, the national production of MSW in Italy was approximately 30 million tons, 400.000 tons lesser than in 2012.

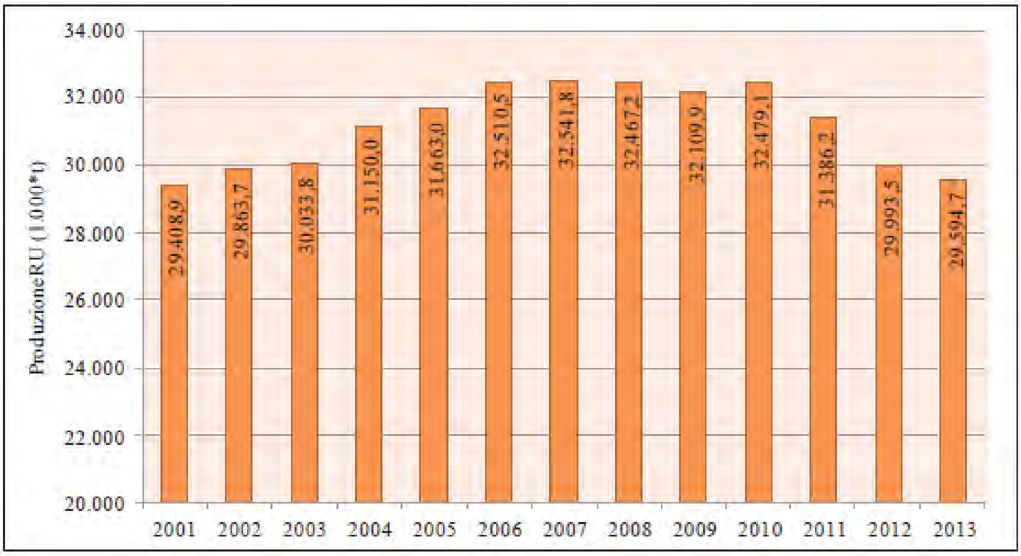


Figure 6.10: *MSW generation in Italy from 2001 to 2013 (ISPRA, 2014)*

The evolution of MSW amount in the years can be related to social and economic factors, in particular with the consumption habits of Italian families. Until the year 2006 the Italian GDP was growing, since that year it became stable and decreases in the following years.

Since the cultural and social aspects and the economic development are quite different in Italy from north to south, also MSW composition and management is consequently different. In the following figure the MSW amount is divided in the three zones North, Center and South, from the period 2009-2013.

It is possible to notice from Figure 6.11 how the North is the greatest contributor to the national waste production, with 13.5 million tons in 2013. The South instead has produced 9.4 million tons in that year, and the Center 6.6 million.

This values are not really representative of the waste production of the three parts of Italy, since in the north of Italy there live more or less 30.5 million persons, while in the Center 14 million and in the South 15 million. So in the North are living about twice population than in the Center and in the South.

For having an idea about the different MSW production per capita in the three zones, Figure 6.11, shows values expressed as tons per capita per year.

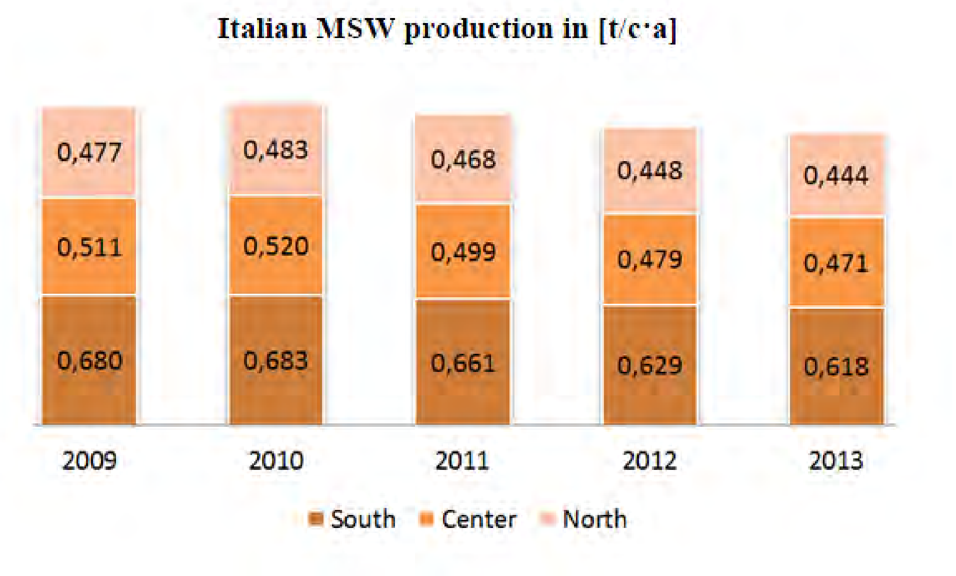


Figure 6.11: *MSW generation in Italy divided in the three macro-areas North, Center and South, expressed in [t/c·y]*
(ISPRA, 2014)

In the North the MSW production per capita in 2013 was slightly under 450 kg, while the values for the Center and the South are 471 and 618 kg per capita.

So the population in the South produce much more MSW per capita as the population in the Center and in the North (about 30% more).

This can be explained by an insufficient implementation of the waste hierarchy, inadequate waste segregation and collection methods and the negligence of European and national laws about waste management.

Since this differences from north to south, the average MSW composition values of Italy are not that representative all over the country as they are in Germany. Especially in the South and in the islands the waste composition results different respect to the rest of the country, with a greater amount of putrescible waste and a reduced amount of cellulosic material and paper.

The following waste characterization represents an average value of the whole country, but it does not represent really well single regions, since the big difference in MSW composition over the country.

The data used for the calculation of the average values has been collected during the university course: *Solid Waste Management*, held by Prof. Cossu R. at the Università degli Studi di Padova, Padova, in 2012. This data regard a great part of Italy, and is representative of the period 2011-2012.

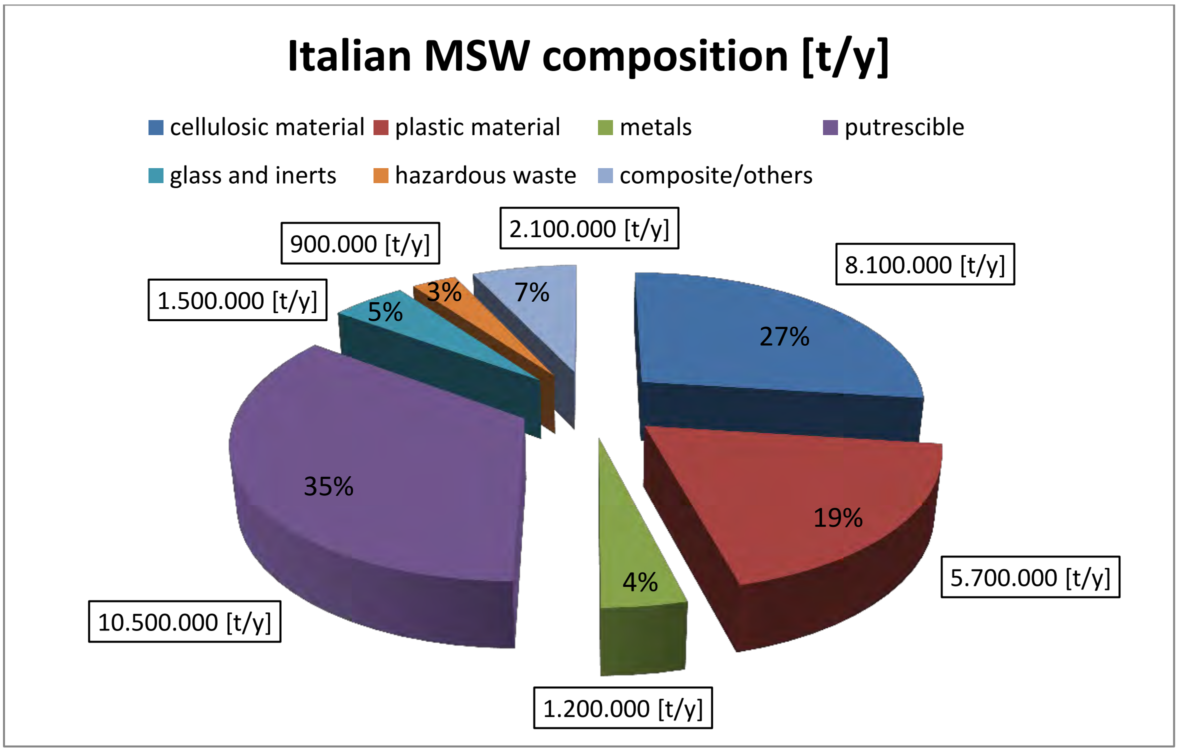


Figure 6.12*: Average MSW composition in Italy, subdivided in different categories (Cossu, 2012)*

The total amount of waste produced according the considered data is 30 million tons.
Comparing the Italian MSW composition with the German one, it is possible to notice a greater amount of cellulosic material in Italy (27%) respect to this value in Germany (19%). Also the plastic material fraction in Italy is consistently higher than in Germany (19% to 7%). This is probably caused by the great use of plastic shopping bags in Italy, and also by the fact that beverages in Italy are usually sold in plastic material, while in Germany glass is used in a greater amount (12%). The difference of this values could also be explained mentioning that Germany use a "Pfand" system (pledge) for bottles, that means that beverages have an extra price, which the purchaser will receive back when he bring the bottle to a collection center (usually shops), after its use. From the implementation of this method follows that bottles are in greatest part glass bottles or high quality plastic bottles.
The presence of metals in the two countries seems to be more or less the same, and the same think can be said for putrescible material and hazardous waste.

6.5 Grading Curve

There exist different methods to perform a waste characterization, one of them is based on the concept of the so called Grading Curve.

The analytical method used, known as "IMAGE Method", has been developed by the Environmental Engineering department of the University of Padua.

The Grading Curve is an important tool in waste characterization. It is used for the planning of separate collection, the sizing and the choice of the disposal system. It considers the heterogeneity of a certain amount of waste and divide it according the size of the different fractions constituting the waste itself. Each fraction is defined by same properties, the fraction considered are the same used in the German and Italian waste characterization.

The process to obtain the curve is quite simple: the test is performed on a MSW waste sample, which must be representative of the area. To avoid that the waste sample is not representative, different waste samples in different points of the chosen area have to be taken.

From this waste sample (which usually has a weight of one ton), about 200 kg are taken for the analysis.

The waste amount is spilled over more layers of sieves, with different diameters (the overlapped sieves are putted in the way that the diameters are in a descendent order).

So the sieves with higher diameters are on the top, while the sieves with small diameters are on the bottom.

On the first sieve on the top is spilled the MSW sample. The sieves are softly moved, this allows that smaller waste fractions fall down through the sieves, while the bigger waste will be retained by the sieves on the top. The waste pass through the different sieves, and will be retained by a specific sieve. Each sieve retain a specific amount of waste.

According with this method the sample has been sieved using a pile of sieves with holes of decreasing sizes (200 mm, 100 mm, 80 mm, 40 mm, 20 mm). The fraction not passing each sieve has been analyzed.

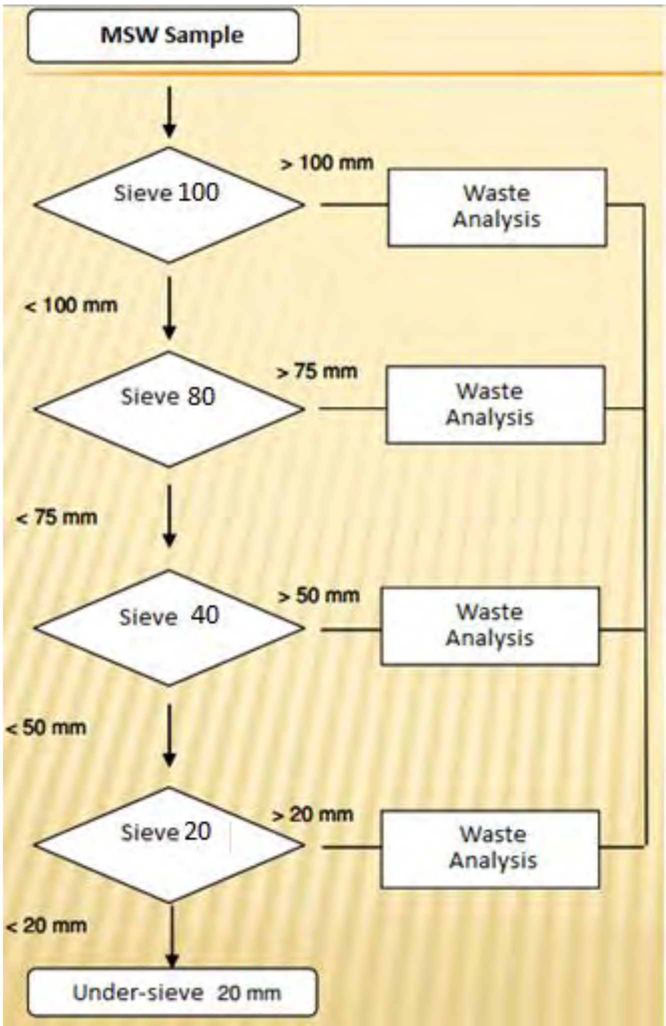


***Figure 6.13**: Scheme of the waste analysis according the IMAGE Method, using different sieves (Cossu, 2012)*

The fraction retained from each sieve is then manually separated in the seven waste classes (putrescible waste, cellulosic material, etc.).

So for each waste category are available the weight and the size of the diameter which retained the different fractions of that category.

This allows to know the amount of waste of each category, and the average size of waste types belonging to the category.

The analysis was performed in Voltabarozzo (Padua), at the universities department for waste management. More MSW samples of that area have been considered. The sample is a good representation of the average MSW composition in Italy. No analysis with a German waste sample has been performed, but the MSW composition is quite similar, so the grading curves can be considered representative also for German MSW.

***Figure 6.14**: Different overlapped sieves, which are manually moved, allowing the smaller waste fraction to reach the bottom layers (Cossu, 2012)*

Results are presented in Table 6.3. This study was performed with a sample of 561,4 kg.

	>200 mm		>100 mm		>80 mm		>40 mm		>20 mm		<20mm	
CATEGORY	WEIGHT(g)	%	WEIGHT(g)	%	WEIGHT(g)	%	WEIGHT(g)	%	WEIGHT(g)	%	WEIGHT(g)	%
PUTRESCIBLE WASTE	162.274	90	120.804	67	54.091	30	18.030	1	0	0	0	0
CELLULOSIC MATERIAL	147.381	85	98.832	57	38.145	22	6.935	4	0	0	0	0
METALS	16.555	92	12.956	72	6.118	34	719	4	0	0	0	0
PLASTIC MATERIALS	105.653	90	52.826	45	24.652	21	11.739	10	0	0	0	0
GLASS & INERTS	13.970	65	5.373	25	3.223	15	2.149	10	0	0	0	0
COMPOSITES	25.674	83	14.229	46	3.402	11	1.855	6	0	0	0	0
HAZARDOUS WASTE	14.262	70	11.206	55	5.297	26	3.260	16	0	0	0	0

***Table 6.3**: Amount of passant material for each sieve*

On the lines of Table 6.3 are represented the different waste categories, and the amount of waste passing per category by each sieve, expressed in grams. On the columns are represented the sieves, in descendent order (at the end the under-sieve).

Near the weight is specified the percentage of passant material. For instance 162,2 kg of putrescible waste are not retained by the first sieve. 90% of the total amount of putrescible waste pass the “200 mm sieve”.

For the glass instead, only 65% are able to pass the “200 mm layer”, 35% are retained by the first layer. That make sense since glass (usually bottles) can be bigger than 200 mm.

No waste pass the 20 mm sieve, which has to small diameters far all waste categories. For that reason all the values in the 20 mm column are equal to zero. Also no waste has been found in the under-sieve (on the ground).

Putting the data of Table 6.3 in a graph which has on the x-axis the descending sieve diameters and on the y-axis the percentage of passing material, for each category, it is possible to obtain the Grading Curves.

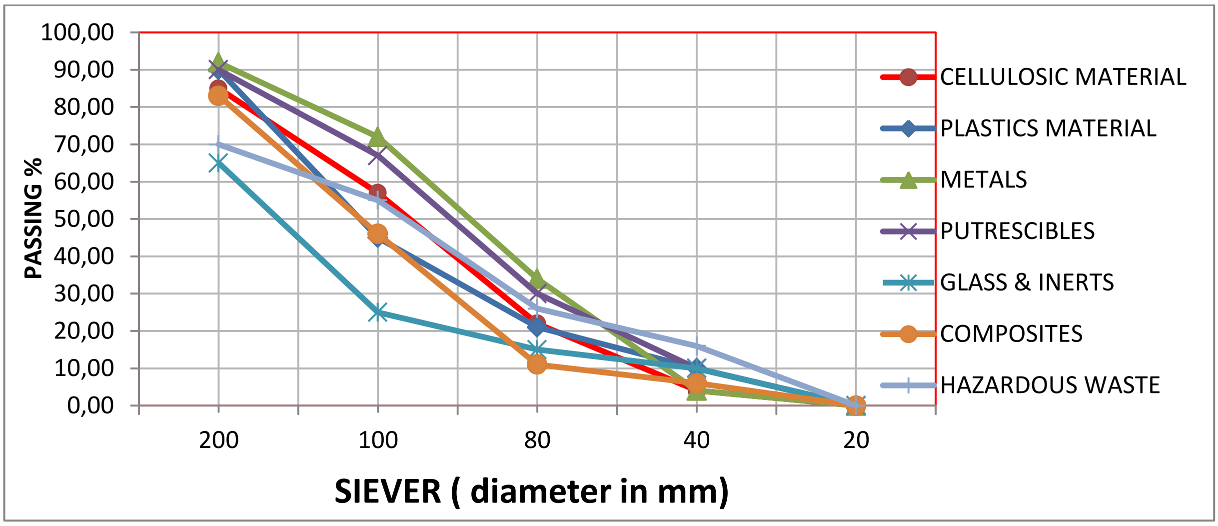


***Figure 6.15**: Grading curves of the different MSW categories*

7. MSW segregation and collection methods

Waste segregation and collection are two important steps in the process of waste management. Segregation or sorting is the process by which waste is separated into different categories. Waste sorting can occur manually at the household, or automatically separated in material recovery facilities, or in mechanical biological treatment systems. Hand sorting was the first method used in the history of waste sorting, and is still the most used in MSW management.

Waste segregation means divide waste in different categories, usually with the same or similar physical properties. This allows to collect easier the waste, and so to increase recycling, reuse, and to facilitate the next steps of management.

Increasing the number of waste fractions collected has also negative aspects, like higher collection costs, it became more complicated for citizens to separate the waste, and the risk for a wrong separation increase *(Cossu et al., 2013*). For this reason a good equilibrium must be found in each situation, based also on aspects related to the area.

Table 7.1 shows an average segregation efficiency for different waste types and more collection methods. The values represent the purity which can be obtained in the different treatments.

Segregation efficiencies (%)	Glass	Paper	Metal	Plastic	Packaging (no glass)	Biowaste (kitchen)
Curb-side collection, permanent	**70-85**	**75-90**	**70-85**	**40-50**	**?**	**60-80**
Curb-side collection, scheduled	**65-80**	**70-85**	**65-80**	**30-40**	**65-80**	**?**
Collection points, joint	**60-75**	**65-80**	**60-75**	**60-70**	**60-70**	**40-60**
Collection points, public	**40-60**	**40-60**	**40-60**	***30-50***	***20-30***	**40-60**
Collection centers	**10-20**	**10-20**	**10-20**	***10-20***	**10-20**	**n.a.**

Table 7.1: *Segregation efficiency (T. H. Christensen et al., 2013)*

It is possible to notice from the data in Table 7.1 how it is easier to segregate glass, paper and metals respect plastic. This because glass for example is usually present in bottles, which can be easily separated and do not contain a lot of impurities, while plastic can be present in the waste in small pieces and very difficult to separate.

Waste collection is the transfer of solid waste from the point of use or temporary storage, to the point of treatment or landfill.

The way of waste collection depends from many aspects, like size of the area, the economic structure, the zoning and law ordinances, the user demands, the traffic situation, the kind and size of the buildings and many other factors.

The main and most implemented waste collection systems are the drop off system, the curbside collection and the door to door collection.

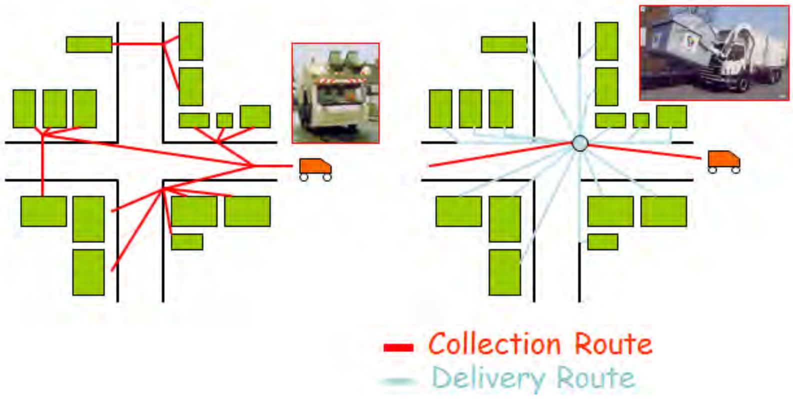


Figure 7.1: *Graphical representation of curbside collection (left) and drop of system (right) (Cossu et al., 2013)*

In the curbside collection method, the waste collection vehicle pick up the waste from small bins used by a single household, while in the drop of system the bins are used by more households of that area. In the door to door system the waste is directly collected from the household.

About the frequency of collection, there doesn't exist a fixed range of days. It depends from the amount of waste, the size of the container and also the kind of waste. For example bio-waste shouldn't stay in the bin for more than 2 weeks, for obvious reasons. In Table 7.2 there is represented the average collection period for different types of waste in Germany.

Fraction	each week	every second week	every fourth week	other
RMSW	28 %	42.1 %	10.4 %	19.5 %
Biowaste	33.8 %	63.6 %	0.0 %	2.0 %
Paper	22.6 %	23.7 %	41.2 %	14.5 %
Light packaging material	7.5 %	43.7%	43.0 %	3.7 %

Table 7.2: *Collection frequency of different waste fractions in Germany (Cossu et al., 2013)*

With Raw Municipal Solid Waste is defined all the waste which does not fit with a category of the separate collection.

About the costs of waste collection, data of some European States is provided in Table 7.3, to have an idea about the ranges.

	Costs (€/tonne)			Costs (€/hhld)			Frequency
	Low	High	Best Est.	Low	High	Best Est.	
AU			70				Every two weeks, sometimes more frequent in summer
BE F Br	58	92	75 56	14	22	18	Mostly every two weeks, sometimes weekly
DK			126			62	Weekly
FI	15 (urb)	32 (rur)		17 (urban)	37 (rural)		Weekly, biweekly or monthly per household depending route or area (excludes container costs at household)
FR	54 (urb) 63 (rur)	65 (urb) 74 (rur)	60 (urb) 70 (rur)				e.g. Five times a week in urban areas e.g. Twice a week in rural areas
GE	39 (urb) 48 (rur)	81 (urb) 91 (rur)	67 (urb) 71 (rur)			30 (urb) 40 (rur)	May be every two weeks, weekly in summer months. Lower costs likely to be for biweekly collections
GR	25 (urb) 40 (rur)	36 (urb) 67 (rur)	30 (urb) 55 (rur)			32 (urb) 57 (rur)	Ranging from daily for some urban areas, weekly for some rural. Lower per tonne cost for larger settlements
IR	60	70	65	70	80	75	Weekly
IT	48	255	75	15	45	25	Varies – weekly or twice weekly in cost optimised systems collecting food waste (costed here), may be three or four times daily in some areas with no food waste collection
LUX	85	104	85				Every two weeks
NL	75	123	100				Weekly
PO			45[e]				
SP	19	91	60	10	43	25	Likely to be daily in urban areas
SW	59	80	65				Every two weeks in single family houses, weekly in urban areas with multi-occupancy buildings
UK	32 (urb) 50 (rur)	50 (urb) 80 (rur)	42 (urb) 60 (rur)	24 (urb) 38 (rur)	38 (urb) 60 (rur)	31 (urb) 45 (rur)	Usually weekly – a few local authorities alternate residual waste collection with collection of biowaste (fortnightly)

[e] *Estimate*

Table 7.3: *Costs of waste collection (Ecotec Research & Consulting, 2010).*

7.1 Waste collection in Germany

In Germany the waste is sorted mostly by the consumer. In relation with the waste policy of the Federal State, waste segregation and collection varies between regions. The collection method for the cities is usually the drop off system.

The sorted fractions are usually paper, glass, packaging material, biowaste and RMSW.

Paper is used in the production of recycled paper and other products like cardboard. It is collected in containers by the municipality, a company hired by the municipality or a private company. They in turn send the waste to other companies which continue with the waste treating. Nowadays plenty paper factories use recycled paper instead of wood fiber.

In Germany, a great part of used glass is reused and recycled. The glass is collected in containers and can be sorted in different containers in green, brown and white glass, or can be sorted after the collection with an optical separator. Glass bottles with a particular sign can be brought back in the shop and the customer get a pledge (the so called “Pfand”). This method helps to promote the reuse of glass bottles. Two uses after the return of bottles exist, the so called “Mehrwegpfand-System” and the “Einwegpfand-System”.

In the first case the bottle will be refilled again, while in the second case the bottle will be recycled and new bottles are created.
For "Mehrwertpfand-bottles" the pledge is of 0.08 €, while for "Einwegpfand-bottles" (which have a particular logo) the pledge is of 0.25 €.

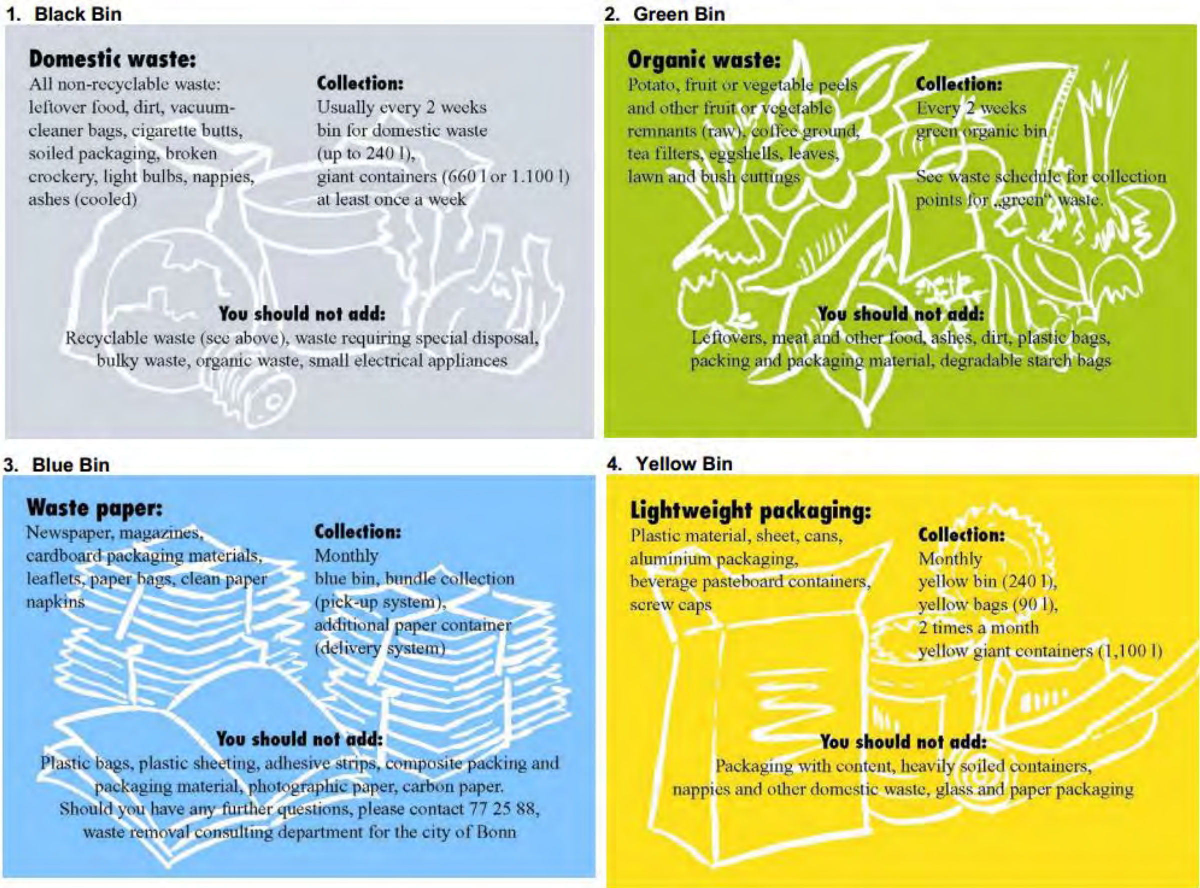
Figure 7.2: *Logo for the Einwegpfand-bottles with 0.25 € pledge*

Regarding the packaging material, the operator called "Der Grüne Punkt – Duales System Deutschland GmbH (DSD)" takes care of the management of this kind of waste.
As the name of the operator suggests, the products which have as logo a green dot, are part of this system.
The operator takes care of the final disposal or treatments of the waste, and leaves the collection and the transport of waste to other companies, like local municipalities. All the companies with products which have the green dot have to pay a fee to DSD.

Figure 7.3: *Logo for the DSD system for packaging material treatment and disposal in Germany*

Bio-waste is usually collected in a brown bin, and can be used in compost plants to produce fertile earth for the agriculture or in anaerobic plants to produce biogas.

As an example for waste separation and the different kind of bins in Germany, in the next figure the four bin types used in the city of Bonn are shown.



Glass (non-returnable bottles, food containers such as jam jars) has to be disposed of separately. In all neighbourhoods one can find glass containers. The glass has to be sorted according to its colour (brown, green and white glass). The glass containers closest to the MPI are situated at the corner of Auf dem Hügel/Bleichgraben (road leading to the MPI parking).

Bulky waste
All household furnishings which are too bulky for disposal in waste bins such as furniture, lamps, cupboards/wardrobes, carpets (up to 50 m^2), shelves, tables and chairs.
Collection: Street collection 4 times a year
You should not add: Vehicle parts, old clothes, building waste, domestic waste, electrical appliances, waste requiring special disposal, cartons, packaging

Waste requiring special disposal
- Large electrical appliances
  Such as refrigerators, TV sets or hi-fi equipment, computers, dishwashers, washing machines, etc.
  → For free collection of these please phone: 01801/880066 (SITA Wagner GmbH)
- Small electrical appliances
  Such as toasters, irons, coffee machines, portable radios, hairdryers, etc.
  → Red bins at Lievelingsweg 110 (Office for City Cleaning and Waste Management), town hall
- Paint, lacquer, solvents, fluorescent and energy-saving lamps, alkaline solutions, acids, batteries, cleaning agents
  → Waste Recycling Plant, Am Dickobskreuz

Waste disposal schedules are generally distributed to every household by the city of Bonn (Amt für Stadtreinigung und Abfallwirtschaft).

Figure 7.4: *Separate collection in the city of Bonn (Stadtinformation, 2013)*

Since 2005 its forbidden to deposit untreated MSW in a landfill in Germany. Residual waste is usually disposed after bio-mechanical treatments or after the incineration process. Germany promotes strongly the avoidance and reduction of residual waste generation, since it's economically and energetically more expensive to produce the materials than to dispose it.
For this reasons an efficient waste separation is fundamental.
Since January 1st 2015 it is mandatory in some German Federal States to have also a specific bin for bio-waste. Before bio-waste was often putted in the residual waste, but to increase the rate of composting and anaerobic treatments, bio-waste has to be separated.
In Figure 7.5 is represented the separate collection rate in the German Federal States.
The average rate of separate waste collection in Germany was of 44,9% in 2012, and attending *Statista, 2014* it should be around 46% in 2014.
This value is among the highest in Europe, since German citizens perform a very efficient separate collection.
Some critics raised by the public opinion about the utility of separate collection, since there have been cases (like in Hamburg) where separated waste was sent to incineration plants and burned (especially the plastic material fraction).
Also in the residual waste there is still a big amount of plastic. Plastic material and paper increase the calorific power, for that reason incinerator manager are sometimes "happy" for the presence of plastic and paper impurities in the waste.
It is quite common that shredded wood pieces or plastic are added to the burned waste, to increase the calorific power. Plastic materials as PE and PP have a higher calorific power as gasoline (46 MJ/kg respect 43 MJ/kg).
Despite the waste hierarchy which prefer recycling to incineration, it seems that in some cases in Germany waste burning is preferred to recycling and down-cycling. It is far cheaper to use waste as fuel instead of coal for heat and energy production, and it is also less polluting.
Still Germany has one of the highest recycling rates in Europe, this because of its very efficient separate collection.
Of the total amount of packaging material separately collected, about 30% are recycled, 50% are going to incinerators and 20% are impurities, which are usually disposed.
Incineration is a big business in Germany. Just remember that in 2008 some German Municipalities like Hamburg, received 200.000 tons of Italian MSW (from Naples), because Italy was not able to dispose it. The municipality of Naples had to pay 150 EUR/t, plus the transport costs, without considering the economic benefit that Hamburg had with the thermal energy production. The incinerator of Hamburg provides heat to 18.000 families (*SHZ, 2014*).

In an interview with the Süddeutsche Zeitung, Dr. Michael Angrick, representing the German Federal Environment Office (Umweltbundesamt), states that since the total German waste production is decreasing in the next years, the fight between the incinerator managers and the recycling promoters for plastic will increase.

For working properly the incinerators oven need to be continuously provided with waste, and a waste reduction could be a problem for the incineration plants.

It might seem that economic factors are in contrast with the waste hierarchy, but this is not completely true.

On the other hand it is noteworthy to mention that the packaging material are usually bad quality plastics which could not be recycled easily, and for that reason it is more convenient to burn them for energy. The waste hierarchy of *Directive 2008/98/EC* states that recycling has to be preferred over incineration only in the case that it is economic and ecological convenient.

There exist two main kinds of incineration plants in Germany. The first kind has as main goal the avoidance of dangerous emissions from the combustion of MSW, and the second one (which use only specific waste fractions with a high calorific power) has as main goal the energy production.

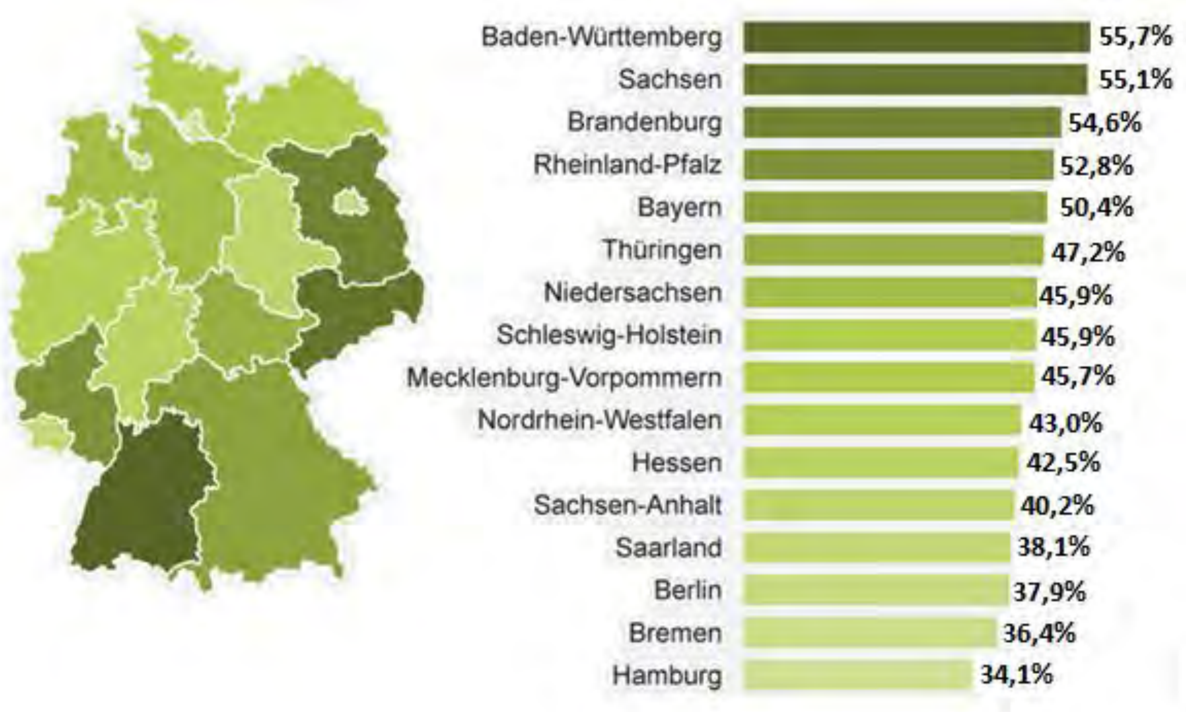


Figure 7.5: *Percentages of separate collection in Germany in 2012 (Statista, 2012)*

Figure 7.5 shows how big cities have usually a lower separate collection rate. The three city states Berlin, Bremen and Hamburg are last in the ranking, while the Federal States Baden-Württemberg and Sachsen have the highest rate of separate collection.

7.2 Waste collection in Italy

In the year 2013 the amount of waste produced in Italy was about 29.6 million tons, 400.000 tons lesser as in 2012.
The amount of waste which is collected separately is increased in the last years. In 2014 the separate collection regards the 35.9% of the national waste production (*ISPRA, 2014*).
The legislative Decree n.152/2006 and the law 296 of November 27 defined the following goals of separate collection:

- At least 35% within December 31 of 2006
- At least 40% within December 31 of 2007
- At least 45% within December 31 of 2008
- At least 50% within December 31 of 2009
- At least 60% within December 31 of 2011
- At least 65% within December 31 of 2012

This national limits have been successfully reached only by a few regions, but not by the rest. Northern regions like Veneto, Trentino-Alto Adige and Friuli have very high separate collection rates, over 55%. Several provinces like Pordenone, Novara, Vercelli and Belluno have very high separate collection rate , close to 70%. For instance the province of Bolzano implemented in 2013 a new separate collection system, and was able in 2014 to collect 67.7% of separated waste (*Seab, 2014*).
On the other hand southern regions like Abruzzo, Calabria and Sicilia have separate collection rates of 5-20%. For that reason the national average is not that high as it could be.
The *European Directive 2008/98/CE* , although not providing a particular target for separate collection, require that the collection is implemented and the procedures for reuse and recycle of the four main categories of separate collection (paper, metal, plastic and glass) are well organized. The mode and the criteria of the calculation of the goals are provided by the decision *2011/753/UE*. Each member state has to communicate to the European Commission the methodology chosen and if the goals have been reached. The goals for preparation for reuse and recycle are currently under review at European level.

The total amount of waste from separate collection in Italy in 2013 is about 12.5 million tons. In the North separate collection reaches the 7.4 million tons, in the Center 2.4 million tons, and in the South 2.7 million tons. Expressed in percentage and related to the amount of inhabitants, it means that in the North the separate collection is the 52.4% of the total waste collection, in the Center the 34.9% and in the South the 17.1%. As already mentioned in the previous chapter, the waste management in Italy is strongly related to cultural, social and economic aspects. This explains the great difference in waste separation values from the North to the South. In Germany the amount of waste which is separately collected is about 45%, so the northern part of Italy has more or less the same collection efficiency, but if we consider a mean value for the country, the value is much lower.

Of course the separate collection has to be improved all over the country, but the weak part in waste management is the Center and especially the South, and until this regions will not pay more attention to environmental aspects, it will be very difficult for Italy to respect the values imposed by the European Community. The southern part of Italy is facing since the beginning of the twentieth century with economic and unemployment problems, and this aspects are reflected in waste management.

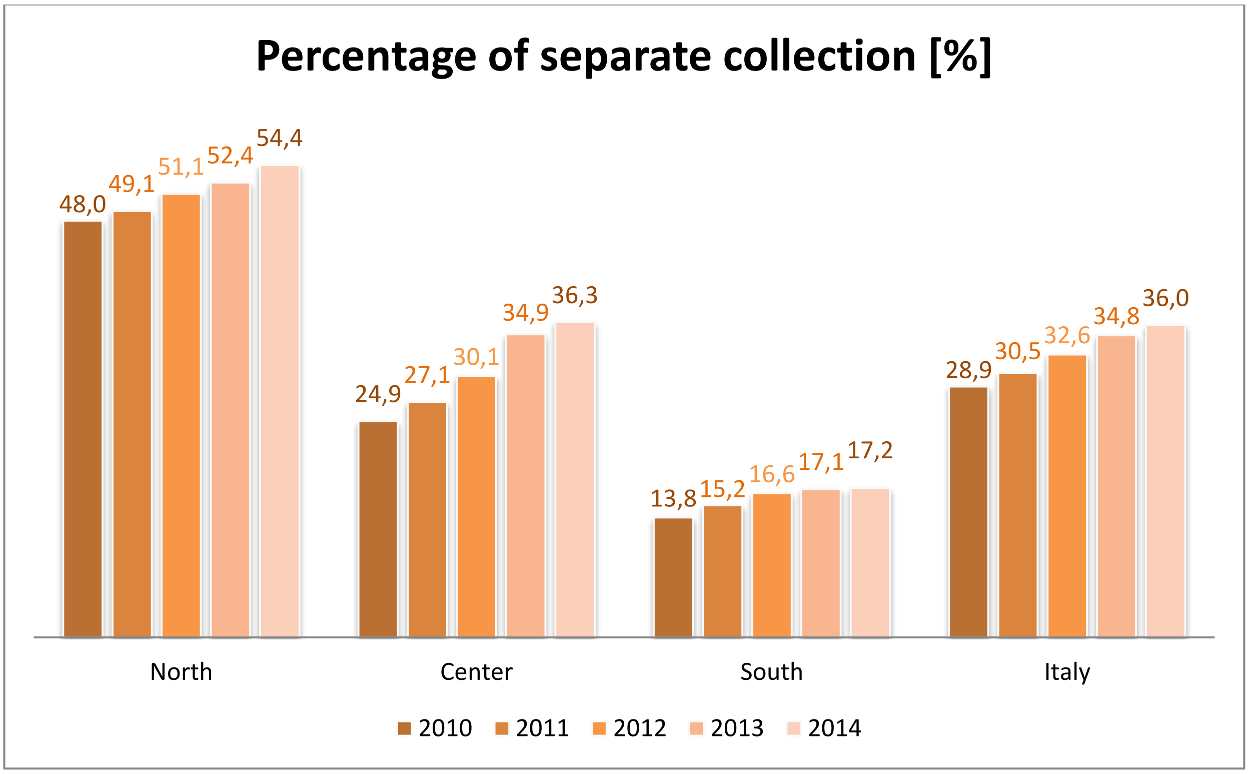


Figure 7.6: *Percentages of separate collection in the different parts of Italy in the last 5 years (ISPRA, 2014)*

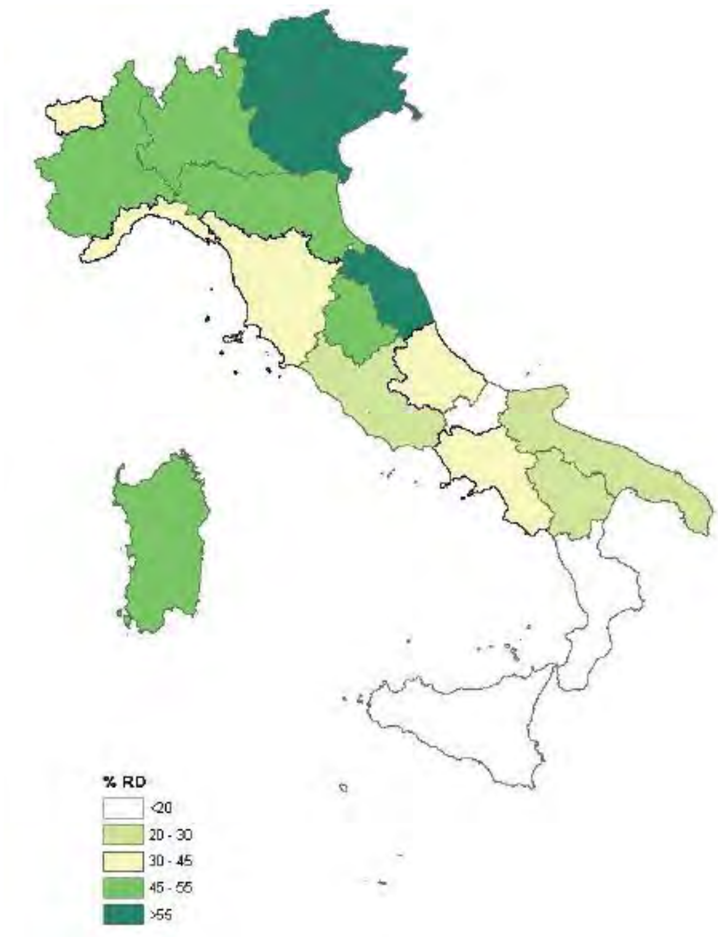


Figure 7.7: *Percentages of separate collection in the different parts of Italy in 2014 (ISPRA, 2014)*

The economic problems of south Italy subsist since the unification of Italy in the 1861. While the northern part starts its strong industrialization process in 1850, helped also by closer geographical location to countries like France, Germany, Great Britain and Belgium, which were already industrialized, the main activity in the South was still agriculture.

After the Italian unification the situation in the south worsened, since the introduction of a national tax system, which was appropriate for an already industrialized an economical developed northern part, but had catastrophic effects on the south.

In the twentieth century Italian policy was mainly focused on promoting the industry and trying to be competitive on a European level, investing great part of public funds in this field, and not considering the continuously growing economical difference between North and South.

In the south, due to cultural reasons, the enforcement of national laws and regulations was since always problematic. Maybe the Spanish occupation in the past and the use of a feudal system for centuries, were the reasons of the difficulties for the South to adapt to a state political entity, were the political and economic power is held by a single institution.

For many years, the State did not face this problem with the necessary attention, and this brought to the developing of organizations which set their own rules and create illegal business. Since the unemployment and the crisis, a lot of persons had the only chance to support this organizations to get a salary.

Too late the Italian State started to face this problems, and it is paying the consequences until today.

This organizations, defined in a general way as "Mafia", control the territory and all the economic activities on it. Waste management is one of this activities.

The Italian association for the protection of the environment "Legambiente" create in the 90's the term "Ecomafia", intending with this term al the illegal activities related with the management and disposal of waste.

Since waste disposal is expensive, it happened that this criminal organizations take firstly care of the waste disposal, earning so the money for the treatment process, but afterwards they do not treat the waste in a proper way, or do not treat the waste at all, burying the waste in dumps, burning it, or hiding it on the sea bed.

Also waste collection and waste transport are businesses which brought important gains to criminal organizations, all this at the expense of human health and the environment.

In the last decade the battle against the "Mafie" in Italy brought to several successes, and also the number of environmental crimes reduced drastically.

About the color of the waste bins it is possible to find on the streets, they can be different over the country, but mainly they are represented by the following ones:

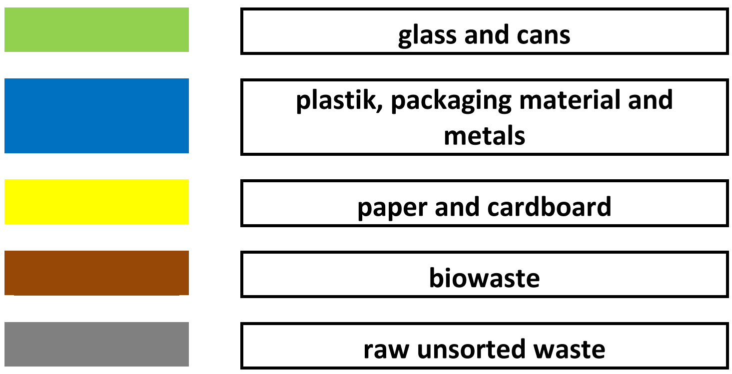


Figure 7.8: *Colors of waste bins in Italy*

The collection method in Italy is mostly the drop off system. Big cities as Milan and Rome have often different ways of municipal waste collection. In Milan the separate collection is performed with a door to door system, in the hole municipality area. The inhabitants have special bins which get emptied periodically.

In Rome there are used drop off bins, and recently in some residential areas also the door to door system is implemented.

In Naples, where there are big problems with separate collection, there is used now a door to door system and in some areas a drop off system. The results are positive but still not satisfying, since the unsorted waste fraction is very high.

Recently a method for the promotion of separate collection has been implemented in many Italian municipalities, the so called "pay as you throw system": the bags for the unsorted waste are sold, and the citizen has to pay the price of the bag added to the weight of the waste in the bag. This will bring the citizens to improve the separate collection, in order to save money. Every citizen get a card, and when he insert his card in the machine he gets a bag. When he brings the waste bag, there is a balance which weight the bag and gives the corresponding price.

In Annex 4 are shown the amounts of separate collected waste for each waste category in Germany and in Italy, in the last years.

8. Waste disposal – Recycling, Incineration and Landfilling

8.1 Municipal solid waste treatment in Europe

Municipal solid waste is managed in a different way all over Europe. The three main waste disposal treatments considered are recycling, incineration and landfilling, where incineration and landfilling are final disposal methods, while recycling allows the reuse of the product after a specific treatment. Since the waste hierarchy shown in Chapter Three, in the last decades there exist a trend in decreasing of landfills and moving towards incineration and recycling, where the latter is the most desirable. There exist therefore a hierarchy of this three disposal methods, but also other factors have to be considered in the implementation of them, and this factors usually define the choice of disposal method. For example countries with a great availability of not used areas can more easily decide to implement a landfill as countries like Japan, which don't have a great availability of land. Also the public opinion is an important factor. In Italy for example in the last decades there was a strong opposition against the construction of incinerators, because the people were afraid of the negative impacts of the flue waste gasses. Only in the last years the implementation of more incinerators is taken seriously in account, because a better environmental knowledge of the public opinion allowed to understand that also landfills can be dangerous and have emissions. Another factor to consider is the economic one, since waste landfilling is usually less expensive respect to other treatments, but not always. Also the legal restriction became really severe for incineration, and the emission limits ensure a not to high emission of dioxins and pollutants in the air.

Since the landfill directive of the EU, many states are now considering incinerators as a possible option.

Table 8.1 shows the amount of MSW treated in the EU-27 for the period 1995-2012 by treatment method, in million tons and kg per capita, while Figure 8.1 shows the amount of waste generated by EU-27 and the amount of waste by treatment category, in kg/capita.

Municipal waste landfilled, incinerated, recycled and composted in the EU-27																			
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	change (%) 1995-2012
million tonnes																			
Landfill	143	140	142	140	139	139	134	131	124	117	109	109	106	99	96	93	86	81	-43%
Incineration	32	33	35	35	36	39	40	41	41	44	48	51	52	55	56	57	60	58	81%
Recycling	25	28	32	35	40	40	42	46	47	49	52	54	59	60	61	63	65	66	162%
Composting	14	16	17	18	19	24	24	26	26	28	29	31	32	35	35	34	34	36	149%
Other	12	14	13	11	12	11	12	12	12	13	16	13	11	10	7	7	6	6	-50%
kg per capita																			
Landfill	300	294	297	290	289	288	278	269	255	239	221	220	213	199	192	186	171	162	-46%
Incineration	67	69	72	74	75	80	82	85	85	90	98	104	105	110	111	114	119	116	72%
Recycling	53	59	66	72	82	83	88	95	97	99	105	109	119	120	122	125	129	132	150%
Composting	30	34	36	37	40	49	50	53	54	58	60	63	64	71	70	68	68	71	137%
Other	24	30	27	24	25	24	24	24	24	27	33	27	22	20	15	13	13	11	-53%

Table 8.1: *Amount of waste treated in the EU by treatment method (Eurostat, 2013)*

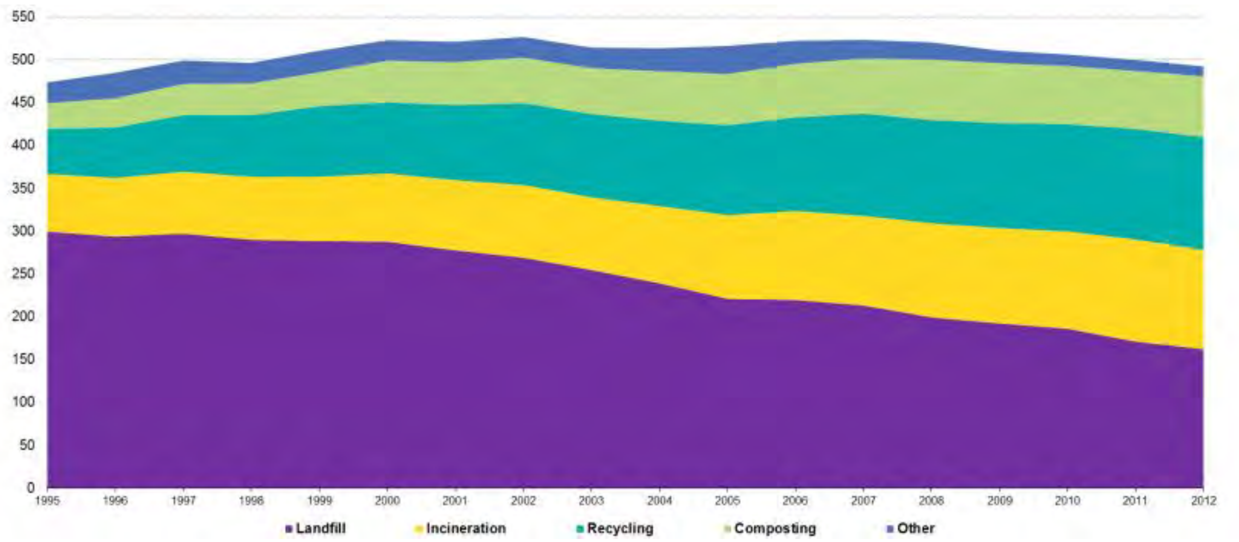


Figure 8.1: *Amount of waste treated in the EU by type of treatment (Eurostat, 2013)*

Even if more waste is being generated in the EU, the total amount of municipal waste landfilled has gone down. In the period considered in the graph, the amount of waste landfilled was reduced from 143 million tons (300 kg per capita) in 1995 to 81.2 million tons (162 kg per capita) in 2012. This reduction can be partly attributed to the implementation of the European legislation, for example the Directive 62/1994 on packaging waste. Furthermore, the *Landfill Directive 31/1999* stipulated that Member States were obliged to reduce the amount of biodegradable municipal waste going to landfills to 75% by 16 July 2006, to 50% by July 2009 and to 35% by July 2016. The reduction was calculated on the basis of the total amount of biodegradable municipal waste produced in 1995. This directive has led to countries adopting different strategies to stop sending the organic fraction of MSW to landfill, namely composting, incineration and pretreatment such as mechanical and biological treatments.

On the other hand, the amount of waste recycled rose from 25.1 million tons (53 kg per capita) in 1995 to 65.9 million tons (132 kg per capita) in 2012.

The recovery of organic material by composting has grown with an average annual rate of 5.5%.

Also waste incineration has grown steadily in the reference period, though not as much as recycling and composting. Since 1995 the amount of MSW incinerated in Europe has risen by 25.9 million tons to 58.1 million tons in 2012. MSW incinerated has thus risen from 67 to 116 kg per capita.

Mechanical biological treatments (MBT) and sorting of waste are not covered directly as categories in the reporting of municipal waste treatment. This types of pretreatments require an additional final treatment.

In Figure 8.2 is represented the amount of the three ways of disposal considered and also composting, in the different European countries.

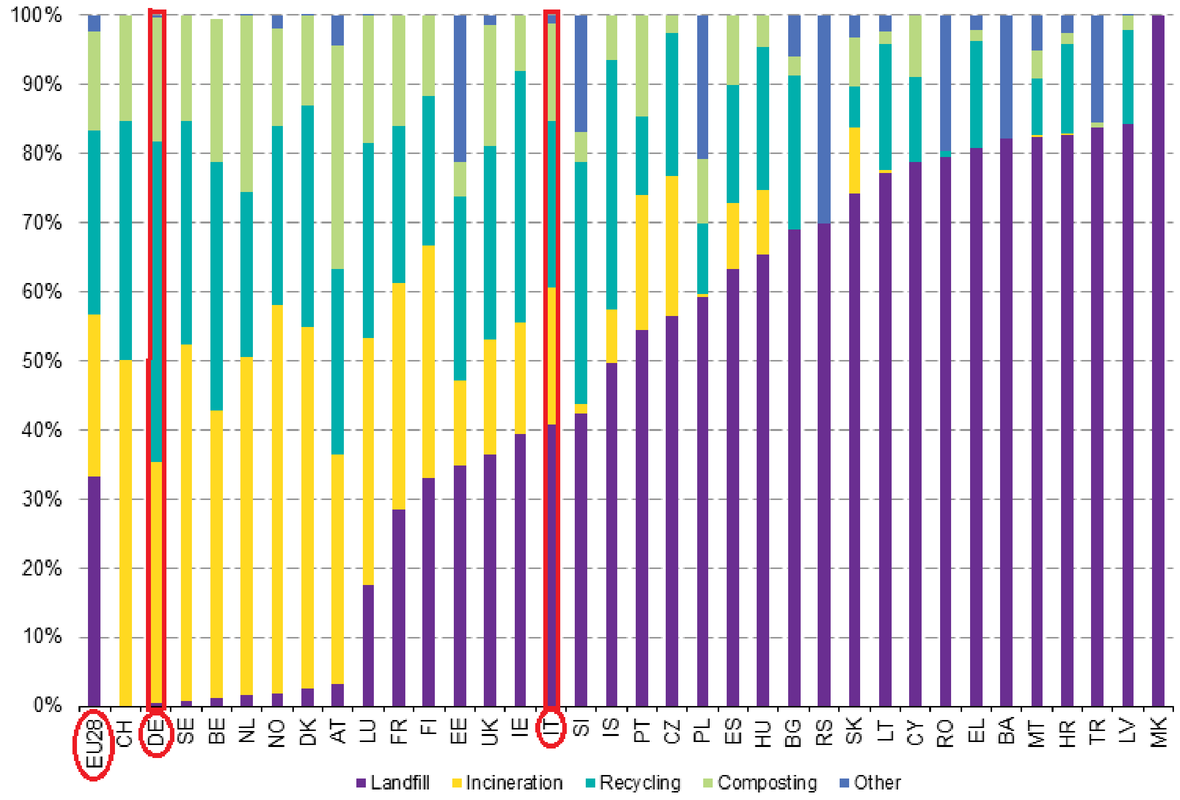


Figure 8.2: *Landfilling, Incineration, Recycling and Composting in the European countries in 2012 (Eurostat, 2013)*

Several countries are very advanced in diverting municipal waste from landfills. This is due to the fact that they have implemented national measures to reduce landfilling. Switzerland, Germany, the Netherlands, Sweden, Austria, Denmark, Norway and Belgium have reported landfill rates below 5%.

In Sweden and Denmark there has been a ban on landfilling combustible waste since 2002 and 1997 respectively. Instead of landfilled, the waste is recycled, composted, treated by anaerobic digestion or incinerated. This two countries have the highest incineration rate of MSW of the EU-27, with an amount of 52% of burned waste.

In most countries, the combined total for recycling and composting is higher than that for incineration.
In Netherlands landfilling rates fell in the 1990s as a result of recycling, composting and incineration of municipal solid waste. They fell even further when the direct disposal of mixed municipal waste was banned as of 2003, resulting in only 8 kg per capita municipal waste directly landfilled in 2012.
In Sweden the amount of landfilled waste dropped from 42 kg per capita in 2004 to 23 kg per capita in 2005 and right down to 3 kg per capita in 2012 after the introduction of a ban on landfilling organic material in 2005.
Also in Germany landfilling has been reduced steadily over the last decade, mainly by recycling, mechanical biological treatments and incineration. It dropped sharply due to the ban on landfilling untreated MSW that entered in force on June the 1st, 2005.
Similarly, also Austria since 2004 allows landfilling only for pretreated waste.
In some cases a low rate of landfill is also due to excluding residues of other operations from reporting. With regard to landfills, this concerns in particular the stabilized fraction from mechanical-biological treatment and residues from sorting. The guidance document on MSW data collection that Eurostat published in 2012 ask the countries to report the outputs of pretreatment under one of the four treatment categories, while residues from incineration don’t have to be reported.
This is the case in all the countries with a MSW statistics that rely on the amounts delivered to the first treatment facilities after collection, like Germany, the Netherlands, Switzerland, Denmark and a part of Belgium. It also applies to some countries with a higher landfill rate such as Portugal, the Czech Republic and Romania.
In some countries the reporting approach hasn’t yet been defined, but should become more transparent now that quality reports for municipal waste have been introduced in the course of the survey for reference year 2012.
The highest rate for recycling were reported by Germany, while for composting Austria has the highest rate.
Regarding the strategies for waste treatment, the European Environmental Agency (EEA) offered a reasonable approach for a grouping that takes into account the combined rates of incineration and material recovery (which is the sum of recycling and composting).
The rationale of the EEA approach is that countries may follow different strategies to divert waste from landfills. This strategies can be a combination of material recovery and incineration, or mainly be focused on material recovery and less on incineration.

If material recovery is supplemented by incineration, a lower level of landfilling may be achieved, as incineration facilities have the advantage of being able to use waste that cannot be used for material recovery but has reasonable calorific power. Incineration may also divert biodegradable material of lower heat value away from landfill after pre-treatment such as stabilization and drying by mechanical-biological treatments.

Figure 8.3 shows the results of this approach for the latest data of reference year 2012. The approach divides the countries in three groups.

The first group shows countries that apply a combined strategy, with high rates of more than 25 % for material recovery as well as incineration.

The second group consists of countries where systems for recycling and composting are established, achieving a high rate of material recovery (over 25%), but with a low incineration rate.

The third group relies mostly on landfilling as a treatment option (*Eurostatis, 2013*).

The trend in waste treatment in the three identified groups is shown in Figure 8.4. The type of treatment is shown as a percentage of waste generation and in kg per capita.

The per capita values were calculated as the sum of treated volume for the countries in one group divided by the sum of the overall inhabitants of the same group and year.

The figures in kg per capita confirm the finding mentioned above, in countries with high landfill rates, the total amounts generated and treated in kg per capita in 2012 are lower than in countries with low landfill rates.

The figure shows that countries in Group 1 had already in 1995 higher values in incineration, recycling and composting as countries of Group 2 and Group 3.

Moreover, in the period 1995-2012, the rate of decreasing of landfills and increase of incineration, recycling and composting is more or less the same in Group 1 and Group 2. That means that countries in Group 1, which were already implementing this disposal ways in 1995, increased incineration, recycling and composting with the same intensity as countries of Group 2, which had a very law rate of incineration, recycling and composting in 1995.

Countries of the Group 3 instead have not shifted from landfilling to incineration, recycling and composting in the last 20 years, and have a stable rate of implementation in this technologies.

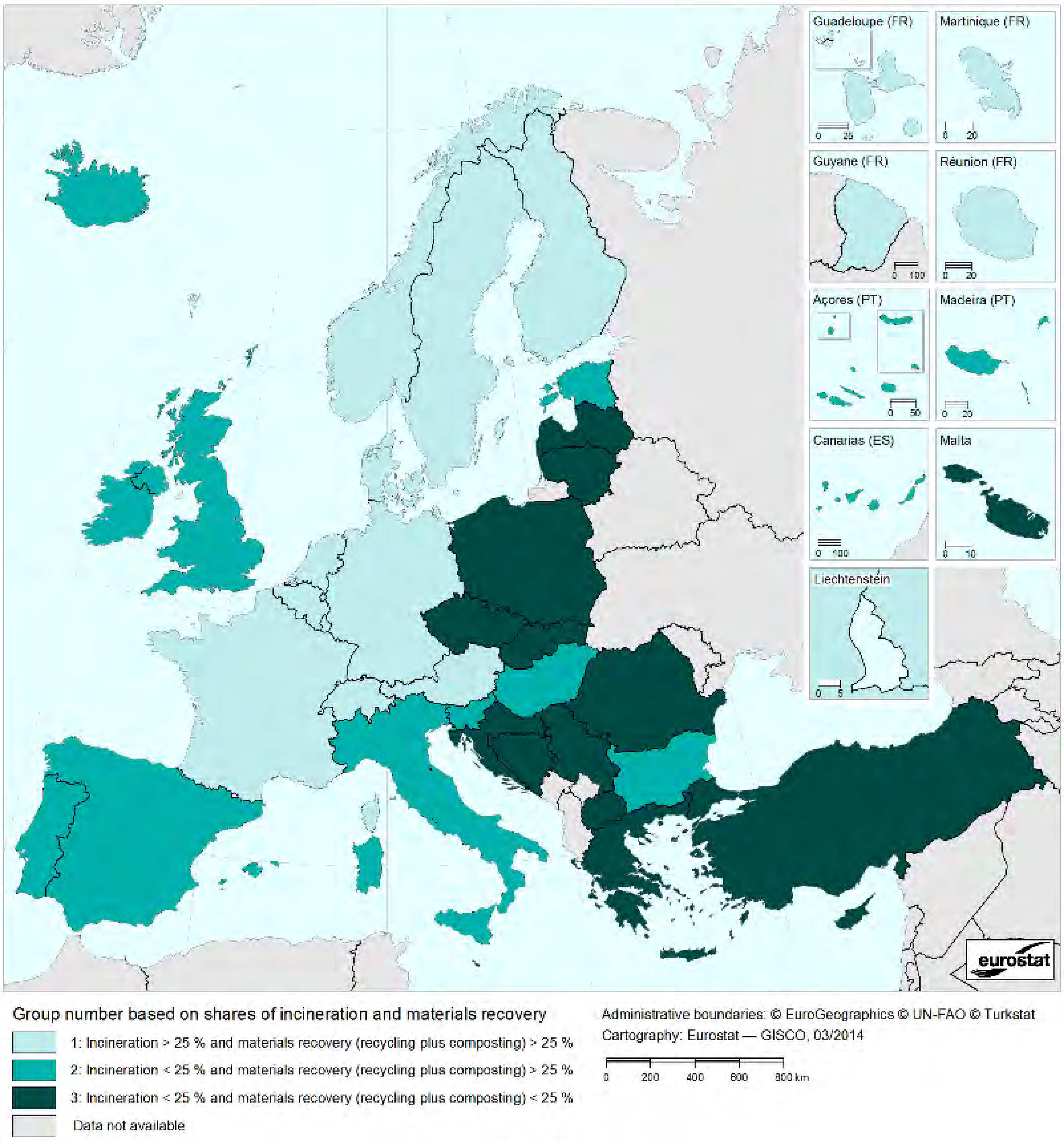


Figure 8.3: *Different waste management strategies in the European countries in 2012 (Eurostat, 2013)*

Figure 8.5 shows the amount of MSW landfilled per capita for each country in 2012.

One of the main objectives of the EU waste policies is the diversion of waste from landfills. The share of landfilling compared to other treatment options is thus a good indicator of the status of MSW management in relation to this objective.

Regions with high landfill rates are not necessarily among the countries with the highest landfilled amounts per capita, as they may generate less waste. For this reason, some regions with high landfill rates, as for instance Poland and Hungary, do not show particularly high amounts of waste landfilled when measured in kg per capita per year.

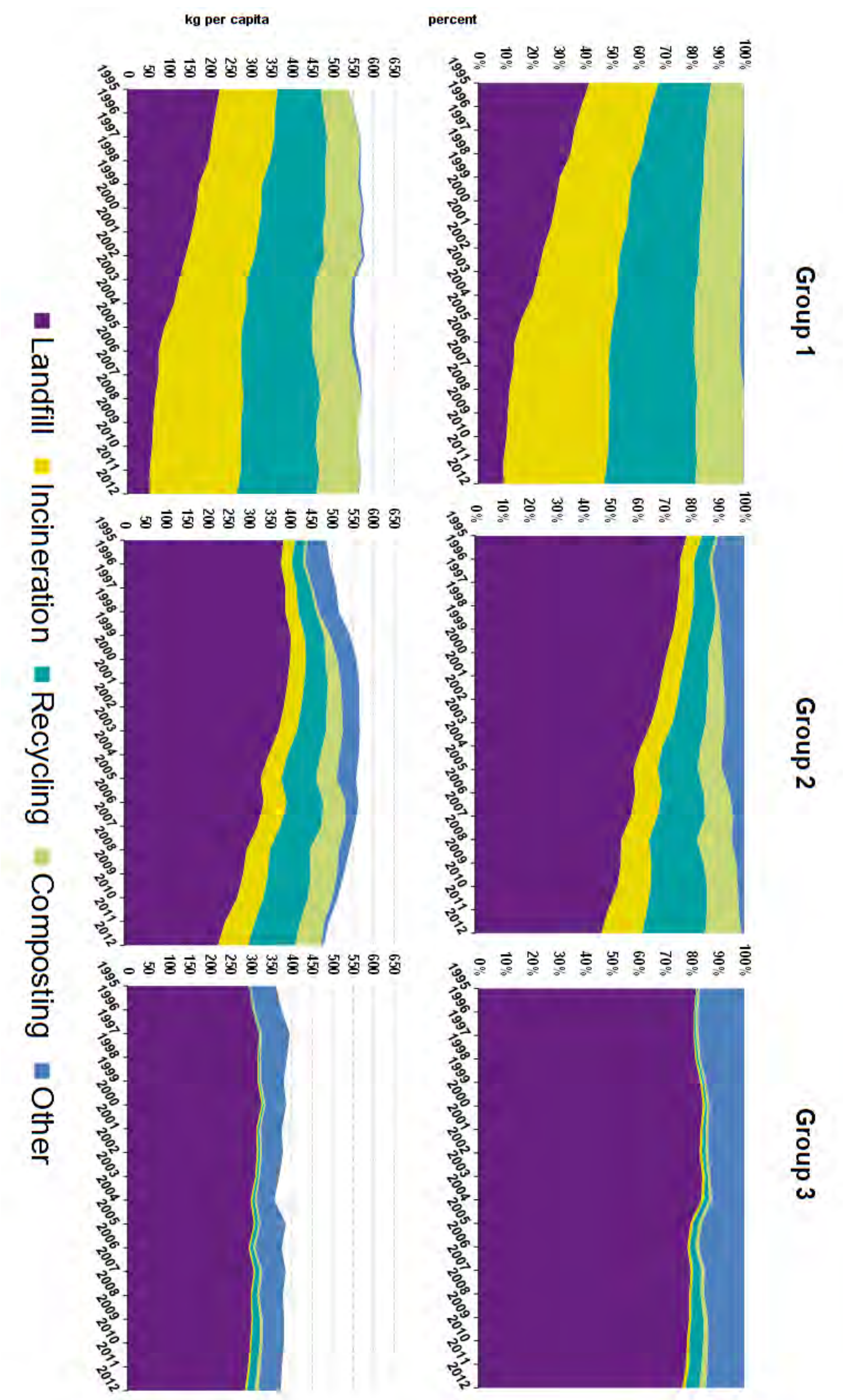


Figure 8.4: *Trends in waste treatment in the three identified groups from 1995 to 2012 (Eurostat, 2013)*

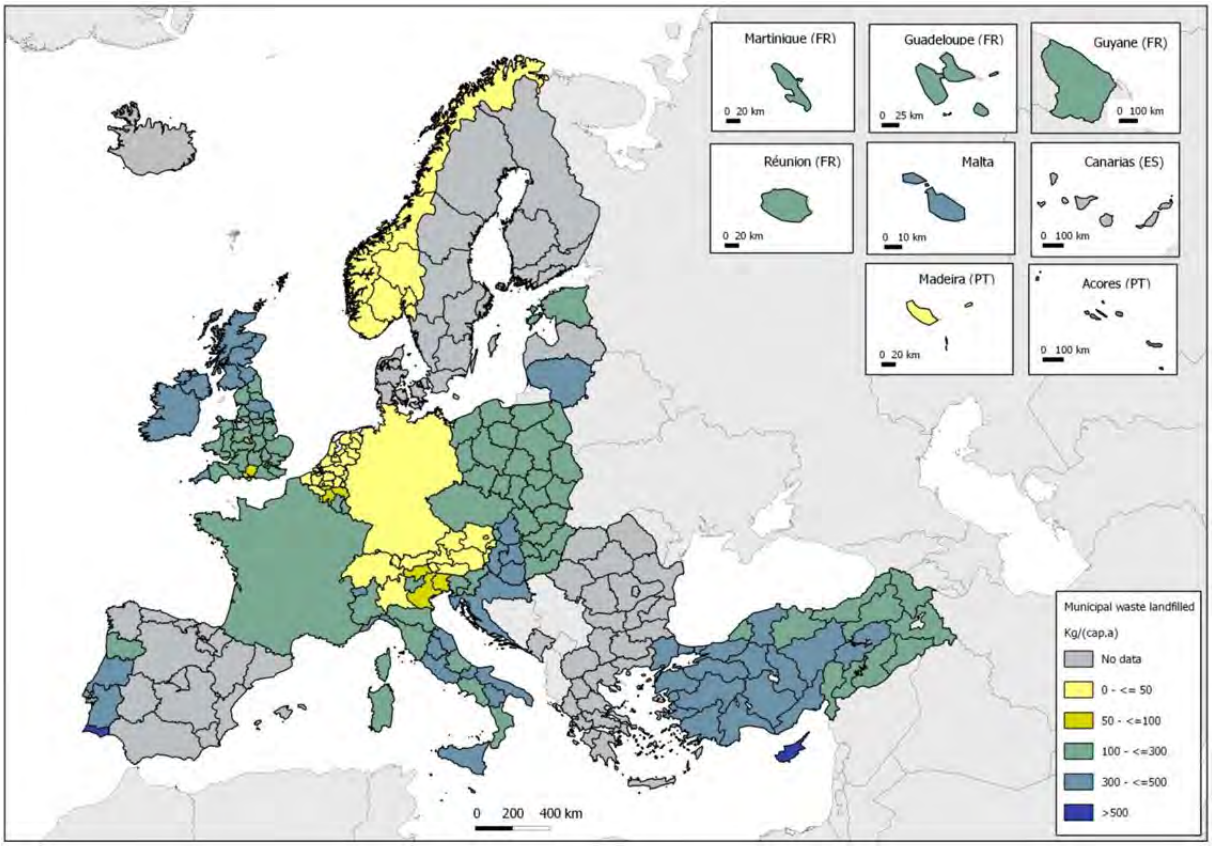


Figure 8.5: *Amount of MSW landfilled per capita in 2012 (Eurostat, 2013)*

8.1.1 Performance against Landfill Directive targets on biodegradable MSW

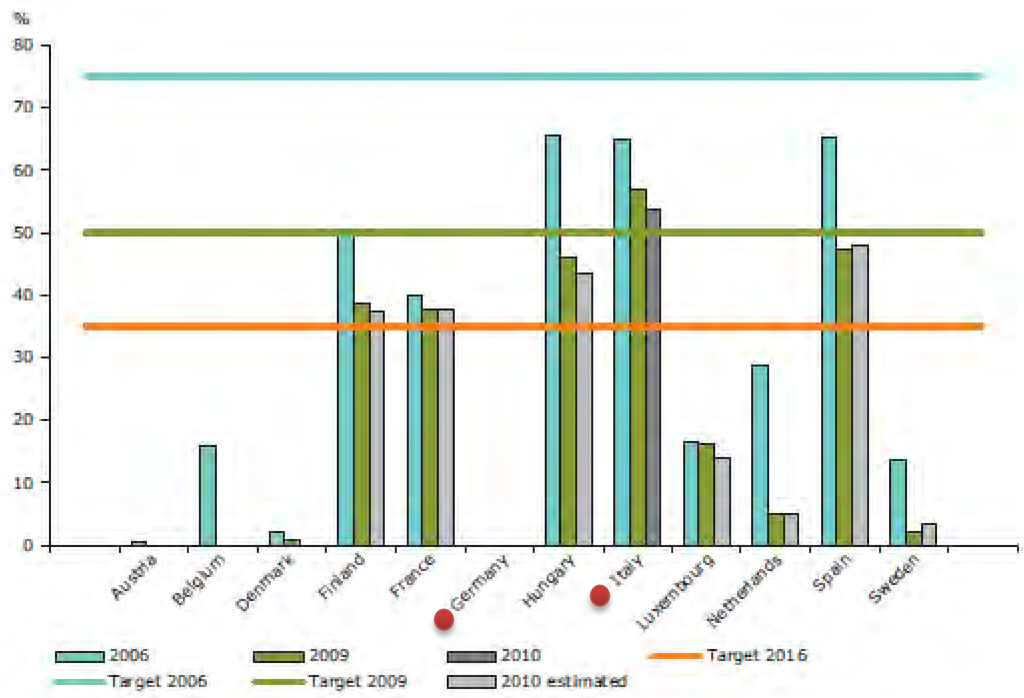
As mentioned previously, there is no legally binding EU limit on landfilling of MSW, but the EU ‘s landfill Directive of 1999 requires that all European member states reduce the amount of biodegradable waste landfilled.

The directive was passed in 1999 and it includes a combination of long-term and intermediate targets for reducing the amount of biodegradable municipal waste landfilled relative to the quantity generated in 1995.

In particular, by 2006 countries must reduce to 75% of the amount they generated in 1995, declining to 50% by 2009 and 35% by 2016.

Twelve countries in Europe have been given a four-year derogation, however, meaning that they must meet their targets by 2010, 2013 and 2020.

Figure 8.6 shows the compliance status of countries without derogation period and Figure 8.7 shows the situation in the EU Member States with a derogation period.



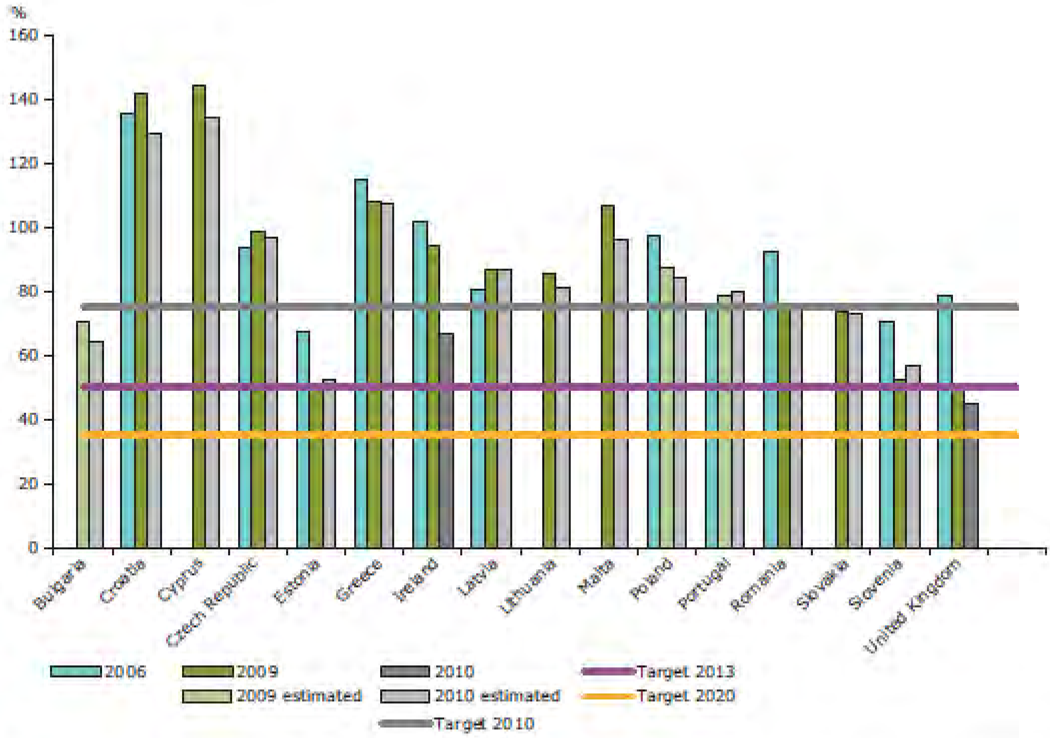
Note: 2010 data are estimated for all countries but Italy.

Source: Data provided by EU Member States to the European Commission (EC, 2012a), ETC/SCP (2013d) and ETC/SCP estimates.

Figure 8.6: *Percentage of biodegradable municipal waste landfilled in 2006, 2009 and 2010 compared with the amount generated in 1995 - countries without derogation period*
(EEA Report No 2, 2013)

In the year 2006 all 12 countries without a derogation period fulfilled the target and landfilled less than 75% of biodegradable municipal waste compared to the amount of 1995. In 2009, 11 countries had fulfilled the 50% target (only Italy did not), and seven countries had already achieved the 2016 target of 35% by 2010.

About the countries with derogation period, seven achieved in 2010 the target of cutting MSW landfilling below 75% of the amount generated in 1995 and one almost achieved the target, based on estimated data. Nine countries were not able to achieve this result in 2010.



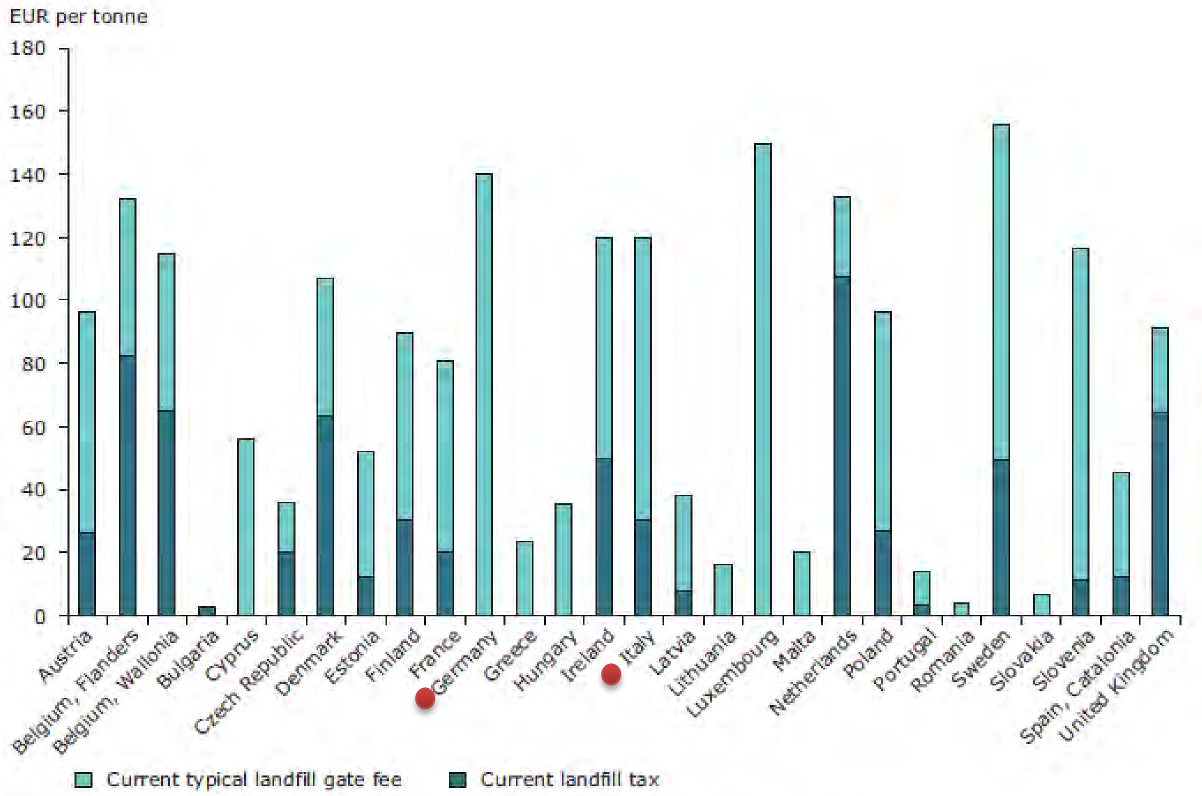
Note: 2009 data are estimated for Bulgaria, Poland and Portugal. The 2010 data are estimated for all countries but Ireland and United Kingdom. Diverting derogations: Ireland: derogation only for the 2006 and 2009 targets, to be met 2010 and 2013. Portugal: derogation only for the 2009 and 2016 targets, to be met in 2013 and 2020. Slovenia: derogation only for the 2016 target, to be met by 2020. Croatia must meet the targets by 2013, 2016 and 2020.

Source: Data provided by EU Member States to the European Commission (EC, 2012a), ETC/SCP estimates (2013c, 2013g).

Figure 8.7: *Percentage of biodegradable municipal waste landfilled in 2010, 2013 and 2020 compared with the amount generated in 1995 - countries with derogation period (EEA Report No 2, 2013)*

8.1.2 The relationship between landfill tax, landfilling and recycling level

Twenty European countries have introduced a tax on waste sent to landfill.
The greatest part of this countries have a tax level for municipal waste landfilling exceeding EUR 30 per ton of waste. Many countries are increasing the tax rate, so that it is already or will soon be between EUR 50 and EUR 70 per ton.
Figure 8.8 shows the typical charge for legal landfilling of non-hazardous MSW in EU States and regions.
Other factors also play an important role in shaping waste management decisions. For instance, landfill taxes often complement other policy measures such as bans on landfilling biodegradable municipal waste or non-pretreated municipal waste, mandatory separate collection schemes for recycling of MSW types, or economic support to build up recycling infrastructure.



Note: Taxes and fees may have changed since the publication of the report in April 2012.

Source: Bio Intelligence Service, 2012.

Figure 8.8: *Typical charge (gate fee and landfill tax) for legal landfilling of non-hazardous municipal waste in EU Member States*

(EEA Report No 2, 2013)

Germany has managed to achieve one of the highest recycling rates of MSW in Europe without using landfill tax but with a combination of other instruments.

The higher the cost of landfilling, the more municipal waste is pushed up the waste hierarchy towards treatment via recycling and composting, as shown in chapter number one.

Member States appear much more likely to meet 50% recycling target once landfill charges approach EUR 100 per ton. Such charges will tend to drive the economics of recycling, composting and incineration.

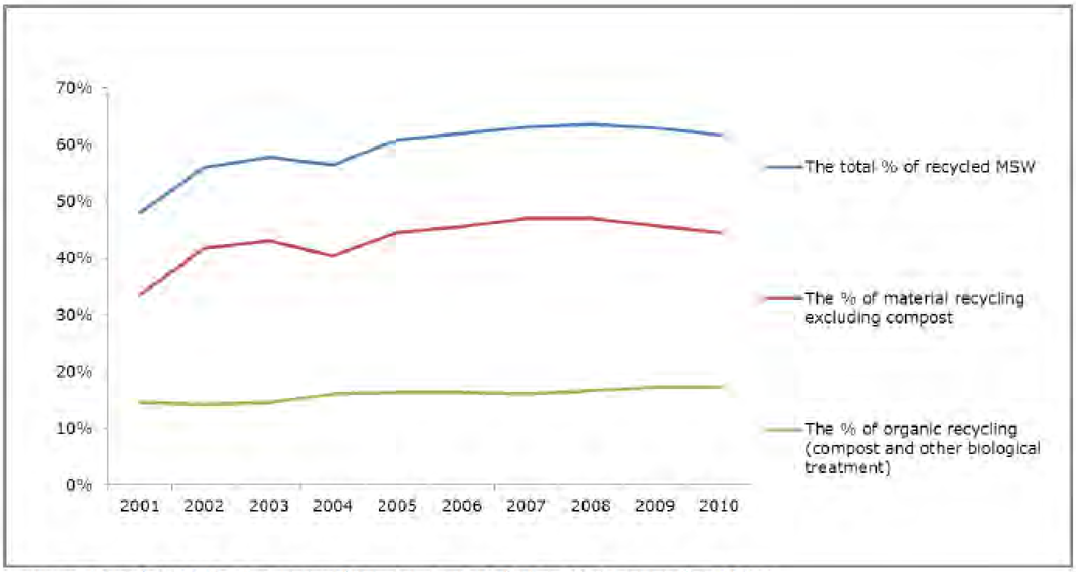
Landfill taxes can therefore, in combination with other instruments, play an important role in incentivizing a shift up the waste hierarchy and generate revenues for building up recycling infrastructure.

8.2 Recycling of MSW and landfilling of the biodegradable fraction in Germany

In Germany, the National Ministry of the Environment sets priorities, participates in the enactment of laws, oversees strategic planning, information and public relations and defines requirements for waste facilities. Each Federal State has then to adopt its own waste management act, which contains supplementary regulations for disposal. There is no national waste management planning in Germany.

Germany was the first country in Europe to introduce the producer responsibility with a packaging waste regulation in 1991. According to this principle the producer of a product is generally responsible for the product when it becomes waste. This principle has been implemented for packaging material, electronic waste, vehicles, solvents, waste oil and batteries.

For MSW generated in households the Recycling Management and Waste Act assigns responsibility to the local public waste disposal authorities. Their responsibility covers collecting, transporting and prevention of waste, and also the construction and operation of waste disposal facilities. Municipalities have more practical tasks such as providing sites for waste collection. This facts and a very efficient separate collection allow Germany to be the European leader in recycling. Recycling in Germany is about 62%, as Figure 8.9 shows.



Source: Eurostat, 2012. The percentages are calculated as % of generated MSW.

Figure 8.9: *Recycling of MSW in Germany from 2001 to 2010 (EEA Report No 2, 2013)*

As mentioned previously, it is a general requirement of the EU Landfill Directive that all Member States have to reduce the amount of biodegradable MSW landfilled by a certain percentage by 2006, 2009 and 2016. The targets are related to 1995, and in that year in Germany the amount of RMSW was about 28.4 million tons.

Germany has reported to the Commission that zero tons of RMSW were landfilled in 2006, 2007, 2008 and 2009. This is due to the fact that Germany introduced a ban on non-pretreated MSW, which was introduced in two steps.

The first step was an administrative regulation (TASi) in 1993. The second step were two ordinances in 2001 and 2002 that aimed at closing some of the loopholes within the 1993 administrative regulation and setting the following requirements:

- Municipal waste after June 2005: maximal 5% carbon content in waste direct landfilled
- Municipal waste, which has been mechanically or biologically pretreated: max 18% carbon content and very low content of biodegradable organic carbon in waste landfilled, measured with degradation tests

In 2005 a regulation prohibit the waste disposal in landfills of untreated MSW. This regulation called "*Bericht-Siedlungsabfallentsorgung*" entered into force at June the 1st 2005.

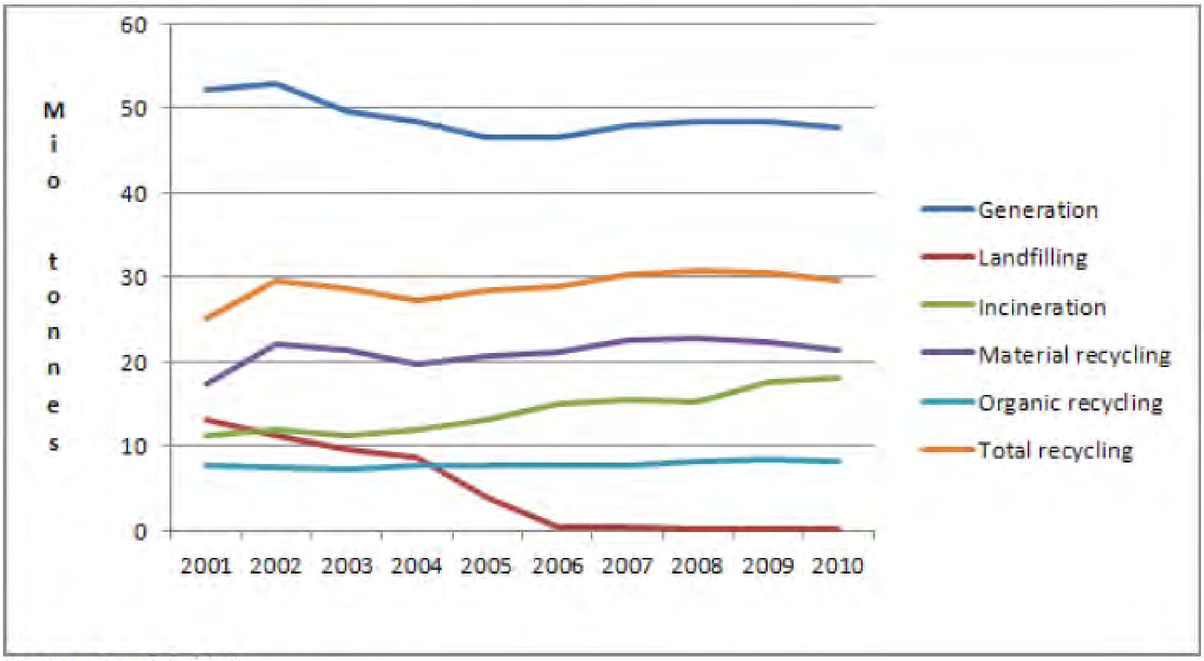
Twenty countries in Europe are using a landfill tax but this does not include Germany, which has a very high level of recycling of MSW.

It is interesting that Germany has achieved this without using a landfill tax.

The requirement of pretreatment of MSW before it can be landfilled combined with other management activities such as producer responsibility have been strong drivers in diverting MSW away from landfills and towards recycling.

Figure 8.10 shows that the ban on non-pretreated MSW in 2005 has had a huge impact on the amount of waste landfilled. The figure also shows that recycling increased in the considered period, but incineration increased particularly.

The incineration capacities of Germany increased substantially since the late 1990s.



Source:Eurostat, 2012

Figure 8.10: *Development of landfilling, incineration and recycling of MSW in Germany (stated in millions of tons)*

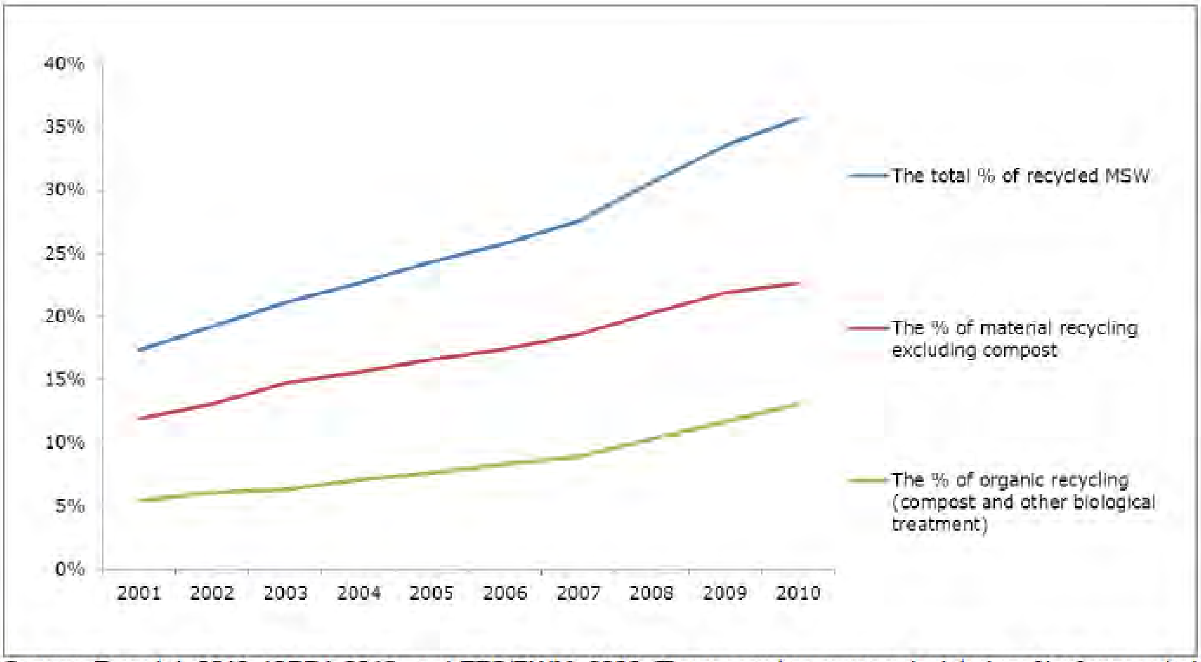
(EEA Report, 2013)

8.3 Recycling of MSW and landfilling of the biodegradable fraction in Italy

Figure 8.11 shows the development of recycling of MSW in Italy related to the total recycling, material recycling and organic recycling. Both material recycling and organic recycling have increased between 2001 and 2010.

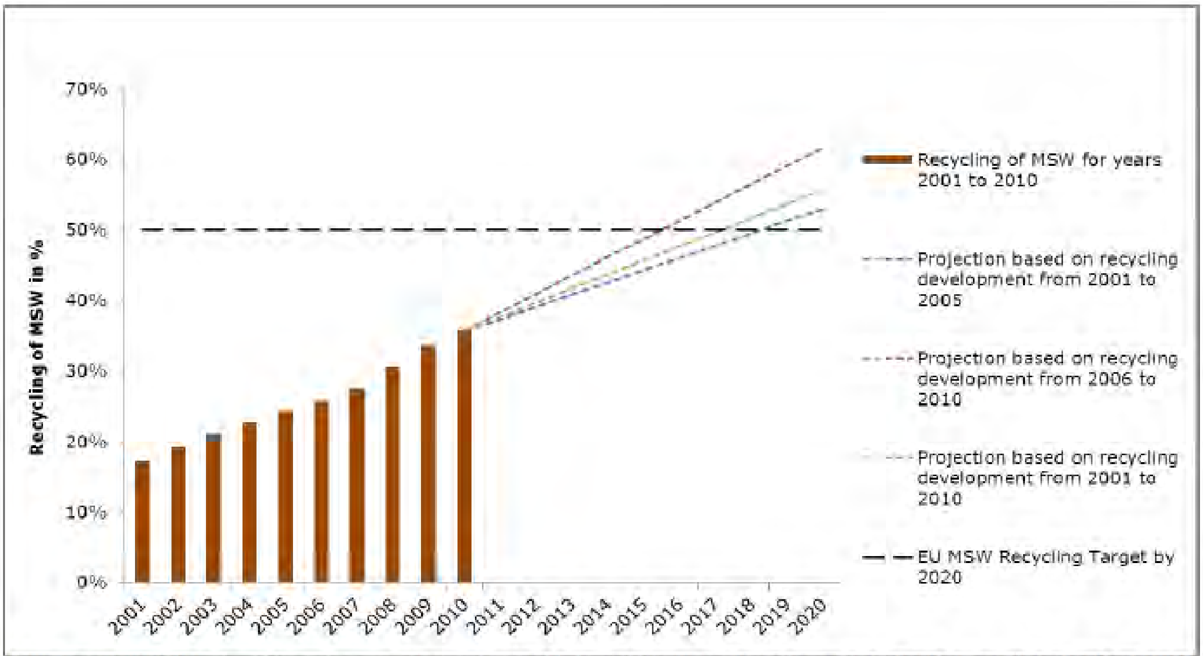
In order to assess the prospects for Italy to meet the 50% recycling target as set out in the Waste Framework Directive, three scenarios have been developed by the EEA in the report: "*Municipal waste management in Italy",* of February 2013. This scenarios assume that recycling in the period 2010 - 2020 develops, based on a linear regression, with the increase rates of recycling in the periods 2001 - 2005, 2006 - 2010 and 2001 - 2010.

Figure 8.12 shows that Italy would be able to reach the recycling target of 50% by 2020, even if the increase of recycling follows the 2001 – 2010 overall trend or the 2001 – 2005 trend, which is the worst scenario. The target would be achieved in 2016, 2017 and 2019, according to the best, intermediate and worst scenarios respectively.



Source: Eurostat, 2012, ISPRA 2012, and ETC/RWM, 2008. The percentages are calculated as % of generated MSW

Figure 8.11: *Recycling of MSW in Italy (EEA Report, 2013)*



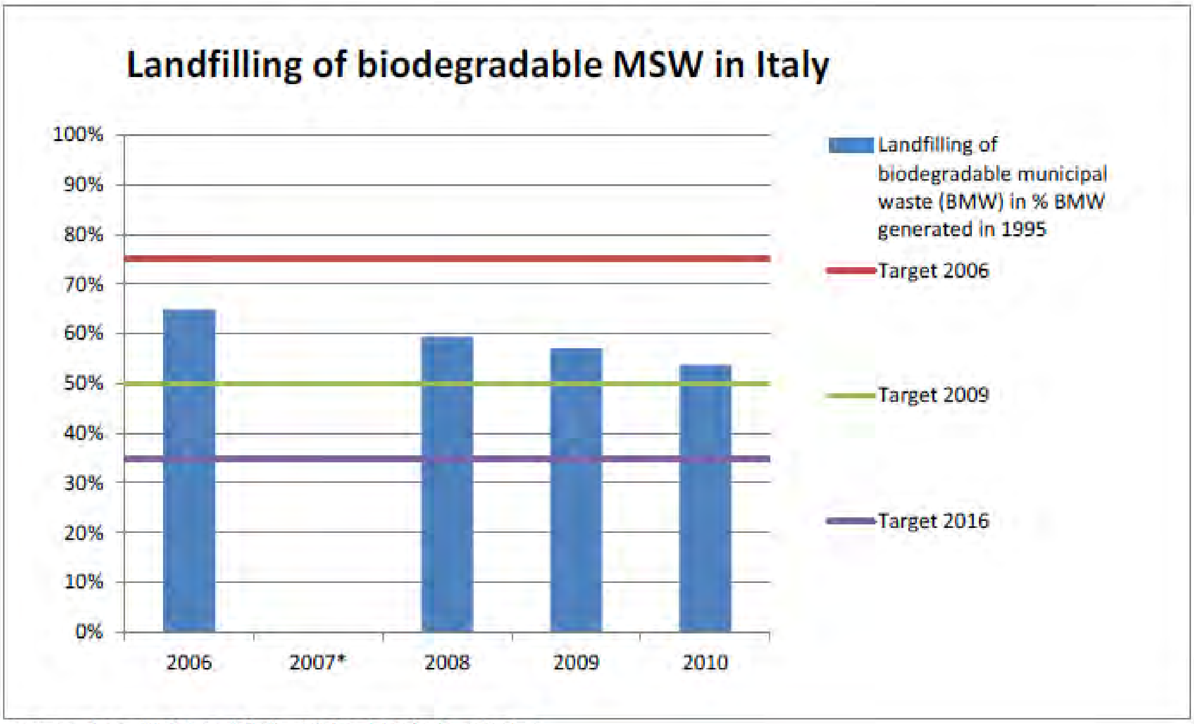
Source: Calculation by Copenhagen Resource Institute (CRI), based on Eurostat, 2012 Eurostat, 2012, ISPRA 2012, and ETC/RWM, 2008

Figure 8.12: *Future recycling scenario of MSW in Italy (EEA Report, 2013)*

Italy landfilled 82% of its biodegradable MSW in 1995, and it could have got a four year derogation period from the above mentioned targets, but it decided not to request a derogation. Instead of transposing the percentage based targets set out in the Landfill Directive, Italy adopted targets based on the quantity of biodegradable MSW produced per capita, which shall be reached at ATO level (Optimal Management Areas). That decision was based on the fact that there was a lack of reliable data on the quantity of biodegradable MSW landfilled in 1995.

Targets have been defined for 2008, 2011 and 2018, since Italy transposed the Landfill Directive into the national law in January 2013, 18 months after the deadline. As such the targets follow the intervals of the Directive with a delay of two years.

Figure 8.13 shows that the 2006 target of the European Landfill Directive has been met, while the 2009 one has not, since in that year Italy landfilled 57% of biodegradable MSW produced in 1995.

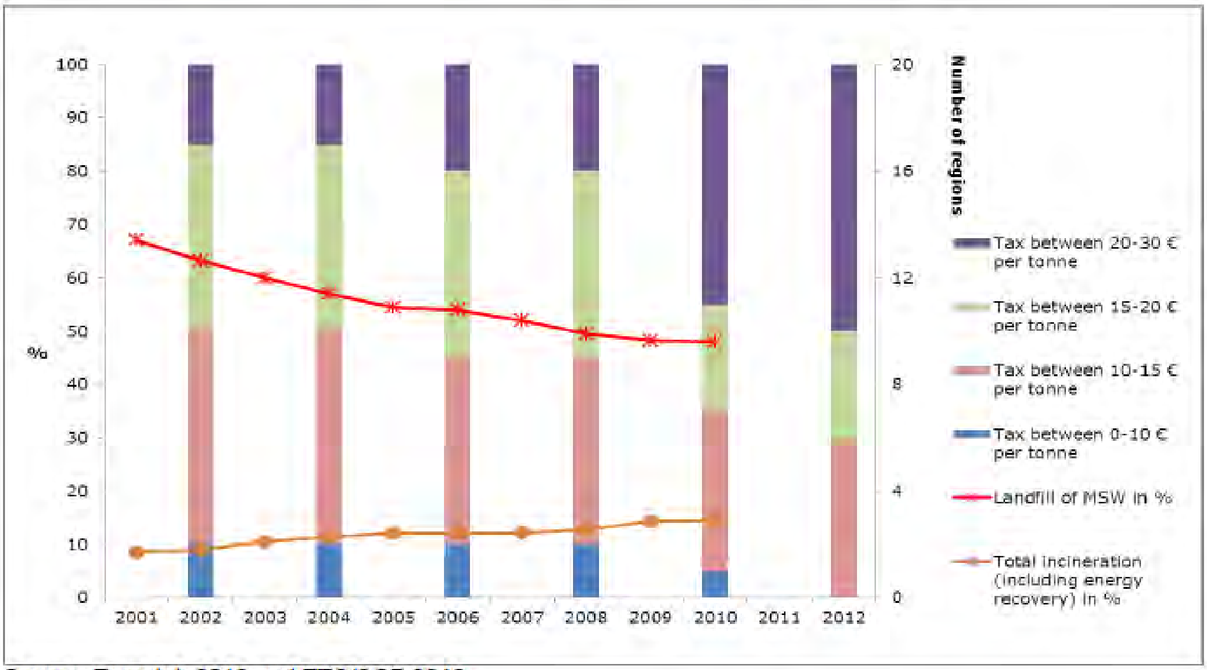


Source: EC, 2012 and Italy, 2012. * Data is missing

Figure 8.13: *Landfilling of biodegradable MSW in Italy (EEA Report, 2013)*

The landfill tax was introduced in Italy in 1996, based on *Law 549/1995*. This law defines the upper and the lower level of the tax and is applied at a regional level. The tax is directly paid to the regions by landfill operators.

The price of the tax varies in the different regions, and has a range from 5.2 to 25.8 EUR per ton. The average landfill tax for all the regions increased from EUR 14.24 per ton in 2001 to EUR 18.84 per ton in 2012. The actual average level of the tax is among the lowest compared with western European countries.



Source: Eurostat, 2012 and ETC/SCP 2012

Figure 8.14: *Development of landfilling and incineration of MSW and landfill tax in Italy – distribution of taxes across the different regions*

The increase of the landfill tax coupled with the stabilization of the generation of municipal waste since 2007 and higher rates of separate collection produced a strong reduction in the amount of disposable waste and a significant increase in the total incineration. It is also reflected in the positive trend of recycling.

9. Landfill emissions

9.1 Fundamentals of sanitary landfilling

A landfill site is a site for the disposal of waste materials by burial and is the oldest form of waste treatment. Historically, landfills have been the most common method of organized waste disposal and remain so in many places around the world. Some landfills are also used for waste management purposes, such as the temporary storage, consolidation and transfer, or processing of waste material (sorting, treatment or recycling).

With landfills are usually intended sanitary landfills, which are the modern way of burying waste, taking care of the environment and human health, means physical protection barriers and other technical procedures.

Landfills are the evolution of the so called dump sites, which consist in the simple burying of waste under the ground, without any other safety procedures. Dump sites are still used in most developing countries, and also in Europe there are several old dump sites used in the twentieth century. Big efforts are being made nowadays also in Germany and Italy for the remediation of old dump sites, since some of them are still emitting pollutants in the environment.

An important concept for the prevention and protection related to landfill emissions is the multi-barrier concept (*Cossu R., 2012*), which groups four separated concepts to minimize the emission potential. Every sanitary landfill is planned basing on such a concept.

A good quality of the waste, with a low biodegradable content is the first and most important way to reduce emissions. Proper physical barriers (bottom and top covers) are also important. The continuous control and extraction of leachate and biogas and a modern landfill concept, based on aeration of the waste is as much important.

The *Landfill Directive 99/31/EC* require that the following criteria have to be respected in the course of a landfill siting:

- Geological barrier thickness of at least 3 m with a permeability lesser than $1 \cdot 10^{-7}$ m/s
- Baseline of the landfill at least 1 m above the highest point of the groundwater level
- Near to the landfill side there must not be a drinking water catchment area, a nature conservation area or a flooding-risk area
- Site at least 300 m away from residential areas
- Low permeability of the rock (clay soil preferred to lime and gravel)

There exist different ways to structure the landfill body. Nowadays the Above-ground Landfills are preferred, because it is easier to control the landfill body and the emissions, and notice some possible leakages. In particular aerated Above-ground Landfills are one of the most used landfill types, since the aeration of the landfill body reduce the leachate and biogas production, as will be explained further.

The bottom lining system is a very important component, since a failure of it can release leachate in the soil and in the groundwater. Usually it is composed by a leachate collection system (pipes with slots which carry the leachate to the leachate treatment system), a drainage layer (gravel) and a bottom layer.

There exist different combinations for the bottom liner. A bottom layer composed of more layers ensure a lower leaking probability over time, but is more expensive. Figure 9.1 shows the minimum bottom layer composition that a landfill must have nowadays in some countries, in accordance with the different regulations in this countries.

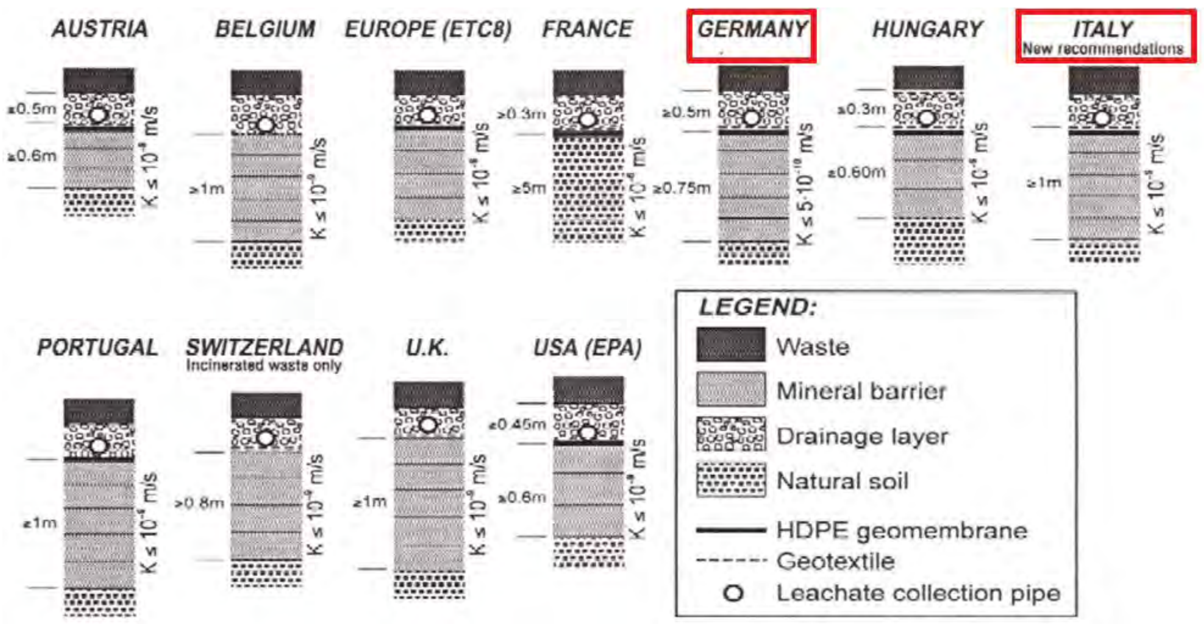


Figure 9.1: *Minimum bottom layer composition in some European countries and the US (Cossu R., 2012)*

Also the final top-cover (besides there can be used also a daily cover to avoid that the waste can be blown away by the wind and the presence of birds and scavengers) is made by a composition of different layers.

An important principle of sanitary landfills, based on the concept of sustainability, is to ensure that after the closure of the landfill side and its aftercare period, the emission potential is reduced to zero.
Known the fact that the containment materials which compose the bottom layers will break over the time (they can break for several reasons: aging, stress, welding failures, compaction damages, gravel damages, machinery and others), the best strategy is to ensure that there will be no emission potential when the barriers will break, rather than try to isolate the waste, without extracting leachate and biogas and create aerated conditions.
In the past landfills where planned isolating the waste from the outside, without allowing air and rain to enter in the landfill body. The consequences were that after the closure and the breaking of the bottom layer, the emission potential of the landfills were still high, since the waste "mummified", due to anaerobic processes, and this brought to leaking and pollution into soil and groundwater.
Aeration prevent and reduce the formation of anaerobic processes and so biogas production, and the rain which drain trough the waste allow to extract the contaminated leachate from the bottom.
The open dump has very high emission potential peak in the first years, since there are no protection covers. Anaerobic processes are strongly taking place, and a high amount of biogas is produced. Besides the rain draining through the landfill produce leachate which goes directly in the soil. The emission potential is reduced after some years.
In the case of a dry tomb or a contained landfill, air and rain can't enter the landfill body, since the isolating top cover. Anaerobic processes are taking place and no leachate extraction is performed. After about 30 years, when the bottom layer materials start to fail and the top cover breaks, rain reach the "mummified" waste, and a very polluted leachate flows through the broken bottom cover, polluting the environment.
The optimal solution seems to be the sanitary landfill. Leachate and biogas are regularly extracted, anaerobic process are reduced to the minimum due to aeration, and when the covers will break the waste has no significant emission potential anymore.
As already mentioned, landfills have two main kinds of emissions: leachate and biogas, which can be harmful for respectively the soil, the groundwater and the air.

Landfills are significant sources of CH_4 emission, with about 8-12% of the global amount of production (*Cossu R., 2012*). Since methane has a 21-25 times higher global warming potential as CO_2, landfills are a quite significant contributory cause to global warming. The methane emissions are mostly given by the biodegradable fraction in the waste.
If methane is present in a great amount, there can be the presence of small localized explosions on or in the landfill body.
Also the ozone depletion can be caused by landfill gasses, since they can contain chlorinated and fluorinated compounds and Freon.
Toxic VOCs as vinyl chloride and benzene can be contained in the biogas. Close to the landfill side bad odors can be perceived, since H_2S and mercaptans can be present if the biological fraction is consistent. Noise due to the compactors and the intense traffic of the waste delivery is usually present.
Asphyxia by removal of O_2 from root zone due to replacement or oxidation of the methane can damage the plants close to the side.

9.2 Biochemical processes in a landfill

Degradation processes inside the landfill are the key to understand and control the environmental impacts. Physical, chemical and microbial processes are taking place. In most landfills, assuming that they receive some organic waste, the microbial processes will dominate the stabilization of the waste and hence govern the generation of landfill gas.
The predominant part of a landfill will soon after disposal become anaerobic, and bacteria will start degrading the solid organic carbon, eventually to CO_2 and CH_4.
The microbial processes converting organic carbon in the waste are rather complex. In a general way the biochemical processes in a landfill can be subdivided in aerobic and anaerobic processes (*Stegmann R., 2013*).

$$\text{AEROBIC} \qquad \text{Organic matter} \xrightarrow[micro-organisms]{O_2} CO_2 + H_2O$$

$$\text{ANAEROBIC} \qquad \text{Organic matter} \xrightarrow[micro-organisms]{} CO_2 + CH_4$$

The anaerobic degradation can be viewed as consisting in four stages.

In the first stage large polymers are converted to simple monomers, solid organic matter and complex dissolved organic matter are hydrolyzed and fermented by the fermenters to primary volatile fatty acids, alcohols, H_2 and CO_2. The hydrolysis process is very important in the landfill, since the solid organic waste must be solubilized before the microorganisms can convert it.

After the smaller, easily soluble part of the organic matter has been converted, the hydrolysis may prove to be the overall rate-limiting process in a landfill environment (*Leuscher, 1983; McInerney and Bryant, 1983*). The hydrolysis is caused by extracellular enzymes produced by the fermenting bacetria (*Jones et al., 1983*). The fermenters are large, heterogeneous group of anaerobic and optional anaerobic bacteria.

The second stage consist in the conversion by an acetogenic group of bacteria of the products of the first stage (e.g. glucose, amino acids and fatty acids) to volatile fatty acids (76 %), H_2 (4 %) and acetic acid (20 %) (*Cossu R., 2012*).

In the acetogenic phase, the third one, volatile fatty acids are converted to acetic acid, H_2 and CO_2.

Finally in the methanogenesis, methanogenic bacteria produce CH_4. Acetophilic bacteria convert acetic acid (CH_3COOH) to CH_4 and CO_2, and hydrogenophilic bacteria convert H_2 and CO_2 to CH_4.

The overall process of converting organic compounds to CH_4 and CO_2 may stoichiometrically be expresses by (*Buswell and Müller, 1952*):

$$C_nH_aO_b + \left(n - \frac{a}{4} - \frac{b}{2}\right) H_2O \rightarrow \left(\frac{n}{2} - \frac{a}{4} + \frac{b}{4}\right) CO_2 + \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right) CH_4$$

Table 9.1 shows the main reactions involved in the four steps of anaerobic degradation. The conversion of acetic acid to methane is by far the most important part of the methane-forming process (70%).

The sulphate-reducing bacteria resemble the methanogenic group, and they convert H_2, acetic acid and higher volatile fatty acids during the sulphate reduction. A high activity of sulphate reducers hence may decrease the amount of organics available for methane production.

Reactants converted to products	
Fermentative processes	
$C_6H_{12}O_6 + 2H_2O$	$2CH_3COOH + H_2 + 2CO_2$
$C_6H_{12}O_6$	$CH_3C_2H_4COOH + 2H_2 + 2CO_2$
$C_6H_{12}O_6$	$2CH_3CH_2OH + 2CO_2$
Acetogenic processes	
$CH_3CH_2COOH + 2H_2O$	$CH_3COOH + CO_2 + 3H_2$
$CH_3C_2H_4COOH + 2H_2O$	$2CH_3COOH + 2H_2$
$CH_3CH_2OH + H_2O$	$CH_3COOH + 2H_2$
$C_6H_5COOH + 4H_2O$	$3CH_3COOH + H_2$
Methanogenic processes	
$4H_2 + CO_2$	$CH_4 + 2H_2O$
CH_3COOH	$CH_4 + CO_2$
$HCOOH + 3H_2$	$CH_4 + 2H_2O$
$CH_3OH + H_2$	$CH_4 + H_2O$
Sulphate reducing processes	
$4H_2 + SO_4^{2-} + H^+$	$HS^- + 4H_2O$
$CH_3COOH + SO_4^{2-}$	$CO_2 + HS^- + HCO_3^- + H_2O$
$2CH_3C_2H_4COOH + SO_4^{2-} + H^+$	$4CH_3COOH + HS^-$

$HCOOH$: formic acid, CH_3COOH: acetic acid, CH_3CH_2COOH: propionic acid, $CH_3C_2H_4COOH$: butyric acid, $C_6H_{12}O_6$: glucose, CH_3OH: methanol, CH_3CH_2OH: ethanol, C_6H_5COOH: benzoic acid, CH_4: methane, CO_2: carbon dioxide, H_2: hydrogen, SO_4^{2-}: sulphate, HS^-: hydrogen sulphide, HCO_3^-: hydrogencarbonate, H^+: protone, H_2O: water.

Acetotrophic methanogens

$$4\,CH_3COOH \rightarrow 4\,CO_2 + 2\,H_2$$

Methylotrophic methanogens

$$4\,CH_3OH + 6\,H_2 \rightarrow 3\,CH_4 + 2\,H_2O$$

Hydrogenotrophic methanogens

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O$$

Table 9.1: *Anaerobic degradation reactions and methanogenic reactions (McInerney and Bryant, 1983)*

The first methanogenic process is the reduction of CO_2, and the second the splitting of acetic acid.

The bacterial groups participating in the methane-forming ecosystem are exposed to a variety of highly variable abiotic factors in the landfilled waste.

Oxygen:

The absence of free O_2 is a must for the anaerobic bacteria to grow and perform the above-mentioned processes. Aerobic bacteria in the top of the landfill waste will readily consume the oxygen and limit the aerobic zone to less than 1 m of compacted waste.

Extensive gas-recovery pumping may create a substantial vacuum in the landfill, forcing atmospheric air to enter the landfill. This may extend the aerobic zone in the waste and eventually prevent formation of methane in these layers (*Christensen and Kjeldsen, 1989*).

Hydrogen:

H_2 is produced by both the fermentative and the acetogenic bacteria and the generated H_2 pressure affects the biochemical pathways.

The fermentative bacteria yield hydrogen, CO_2 and acetic acid at low hydrogen pressures, while H_2, CO_2 and ethanol, butyric acid and propionic acid are generated at higher hydrogen pressures *(Christensen and Kjeldsen, 1989).*

pH and Alkalinity:

Methanogenic bacteria operate only within a narrow pH-range of 6-8.
The pH range for fermentative and acetogenic bacteria is much wider than for the methanogenic bacteria.

Sulphate:

Both the sulphate-reducing bacteria and methanogenic bacteria convert acetic acid and H_2. Experiments have shown that when sulphate is present the methane production is dramatically reduced. The suppression of methane formation by sulphate is not related to any toxic effects of sulphate on methanogenic bacteria but due to simple substrate competition.

Nutrients:

Besides organic matter the anaerobic ecosystem must have access to all required nutrients, in particular nitrogen and phosphorus. All the necessary micronutrients (e.g. sulphur, calcium, magnesium, potassium, iron, zinc, copper, cobalt, molybdanate and selenium) are considered to be present in most biodegradable waste types.
The anaerobic ecosystem assimilates only a very small part of the substrate into new cells and therefore requires much less nitrogen and phosphorous than the aerobic system *(Christensen and Kjeldsen, 1989)*.

Inhibitors:

As well as the already mentioned oxygen, hydrogen and sulphate, also substrate concentration, CO_2, salt ions, sulphide, heavy metals and specific organic compounds will can have inhibitory effects (*Stegmann R., 2013*).

Temperature:

The methanogenic bacteria contain a mesophilic group with a rate maximum around 40 ºC, and a thermophilic group with a maximum around 70 ºC. Only the former group is relevant in landfills.
In a deep landfill with a moderate water flux, the flux of heat from the landfill to the surroundings is small due to the insulating capacities of the waste, and the heat generated by the anaerobic decomposition process may cause a temperature rise in the landfill (*Rees, 1980*).

Moisture content:

Several laboratory investigations have shown that the methane production rate increases for increasing moisture content of the waste. Findings from literature suggest an exponential increase in gas production with a water content between 25-60% *(Christensen and Kjeldsen, 1989).*

9.3 Biogas emissions

The average quantity and composition of landfill gas change over time, since it depends from the biodegradation process of the waste, which varies in time. The readily biodegradable fraction is the part of the waste which mostly influence biogas and leachate production.

GAS	CONCENTRATION
Methane	45-65 % vol
Carbon dioxide	35-55 % vol
Cabon monoxide	<< 1 % vol
Hydrogen	<< 1 % vol
Hydrogen sulfide	< 50 ppm
R-SH	< 50 ppm
Trichloroethylene	< 50 ppm
Tetrachlomethylene	< 50 ppm
Carbon tetrachloride	< 5 ppm
Vynilchloride	< 20 ppm
Steam	2-4 % vol
Oxygen	<< 1 % vol
Nitrogen	<< 1 % vol
Argon	< 1 % vol
Traces	< 1 % vol

Table 9.2: *Average landfill gas composition (Cossu R., 2012)*

Table 9.2 show the average amount of the components and elements present in the landfill gas. CH_4 and CO_2 are the most present gasses, since they are the final result of the anaerobic degradation process. The composition depends on the type of biodegradable waste present in the landfill side.

Figure 9.2 shows the amount of landfill gas in m^3/t waste/y over time. It is notable how the greatest amount of biogas is produced between 6 and 15 years after the disposal of the waste, since this is the time required by the anaerobic processes in the landfill body to perform.

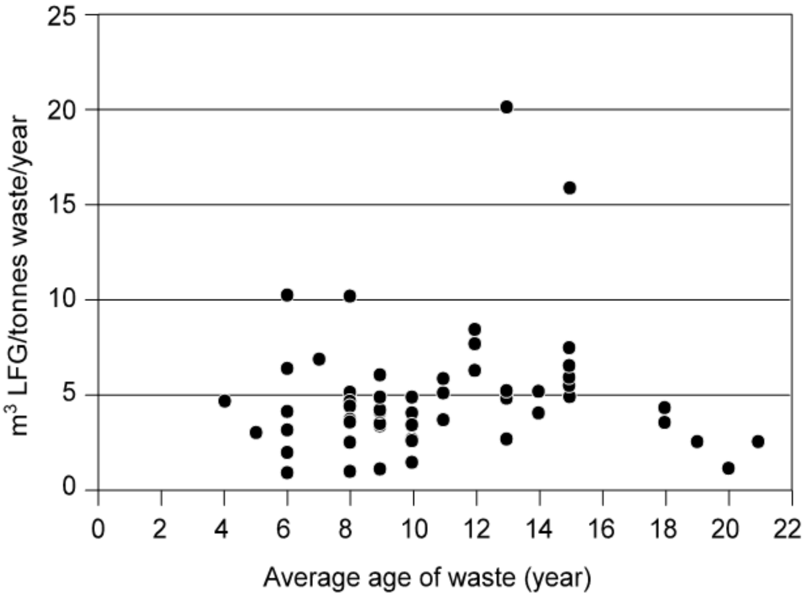


Figure 9.2: *Landfill biogas production over time (Cossu R., 2012)*

It is important to mention that the specific methane production rate expressed as m^3 of landfill gas per ton may vary substantially from landfill to landfill owing to variations in waste composition, moisture content, microbial activity in the waste and supposedly also according to the age of the waste as a measure of the stability of the organic matter present in the waste. Observed methane production rates at actual landfills may vary owing to different efficiencies of the gas extraction systems, which may be influenced by the shape of the landfill, the top cover, the type of extraction system and the pumping rate applied.

9.3.1 Landfill gas composition over time

Due to the anaerobic process, the LFG composition changes over time. This process can be separated in eight different phases (this idealized degradation sequence is dealing with a homogeneous waste volume, in a real landfill with cells of highly varying age and composition the overall picture may be somewhat different).

In the first phase there is a short aerobic period, immediately after the landfilling of waste, where easily degradable organic matter aerobically decomposed is, with CO_2 and H_2O generation.

The second phase consists in a first intermediate anaerobic period, where the activity of fermentative and also the acetogenic bacteria bring to a rapid generation of volatile fatty acids, CO_2 and H_2. The acidic leachate may contain high concentration of fatty acids, calcium, iron, heavy metals and ammonia.
The content of nitrogen in the gas is reduced due to the generation of CO_2 and H_2.
In Phase 3 a second intermediate anaerobic phase will start with slow growth of methanogenic bacteria. The CH_4 concentration in the gas increases.
In Phase 4 there is a stable CH_4 production resulting in a CH_4 concentration in the gas of 50-65% by volume. The high rate of CH_4 formation maintains low concentrations of volatile fatty acids and H_2.
In Phase 5 only the more refractory organic carbon remains, the CH_4 production rate will be so low that N_2 will start appearing in the landfill gas again due to diffusion from the atmosphere. Aerobic zones and zones with redox potential too high for CH_4 formation will appear in the upper layers of the landfill *(Christensen and Kjeldsen, 1989).*
In the sixth phase occur the methane oxidation, since O_2 enters again in the landfill body. The CH_4 production decrease and the CO_2 production increase.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + biomass + heat$$

In the seventh and eighth phase, O_2 is growing inside the landfill body, and this allows aerobic degradation processes, with the production of CO_2 and H_2O. The CH_4 production in the landfill runs out completely (*Stepniewski W. 2012*).

9.3.2 Modelling biogas production

Field testing of landfills to determine present gas generation rates or long-term gas production potential is difficult and inexact, subject to problems in obtaining reliable data but also to problems arising from the heterogeneity of the waste.
A good solution is to use several different techniques. One technique is to try to simulate the landfill by enclosing portions of the landfill or a simulated landfill in a test volume in order to measure the gas generated (lysimeter testing).
Another option is to pump gas from the landfill, measuring the amount and composition but also attempting to delineate the volume of the landfill giving rise to the gas being collected.
It is also possible to measure gas generated by samples of refuse taken directly from the landfill (anaerobic sampling).

Finally another possibility is to measure the gas passing into the atmosphere (flux testing).
A landfill biogas model can include different sub-models (e.g. stoichiometric, kinetic), in relation to what want to be described.
The reaction representing the overall CH_4 fermentation process for organics in solid waste can be represented by the following equation (*Christensen, Cossu, Stegmann, 1996*):

$$C_aH_bO_cN_d + nH_2O \rightarrow xCH_4 + yCO_2 + wNH_3 + zC_5H_7O_2N + energy$$

↑ ↑

Biodegradable organics in solid waste Bacterial cells

$C_aH_bO_cN_d$ represents an empirical chemical formulation for biodegradable organics in solid waste, and $C_5H_7O_2N$ is the chemical formulation of bacterial cells.

9.3.3 Biogas extraction and utilization

The biogas may be applied in direct combustion systems (boilers, turbines, or fuel cells) for producing space heating, water heating, drying, absorption cooling, and steam production. The gas used directly in gas turbines and fuel cells may produce electricity.
An alternative choice in biogas conversion is the use in stationary or mobile internal combustion engines which may results in shaft horsepower, cogeneration of electricity, and/or vehicular transportation. A final opportunity exists for sale of the biogas through injection into a natural gas pipeline.

9.4 Leachate emissions

With leachate is intended the wastewater produced by the infiltration of water (usually rain) in the landfill body. The water percolating through the waste removes organic compounds, metals and salts.
The quality of the leachate depends by the pH, the type and the age of the waste and of the presence of oxygen.
The quantity of the leachate depends by the characteristics of the site, the physical characteristics of the waste, the barrier system and of course the amount and intensity of rain (in Chapter 5 is shown the average rain intensity per month in both Germany and Italy). So the amount of leachate depends from the location and from the period of the year.

The predicted amount of rain in a particular area gives an idea about the amount of leachate to extract from a landfill in that area, and is so useful for the sizing of the leachate extraction system.

This considerations are valid for a sanitary landfill which allows rain to enter the landfill body.

It is possible to perform a hydrological balance of a landfill body, in order to know the amount of the single liquid fractions (*Cossu R., 2012*).

Some of this parameters do not depend on human actions and can't be controlled (precipitation, evaporation, moisture variation of top-cover), while others are related to human actions and can be controlled (precipitation entering the landfill body, runoff from the surroundings to the landfill, evapo-traspiration, moisture variation of waste).

The goal for a correct landfill management is to avoid R* (runoff from surroundings to the landfill) and S (surface water infiltration), to avoid an increase in leachate production. Controlling the runoff of the surrounding areas and isolating the sides and the bottom of the landfill in a proper manner this is possible.

Also G (groundwater infiltration) must be avoided, since groundwater pollution is a threat for human health and the environment.

L_i (uncontrolled leachate infiltration) must be avoided, for the same reasons. Considering a sanitary landfill working properly, this four parameters could be considered equal to zero.

The equations which allow to estimate the amount of collected leachate starting from this parameters are (*Cossu R., 2012*):

$$L = P_i + S + G \pm \Delta U_s \pm \Delta U_w \pm \Delta U_{bio}$$

$$P_i = P + R^* - R - ET$$

$$L_c = L - L_i$$

Since R*, S, G and L_i are considered equal to zero, this system can be represented by the equation:

$$L_c = L = P - R - ET \pm \Delta U_s \pm \Delta U_w \pm \Delta U_{bio}$$

About the values of the single parameters, the rainfall can be estimated by pluviometers or meteorological radars. The surface runoff can be estimated multiplying the rainfall [mm/d] with a runoff coefficient, which can be found in literature. The Thorntwaite formula allows to estimate the evapo-transpiration, and the Turc formula the evaporation rate (both formulas are functions of the temperature - temperature values for Germany and Italy are provided in

Chapter 5). Their values and parameters can be found easily in literature and are not presented now, because it falls outside this study.

The leachate can be treated in several ways: aerated lagoons, activated sludge plants, in a sequential batch reactor and is in some cases threated together with urban waste water. It can be recirculated in the landfill body for decreasing the pollutant level in the leachate (*Stegmann R., 2013*).

Figure 9.3 shows the leachate composition over time..

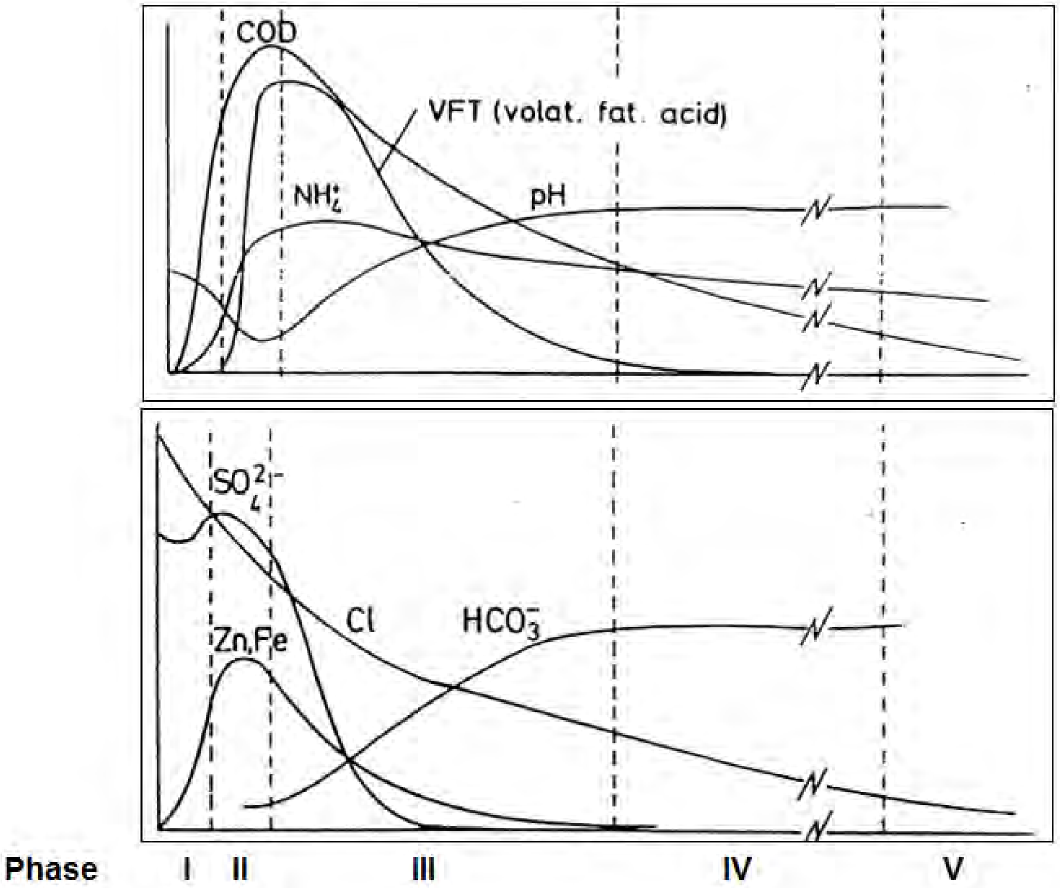


Figure 9.3: *Landfill leachate composition over time (Christensen and Kjeldsen, 1989)*

In Table 9.3 are represented the average concentrations of biochemical influenced leachate components:

		average values acetogenic phase		average values methanogenic phase	
		Ehrig, 1989	Kruse, 1994	Ehrig, 1989	Kruse, 1994
pH	[-]	6,1	7,4	8,0	7,6
BSB_5	[mg / l]	13000	6300	180	230
CSB	[mg / l]	22000	9500	3000	2500
BSB_5 / CSB	[-]	0,58		0,06	
Sulfat	[mg / l]	500	200	80	240
Ca	[mg / l]	1200	650	60	200
Mg	[mg / l]	470	285	180	150
Fe	[mg / l]	780	135	15	25
Mn	[mg / l]	25	11	0,7	2
Zn	[mg / l]	5	2,2	0,6	0,6
Sr	[mg / l]	7		1	
AOX	[µg / l]	1674	2400	1040	1725

		Ehrig, 1989	Kruse, 1994
TKN	[mg / l]	1250	920
NH4-N	[mg / l]	740	740
ges. P / *total P*	[mg / l]	6	6,8
Chlorid	[mg / l]	2100	2150
Na	[mg / l]	1350	1150
K	[mg / l]	1100	880
As	[µg / l]	160	25,5
Pb	[µg / l]	90	160
Cd	[µg / l]	6	37,5
Cr	[µg / l]	300	155
Co	[µg / l]	55	
Cu	[µg / l]	80	90
Ni	[µg / l]	200	190
Hg	[µg / l]		1,5

Table 9.3: *Average concentrations of biochemical influenced leachate components (Stegmann R., 2013)*

9.5 Biological waste stability

The biological waste fraction is the one that dominate the waste degradation process. The amount of biodegradable material in the waste is directly proportional to the landfill emission potential. For this reason the European Landfill Directive EC/99/31 promotes the minimization of the biological fraction, and some European countries as Germany introduced a landfill ban for untreated MSW. Pretreatments can stabilize the waste and decrease so the emission potential.

According the waste composition presented in the sixth chapter, in Germany the biological waste fraction represents the 37% of MSW from the households (17.760.000 t/y), and in Italy the 35% (10.500.000 t/y). Percentage and composition of biodegradable waste are almost the same in both countries. In Annex 3 the biological waste fraction is furthermore divided in kitchen waste and garden waste, and the respective percentages are shown.

Carbon has a percentage of 20-22% in weight on the total MSW composition of an untreated MSW sample. After Water it is the most present substance in MSW. The greatest part of carbon elements have a biogenic orgigin, like lignin, cellulose, hemicellulose, hydrocarbons, proteins, fats, paper and plastic. Some of them are readily biodegradable (e.g. cellulose) and other take more time (e.g. lignin). The biodegradable carbon elements are about 70% of the carbon elements present in the MSW (*Cossu et al., 2012*).

About the time that biomass needs to degrade in a landfill body, there exist three groups which are represented in Figure 9.4, which subdivide elements which are readily biodegradable, slowly biodegradable and persistent under anaerobic conditions. Cellulose is readily biodegradable under anaerobic landfill conditions and is degraded by hydrolysis and oxidation. Hemicellulose takes more time, and lignin is persistent under anaerobic conditions, and perform its degradation usually when the anaerobic processes in a landfill are over.

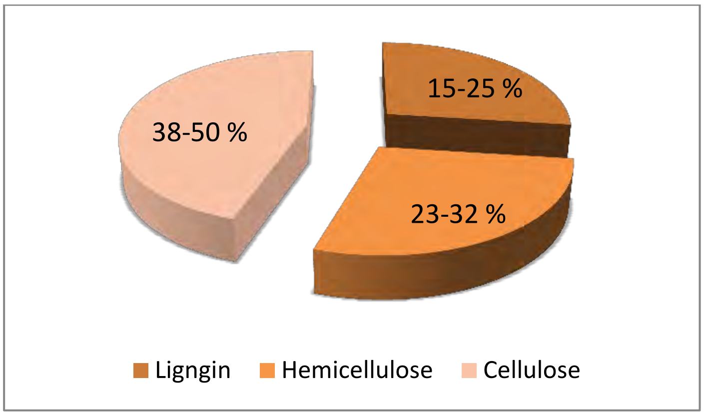


Figure 9.4: *Biomass composition and degradability (Cossu R., 2012)*

Readily biodegradable	Food residuals, Biowaste
Middle- term biodegradeble	Garden residues (Leaves ect...) Paper, Cardbord, Newspaper, Magazines Nappies, sanitary products
Long- term biodegradable	Textiles (Cotton, Silk, Wool), Residual- and Finefraction Beverage packages (composite materials) fine wood chips
Persistent	Plastics, Plastic packages Composite Materials Woodblocks, Rubber, Leather Synthetic Textiles
Inert	Minerals Glass Iron, Metalls Metall containing Packages

Table 9.4: *Bio-waste composition and degradability (Cossu R., 2012)*

Table 9.5 gives an idea about the degradation time of different biodegradable waste types, dividing them in readily, middle, long-term biodegradable, persistent and inert, which means they are not degradable.

Food and garden waste degrade quite fast in a landfill, while textile and wood need more time. Plastic is very persistent (it depends from the type but usually the degradation period is of 100-400 years). Minerals and Glass are considered as inert waste.
Table 9.5 shows the biogas emission potential for some types of waste.

Sample	Methane Yield [m^3/kg VS]
Mixed MSW	0.186 - 0.222
Mixed yard waste	0.143
Office paper	0.369
Newsprint	0.084
Magazine	0.203
Food board	0.343
Milk carton	0.318
Wax paper	0.341

Table 9.5: *Biogas emission potential for different waste types (Owens J.M. and Chinoweth D.P., 1998)*

9.5.1 Methods for assessing bio-waste stability

Although the Landfill Directive has set targets for reduce the amount of biodegradable matter entering non-hazardous landfills, no official parameters and limit values were considered for the description of the quality in terms of evaluation of residual biodegradability of the waste to be landfilled (*Cossu R. and Raga R., 2007*).
Some EU member states have set their own parameters. There is currently a pressing need for the establishment of standard parameters, test methods and limit values at an international level.
Early studies (*Leikam and Stegmann, 1997*) carried out for the characterization of waste during a mechanical-biological pretreatment process reported that the monitoring of the biological stabilization process may be successfully carried out by measuring the respiration rate in waste samples taken during the process.
The cumulative oxygen consumption after 96 h per unit of dry matter [mg O_2/g DM], not yet referred as RI_4, varied from 50 to less than 5, after four months under aerobic conditions.
The following list shows the most used parameters nowadays for assessing MSW stability.

- Respirometric Index (RI_4, RI_7): measures in a given time, 4 or 7 days, the consumption of oxygen, it can be carried out in both static and dynamic conditions and it is applied to different organic waste to simulate their biodegradation process. It is measured by means of Sapromat apparatus, and it is expressed as [mg O_2/g DM]

- Biomethane potential production (GB_{21}): carried out from the fermentation test under anaerobic conditions and measures the production of methane in 21 days. It is associated to the biodegradation of organic waste under the anaerobic conditions. It is expressed as [Nl/kg DM]
- BOD_5/COD: measures the biodegradable fraction of the total organic matter present in a solid waste, it is derived from the evaluation of both BOD_5 and the COD of the eluate of the waste coming from leaching test (which assesses the capacity of the waste to release substances to the leachate). It is a dimensionless ratio because both BOD_5 and the COD are expressed as mgO_2/l]
- Black Index (BI): provides an indication of waste biological stability based on the observation of the change of color of a lead acetate test paper. The lead acetate on the test paper reacts with the hydrogen sulphide yielding black lead sulphide as precipitate on the test paper. It is expressed as [d^{-1}*kg^{-1}]
- % Total Volatile Solids: estimates the percentage of organic matter content in a dried sample by means of heating it at 550°C
- TOC: measures the contents of total organic carbon by means of combustion (at high T°) of the sample and determination of CO_2 released by IR analyzer system (because during the combustion all the organic carbon is converted to CO_2)
- Ammonia and Nitrate (NH_4-N, NO_3-N): are important parameters to be monitored in the specific case of the aerobic conditions, because it can be assesses if the nitrification process is occurring, in fact during the previous one ammonia is oxidized to nitrate. Therefore can be considered as an index of the biodegradation of the organic matter because under aerobic conditions it occurs too

In the same period of the studies performed by Leikam and Stegmann, following the publication of the landfill directive in Austria, which had set standards for acceptance of MSW landfilled based on, among others, the maximum content of organic matter measured as TOC and volatile solids, *Binner et al. 1997* proposed the possible consideration of an update of the national regulation and the utilization of the respiration activity (RI_4), and the biogas production in 21 days (GS_{21}).

The successive legislation in Austria included limit values for RI_4 (7 mg O_2/g DM) and GB_{21} (20 Nl/kg DM).

The German ordinance on environmentally compatible storage of waste from human settlements and on biological waste treatment facilities set limit values as well for the same parameters equal to 5 mg [O_2/ g DM] and 20 [Nl/kg DM] for GB_{21} (*Cossu R. and Raga R. 2007*).

Italy has not yet applied such limit values for this parameters.

The use of a respiration index has become popular around Europe, and numerous authors have considered it for waste characterization.

The respiration index as measured with the RI_4 may be considered a static index, since no air flow through the waste sample is provided as in dynamic respiration tests. In the case of waste showing high biological activity, the use of a dynamic respiration index might be advisable (*Heerenklage and Stegmann, 2005*).

Other tests methods for the evaluation of waste biological stability have been recently considered, including tests for the evaluation of the lignin and cellulose content (*Decottignies et al., 2005*). Simple and cost effective tests such as the determination of the ratio of BOD_5 to COD in leaching test eluate and the black index where proposed by *Cossu et al., 1999, 2001*.

In the following lines the results of a study aimed to assess the MSW biological stability are shown. The study was performed by *Cossu R., and Raga R. in 2007*, and is based on samples of pretreated waste and on samples of waste excavated from MSW landfills. The pretreated waste was collected at different times at a MSW pretreatment plant in northern Italy. The plant receives the unsorted waste of the area. The biological fraction in the waste is considerable. The treatment process includes a mechanical step (bag opening, shredding and sieving) and a biological treatment for a period of two months.

The waste from MSW landfills was removed by means of 10 cm diameter probes in three Italian landfills.

The sample preparation may affect the results of the evaluation of the biological stability index. In most of the cases the tests are conducted after screening to < 20 mm (*Leikam and Stegmann, 1997*).

The samples taken were divided into two parts: one part was sieved and the fraction < 10 mm was used for characterization. The other part was shredded and then sieved to obtain a < 10 mm fraction.

In both cases the respiration index showed an exponential decrease from approximately 80 mg O_2/g DM at the beginning of the stabilization process to 6 mg O_2/g DM and 16 mg O_2/g DM for the sieved fraction and for the shredded and sieved fraction respectively.

About the test methods, the RI_4 was measured as the cumulative oxygen consumption in 4 days in the Sapromat apparatus (*H+P Labortechnik, Germany*). The test was carried out on the basis of the current German regulation that refers to a procedure set up by the German Institute for Standardization (*DIN, 1985*), with the exception that the fraction < 20 mm was used without shredding.

The fermentation tests were carried out at 35 ºC. Air tight glass bottles were filled with 50 g of sample and microbial inoculum and water were added.

Leaching tests with distilled water were performed with a liquid/solid ration equal to 10 on the waste fraction < 20 mm. BOD_5 and COD were measured after filtration through a 0.45 µm filter.

The black index is a simple parameter proposed Cossu et al. (1999,2001) that provides an indication of waste biological stability based on the observation of the change of color of a lead acetate test paper. Lead acetate paper is commercially available as strips made of filter paper impregnated with lead acetate. The test paper is normally used as an indicator for the detection of hydrogen sulfide production by microorganisms in various processes among others anaerobic digestion of waste. The lead acetate on the test paper reacts with the hydrogen sulfide yielding black lead sulfide as precipitate on the test paper. The color of the test paper thus changes from white to brown, gray or black, depending on the concentration of hydrogen sulfide in the atmosphere near the lead acetate paper and on the duration of the test. It is expressed as the inverse of the time needed by the test paper for the change in color, per unit of dry mass [BI, d^{-1} kg DM^{-1}].

The result of this tests show that for the excavated waste, the RI_4 index varied a little less than 1 to 20 mg O_2/g DM. The landfills are composed of different sectors or layers of age of deposition varying from 2 to 25 years. The highest values were measured for samples taken from the new sectors or from the upper layers.

For the same samples, the biogas production GB_{21} varied from 0 to around 35 Nl/kg DM. The black index varied from a little less than 10 to 40 d^{-1} kg^{-1}.

Although the values for BOD_5 and COD in the two leaching test eluate were very different for the two samples, the BOD_5/COD ratio was very similar, and decreases with time.

Figure 10.2 shows the relation between GB_{21} and RI_4 based on the average values of the samples taken in three different landfills. The determination coefficient R^2 is equal to 0.80.

The linear relationship is easily notable. Figure 9.5 shows the variation of the black index in relation with the respiration index.

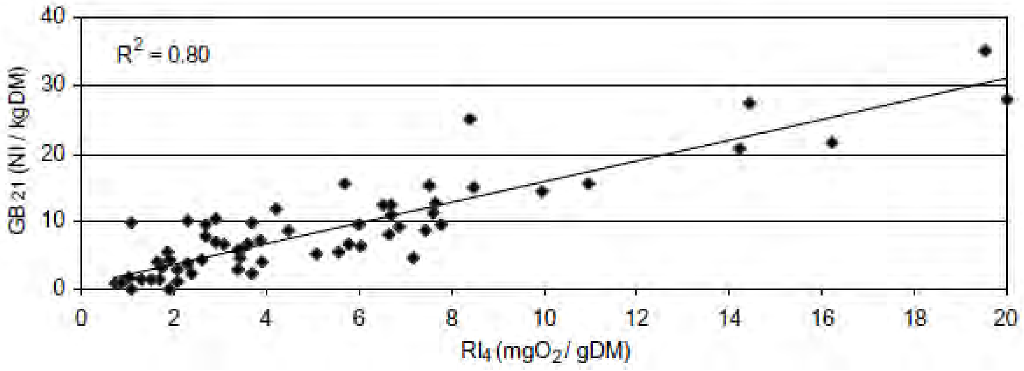


Figure 9.5: *Relationship between GB_{21} and RI_4 (Cossu R. and Raga R., 2007)*

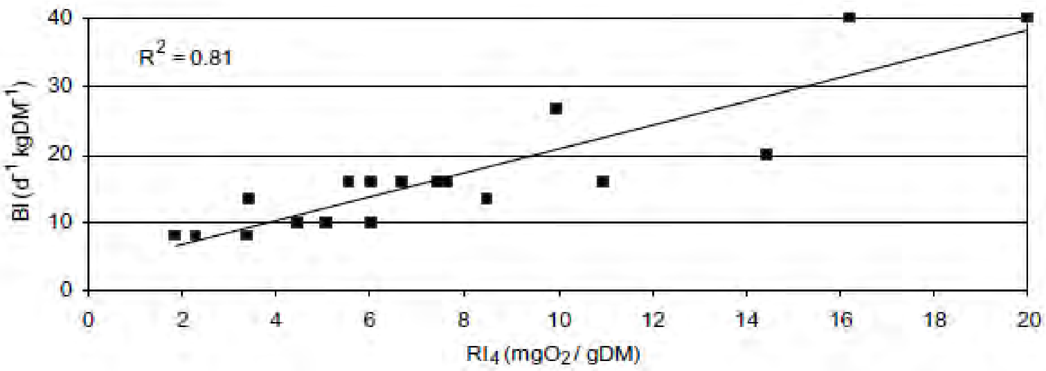


Figure 9.6: *Relationship between BI and RI_4 (Cossu R. and Raga R., 2007)*

Parameters	Sample	
	S2b	S3a
BOD_5 (mg/l)	3	80
COD (mg/l)	70	1940
BOD_5/COD	0.043	0.041
RI_4 (mg O_2/g DM)	1.9	7.8
GB_{21} (Nl/kg DM)	4.4	9.6

Very different materials may have similar values for the BOD_5/COD.

Table 9.6: *Example of values for the parameters measured in two samples of excavated waste (Cossu R. and Raga R., 2007)*

About the pretreated waste samples, collected at the previously mentioned pretreatment plant before the start of the stabilization process, they were studied in a 2 m^3 lysimeter where the aerobic degradation occurred under controlled conditions of air flow and moisture content.

Samples were taken from the lysimeter every 15-20 days during the process and analyzed for characterization.

The BOD_5/COD ratio expressed in Figure 9.7 shows the increased biological stability of samples that underwent a longer degradation process in the lysimeter. The same figure show also the variation with time of the respiration index.

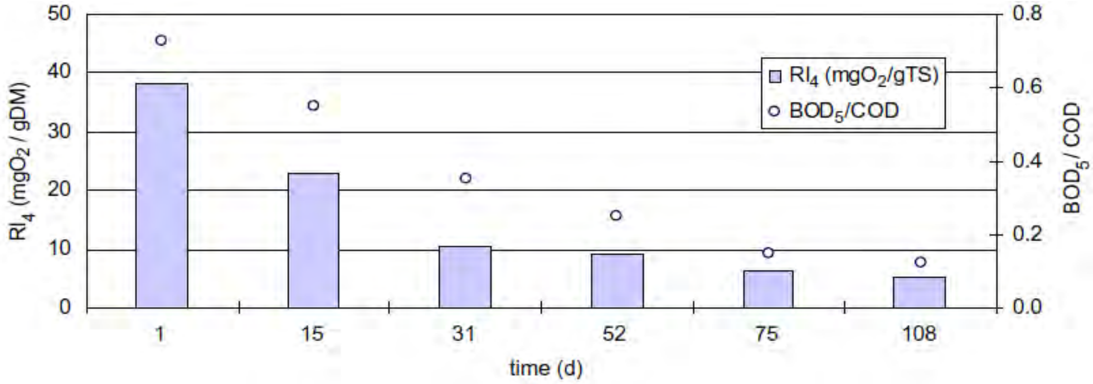


Figure 9.7: *BOD_5/COD ratio and RI_4 variation over time (Cossu R. and Raga R., 2007)*

The previous graph shows that as long as the aerobic conditions occur, the biodegradation process is really active in time in fact both RI_4 and the BOD_5/COD indexes decrease as well, giving the same information.

Figure 9.8 shows the correlation between the RI_4 and the GB_{21} for the pretreated waste samples, and Figure 9.9 the correlation between RI_4 and BI.

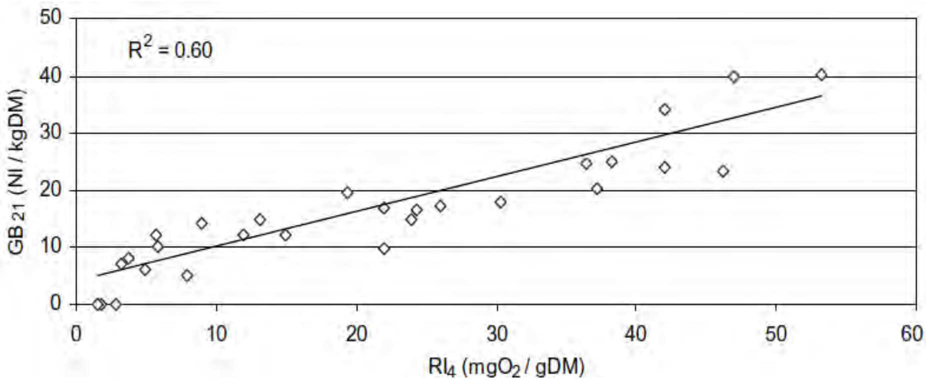


Figure 9.8: *Relationship between GB_{21} and RI_4 for the pretreated waste sample (Cossu R. and Raga R., 2007)*

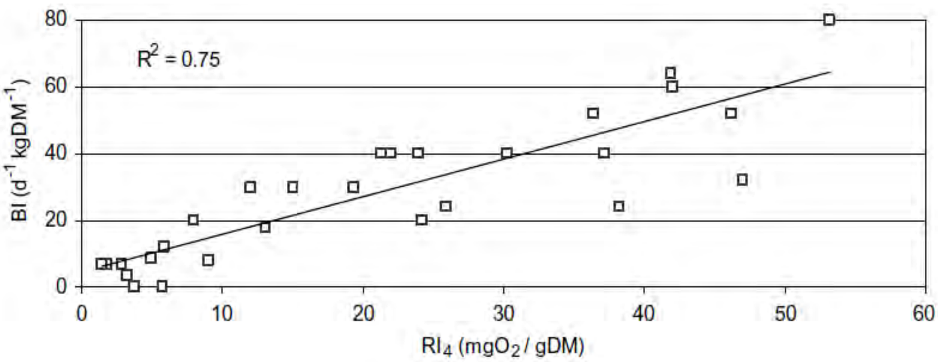


Figure 9.9: *Relationship between BI and RI_4 for the pretreated waste sample (Cossu R. and Raga R., 2007)*

To show the variation in time of the biogas potential production index GB_{21} and the black index BI, it can be used an expedient. In fact, the waste taken from the three different landfills was taken at different depth of them, so the deepest samples were the oldest one, related to about 25 years from the disposal moment, and the upper one were the younger one, related to only 2 years from the disposal moment. Then those samples were analyzed and were determined RI_4, GB_{21} and the BI and finally they were correlated each other.

So in the results is not clearly specified the trend in time of those indexes, but it can be deduced, because the samples referred to specific range of time that is 23 years in which the biodegradable organic matter contained in the waste has been consumed.

As can be noticeable from those graphs, the lower values of the indexes are related to the oldest waste samples, which were taken from the bottom of the landfills, instead, the higher values are related to youngest waste samples taken from the upper layers of the landfills. This evidence means that, at the beginning of the disposal the biodegradation process acts strongly, and then proceeds progressively slowly due to the incrementing of the biological stability of the wastes. Consequently, the trends in time of the GB_{21} and of the BI will progressively decrease.

Another parameter which can give information about the organic matter content of a waste, so its biological stability, is the percentage of volatile solids of a dried sample, because, during the heating at 550°C, has been proven that almost all the organic matter volatilize.

To see the evolution in time of this parameter, which is quite deducible, another case study is taken in consideration (*Francois et al., 2006*) in which the percentage of VS was evaluated in several domestic wastes of different age. The results are shown in Figure 9.10:

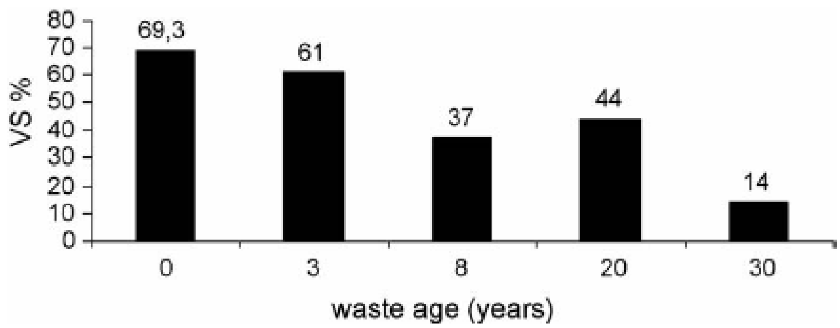


Figure 9.10: *Evolution of the % of VS according waste age (Francois et al., 2006)*

It can be seen from Figure 9.10 that, except of the 8 year old waste, the percentage of VS progressively decrease with time, indicating the efficiency of the biodegradation process which consumes the organic matter.

As a conclusion, the results of the different tests provided further confirmation that the respiration index and the biogas production tests are reliable for the evaluation of biological stability of waste. For waste from a mechanical-biological pretreatment plant, useful information can be obtained in a simple cost effective way by measuring the BOD_5 and COD in leaching eluate.
The black index test may be used as an economical preliminary test. High values of the BI are typical of waste with high biological activity.

9.5.2 Demonstration of the emission potential of untreated waste and pretreated waste in landfills

In the previous pages there have already been provided some values of the emission potential and composition of biogas and leachate of MSW, in the case of untreated waste and treated waste.
In this paragraph there is presented a detailed comparison between the composition and the amount of emissions in the case of untreated MSW and mechanical biological pretreated MSW.
The major benefits of biological pretreatment are:

- Reducing the waste mass by about 15% due to degradation of organic components
- Landfill gas production is reduced substantially by 95%
- Improving the leachate quality (COD to about 500 mg/l, $BOD_5 < 20$ mg/l)
- Increasing the waste density from 0.8 t/m^3 up to 1.2 t/m^3

The BOD_5/COD ratio decreases during the pretreatment process, and values lower than 0.1 can be considered typical of well stabilized waste, corresponding to values lower than 5 mg O_2/g DM measured for the respiration index (*Cossu R., Raga R., 2007*).
High BOD and COD values are issues in the landfill, because they make the landfill biologically instable. The young landfill leachate generated in landfills with not or not well pre-stabilized waste is commonly characterized by high biochemical oxygen demand (4000-13.000 mg/l) and chemical oxygen demand (30.000-60.000 mg/l), moderately high content of ammonium nitrogen (500–2000 mg/l), high ratio of BOD_5/COD (ranging from 0.4 to 0.7), and low pH values (as low as 4.0), with biodegradable volatile fatty acids (VFAs) appear to be its major constituents.

With an increase in the landfill age and decomposing of VFAs in the landfill leachate by anaerobe bacteria over a period of 10 years, the old leachates are catalogued as stabilized and characterized by a relatively low COD (< 4000 mg/l), slightly basic pH (7.5-8.5), low biodegradability (BOD_5/COD < 0.1), and high molecular weight compounds. Just here can be seen that the percentage of VS is a valid index to assess the organic matter content in a generic system, so, if high values are found in a landfill sample, means that high bio-reactivity of waste is expected.
As a matter of fact, it is known that the lower the BOD and COD values, the more biologically stable will be the landfill. Of course there is a relationship between BOD values and RI_4. The higher are the values of organic matter (TOC would be high too), the higher is the amount of oxygen required to decompose the organic matter. Now, the relationship between RI_4 and emission potential can be sorted out: the more oxygen is present in a specific time range in a landfill, the faster will be the biological degradation and so the stability of the waste. Oxygen is required in landfill, starting from hydrolysis and then for the other oxidation processes of the waste.
Methane production varies greatly from landfill to landfill depending on site-specific characteristics such as waste in place, waste composition, moisture content, landfill design and operating practices, and climate. Increased recycling and alternative waste disposal methods are contributing to a forecasted decline in landfill methane emissions, by slowing the rate of waste going into landfills. For the methanogenesis process anaerobic conditions are required, so the IR_4 index, which measures O_2 consumption, should be approximately zero. Instead, during methane production, higher values of GB_{21} are expected since it evaluates bio-methane potential production.
Table 9.7 shows the effect on leachate concentration of a mechanical-biological pretreated waste. It is easy to notice the big difference respect to the just mentioned emission values for not pretreated MSW. Furthermore it can be noticed that the already low emission values are decreasing in less than a year. The emission potential of pretreated waste is furtherly reduced also after the disposal, and this reduction performs much faster as the one for not pretreated MSW.

Basis leachate					
	12 days	69 days	90 days	161 days	208 days
pH-value [-]	7.1	7.4	7.1	6.8	7.5
EC [µS/cm]	16.600	8.420	7.840	5.030	3.710
TOC [mg/l]	1.812	354	299	180	98
COD [mg/l]	4.670	1.061	961	644	452
BOD_5 [mg/l]	244	290	119	18	15
NH_4-N [mg/l]	392	16	76	< 5	< 5

Table 9.7: *Leachate composition over time in case of MBP waste (Münnich et al., 2006)*

Table 9.8 provides an overview on waste properties after comprehensive biological treatment in comparison to the properties of untreated waste.

Parameter	**Biotreatment (chimney-effect) 12 – 16 months**	**MSW untreated**
Solids (mechanical)		
Wet density [Mg / m³]	1.2	0.85-1.0
Solids (chemical)		
Ignition loss [mass %]	33 – 40	75 – 85
Total Organics (TOC) [mass %]	7 – 12	27 – 32
Leachate		
TOC [mg/ l]	95	1,000 – 3,000
COD [mg/ l]	210	3,000 – 6,000
BDD5 [mg/ l]	17	800 – 2,000
NH_4-N [mg/ l]	16	20 – 200
Gas		
Respiration activity (aerob) per 4 days [g O_2/ kg]	<5	>50
Gas production (anaerob) [l/ kg]	1 – 1.8	15 – 200

Table 9.8: *Waste properties after biological treatment and without treatment (Ramke H. G., 2004)*

Some further values of mechanical-biological pretreated waste leachate composition are provided. A study performed by Zdanevitch et al., 2014, titled "*Comparison of polluting potentials of liquid emissions from MBT plants*", considers two waste management plants which include MBT, and an associated landfill. Leachates have been sampled on different parts of the landfill. Leachate show different behaviors depending on the compound.

Both plants (called Site A and Site B) undergo an aerobic stabilization treatment of the waste prior to landfilling, and both plants have their own landfill. Meanwhile, there are differences in both mechanical and biological treatments.

In Site A is situated in a rural area of France, and receives waste from approximately 40.000 people. There is no grinding of waste at the entrance of the plant. Waste undergo a first sorting: the large fraction (> 450 mm) goes directly to the landfill, the fine fraction (< 70 mm) is sent to the composting area, and the intermediary fraction goes to a rotating tube where it is humidified, and stays for 2 to 3 days. There aerobic degradation starts. This fraction is then sorted. The larger fraction is mainly constituted by plastic. The finer fraction (< 50 mm) goes to the composting windrows but separately from the first fine fraction.

Windrows are aerated by forced air blowing under the material. The controlled composting process generally lasts 4 weeks. After the first step, waste is deposited in windrows for a maturation step of several months. This site has four leachate ponds: Pond 1 for the larger fraction (which contains very little organic matter), Pond 2 which receives leachates from the stabilized fine fraction, Pond 3 which receives leachates from the intermediary fraction (mainly plastics with little degradable matter) and Pond 4 which receives the waters from different steps of the process.

Site B is located in a both rural and urban area. Residual waste which enters the stabilization plant contains less organic matter, since the waste fractions of packaging and biowaste are separately collected. The plant treats the waste from around 180.000 people.

The waste is first grinded and iron is separated. The waste is then homogenized and humidified, and goes to composting tunnels for around 5 weeks. After that the waste goes to landfill which is situated at a few kilometers from the plant. The landfill is separated in two areas. The first one received mixed untreated waste until 2006, while the second one is constituted of smaller independent cells which receive only stabilized waste since 2006. Leachates are collected separately from the two zones, but go to the same pond.

Table 9.9 shows the values of the components of the different leachates produced in the two sides. Pond 1 has very low emissions, since it contains the larger fraction with very little organic content. Pond 1 has a higher COD, since the fine fraction is mainly organic matter from the composting process. Pond 3 receives the intermediate fraction leachate, which is quite stabilized, while Pond 4 which receives the waste waters has higher values of BOD_5, suspended matter and BOD_5/COD ratio, which is quite high, sign the emission potential is still elevated. In the values of Site B it is easily notable that the emission potential of the untreated waste leachate are still close to the one of the pretreated waste fraction.

	Site A				Site B		Typical values	
	Pond 1	Pond 2	Pond 3	Pond 4	Leach K1	Leach K2	Kjeldsen	Robinson
pH (1)	7.2	7.95	7.6	7.1	8.05	8.6	4.5-9	7.5-8.5
Conductivity mS/cm (1)	9.14	30.4	18.8	18.5	18	7.98	2.5-35	10-20
Suspended matter , mg/l	12	44	68	300	14	110		
COD, mg O2/l	1 240	12 800	5 680	7 200	3 010	8 940	140-152 000	1 000-5 000
BOD5, mg O2/l	69	230	210	4 590	120	390	20-57 000	20-200
BOD/COD	0.06	0.02	0.04	0.64	0.04	0.04	0.02-0.8	
Ammonia, mg/l	633	1 787	1 530	379	2 070	1 690	50-2200	50-1000
Chloride, mg/l	610	3 270	1 430	620	1 630	2 870	150-4 500	4 000-8 000
TOC, mg/l	440	3 700	1 700	2 200	1 040	2 700	30-29 000	500-2 000
PO4, mg/l	12.6	86.9	76.8	50.6	25.5	19.6	0.1-23 (4)	1-15 (4)
Ca, mg/l	275	375	340	1 730	51	220	10-7 200	100-800
SO4, mg/l	20	9	<5	<5	29	500	8-7 750	1 000-5 000
AOX (2), mg/l	0.72	2.3	5.2	0.32	1.1	1.9		
Metals (3) : Al (mg/l)	0.6	20	6	3.9	0.91	11		
As	<2	50	58	9.8	110	430	<1 000 (5)	10-100
Cd	<10	<20	<10	<10	<10	<10	<400	5-100
Cr (mg/l)	0.39	2.2	3.6	0.1	0.62	4	<1.5	0.1-0.5
Cu (mg/l)	<0.2	0.3	0.14	0.14	<0.1	0.17	<10	0.2-0.5
Fe (mg/l)	3.2	76	21	25	12	14		5-20
Hg	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<160	<10 (5)
Ni	<100	810	270	250	170	430	<13000	<700
Pb	<100	220	<100	<100	<100	<100	<5 000	<400
Se	<200	<400	<200	<200	<100	<100		
Zn (mg/l)	0.14	1.7	0.88	2.5	0.19	0.71	<1 000	0.5-3

(1) Laboratory measurements
(2) Adsorbable halogens
(3) µg/l unless stated
(4) as total phosphorous
(5) only maximum values are reported

***Table 9.9:** Leachate composition of the two landfills Site A and Site B (Zdanevitch et al., 2014)*

Stegmann R., 2013, provides the results of a Landfill Simulation Reactor (LSR), which based on the extraction and analysis of some MSW samples, compares graphically some parameters as biogas production, pH, BOD_5 COD and nitrogen, in the case of pretreated or untreated MSW. In Annex 5 is shown this graphical comparison.

10. MSW pretreatments

Pretreatment of MSW is essential to minimize the waste emission potential and to reduce the waste volume, and fulfill so the European Landfill Directive. There exist two main kinds of pretreatments to achieve landfill emission reduction: mechanical and biological pretreatments.
Mechanical treatments result in less waste amount to be disposed of as well as smaller average particle size, what makes the final compaction easier.
Biological treatments are more relevant for the disposal properties of residual waste. The main goal is to reduce the overall organic waste content and to improve the biological stability of waste components.
Since biological treatments require a mechanical preparation step, the treatment process happens combined in mechanical-biological treatment plants (MBT plants). Figure 10.1 shows the operational sequence from the delivery of waste to the MBT plants to the final destination, which can be material recycling, energy recovery and landfilling.

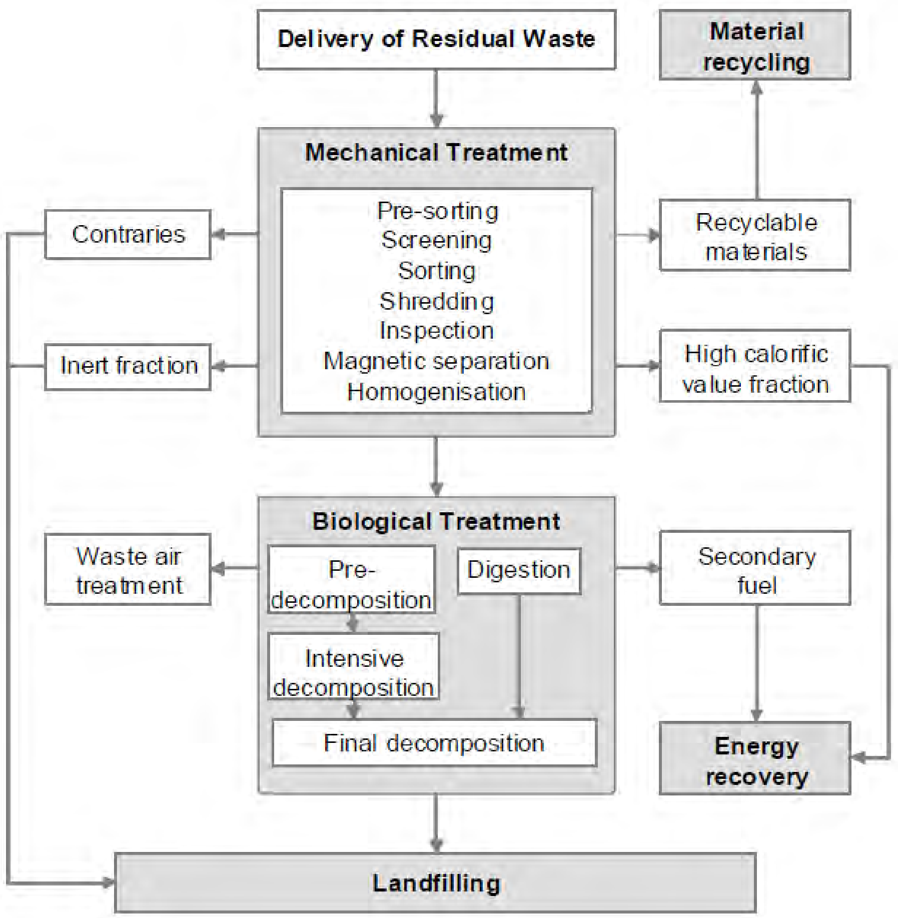


Figure 10.1: *Pretreated waste operation sequence (Ramke H. G., 2004)*

MBT have also other secondary positive effects, like reducing the presence of scavengers and birds on the landfill side, a reduced risk of explosions and fires, landfill gas emission is reduced and there is no need of a daily coverage, since the fine fraction has properties similar to soil and matches the main requirements for daily cover material.
The output material of the MBT, the so-called stabilized biomass, consists mainly of stabilized organic materials, inerts and synthetics (*Ramke H. G., 2004*).

10.1 Mechanical pretreatments

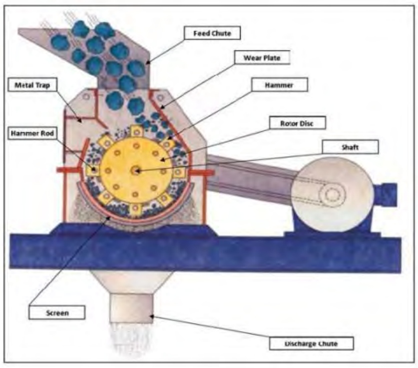
The purpose of mechanical treatments is to facilitate handling and transport and to improve performance of biological and/or thermal treatment processes by means of size reduction (particle size is reduced, so specific surface is increased), separation (according to particle size, according to particles density or by magnetic, electrical, optical properties), or compaction (increasing bulk density). They affect only physical characteristics, without causing any reactions or conversion.
Mechanical treatments are also used because they improve the separation of recyclable materials present in waste, such as paper, metals, plastics and glass, which will go to facilities that can recycle it. Typically are used conveyor belts, industrial magnets, eddy current separators, Drum screens, sieve discs, shredders and other appropriate equipment.
The main and most applied strategies and methods of mechanical pretreatments are listed and briefly presented in the following lines. There exist five main different kinds of mechanical pretreatments (*Cossu R., 2012*):

- Size reduction (reducing particle size and increasing specific surface)
- Screening (separation by particle size)
- Classification (separation according to particles density)
- Separation and sorting (magnetic, electrical, optical properties)
- Compaction (increasing bulk density)

10.1.1 Size reduction

The goals of the size reduction are to improve the reaction surface, facilitate the separation and further treatments, facilitate the transport and increase the density.

Hammer mill



The hammer mill is a machinery used for the size reduction of waste, and is used mostly for unsorted MSW, wood and paper, but not only. The machine consists in a rotating tree which has some perpendicular hammers on his surface, which rotate with a frequency of 1000 min^{-1} and reduce the size of the waste. The waste is shredded until it passes the grate size.

Figure 10.2: *Hammer mill (Hammermills.com, 2015)*

Chipper

The chipper reduces particle size and increase specific surface, and works with low speed (25-150 min^{-1}). The mill can be equipped with one or even two horizontal shafts, and because of the rotation of the shafts in opposite direction against a cutting edge, the material is drawn towards them. The minimization occurs between the cutting edges regardless if it is hard or soft material. The degree of reduction is decided by the choice of the pitch between the blades and also the width of the tooth face of the rotary cutter. Rotary drum cutters are most often used for size reduction of plastics.

Figure 10.3: *Chipper (Vecoplan, 2015)*

Hammer mill does not produces an homogeneous size: ceramics, stone and glass are crushed into particles smaller than metals. Chippers produces more homogeneous waste fractions.

Jaw crusher

The Jaw crusher is used mainly for the demolition of construction waste, stones, concrete and others. It consists in two big metallic “jaws” which press against each other, crumbling the material between them. The material falls then on a conveyor belt, and is collected in a container.

Figure 10.4: *Jaw crusher (Cmb.UK, 2015)*

10.1.2 Screening

Drum screen

The Drum screen consists of an empty cylinder which is filled with waste and starts then to rotate for a certain time. The fine waste fraction will pass through some slots or holes in the cylinder, while the bigger fraction is retained. There can be different size of the holes, this allows to separate the fine fraction, according the size of the waste.

Figure 10.5: *Drum screen (Laeckeby, 2015)*

It can be used for the removal of plastic film from mixed waste and for the removal of structure material from the mature compost. Usually the diameter of the cylinder is about 1.5-3 m, the length of 5-10 m, the rotating speed approximately 8-30 round/min and the throughput up to 100 m^3/h, depending on the material. The residence time is approximately 30 min, the slope between 2-5°, and the trammel volume is filled with 1/3 of the diameter. Knowing the flowrate, the waste density, the filling rate and the Trommel slope, it is possible to determine the diameter, with some formulas present in literature.

Disc screen

The Disc screen is a kind of sieving equipment. It consists in the rotation of more discs fixed on different axes, and the waste is carried on the top of them. Because of the movement of the screen layer, the materials are separated into various sizes, and oversize materials are thrown away.

Figure 10.6: *Disc screen (Mclanahan, 2015)*

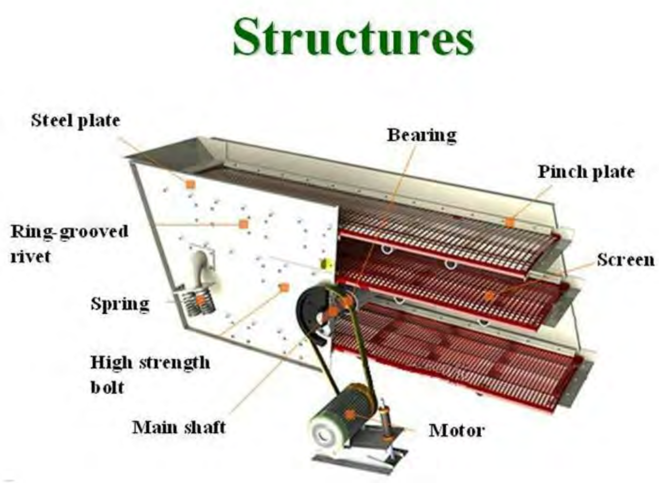


Figure 10.7: *Vibrating screen (Aliimg, 2015)*

Vibrating screen

The vibrating screen has a small negative slope and vibrates. This allows the waste to be carried on the screen. The screen has different sized holes, which allow the different material to fall down and be collected.

It is suitable for separating dry fractions like glass, wood and metals from compost.

10.1.3 Classification

Air classifier

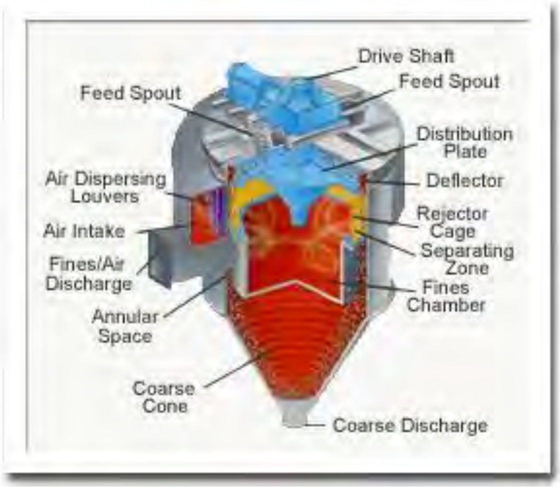


Figure 10.8: *Air classifier (Sturtevant, 2015)*

In a zig-zag shaped column, air flows from the bottom upwards. Lighter waste goes to the top where it is collected, while heavier waste is extracted before.

This technique can be used for the removal of plastics from shredded end-of-life vehicles or compost. Table 10.1 shows the separation in light and heavy fraction of a mixed waste sample, and the related recovery rate.

Ballistic separator

Figure 10.9: Ballistic separator (BMGEnvironment, 2015)

The ballistic separator can separate different waste fractions by their weight. The waste is brought by a conveyor belt, and pass through a rotor which gives the waste kinetic energy. The heavier waste fraction (black dots) will go further respect the lighter one (white dots), since they are heavier they are less affected by the air resistance.

Swim-sink separation

Figure 10.10: Swim-sink separator (Ctsmachinery, 2015)

The Swim-sink separation is a density sorting, and it is often used for sorting plastics. This technology can result in purity grades of over 98 % for mixed plastics. The hydrophobic nature of plastics is easily enhanced during sorting with the aid of wetting agents.

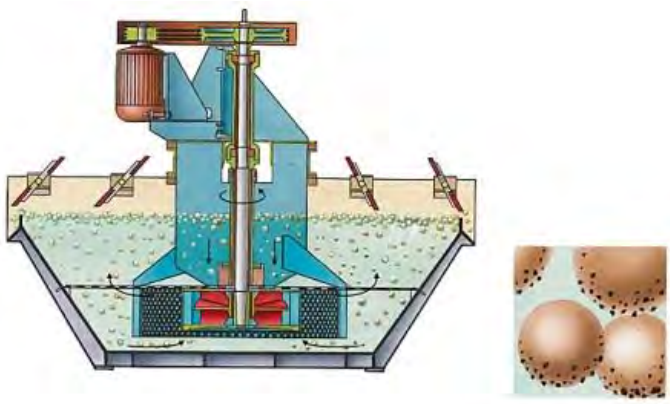
The separating liquid is adjusted to the density range of mixed plastic components from household and commercial waste by adding $CaCl_2$. One fraction will stay afloat, while the other one sinks. It is then possible to extract the materials.

Table 10.1 shows different separation mediums for more materials.

Material	density [kg m^{-3}]	Separation Medium	density [kg m^{-3}]
wood	400-800		
polypropylene (PP)	900-910	water-alcohol-mix	910-930
polyethylene (PE)	920-960	water	1000
polystyrene (PS)	1040-1090	aqueous salt solutions	1050-1200
polyvinylchloride (PVC)	1200-1400		
concrete	2200-2800	heavy suspensions	1300-3500
glass	2500		
aluminium	2600-2850		
iron, copper	> 7500		

Table 10.1: *Separation medium used in Swim-sink separation for different materials (Cossu R., 2012)*

Flotation



Flotation consists in the separation of waste due to attachment of particles to air bubbles. One waste fraction will ascend to the surface due to air bubbles attachment, while another fraction will settle on the ground. Both fractions can then easily be extracted from the tank.

Figure 10.11: *Flotation tank (Larousse, 2015)*

10.1.4 Sorting techniques

Magnetic separator

Magnetic separation is a process in which magnetically susceptible material is extracted from a mixture using a magnetic force: the separator has a magnetic pulley installed in the conveyor belt, that separate iron and magnetic steel from waste. The magnetic field keeps the magnetisable material on the belt longer than the rest material, that falls with the normal trajectory.

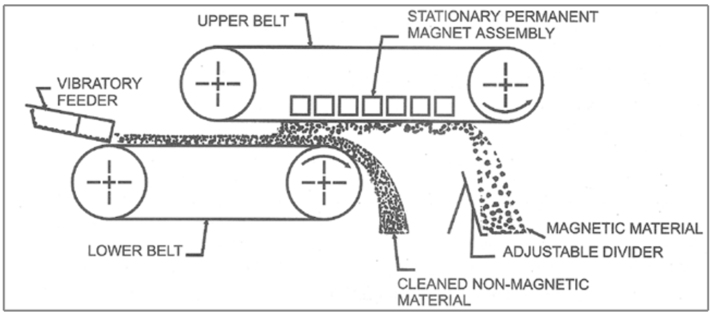
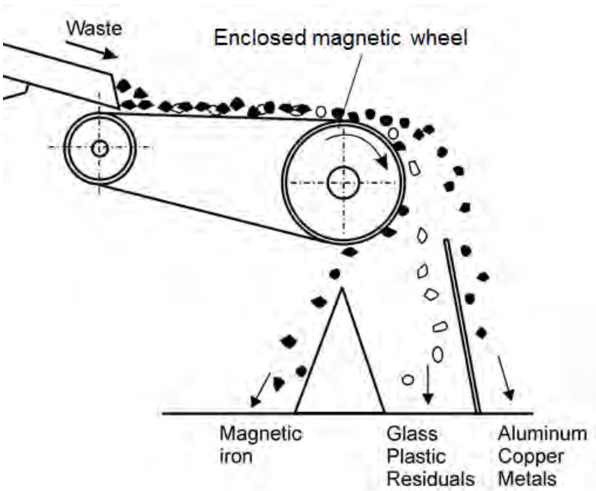


Figure 10.12: *Magnetic separator (Jupitermagneitcs, 2015)*

Magnetic separation efficiency is sensitive to the depth of waste, as small ferrous items will not attract to the magnet if they are under (or buried in) non-ferrous materials, while larger ferrous items can drag non-ferrous items like plastics and paper. It is effective with iron and most steel, but does not separate aluminium, copper, or other non-ferrous metals.

Eddy current separator



The Eddy current separator consists in a conveyor belt transporting a thin layer of mixed waste, and a rotor at the end, that uses a powerful magnetic field to separate metals from non-metals in garbage. This technology works by exerting repulsive forces on electrically conductive materials: cans literally jump off the conveyor belt into a waiting bin.

Figure 10.13: *Eddy current separator (Cossu R., 2012)*

In this kind of separator the rotor produce a magnetic field with lines in alternating polarity (north - south) around its circumference. This is rotated at high speed within a drum around which runs a conveyor belt, generating an alternating the magnetic field rotary and high frequency (350-1000Hz).

Electro-optical sorting

Electro-optical sorters recognize the color, the density or the molecular structure of the particles, and separation is carried out by air blasts which blow the particles into appropriate bins.This mechanical treatment is used to divide glass by different colors, considering that in this way the glassware can choose the part they need and recycling it. It can be used also for PET sorting.For glass the average throughput is of 25 t/h, and the minimum size of the pieces must be 5 mm.

Figure 10.14: *Electro-optical sorting (Cossu R., 2012)*

Manual sorting

Manual sorting consists in personnel which sort the waste manually, usually using a conveyor belt. It is associated with high personnel costs, so mechanised processing should be installed. Positive sorting involves the manual collection of recyclables from the waste stream, while negative sorting refers to the removal of unwanted components from a material stream, with the desired fraction remaining on the conveyor belt.

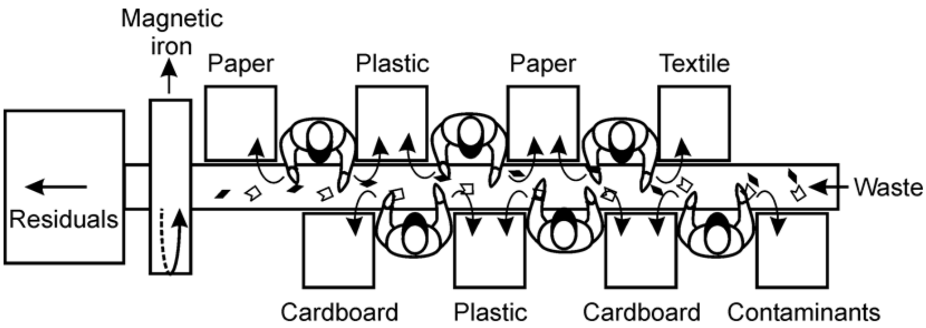


Figure 10.15: *Manual sorting (Cossu R., 2012)*

10.1.5 Compaction techniques

The most used compaction techniques are the Bale press, the Brikette press and the Pellet press. They all aim to the same goal. The purpose is to facilitate handling and transport: baling press is a machine used to compress waste into compact bales, it reduces the volume of the waste piles, that means that it is saved valuable space that the bulky packaging materials take up on-site. These machines are capable of compressing various leftover of waste into cuboids bales.

Figure 10.16: *Bale press (Cossu R., 2012)*

10.2 Material Recovery Facilities and RDFs

A MRF is a specialized plant that receives, separates and prepares recyclable materials for marketing to end-user manufacturers. Generally, there are two different types: clean and dirty MRFs.

A clean MRF accepts recyclable commingled materials that have already been separated at the source from municipal solid waste generated by either residential or commercial sources. There are a variety of clean MRFs. The most common are single stream MRFs where all recyclable material is mixed, or dual stream MRFs, where source-separated recyclables are delivered in a mixed container stream (typically glass, ferrous metal, aluminum and other non-ferrous metals, PET and HDPE) and a mixed paper stream (including OCC, ONP, OMG, Office packs, junk mail, etc.). Material is sorted to specifications, then baled, shredded, crushed, compacted, or otherwise prepared for shipment to market (*Dubanowitz, 2000*).

A dirty MRF accepts a mixed solid waste stream and then proceeds to separate out designated recyclable materials through a combination of manual and mechanical sorting. The sorted recyclable materials may undergo further processing required to meet technical specifications established by end-markets while the balance of the mixed waste stream is sent to a disposal facility such as a landfill.

The percentage of residuals from a properly operated clean MRF supported by an effective public outreach and education program should not exceed 10% by weight of the total delivered stream and in many cases it can be significantly below 5%.

A dirty MRF recovers between 5% and 45% of the incoming material as recyclables, then the remainder is landfilled or otherwise disposed (*Cossu et al., 2012*).

A dirty MRF can be capable of higher recovery rates than a clean MRF, since it ensures that 100 % of the waste stream is subjected to the sorting process, and can target a greater number of materials for recovery than can usually be accommodated by sorting at the source. However, the dirty MRF process is necessarily labor-intensive, and a facility that accepts mixed solid waste is usually more challenging and more expensive to site.

New mechanical biological treatment technologies are now beginning to implement wet MRFs. This combines a dirty MRF with water, which acts to densify, separate and clean the output streams. It also dissolves biodegradable organics in solution to make them suitable for anaerobic digestion (Dubanowitz, 2000).

In Annex 6 are presented some possible combinations of mechanical pretreatments for different waste fractions. Figure11.17 shows a possible selection of mechanical pretreatments for a commingled packaging MRF, which receives glass, plastic and metal. Firstly the iron is extracted with a Magnetic separator, then a screen separate the smaller fractions from the bigger one. An Air classifier us used for the separation of the plastic, which is then manually sorted in HDPE, PET and others. The Eddy current separates aluminum, and finally a glass sorter separates the different glass fractions.

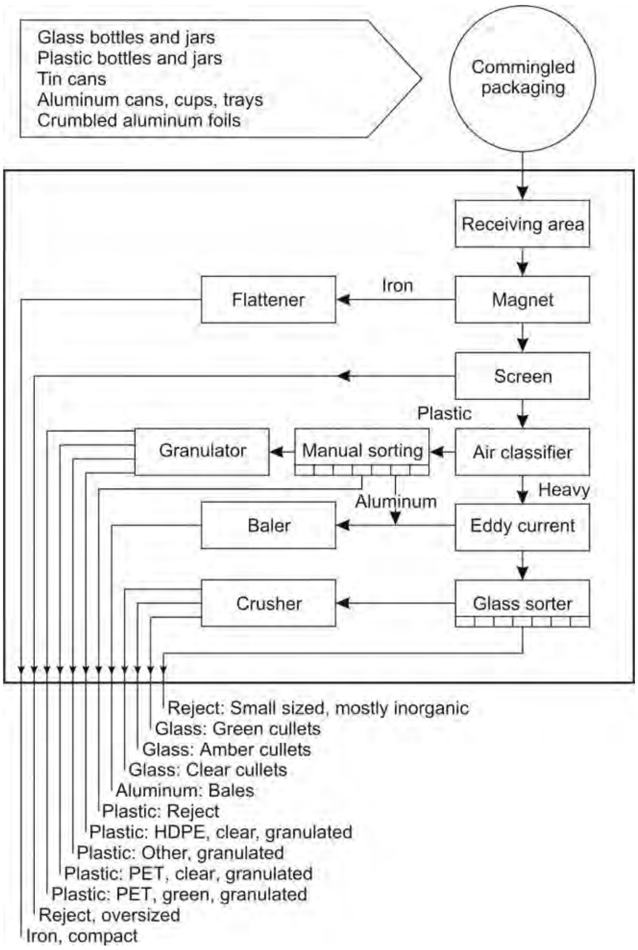


Figure 11.17: *MRF for commingled packaging (Cossu R., 2012)*

Mechanical treatments have also the goal to separate the waste fraction with a higher calorific power from the rest of the waste. Especially in countries with a high rate of incineration implementation, like Germany, it is fundamental to select a part of the whole MSW which is more suitable for burning. This waste fraction is called Refuse Derived Fuel waste fraction (RDF). Usually a lot of plastic material and paper are present in the RDF, since their high calorific power and consequent energy production.

The mechanical biological pretreatments are closely related with the concept of RDF, since if part of the MSW of an area goes to an incinerator, the pretreatment combination is selected in order to maximize the RDFs.

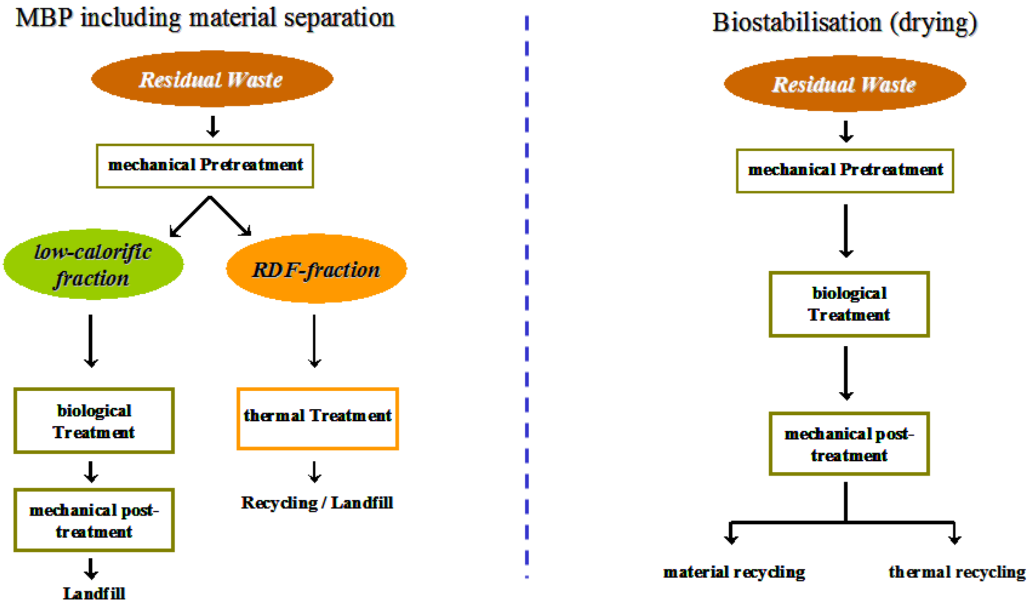


Figure 10.18: *Relation between MBP and RDF waste fraction (Stegmann R., 2013)*

Figure 10.18 shows the typical scheme which relates mechanical and biological treatment and RDF fraction. In the first case, where the final disposal options are both a landfill and an incinerator, some mechanical treatments are performed on the MSW to separate the low calorific fraction from the RDF fraction. The first one is subjected then to a biological treatment, a following mechanical post-treatment and the unrecoverable waste goes then to landfill. The RDF fraction instead goes to an incineration plant. The rests which are not usable anymore go then to landfill. The second option consider a different procedure, where firstly a mechanical pretreatment is performed on the MSW, then a biological treatment and a mechanical post-treatment. Finally the material can be recycled or subjected to thermal treatment.

10.3 Biological pretreatments

The biological treatment process is characterized by a degradation of organic waste components through activity of microorganisms. The degradation runs either under aerobe or anaerobe conditions, and there exist also some treatments between this two methods. Figure 10.19 shows similarly as Figure 10.18 the typical steps of MSW treatments in Germany.

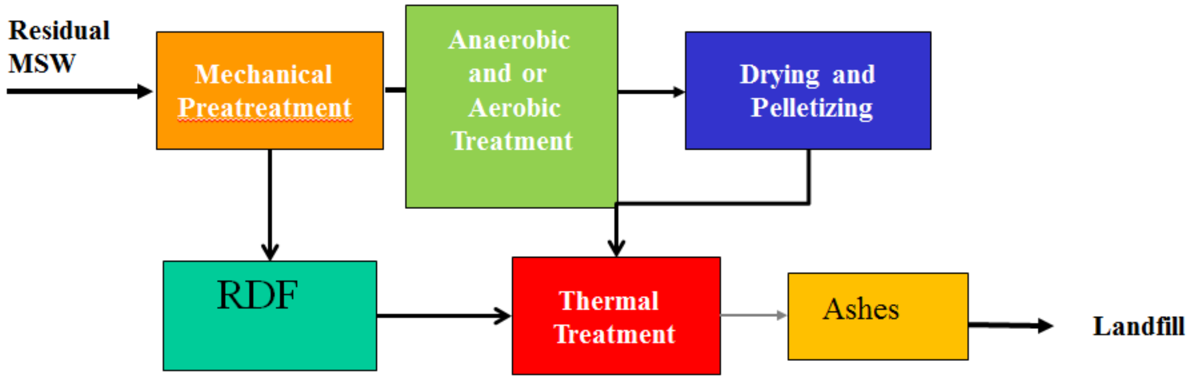


Figure 10.19: *Typical scheme of German MSW treatment steps (Stegmann R., 2013)*

10.3.1 Aerobic processing

Aerobe process require sufficient supply of oxygen, nutrients and moisture. Optimum process temperature ranges from 40 to 60 °C. Some aerobe processes run in hotter environment as well. An aerobic degradation is a transformation process for organic substances by a variety of microbes, in aerobic conditions and in solid state. The process is exergonic, results in heating up of the stabilizing material, and it leads to the formation of carbon dioxide and water. A humus rich material is generated. Under specific quality control of the substrate and of the process the final product may be classified as compost, which is a stabilized and sanitized product which is beneficial to plant growth.

The main actors in aerobic digestion are:

- Bacteria: Rod shaped or cocci, can be extremely fast-growing, mobile or non-mobile, but they need a water-film to move
- Actinomycetes: String-shaped bacteria, slower growing, sensitive to pH change
- Fungi: Grow as hyphae can therefore penetrate dry material, less sensitive to pH change, degrade lignin, cellulose etc.
- Others: worms, beetles etc.

The temperature depends on the amount of substrate, the isolation, aeration, climatic conditions and the porosity of composting mass.

At the beginning the easily degradable materials are degraded, while the temperature starts to rise (mesophilic and thermophilic phase). The mesophilic phase reach a temperature of 42 ºC, while the thermophilic phase is between 50 – 70 ºC. Some anaerobic bacteria can be present at the beginning. In this phase a release of energy results from the degradation of organic substance. Then the temperature, after reaching a peak, decreases and also medium degradable and then hardly degradable materials are degraded (*Cossu R., 2012*).

The basic reaction of the aerobic degradation can be represented by:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{energy} + \text{biomass}$$

The ideal density for composting of MSW is around 0.6 t/m^3 (*Stegmann R., 2013*).

Some typical density ranges for different waste types are provided (*Cossu R., 2012*):

- Garden waste: 0.30 – 0.50 t/m^3
- Wood waste: 0.40 – 0.50 t/m^3
- Bio-waste: 0.50 – 0.80 t/m^3
- Sewage sludge: 0.85 – 0.95 t/m^3
- Paper mill waste: 0.75 – 0.85 t/m^3
- Livestock waste: 0.65 – 0.75 t/m^3
- Agriculture waste: 0.50 – 0.60 t/m^3
- Textiles and Paper: 0.65 – 0.75 t/m^3

Figure 10.20 shows the scheme of mass transfer in composting, after a period of three weeks. Fast volatile solids and water are strongly reduced after this period, and carbon dioxide is produced. The slow degrading volatile solids are only partly reduced, while the non-volatile solids remain the same.

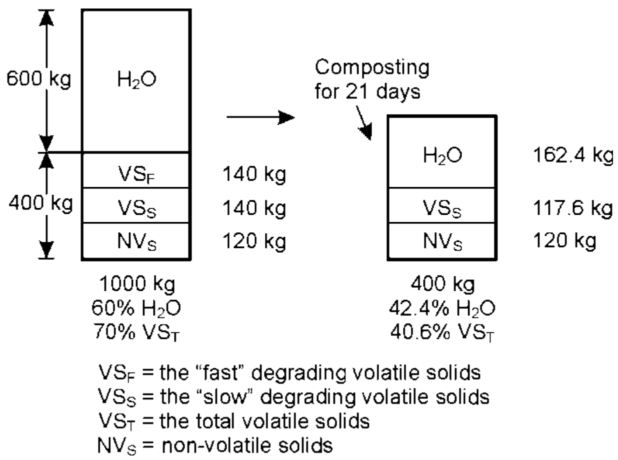


Figure 10.20: *Mass transfer in composting (Cossu R., 2012)*

Usually a windrow turning is performed in a composting process, to keep the temperature in an ideal range.

Before	Water content	Shredding, Sorting, Classification, Mixing
	Structure	
	Substrate composition	
	Nutrient content	
During	Temperature	Aeration, Turning, Moistening, Buffering
	Water content	
	Oxygen content	
	Structure/Porosity	
	pH values	
After	Structure	Classification, Sorting, Mixing
	Compost properties	

Table 10.2: *Operational controlling parameters (Cossu R., 2012)*

Table 10.2 provides the operational controlling parameters which have to be monitored and controlled before, during and after the composting period, and with which treatment techniques this parameters can be regulated.

The MSW undergoes firstly to a pre-processing, before the compost phase. After the composting, a post-processing treatment is applied, an odor control is usually performed and the final compost output is produced.

The oxygen presence is very important, and depend on the temperature, the water content and the composition. For easily degradable substances 1.2 - 1.7 l O_2/(kg TS*h) are required, and for the later degradation phase around 0.55 l O_2/(kg TS*h) (*Cossu R., 2012*). The optimum C/N ratio in substrate is around 25-35:1 (*Cossu R., 2012*).

Structure material is often added to the waste (up to 40 %), to optimize the average size of the materials, to allow aeration. Wood chips, straw, shredded paper and shredded tires are the most used.

The pH can be between 6 and 10, but an optimal range is 7-8 (*Flemming et al., 1995*). The water film on the substrate surface is the most important region for microbial activity. An optimal water content is of 40-70%. More than 70% limits the oxygen supply (*Cossu et al., 2012*).

There exist different composting techniques, which can be applied indoor, outdoor and in-vessel technologies. The windrow can be static or agitated. In the following lines the main technologies are presented.

Non aerated windrows

Open non aerated windrows mark are the simplest biological treatment process in MSW. The biological decay process is maintained by supplying sufficient moisture to the heaps using simple irrigation methods, while the oxygen provision is ensured by means of frequently turning the heaps.

The revolving procedure further allows cooling down the heaps in case the temperature inside becomes too high and starts the bio process. The turning is executed either by a special machinery or by a simple loader. For turning heap procedure the piles are placed in triangular shape with a maximum height of 1.5-2 m. Passive aeration effects arise mainly on the surface of the heaps, when oxygen is penetrating into the pile from outside. Since the inner part of the heap may be lacking oxygen a frequent turning is required, quite similar as in composting but less often.

Aerobic treatment works best, if the waste is homogeneous with most waste particles smaller than 150-200 mm. Hence, shredding is eventually useful for some larger particles (*Ramke H. G., 2004*).

Passively aerated systems

One of the most popular passively aerated treatment method is called chimney effect procedure. The waste is placed on a ventilation layer made of coarse material or bulky waste, and ventilation pipes are installed in the trapezoid windrows. The oxygen supply results from passive aeration due to thermal dynamic effects and is not controlled. The heaps are piled with an average height of 2-2.5 m (*Ramke H. G. 2004*). The trapezoid windrows may be covered with bio filter material for insulation and avoidance of odor emissions.

As the entire process is not encapsulated, possibilities of emission control are limited. If the process is not performing properly, for instance the passive aeration is insufficient or completely inhibited in parts of the windrow or the entire windrow, anaerobic conditions can occur.

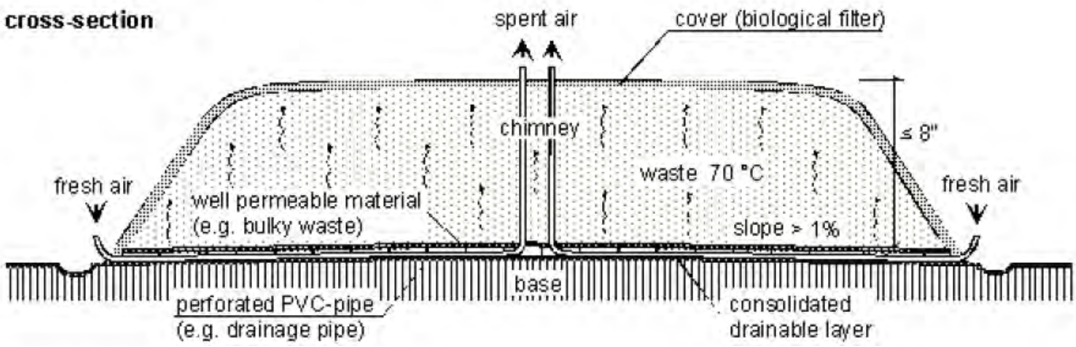


Figure 10.21: *Typical scheme of an open static passively aerated windrow according to chimney effect procedure (Ramke H. G., 2004)*

Actively aerated systems

Actively aerated systems require more technical effort than the passively aerated systems. The biological process is supported by maintaining the moisture content inside the piles and sufficient oxygen supply. Aeration can be carried out by pressing air into or sucking air out of the heaps. In order to achieve a homogeneous distribution of the air and to discharge the energy limiting the temperature, the heaps need to be turned frequently.

After finalizing the bio-process the material will be removed from the treatment area and will be separated into valuable and useless material. The treatment area for actively aerated windrows amounts to approximately 1 m^2/t for a treatment period of 12-16 weeks. The process cannot be operated on the landfill area, but need specially constructed facilities. It can be operated either open air or under roof. Exhaust air is captured and treated in a bio-filter (*Ramke H. G. 2004*).

In-vessel actively aerated systems

In this kind of treatments, the entire degradation process takes place in an enclosed compartment, which can be realized in a wide variety of technical solutions.
Several in-vessel systems are available and implemented in Europe. Biological degradation can be performed, for instance, in bio-boxes from reinforced concrete, containers, tunnels, rotating drums and closed maturation halls. The filling and emptying of in-vessel systems will be done either automatically with conveyers or moving floors or with mobile manned equipment, such as wheel loaders, excavators and cranes. Aeration is provided by pressure or suction of air for supply of the organic material with sufficient oxygen. The exhaust air is collected and cleaned with bio-filters or regenerative thermal oxidation (RTO).

Also moisture is extracted, and active aeration is additionally used to adjust the preferred temperature for biodegradation. To prevent drying, agglutination and air channeling, turning and mixing of the material on a regular schedule is also required.

The degradation process is automatically controlled in terms of an adjusted favored constant temperature and moisture profile, therefore conditions for biological degradation are optimized, which results in considerable shorter duration of the stabilization process of 8 to 12 weeks, compared with the retention time for open passively or actively aerated degradation systems.

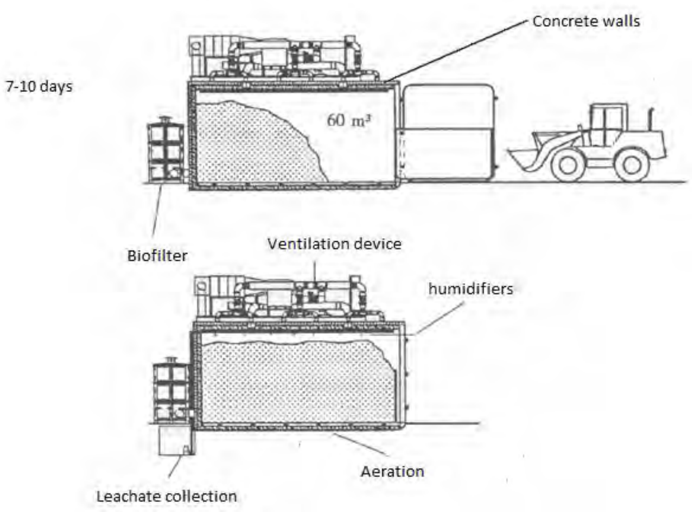


Figure 10.22: *Static biocells (Cossu R., 2012)*

Biological drying

Unlike other aerobic treatment options, the biological drying of waste is not aiming for a maximum degradation of the organic matter but for a short term drying process of around 7 days in order to enhance significantly the sorting capabilities for an efficient separation of RDF and recyclables.

The fraction to be landfilled is reduced to an amount of 15-20% and consists mainly of non-organic parts, such as sand, stones and glass. Once the waste is dried combustibles like plastics, paper, textiles, wood and fine organic matter can easily be separated by means of air separation as to their low density.

Recyclables like ferrous and non-ferrous metals can be separated with high purities in order to sell them to the recycling market.

After the mechanical pre-treatments, in case of bio-drying, the waste is putted in huge boxes made of reinforced concrete. Each drying box has an effective volume of approximately 600 m^3 and can take 300 t of waste. A controlled forced aeration is performed, in order to reduce moisture in a short time.

The amount of separated RDF is in the range of 40-50% by weight. Unlike MSW which cannot be stored for a while without generating gas and leachate emissions, RDF becomes biologically stable and storable after the biological drying process.

The exhaust air arising from the drying and sorting processes contains significant quantities of dust as well as steam, mercaptans, CO_2 and smelling substances. This air is partly reused for the biological drying process.

Figure 10.23 shows the trend of the Respirometric Index provided by *Cossu R. 2012*, considering material which undergoes an aerobic degradation in an in-vessel activated aerated system. The oxygen demand is drastically reduced in the first 60 days, that means that the material has mostly undergone degradation.

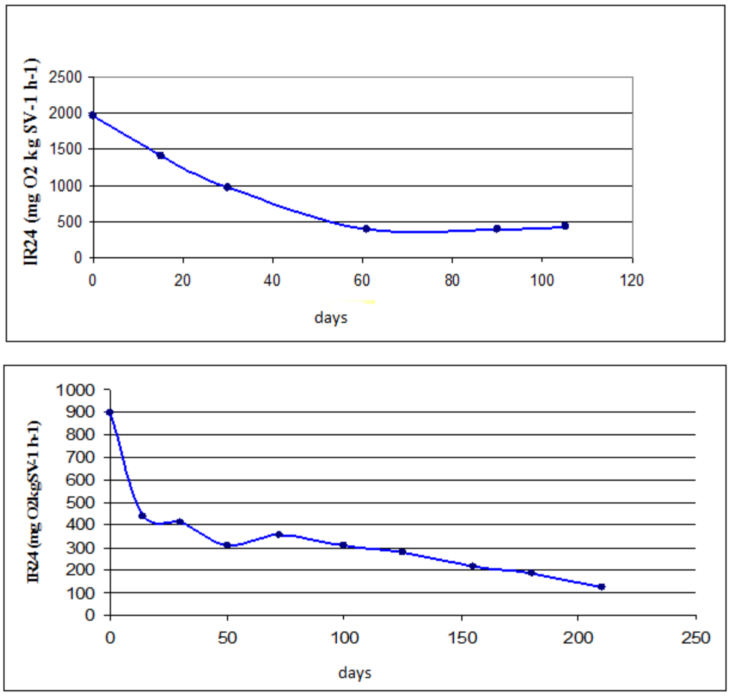


Figure 10.23: *RI trend in a biocell (Cossu R., 2012)*

A study performed by Krebs and Bergbach in 2007 showed that 38% of the produced compost in Germany is used in agriculture, 17% in landscaping, 13% as substrate in other processes, 9% in hobby and gardening and 10% as soil in construction projects.

To project and size a composting plant, some general indications are provided:

A general formula which can be utilized to determine the number of channel required in a composting plant is the following one (*Cossu R., 2012*):

$$N°channels = \frac{Q * i}{\rho_w * L_a * L_t * H}$$

Where:

- Q= flow [t/d]
- i=days between two turnings
- ρ_w=waste density [t/m^3]
- L_a = channel width [m]
- L_t = displacement [m]
- H =height of the channel [m]

The Volume can be estimated by Qi/ρ.

10.3.2 Anaerobic digestion

Anaerobic digestion is usually defined as a process by which microorganisms breakdown biodegradable material in absence of oxygen, with the production of biogas. In Chapter 9 have already been discussed the steps of an anaerobic process and the biogas composition.
The purpose of the anaerobic process is to convert waste and sludge to end products of liquid and gases while producing as little biomass as possible. The process is much more economical than aerobic digestion. Biogas can then be used for energy production.
Other aims are reduction of volume and mass of organic waste, stabilization and sanitation of the waste, and the recirculation of the natural substances in the natural cycle. As already mentioned, the process can be described by the following four steps (*Stegmann R., 2013*):

- Hydrolysis: large polymers are broken down by enzymes
- Fermentation: acidogenic fermentations are most important, acetate is the main end product. Volatile fatty acids are also produced along with carbon dioxide and hydrogen
- Acetogenesis: breakdown of volatile acids to acetate and hydrogen
- Methanogenesis: acetate, formaldehyde, hydrogen and carbon dioxide are converted to methane and water

The stability of the anaerobic process is very fragile. The balance between several microbial populations must be maintained. The hydrolysis and fermentation phases have the most robust organisms. They have the broadest environment range in which they thrive. They react quickly to increased food availability. Thereby, increasing the amounts of their products the volatile fatty acid concentration rises very quickly. This is kept in check by the buffering action of the system provided by carbon dioxide in the form of biocarbonate alkalinity.
The moisture is very important for this process, since hydrolysis can’t start without enough water. The pH range is, therefore maintained under normal circumstances. However, during shock loading the acid concentration can overcome the buffering action and raise the pH out of the narrow acceptable limits of the acetogens and the methanogens. When this happens methane production stops and the acid levels rise to the tolerance level of the acid formers. At this point the system fails. Optimum pH ranges are 5.3-6.7 for acidification and 6.8-7.2 for methanogenesis.

Temperature is also a critical element. Sudden changes in temperature adversely affect the methane producers. Several substances are toxic to the system such as heavy metals, chlorinated compounds and detergents. Pretreatment would be necessary for organic waste rich in this substances. A temperature around 55 ºC is optimal for anaerobic digestion.
When operating properly, the digester receives organic waste, primary and secondary, from the other treatment processes. The water content should be of 92 – 98% (*Cossu R., 2012*). The waste is then held in the tank for a period from 10 to 90 days depending on the system.
The sludge goes into the digester, methane, carbon dioxide and traces of hydrogen sulfide go out the gas outlet.

Substrate	C/N [-]	TS [%]	oTS [%]	oTS-degradation rate [%]	biogas-yield from degradated oTS [Nm³/t oTS]
Proteins	3,4 – 4,7	100	100	70 - 90	600 – 1,200
Fats/Oils	∞	100	100	> 90*	1,400
Carbon	∞	100	100	> 90*	750
Biowaste	10 – 25	25 – 35	65 – 78	50 – 60	1,000 – 1,200
Market waste	14	9 – 11	75 – 89	50 – 60	980 – 1,020
Liquid manure	5 - 11	3 - 12	65 - 85	20 – 50	900 – 1,110
Green waste	20	16 - 24	78 - 88	40 – 55	860
Domestic waste	40 – 55	45 – 55	40 – 60	40 – 60	900 – 980
Catering waste	15 - 25	9 - 25	79 - 93	50 – 70	1,100 – 1,300

Table 10.3: *Content of solid material in different organic substrates (Stegmann R., 2013)*

The solid outlet can be used as a fertilizer. Figure 10.24 shows the biogas yield of the anaerobic digestion of different waste types.
The waste is usually pretreated before anaerobic digestion. The main treatments used are: shredding, pulping, pH adjustment, heating, magnetic separation, swim separation and sieving.

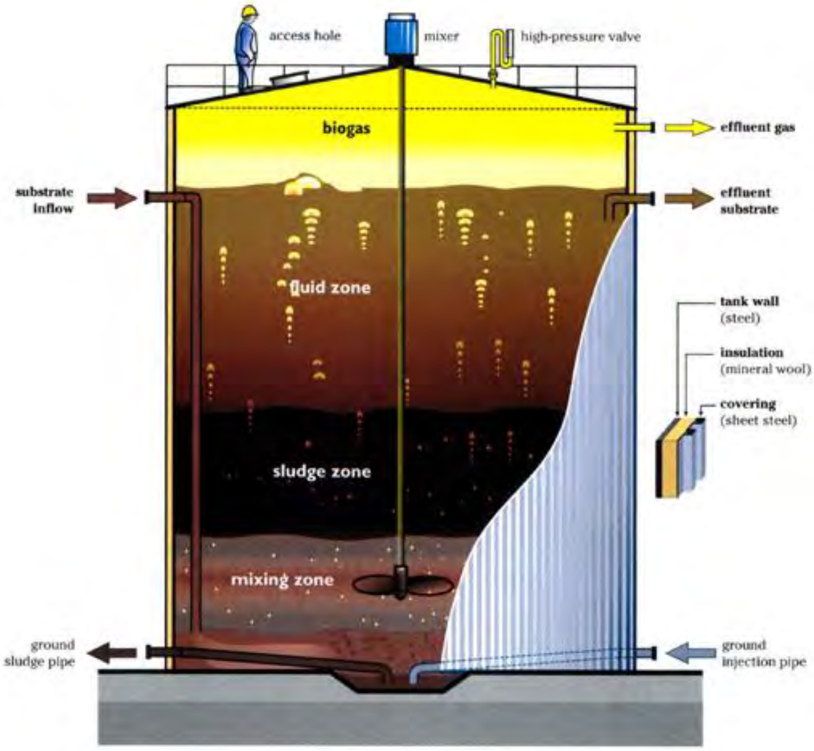


Figure 10.24: *Section of an anaerobic digestion tank (Stegmann R., 2013)*

Anaerobic digestion can be a wet or a dry digestion, depending if the water content is more or less than 90%. There exist different techniques of anaerobic dry digestion. The so called Bekon dry fermentation process is shown as an example in Figure 10.25. The digester is constructed of gas-tight heated reinforced concrete. Heating pipes are situated in the concrete of the floor and walls of the digesters in several warm water heating loops, so that the substrate in the digester is brought to the desired temperatures very quickly and evenly. This type of heating system allows rapid heating of fresh biomass. Low enthalpy waste heat with temperature levels of about 50 ºC can also be used to heat the digester and percolate to attain greater energy efficiency. The rapid switching to the anaerobic phase permits retention of valuable organic ingredients for gas production, significantly raising the system's gas yield and minimizing undesirable emissions.

The waste is inoculated with substrate that has already been fermented to promote quick starting. Continuous inoculation with bacterial matter occurs per recirculation of percolation liquid, which is sprayed over the organic matter in the digester.

All dry digestion methods are single-step batch processes. Hydrolysis, acid and methane formation take place in the same digester. Batch process means that during the fermentation no further material is added or subtracted, despite wet fermentation, where there is a liquidation phase. In the dry fermentation the bio-waste is constantly moisture with its own percolation liquid, guaranteeing ideal living conditions for bacteria.

The dry fermentation is characterized by its high throughput flexibility. Varying the residual inoculation rate from 50:50 to 70:30 and shortening the retention time from 28 to 24 days can result in volume fluctuations of up to 30% (*Ramke H. G., 2004*).

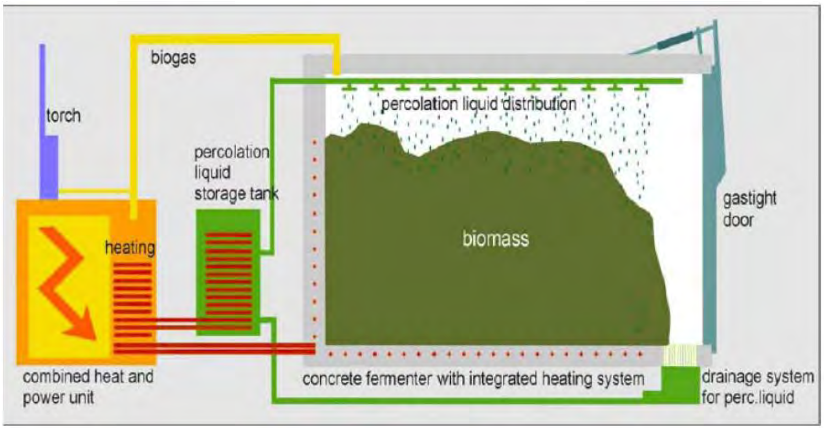


Figure 10.25: *Bekon dry anaerobic digestion (Ramke H. G., 2004)*

As for the dry one, also for wet anaerobic digestion there exist different types of procedures. The BTA-process, a hydro-mechanical waste treatment procedure is one of them. It comprises two steps: a hydro-mechanical pretreatment and a subsequent biological step towards anaerobic digestion.

In the hydro-mechanical pretreatment an efficient removal of impurities as well as a complete separation of digestible organic components into organic suspension will be achieved. this happens with a waste pulper and a grit removal system. Within the waste pulper the feedstock is added to pre-filled process water in order to separate the waste mixture into fractions by taking advantage of natural buoyancy and sedimentation forces. Moreover, non-soluble organic components are reduced to fibers by shearing forces and brought into suspension. Thus, heavy materials are fed aside and light materials are skimmed off.

The fractions are separated in: organic materials, light materials (plastics, foil, textile, wood) and heavy materials (stones, bones, batteries and others).
After the pulper the organic suspension still contains sand and fine impurities, which are removed by the grit.
The cleared bio-suspension is temporarily stored in a suspension tank. The organic fraction is digested within the fermenter, generally under mesophilic conditions between 35-38 ºC.
Further treatment of the digested substrate can be adjusted according to the respective project. Generally, a decanter centrifuge for continuous separation of solids from liquids is employed. The solid material is suitable for the stabilization and production of quality compost (*Ramke H. G., 2004*).

10.4 Incineration

Incineration of waste is the third option in the European waste management hierarchy, and it highlights the importance and the possibility of using waste as a fuel and it is done in order to reach several goals such as:

- Reduction of the waste mass and volume, in particular a mass reduction of approximately 70% and a volume reduction of 90% of waste
- Sanitation of waste by means of kill the pathogens, and destroying the hazardous components of waste
- Inerting of waste by producing stable and non-mobile solid matter (the ashes and dust after proper treatment)
- Energy production, both thermal and electrical, thanks to the hot gasses temperature. The thermal energy released from the combustion can be utilized as it is, or get the fumes flow rate go into a boiler which allows the heating of water producing hot steam utilized from gas turbines to generate electrical energy

Not all the waste is suitable for the incineration process, in fact it regards mostly the combustion of the organic material. Consequently, at first, it has to be evaluated if a waste is suitable for the process and some empirical results can be exploited.
An important factor to consider is the low heating value of the waste, LHW, which is the quantity of energy, as heat, released by a unit mass of waste [KJ/Kg MSW], to evaluate consequently, considered with the waste flow rate incoming, the total thermal capacity of the plant.

An example of waste heating values is reported on the following table:

	water content %	volatile components %	fixed carbon %	ash content %	heating value [kJ/kg]
paper	5	73	9	13	14200
waxed milk carton	3,5	91	4,5	1	26300
vegetable matters	78	17	4	1	4100
fat	0	98	2	0	38300
parc waste (branches)	69	25	5	1	6300
foliage	10	67	19	4	18500
grass	75	19	4	2	4800
leather shoes	8	57	14	21	16900

Table 10.4: *Typical heating values for different waste fractions (Cossu R., 2012)*

A typical configuration of a municipal solid waste incineration plant is reported below.

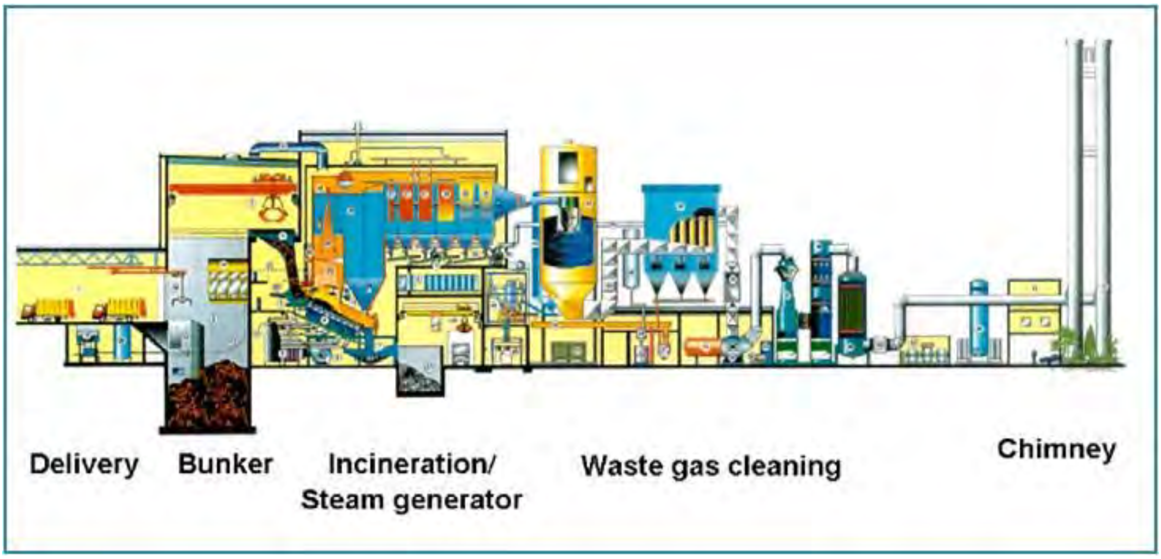


Figure 10.26: *Scheme of an incineration plant (Cossu R., 2012)*

A general scheme of an incineration plant concern firstly the storage of waste in a bunker, designed according to the waste flow incoming per day. Then by means of a crane, waste is introduced in the furnace where it is burned with an excess amount of the stoichiometric air required to ensure the complete combustion of the waste, and under controlled conditions. In particular temperature must stay above the 800 °C to avoid organic residues and must stay below values of 950-1.000 °C in order to prevent the melting of the produced bottom ash.

The combustion reaction, not balanced, can be generically described as follow:

$$C_aH_bO_cN_dS_e\ldots + O_2 \rightarrow CO_2 + H_2O + NO_x + SO_x + \text{excess air} + \text{PAHs} + \text{halogenated acids} + \text{soot} + \text{dust} + \text{dioxins} + \text{PCBs} + \ldots + \Delta H$$

In particular, the products resulting from the combustion are strictly depend on the waste elemental composition.

After combustion, bottom ash is extracted from the bottom and cooled in a quenching bath, while the fumes produced, both gas and fine particulate go through a boiler where heat is transferred from them to water generating water steam useful for electrical energy production. The electrical energy production rate is approximately 450 KWh/t MSW (*Cossu et al., 2012*).

Then, the units which follows the boiler are the so called APCDs, air pollution control devices that cover a great importance in an incineration plant, both in terms of pollutants abatement and also in economic terms since the capital cost of these devices cover almost the 70% of the total cost of the plant.

In particular all the products generated from the combustion, almost always are pollutants such as the dust (which is the principal one), the dioxins, the sulphur oxides, the nitrogen oxides and so on, and before the discharging in the air of the gas require to be removed to avoid dramatic environmental damages and consequences. But it must be remembered that if the combustion reaction occurs properly, less risk of hazardous pollutants generation is expected. Anyway inevitably, some of them forms certainly, so a sequence of several pollutants abatement devices is always necessary.

Many treatments are applied, for instance gas dedusting by means of chemicals addiction and a fabric filter to remove the dust generated, SCR DeNox for NO_x reduction to N_2, powdered activated carbon adsorption for inorganic and organic micropollutants, dioxins, furans etcetera.

Finally the cleaned gas pass through an ID fan and the is discharged into the atmosphere by means of a stack.

10.5 MBP in Germany and Italy

Comparing the MSW pretreatments to achieve landfill stability in Germany and in Italy, the first important consideration before making an evaluation, is that in Italy more than 40 % of the total MSW is landfilled, while in Germany it is less than 1 %, and it regards mostly the residues of the incineration process. Incineration allows to reduce the waste mass of 80% - 95%, and the ashes occupy much less volume in the landfill. Germany has a landfill ban since 2005 for untreated waste, and this increased incineration in the last decade. Since Germany implements less landfill technology and more incineration and recycling compared to Italy, the MSW pretreatments are different. The incineration itself can be seen as a waste pretreatment, since ashes and used filters are then disposed in landfills.

Italy implements strongly mechanical pretreatments, in order to extract the recyclable fractions, and also mechanical-biological treatments, to reduce to biodegradable fraction and dispose less emitting waste in landfills. Also composting and anaerobic digestion are common in the country, especially in the northern part. The same consideration can be made for incineration, which contributes to dispose a significant amount of waste in the northern regions, but is not diffused in the center and in the south.

In Germany biological treatments (composting and anaerobic digestion) are more common as mechanical, since the main goal of pretreatments in Germany is to dispose the biological fraction and to prepare a suitable fraction for the incineration process.

Pretreatments consist mainly in the separation of waste with a high calorific power (which will then be burned), the extraction of recyclable materials, and the separation of kitchen and garden waste, which will largely be biologically treated.

10.5.1 Pretreatments in Italy

As already mentioned in this work, it is not representative to give some main values related to waste management in Italy, since the situation from north to south is really different. The same applies for an evaluation of the MSW pretreatment technologies.

Table 10.5 shows the amount of different types of waste pretreatment plants in Italy, and how much waste they can treat (*Enea, 2010*).

TECHNOLOGY	PLANTS	TREATMENT CAPACITY [t/y]
Mechanical pretreatment	33	unknown
Composting	195	5.350.685
MBP	135	14.539.369
Anaerobic digestion	10	487.000
Thermal treatment	53	6.667.052
TOTAL	426	27.044.106

Table 10.5: *Pretreatment plants in Italy (Enea, 2010)*

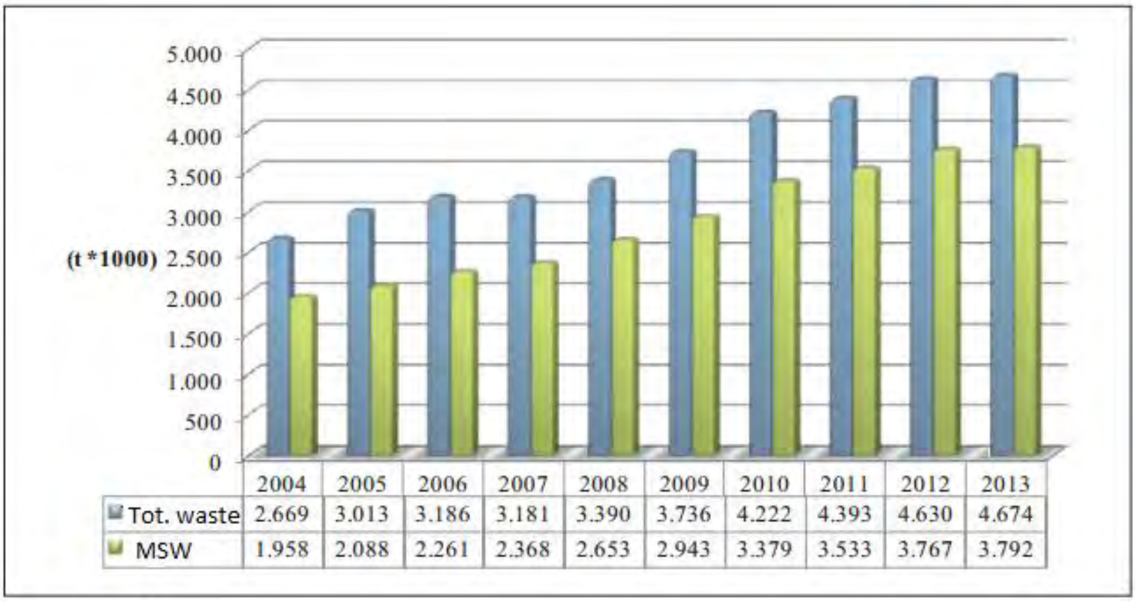
The plants listed in the table are only the one with treatment capacity higher than 1.000 t/y. This is in consideration of the fact that, according to the information received, those below this size, although quite numerous, cover a very small percentage in terms of treatment capacity.

About anaerobic digestion plants, there were taken into account only plants handling exclusively MSW, omitting those dedicated to the treatment of other types of waste such as sludge, livestock waste and waste from the food industry.

The total amount of waste which can be pretreated considering this plants is 27 million tons. Since the total amount of MSW produced per year in Italy is about 30 million, 3 million tons of MSW cannot be pretreated due to lack of treatment plants (*Enea, 2010*).

Composting plants are increasing constantly on the national area, thanks, above all, the increase in quantities of organic waste from separate collection.

The graph in Figure 10.27 shows the quantity of the total composted waste, in the period from 2004 to 2013, with the detail referring only to the organic fraction from the separate collection (kitchen and garden waste). It is notable how the total composted waste in 2013 was about 4.5 million tons, and more than 3.5 of that amount belong to the MSW fraction.



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Tot. waste	2.669	3.013	3.186	3.181	3.390	3.736	4.222	4.393	4.630	4.674
MSW	1.958	2.088	2.261	2.368	2.653	2.943	3.379	3.533	3.767	3.792

Source: ISPRA

Figure 10.27: *Amount of composted waste in Italy (ISPRA, 2014)*

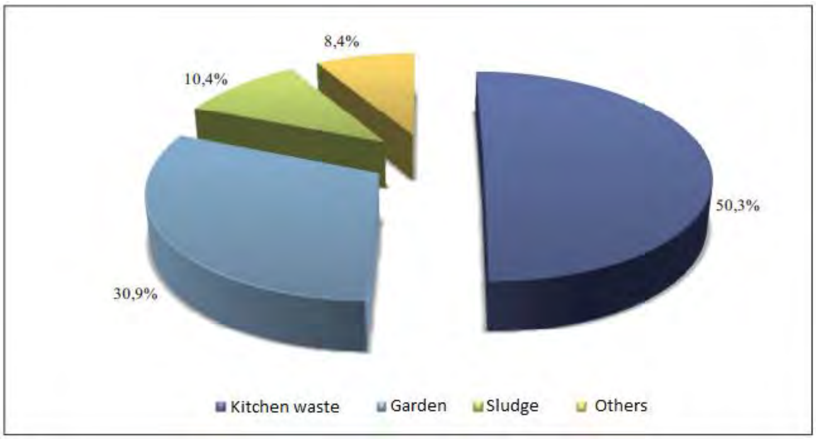


Figure 10.28: *Composted MSW fractions (ISPRA, 2014)*

Figure 10.28 shows the amount of the different waste fractions which are composted. Kitchen and garden waste from the separate collection are about 80% of the total waste composted. Sludge from waste water treatment plants is about 10%, and 8% are other waste fractions.

Figure 10.29 shows the amount of separately collected waste which is composted, divided in the three macro-areas North, Center and South.

It is easily notable how in the northern part composting is strongly implemented respect the Center and the South, since the presence on the territory of several composting plants. The reason of the low composting rate in the Center and the South is firstly an inefficient separate collection rate, which hinder the extraction of the biodegradable fraction and its further treatment. In each of the three zones the composting rate has a positive growing trend from 2009 to 2013.

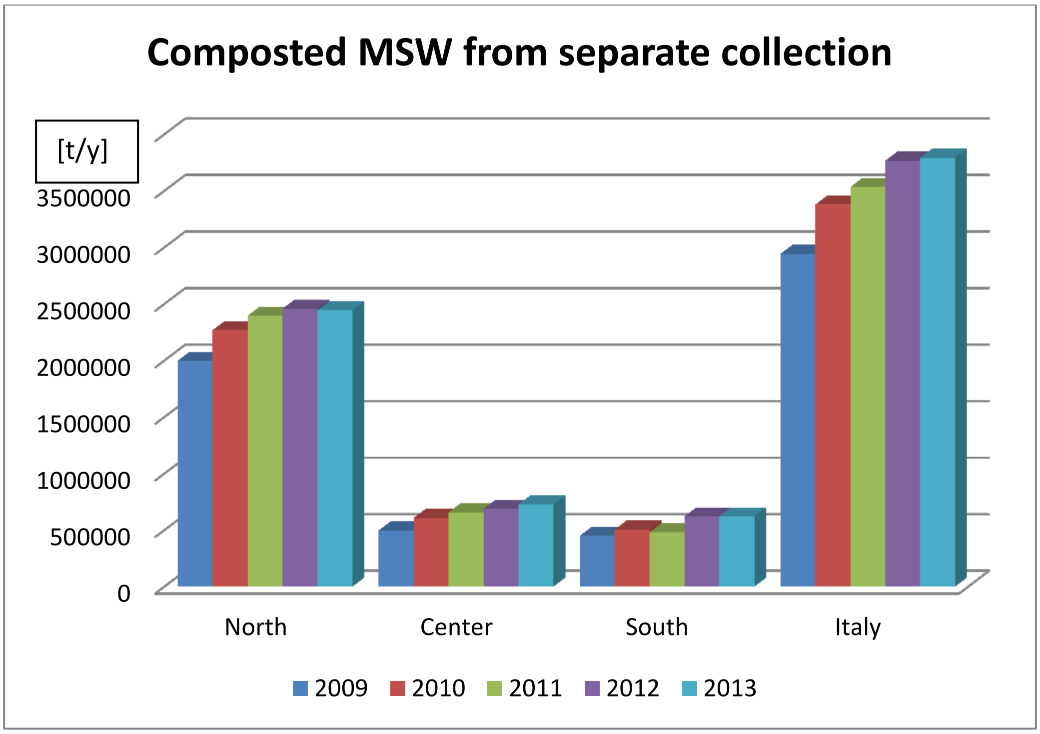


Figure 10.29: *Composted MSW separately collected in Italy (ISPRA, 2014)*

Also anaerobic digestion implementation had a growth in the last years. In particular the anaerobic digestion process connected and functional to a subsequent treatment step of aerobic quality composting.

About the kind of waste treated, Figure 10.30 shows the different waste fractions.

The MSW fraction sent to anaerobic digestion was about 450.000 tons in 2013, so more or less the half of the total waste treated with this technique in Italy in the same year. Same as for the composting, in 2013 in the North 460.548 tons of waste were subjected to this treatment, while in the center only 83.223 tons and in the South 66.337 tons (*Enea, 2010*). The reason is always related to a less developed collection system and to socio-economic aspects.

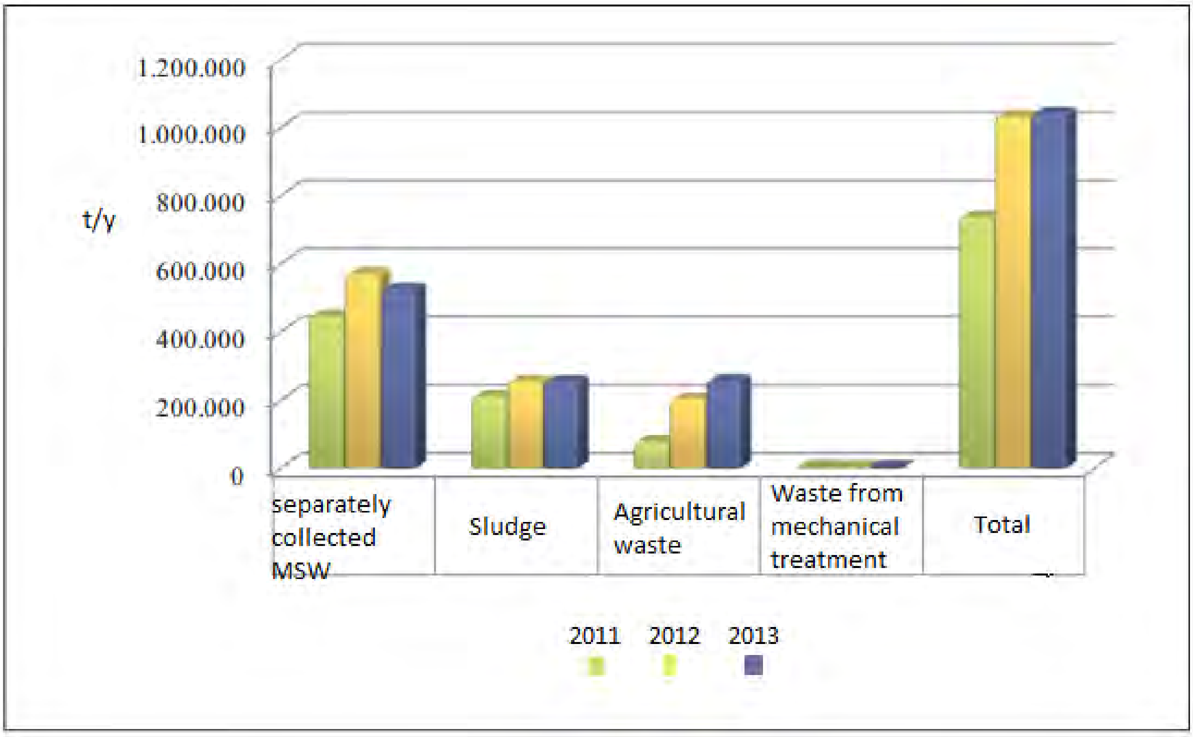


Figure 10.30: *Waste types used in anaerobic digestion treatments in Italy (ISPRA, 2014)*

In the year 2013, a quantity of waste of more than 9 million tons have been mechanically-biologically (usually with an aerobic treatment) pretreated. 8.5% more compared to 2012. These waste is made of 86.7% of unsorted MSW (7.9 million tons), for 8.6% (about 783.000 tons) of waste generated from the treatment of urban waste, to 2.1% (194.000 tons) from separate collection and its impurities (paper, plastic, metal, wood, glass and organic fractions from recycling), and 2.6% (233.000 tons) from waste from industrial sectors.

The organic fraction pretreated from separate collection amounted in 2013 to 28.000 tons.

In 2013 the MBT plants in Italy were 117. There are 39 plants in the North, 32 in the Center and 46 in the South. In the North, were brought to MBT plants over 2.4 million tons (26.5% of the total national), compared to 2012, there was a reduction of over 154.000 tons (- 6%).

At the center, the mechanical biological treatment regards a quantity of 2.9 million tons (31.9% of the total). Compared to 2012, there was an increase of more than 632.000 tons (27.8 %) attributable to an increase in the household waste treated in the Lazio region (*Enea, 2010*). In the South the amount of waste pretreated in 2013 was about 3.8 million tons (41.6% of the national total), compared the previous year, an increase of about 236.000 tons (6.6 %).

The explanation for the fact the Center and the South have a higher rate of implementation of mechanical biological pretreatments, is that in the North a considerable waste fraction goes to incinerators and to composting and anaerobic digestion, so other kinds of pretreatments are provided, which are not counted here.

In the year 2013, 53% of the waste pretreated in MBT plants went finally to landfill. 24% went to incineration, 8% was used as energy recovery and 5% went to bio-stabilization plants.
In 2013 were operating 44 plants for municipal waste incineration in Italy. Compared to 2012 entered into force the plants in Parma (authorized capacity of 130.000 tons), Turin (permitted capacity of 421.000 tons) and Bolzano (130.000 tons). Twenty-eight plants are in the northern part, in particular in Lombardy and Emilia Romagna with respectively, 13 and 8 operating plants.
The total waste incinerated in 2013 was 5.8 million tons, of which 2.5 million separated MSW, about 1.8 million unsorted waste, more than 1 million tons of waste derived fuel, 418.000 tons special waste of which almost 35.000 tons medical waste. Special hazardous waste, in prevalence of home health care, amounted to about 49 thousand tons.
In 2013, approximately 18.2% of municipal waste is incinerated (*Enea, 2010*). All plants nationwide produce energy, and recover almost 2.5 million MWh of electrical energy.
This data show a good implementation of the northern part of Italy in pretreatment techniques, while the pretreatment in the Center and in the South must still be improved.
On May the 31 the European Commission urged Italy to increase the implementation of MBP in the region of Lazio, since a waste fraction went to landfill without all the necessary pretreatments. There is the need in some regions to increase the pretreatments, enlarging the amount of facilities and plants. In the Centre and South there is furthermore a lack of energy recovery plants and, to a lesser extent, of composting plants.

10.5.2 Pretreatments in Germany

Since the ban on landfilling of untreated MSW in 2005, the amount of waste pretreatment plants increased strongly all over the country, and pretreatments are performed mainly in mechanical-biological waste treatment plants.
In Germany, almost all the MSW is mechanically and biologically treated and/or incinerated. Landfilling regards mainly the incineration residue waste.
MBP consist in Germany, depending on the system, in different numbers and combinations of single treatments. Very common are screening, grinding, air classification, infrared sorting, magnetic separation, eddy current separation, and other pretreatments discussed before. The goal of this pretreatments is the material recycling and the preparation of the waste for incineration.

Also biological treatments are very common over the country, especially composting (18% of the total MSW is composted in Germany) and anaerobic digestion.

In 2010, around 12 million tons of biodegradable waste were treated in composting and digestion plants in Germany. The waste was mainly waste from the bio bin, biodegradable garden and park waste, market waste and other biodegradable waste of diverse origins. Of this, 8.8 million tons were collected separately either via the bio bin (4.2 million tons) or as separately collected garden and park waste (4.6 million tons). This is equivalent to an average annual collection rate of 107 kg per citizen.

Of the total biowaste amount, 7.4 million tons were processed in composting facilities and 4.3 million tons were consigned to 992 digestion plants.

Around 3.6 million tons of compost and approximately 2.9 million tons of fermentation products for various purposes were produced from the collected biowaste (*Federal Ministry for the Environment, 2013*).

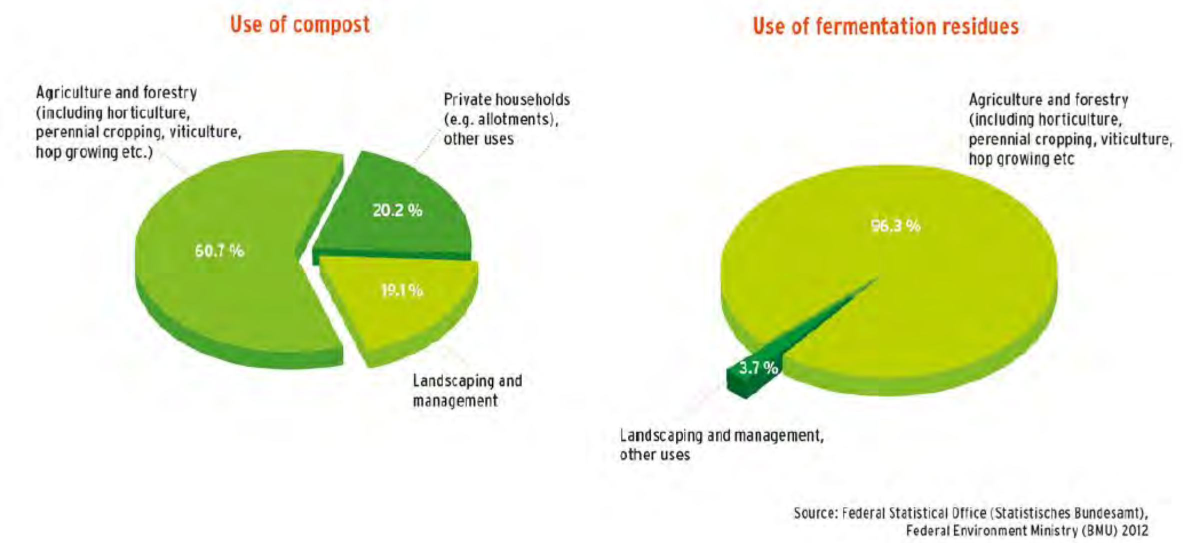


Figure 10.31: *Use of compost and fermentation residues in Germany*

Figure 10.31 shows the different use of compost and fermentation residues. Most of the produced compost and fermentation residues are used in agriculture as fertilizer.

In Germany waste is burned in two kind of incinerators. There are classic waste incinerators, which receive only waste, but also other plants developed in the last decades which use waste as fuel, like in the construction industry (especially in the concrete production) or in rotary kilns. In the first years the incinerators in Germany burned only waste, and the waste disposal was the main goal. Today waste is used in several other combustion plants, and this allow to save other fuels like coal.

In the years, new incineration techniques have been developed, which have almost the same structure as a classic incinerator, with the difference that the MSW is pretreated and mixed with other waste fractions, to allow a higher energy production. This incineration plants are used mainly for the production of electric energy and heat.

In Germany there exist also some plans which use biomass as fuel. In Hameln there exist such kind of plant, with a capacity of 100.000 t/y. In Manheim there is another one (124.000 t/y), and also in Böblingen (20.000 t /y). Only the incinerator in Burgau uses the pyrolysis process.

The mechanical pretreatments are usually performed on the same site as the incinerator, and in some cases in another facility (*Ulf Richers, 2010*).

The capacity of the solid waste incinerators in Germany at the end of 2010 was approximately 19 million t/y, with a total of 70 incineration plants, the one of mechanical-biological treatment plants of 5.9 million t/y, with 50 plants. In 2010 in Germany were burned 19 million tons of waste. That means that 44% of the total MSW has been incinerated.

Approximately 25-30% of MSW and bulky waste are treated in MBP plants, the rest is directly burned.

The pretreatment of waste to obtain a RDF consists in a first shredding phase, to reduce the average size of the waste. Then the metals are extracted, and brought to recycling facilities.

Non-combustible materials such as glass are removed with an air classifier or another mechanical separation processing.

The residual material can be sold in its processed form (depending on the process treatment) or it may be compressed into pellets, bricks or logs and used for other purposes either stand-alone or in a recursive recycling process.

Before burned, the waste is usually mixed, to be more homogeneous and have the same calorific power in the whole waste mass. It is also possible that shredded wood pieces from the bulky waste and non-recyclable plastic is added, in order to increase the calorific power.

Advanced RDF processing methods (pressurized steam treatment in a waste autoclave) can remove or significantly reduce harmful pollutants and heavy metals for use as a material for a variety of manufacturing and related uses. RDF is extracted from municipal solid waste also using mechanical heat treatment, mechanical biological treatment or waste autoclaves.

The production of RDF may involve usually some but not all of the following steps:

- Size screening (post-treatment step for autoclave treatment)
- Magnetic separation (post-treatment for autoclave treatment)
- Coarse shredding (not required for autoclave treatment)
- Refining separation

The moisture content of the mix is usually not bigger than 15% because if so the materials will not burn well in the furnace. The particles will last between 17 to 18 seconds in the furnace usually in a temperature of 1,200 ºC (*Ulf Richers, 2010*).

Not all the waste which is incinerated undergoes to MBP before. There is still a significant waste fraction of MSW in Germany which is directly incinerated after the separate collection. In this case some post-treatments can be performed. It is still possible to extract iron and non-iron metals also after the combustion process, with extraction efficiencies around 90%.

Due to the closure of several landfills and the disposal of only pretreated waste, from 1990 to 2010 estimations made from scientists states that 1.2 million tons of methane emissions have been avoided (*VKU, 2013*). Due to the use of waste as RDF there has been avoided the emission of about 4 million tons of CO_2.

In 2014 there have been burned around 45 million tons of waste (of which 20 million tons of MSW) in Germany. Since the landfill ban in 2005, a lot of new incinerators were put into operation at the time. Also the modernization of the waste disposal technologies in east Germany brought to a greater waste production in the last 20 years. For that reason several incinerations were constructed. In the years waste started to be used as fuel also in other industrial plants, and all this facts made that there is an overcapacity in German incineration plants nowadays (*VKU, 2013*). This fact allows Germany also to import waste from other countries, like from Italy in 2011, to dispose it in incinerators.

11. Conclusions

In this comparison between the German and the Italian waste management system, are easily identifiable the deficiencies of the Italian system. The German system respects almost completely the European directives and guide lines for waste management and the waste hierarchy, while Italy still needs to improve its waste management system.

The basic problem in Italy is the lack of an adequate regulation system about environmental issues, and when the regulation system is suitable, it happens frequently that the laws are not respected, and the responsible institutions do not apply fines or penalties to entities and individuals which do not respect environmental regulation.

The main difference respect to other countries like Germany and Austria is the lack of a landfill ban. If Italy will be able to introduce also a ban for untreated MSW which goes to landfill, the amount of biodegradable waste will be further reduced, and the European landfill directives would be probably completely fulfilled.

It is noteworthy to mention that landfills are the cheapest way of disposal, so it is really difficult to shift towards other disposal methods as incineration and recycling, until the economical welfare in some regions of Italy will not rise.

That what really has to be implemented in a more consistent way in Italy is the waste hierarchy. There must be put more effort especially on prevention and minimization, increase the reuse and recycling rate, and also shift from the use of landfills towards a higher use of incinerators as final disposal.

More economic and legal instruments have to be implemented to fulfill the waste hierarchy.

Environmental safety is still not a priority target in Italy, and the public opinion do not perceive enough environmental issues like a wrong waste management as a treat for human health. Incinerators are still perceived as dangerous and polluting facilities, and landfills as a more save disposal method.

The average Italian citizen has not the awareness of a behavior which favorite a proper waste management system. Separate collection is the basis of an efficient management system, but a lot of citizens do not collect and separate the waste properly, due to negligence or due to insufficient knowledge in the subject. Nor the state or responsible bodies made ever an information campaign to promote the knowledge of a proper separate collection method. Some information were provided at regional level, but in insufficient amount.

As mentioned several times in the previous pages, the economic welfare is distributed in a non-homogenous manner in Italy, since the northern part has a higher welfare compared to the south. For that reason landfilling is still the most implemented technology in this regions.
In the central part of Italy and especially in the south several other problems are present nowadays, like unemployment, criminality, corruption and a low industrialization level. It is almost impossible to implement an efficient waste management system without solving at the same time this issues. The environmental issue cannot be seen as detached from the general crisis which undergoes the whole country in the last years. Waste management is one of the challenges that Italy must win in the next years to remain a country with a high standard of living, in the average with the other European countries.
Regions in the north submit to European standards and directives, have a high rate of separate collection and a good implementation of the waste hierarchy, of *Directive 2008/98/EC* and of the Landfill Directive. A lot of effort have to be putted to do the same on a national scale.
Recycling efficiency needs to be further increased on a national level. There is the need of more waste pretreatment plants and facilities. Currently the MBP plants in Italy have a capacity of 15 million t/y, which needs to be implemented. There is no need to implement more a particular treatment, but the whole composition of pretreatments need to be improved. Incineration capacity was 7 million t/y in 2013. Since the waste hierarchy, Italy needs to shift from landfill as final disposal method towards incineration. Consequently also the pretreatments must be different, since as seen in the previous chapters incineration require other kinds of pretreatments. Also the use of waste as RDF have to be implemented. More waste should be used as secondary fuel in industrial plants. To fulfill this aim, a good cooperation between the waste management companies and the industrial sector is required. The Ministry of the Environment and the responsible bodies should coordinate this cooperation.
Composting and Anaerobic digestion have also the be further implemented. To do this the separate collection efficiency must grow, to extract more biowaste from the MSW.
Finally, a big step away from an excessive landfill use as final disposal, would be a landfill ban for untreated MSW, as in Germany.
Regarding Germany, it is among Austria, Denmark, Sweden and the Netherlands one of the countries which is leader in Europe for waste management. In Annex 1 is shown a ranking of waste management systems in the European countries, carried out by BiPRO GmbH.
Although the German system is very efficient, there exist two aspects of the German waste management which can still be improved.

Firstly, there are currently 91.722 former dump sites. Of this only 46.542 were submitted to a risk analysis for the possible emission potential, and only 16.097 have been remediated. There are still many potential emitting old dumps which have to be submitted to remediation. Germany is currently putting effort in this remediation.

Another point, which is cause of a debate in Germany, is the contrast between incineration and recycling. The waste hierarchy imposed by the European Commission states that recycling have always priority over incineration. It is true that Germany has a very high recycling rate, 47% (without counting composting), but some experts state that it happens in Germany that in certain cases incineration is preferred to recycling, since it is economically more profitable. The main waste fraction which is cause of this debate is the plastic packaging material.

This kind of waste is often incinerated in special combustion plants, which burn a selected waste fraction which is pretreated and mixed with other materials, usually with a very high calorific power. This kind of plants have the energy production as priority, more than the waste disposal, like for traditional incinerators.

On the other hand it is true that some waste fractions, and in particular plastic materials and light packaging material, have very often a very low recycling quality. The recycled plastic has not the same quality as the original one, and can so often not be used for the same purposes, for example in the food industry.

Waste incineration is a big business in Germany, and it happened that waste from other countries has been brought to Germany to be incinerated. In 2008, 22.000 tons of hazardous waste were shipped from Australia to be disposed in the country. The Umweltbundesamt, the German environmental office, states that Germany has a better incineration technology than Australia and it is so more environmental friendly to dispose the waste in Germany. It is clear that also the long travel of the waste has an environmental impact. Several German experts in the field state that there is an economic interest behind this approach.

Another argument of skeptics is that the capacity of German incinerator is too high, and this force the country to reduce recycling and import foreign waste, to keep this plants working.

Nevertheless, Germany is European leader in recycling.

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Regulation

Abfallablagerungsverordnung (AbfAblV)

Abfallbeseitigungsgesetz (AbfG)

Abfallverzeichnis-Verordnung (AbvV)

Council Directive 1999/31/EC

European Directive 75/439/EEC

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Deponieverordnung vom 19. April 2009

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Gesetz zur Neuordnung des Kreislaufwirtschafts- und Abfallrechts

Kreislaufwirtschaftsgesetz (KrWG)

Legge n. 214 del 22 dicembre 2011

Legge n. 147 del 27 dicembre 2013

Siedlungsabfallentsorgung vom. 1. Juni 2005

Technische Anleitung Siedlungsabfall (TASi)

ANNEX 1 - Screening of waste management performance of EU Member States

In 2012 the German company BiPRO GmbH performed on the request of the EC the study called "*Screening Of Waste Management Performance Of EU Member States*".
This study says that the implementation of EU waste legislation shows large differences in the EU Member States, especially with regard to municipal waste management. Major discrepancies prevail particularly in the implementation and application of the WFD.
For the screening the main elements and legal requirements from EU waste directives (mainly from WFD and the *Council Directive 1999/31/EC* on the landfilling of waste) were considered for the design of suitable criteria. These core elements comprise the practical implementation of the waste management hierarchy, application of economic and legal instruments to move up the hierarchy, treatment infrastructure, quality of waste management planning, fulfilment of targets and infringement procedures.
These elements were assessed by 18 criteria for each Member State. For each criterion, two, one or zero points could be achieved, leading to maximum 42 for all criteria. The screening showed three groups differing in performance as follows:

- AT, BE, DK, DE, FI, FR, LU, NL, SE and UK.
  This Member States are performing above average achieving between 31 and 39 points. All of this countries provide for complete collection coverage, sufficient treatment capacity and fulfilment of the targets related to biodegradable waste going to landfills. Further improvements in this countries could include the extended use of pay-as-you-throw systems which for most only reach regional coverage.
- ES, HU, IE, PT and SI.
  This group of member states shows fairly deficits: not all households are connected to a waste collection, planning of future treatment capacity is not sufficient and waste prevention yet is not on the political agenda. In this countries the recycling level is usually not very high.
- BG, CY, CZ, EE, GR, IT, LT, LV, MT, PL, RO and SK.
  This group of Member States show severe deficits within all criteria including waste prevention policies. The below average performance is also reflected in the lack of applying economic and regulatory instruments to divert waste from landfilling and insufficient adaption of existing infrastructure to EU requirements.

> This Countries are highly depending on landfilling, other treatment options are rarely in place. Landfilling is generally not restricted or banned for MSW, and therefore still a large amount of biodegradable waste is disposed in landfills (this is not exactly the case of Italy, which lacks more under other aspects).

About the data considered in this study, different sources have been used, like the EUROSTAT database, reports of the European Commission, national and regional Waste Management Plans and where available also Waste Prevention Programs. In particular, in Germany, as 16 regional WMPs are in place (one for each Federal State), assessments are based also on a statement provided by the Ministry of Environment.

About the treatment capacity, the data is well documented at regional and national level. Data on export/import of municipal waste is not included in the statement. It is most likely that there exists no under-capacity.

Data about actual treatment operation plants and capacity is well documented at regional and national level. The statement says that "the available treatment capacity for municipal waste in Germany is sufficient for more than ten years. There is no capacity overload, rather a small overcapacity in incineration." Information includes capacity data for landfills and incinerators.

In Italy WMPs exist on a regional level (20 regional) and on a provincial level (110 provinces). To assess the situation on a national level, a national statement was requested by the Ministry of Environment. However, such a statement was not provided to BiPRO GmbH. Based on information provided in other information sources, it is most likely that there exists under-capacity.

Available information on Italy shows that there are large differences amongst the regions. There are regions with large under-capacity problems, as the region of Naples. Other regions do have sufficient installations for the treatment of municipal waste in place, for instance the region Lazio. Exemplary figures are available for some regions, however information is not sufficient to picture the situation of Italy as a whole.

In another report performed by BiPRO, Italy provides values for total MSW amounts, for 2007 and 2008. According to these data, in 2007, 73.000 tons of such waste out of the total generated 32.5 million tons were exported for disposal. In 2008, total urban waste generated was 32.5 million tons, of which 187.000 tons were disposed of abroad. The extent of self-sufficiency amounts to 99.8% (2007) and 99.4% (2008).

EU MS / Criterion	1.1 Decoupling	1.2 WPP	1.3 Amount of municipal waste recycled	1.4 Amount of municipal waste recovered (energy recovery)	1.5 Amount of municipal waste disposed	1.6 Development of municipal waste recycling	2.1 Existence of ban/restrictions for the disposal of municipal waste into landfills	2.2 Total typical charge for the disposal of municipal waste in a landfill	2.3 Existence of pay-as-you-throw (PAYT) systems for municipal waste	3.1 Collection coverage for municipal waste	3.2 Available treatment capacity for municipal waste	3.3 Forecast of municipal waste generation and treatment capacity in the WMP	3.4 Existence and quality of projection of municipal waste generation and treatment	3.5 Compliance of existing landfills for non-hazardous waste	4.1 Fulfilment of the targets related to biodegradable municipal waste going to landfills	4.2 Rate of biodegradable municipal waste going to landfills	5.1 Number of infringement procedures – WFD and Landfill Directives	5.2 Number of court cases – WFD and Landfill Directives	Overall score
AT	0	2	2 D	2 D	2 D	2	2	1	2	2	2	2	2	2	2	2	2	2	39
NL	0	2	2 D	2 D	2 D	2	2	2	1	2	2	2	2	2	2	2	2	2	39
DK	0	0	2 D	2 D	2 D	2	2	2	1	2	2	2	2	2	2	2	2	2	37
DE	1	0	2 D	1 D	2 D	2	2	2	2	2	2	2	1	2	2	2	2	2	36
SE	1	2	2 D	2 D	2 D	2	2	2	1	2	2	0	0	1	2	2	2	2	35
BE	1	2	2 D	2 D	2 D	2	2	2	1	2	2	0	0	2	2	2	1	1	34
LU	0	0	2 D	2 D	2 D	2	2	2	1	2	2	0	0	2	2	2	2	2	33
UK	1	2	2 D	1 D	2 D	2	0	1	1	2	2	2	1	1	2	1	2	2	32
FI	1	2	1 D	2 D	1 D	0	1	1	2	2	2	2	1	1	2	2	2	2	31
FR	1	2	1 D	2 D	2 D	1	1	1	1	2	2	2	1	1	2	2	1	1	31
SI	2	0	2 D	1 D	1 D	2	1	2	2	0	2	0	0	0	2	1	1	2	25
ES	2	0	1 D	1 D	1 D	1	0	1	1	2	2	0	0	1	2	1	1	1	21
PT	0	2	0	2 D	1 D	1	0	0	0	2	2	2	2	2	0	0	1	1	21
HU	1	0	1 D	1 D	1 D	2	0	0	1	0	0	0	0	2	2	1	2	2	19
IE	0	2	1 D	1 D	1 D	1	1	2	1	0	2	2	0	2	0	0	0	0	19
CZ	2	0	0 D	1 D	1 D	2	0	1	1	2	2	0	0	1	0	0	1	2	18
PL	1	2	1 D	0 D	1 D	2	1	1	1	0	2	0	0	1	0	0	1	2	18
EE	2	0	1 D	0 D	0 D	0	1	1	1	0	2	0	1	2	2	1	1	1	17
SK	2	0	0 D	1 D	0 D	1	1	0	1	2	2	0	0	1	2	1	1	1	17
IT	0	0	1 D	1 D	1 D	0	1	2	1	2	0	0	0	0	2	1	0	0	15
LV	2	0	0 D	0 D	0 D	1	1	1	0	0	2	0	1	2	0	0	2	2	14
CY	0	0	1 D	0 D	0 D	2	0	0	0	2	0	0	1	0	0	0	2	2	11
RO	2	0	0 D	0 D	0 D	1	0	0	0	0	2	0	1	0	0	1	2	2	11
LT	2	0	0 D	0 D	0 D	1	1	0	1	0	0	0	0	0	0	0	2	2	9
MT	0	0	0 D	0 D	0 D	2	0	0	0	2	0	0	0	2	0	0	1	2	9
BG	2	0	0 D	0 D	0 D	0	0	0	0	0	0	0	0	0	2	1	1	2	8
GR	1	0	0 D	0 D	0 D	0	0	0	0	2	0	0	0	0	0	0	0	0	3

Note: Scores for the criteria 1.3, 1.4 and 1.5 (marked with '**D**') are doubled for overall scoring.

Table A1: *Overview of scoring of each criterion and overall score for each Member State, according to: Bipro, 2012. Screening of Waste Management Performance of EU Member States, Brussels*

ANNEX 2 - Relation between MSW production and GDP

In Paragraph 6.1 of the chapter about waste characterization is presented the relation between MSW and GDP. GDP is used as an indicator for predicting the production of MSW production over time, and their trends usually grow simultaneously.

In this Annex some further considerations are made, in relation Europe.

The GDP and other economic indicators are strongly related to the waste management efficiency, as can be noticed in Figure A1 and Figure A2, which regard the relation of MSW production and GDP in Europe.

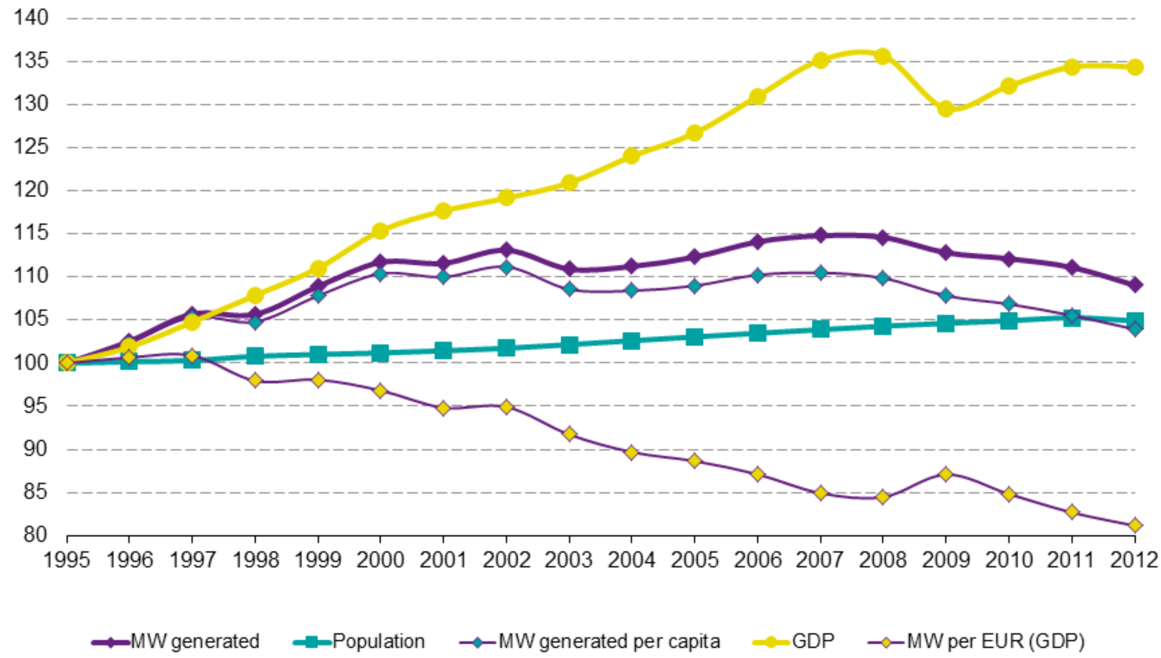


Figure A1: *Relation between MSW generated in Europe and the GDP (www.eurostat.ec)*

From the graph in Figure A1 it's possible to notice that from 1995 to 2002, there was a steady rise in the generation of municipal waste in the EU-27. This trend was interrupted in 2003, which can to some extent be attributed to changes in methodology and classification which reportedly took place in many countries in the period around 2002.

Up to 2002, the increase in waste generation exceeded population growth. Accordingly, the population related indicator on municipal waste generated also rose. The indicator grew at an average rate of 1.5% per year. In 2003, the indicator fell. The subsequent increase in 2007 did not raise the indicator above the level recorded in 2002. By 2012, the indicator fell to approximately the 1997 level (www.epp.eurostat.ec).

The drop in 2009 after growth from 2003 to 2008 was also observed in the series of many countries. This was explained by economic growth until 2008, followed by a decline in 2009.
At EU-27 level, GDP showed an upward trend, with an annual growth rate of 1.7%, from 1995 to 2012. Annual economic growth thus clearly exceeded that of municipal waste generation over that period. Economic growth was much higher than municipal waste generation, especially between 2002 and 2008.
The relationship between economic development and municipal waste generation is illustrated by the line "MSW generation per EUR (GDP)", i.e. a moderate decline up to 2002, by 0.7% per year, and a sharp decline by 1.9% per year between 2002 and 2008. In 2009, the economic decline was even sharper than for waste generation, pushing the value for waste back to the level for 2006.
Figure A2 shows the relations between MSW/GDP (blue line) and MSW/family outgoings (red line) in Italy. It is easy to recognize the relation between them.
In Figure A3 is represented graphically the Gross Domestic Product per inhabitant in Europe.
It's possible to notice the slight difference of GDP in Germany, where the South is a bit richer than the North, and also the former eastern block has a slightly lower GDP per capita.
In Italy it is possible to notice the big difference in GDP per capita from the North to the South, where the North has a GDP upper the European average, while the South is far below this average. As explained previously this aspects influence strongly the waste management system. For that reason it results often difficult to give average values related to waste data about Italy.

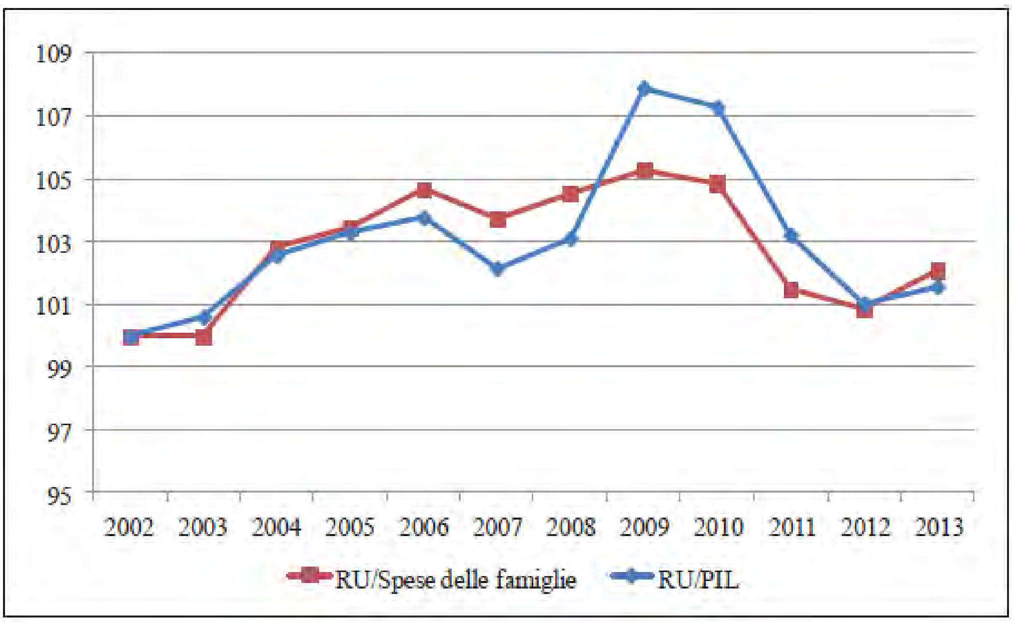


Figure A2: *Relation between MSW, GDP and family outgoings in Italy (ISPRA-Rapporto Rifiuti Urbani)*

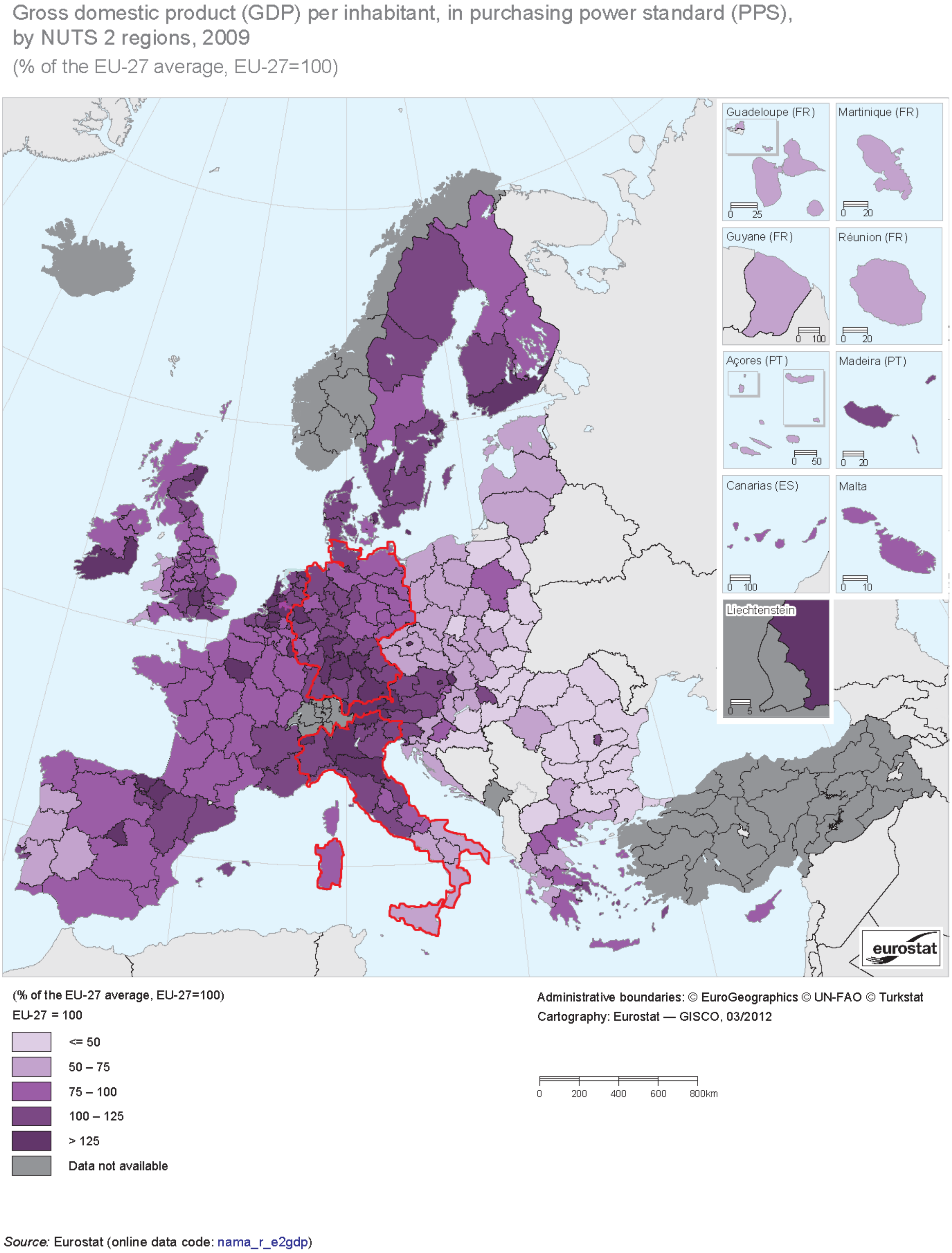


Figure A3: *GDP per inhabitant in the European Union (www.eurostat.ec)*

ANNEX 3 - German and Italian detailed MSW composition

In Chapter 6 the general waste composition in Germany and Italy is shown, providing the percentage and the amount in [t/y] of the seven waste categories defined. As already mentioned, the values are based on the average of different data of the MSW composition in the two countries. For the sources of the data used to create the average values of this study refer to Page 39 and Page 40 of this thesis.

In this annex the composition of the different categories is shown, dividing them in further subcategories, for which are also provided the percentage and the amount expressed in [t/y].

Detailed German MSW composition

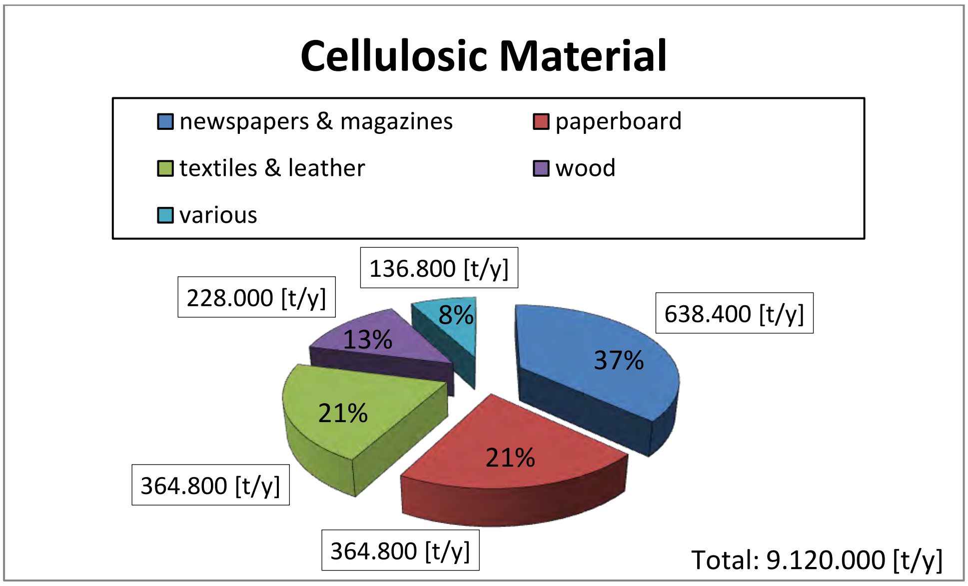


Figure A4: *Cellulosic Material subcategories in Germany*

About the plastic materials, the polyethylene fraction is the biggest fraction, and in it are counted also polyethylene terephthalate (PET) materials, like for example plastic bottles and food containers.

Polyvinylchloride instead is used for example for pipes, cables and other small household tools, due to its high hardness and mechanical properties. Also Polypropylene is used for household tools like bottle plugs, CD boxes, coffee capsules, the typical white plastic glasses and a lot of other things.

Polystyrene is used mostly for packaging material, while polyamides as Nomex and Kevlar are used for firefighters vests, bulletproof vests, ropes and other resistant materials.

Also lots of other plastic materials are produced, and so present in the waste, like glues, lacquers and resins.

In Germany 35% of the plastic material is used for packaging material. In the year 2011 more than 99% of the plastic waste was used again: 42% were reused after a cleaning phase and 56% were used as fuel in energy production.

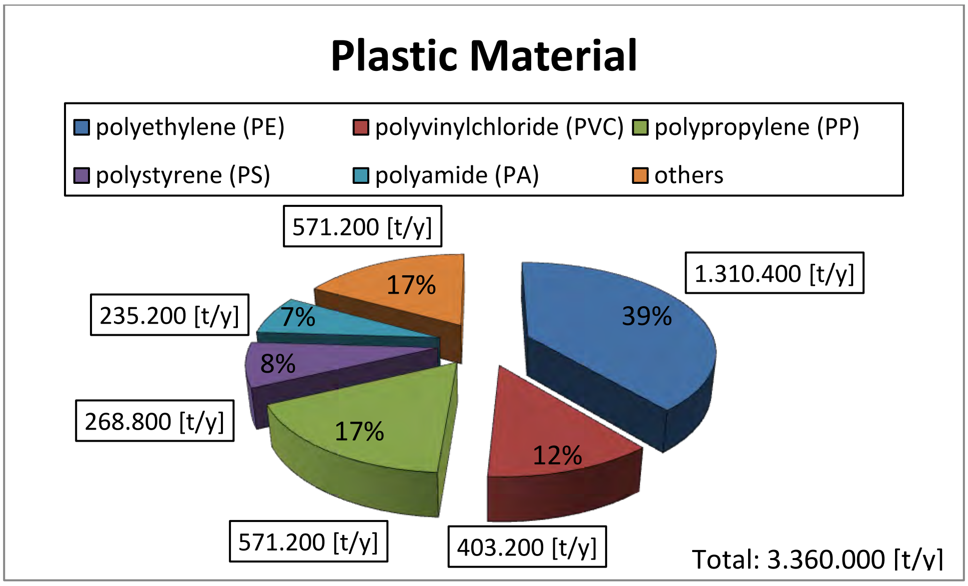


Figure A5: *Plastic Material subcategories in Germany*

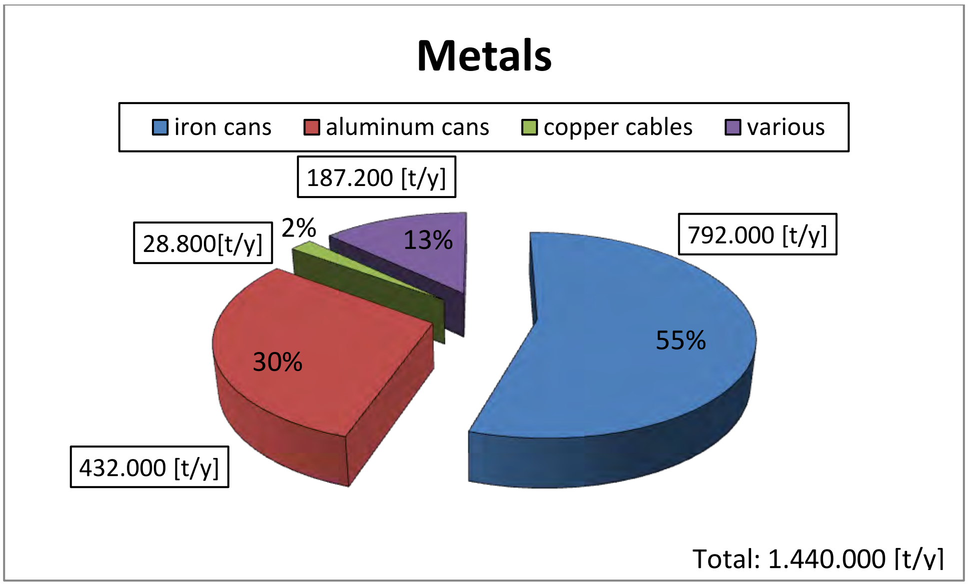


Figure A6: *Metal subcategories in Germany*

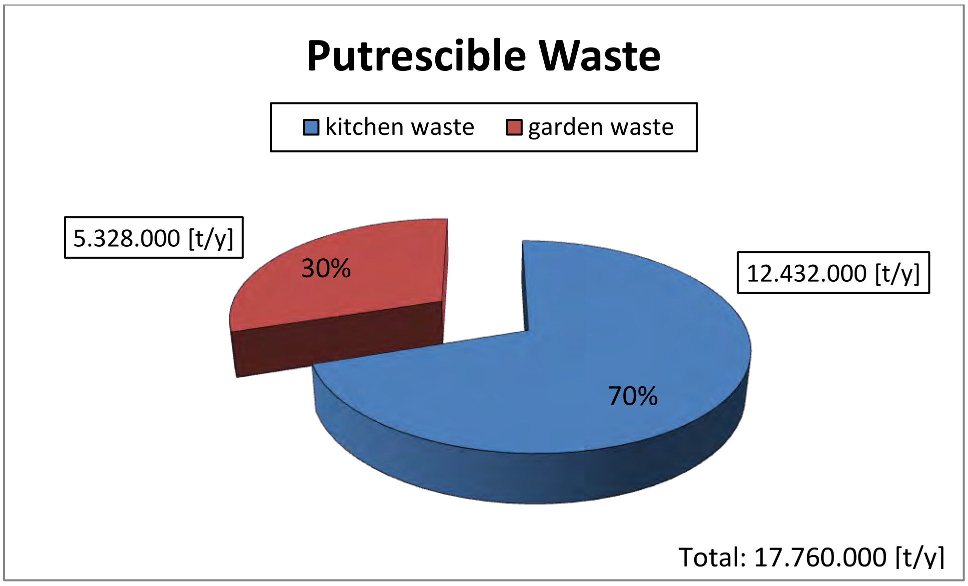


Figure A7: *Putrescible Waste subcategories in Germany*

The putrescible waste (biowaste) is in greatest part composed by the kitchen waste of the households, and partly by the garden waste.

This waste fraction, together with the Cellulosic Materials, is the one which have to be reduced according to *Directive 1999/31/EC,* to reduce the amount of biodegradable waste in landfills.

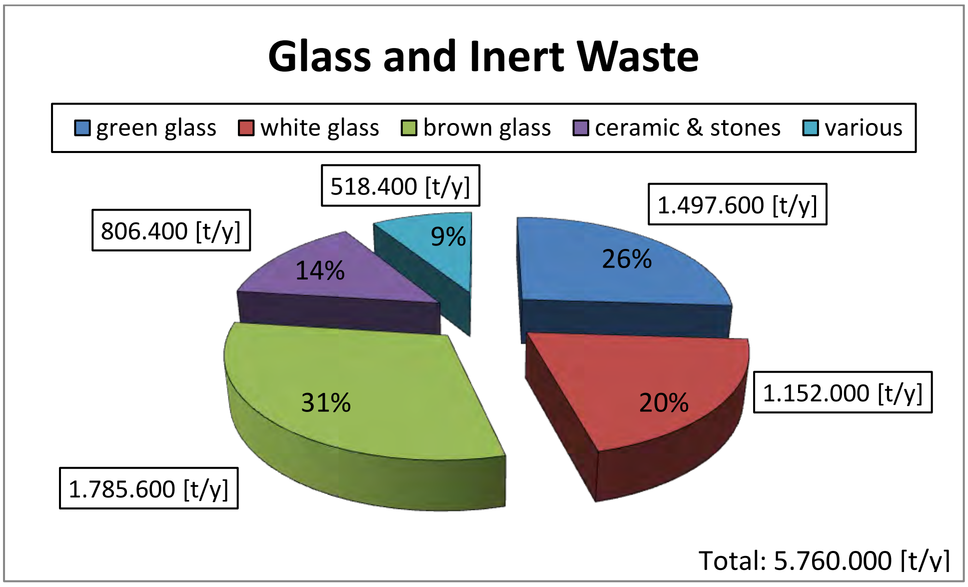


Figure A8: *Glass and Inert Waste subcategories in Germany*

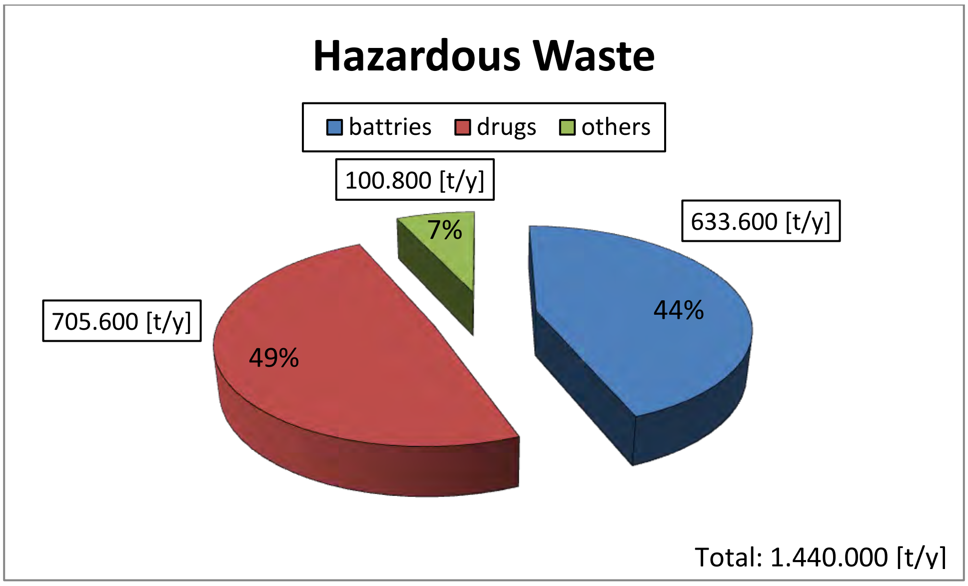


Figure A9: *Hazardous Waste subcategories in Germany*

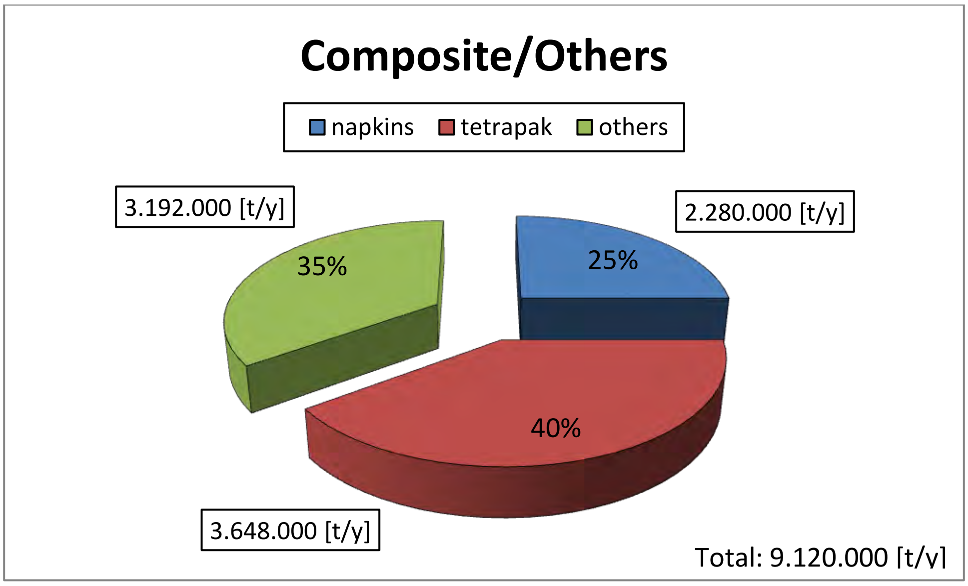


Figure A10: *Composite /Others Waste subcategories in Germany*

Detailed Italian MSW composition

In the same way as done for the German waste composition, in the following pages the Italian MSW composition is shown, defining the amount of each subcategory.

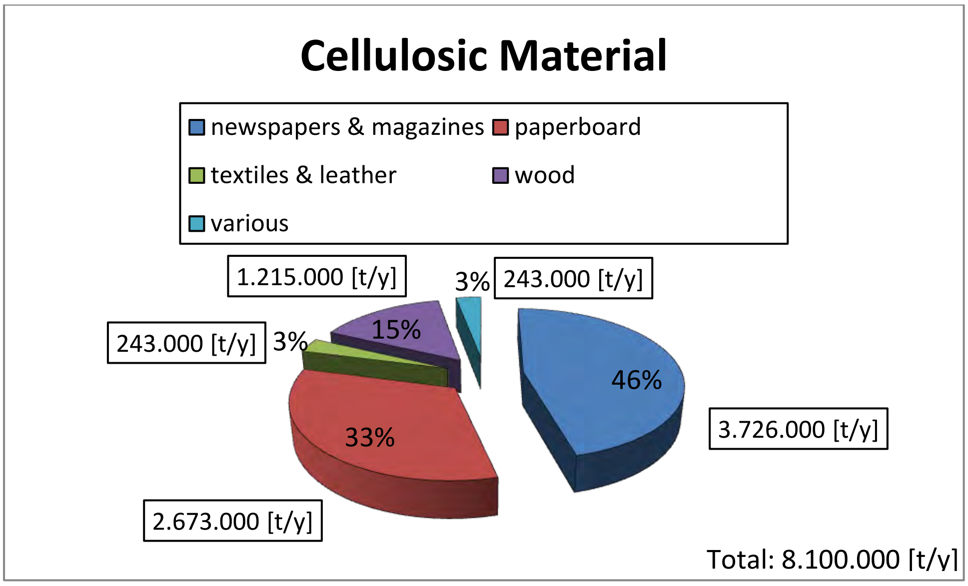


Figure A11: *Cellulosic Material subcategories in Italy*

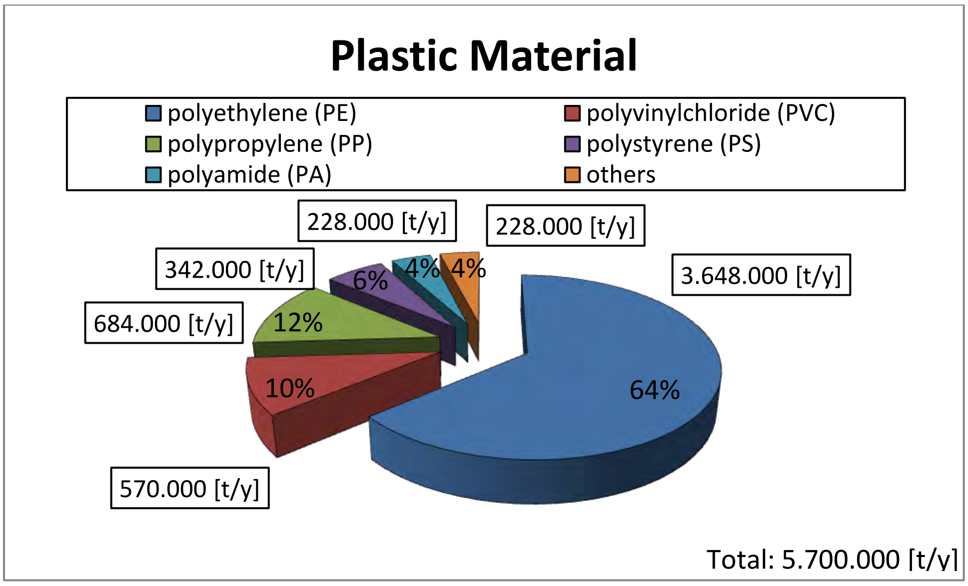


Figure A12: *Plastic Material subcategories in Italy*

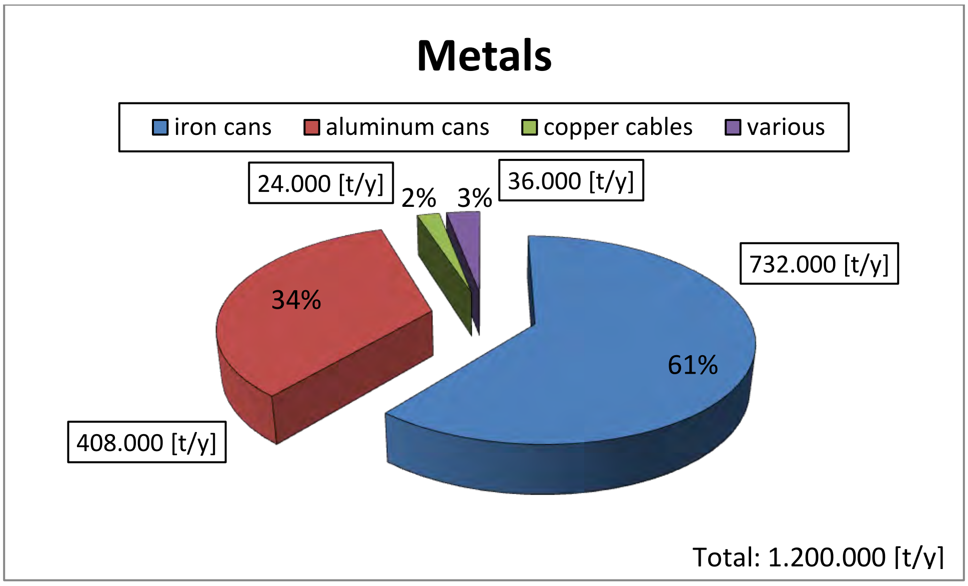


Figure A13: *Metal subcategories in Italy*

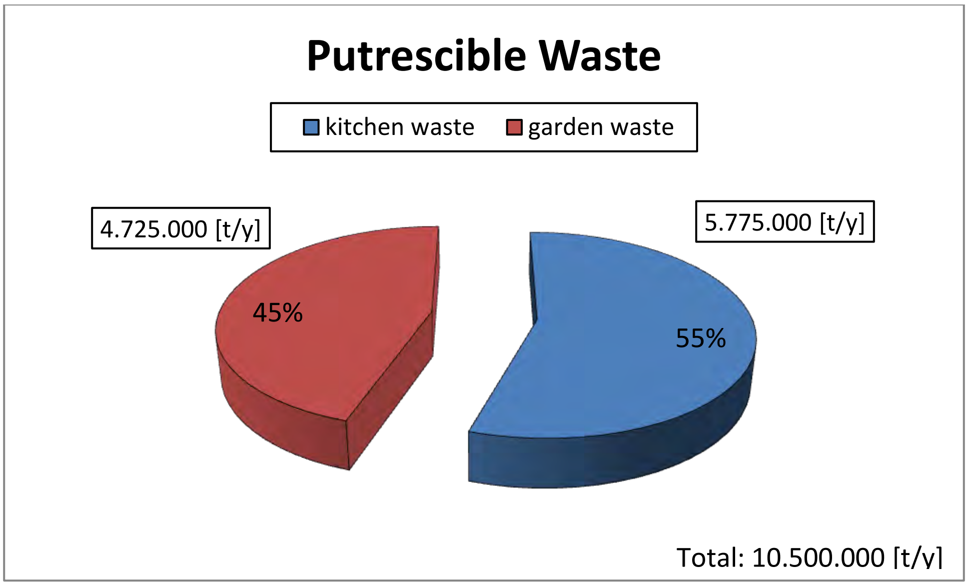


Figure A14: *Putrescible Waste subcategories in Italy*

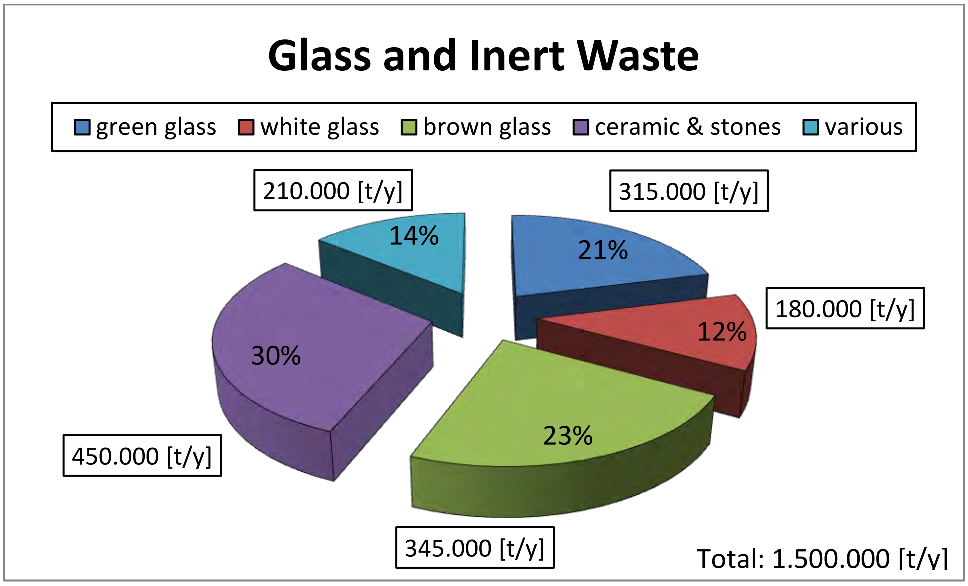


Figure A15: *Glass and Inert Waste subcategories in Italy*

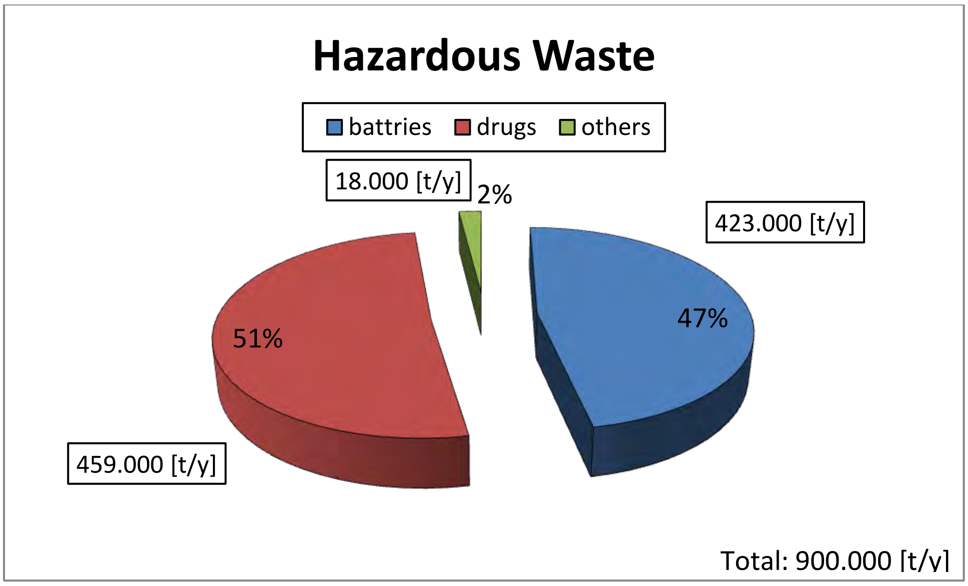


Figure A16: *Hazardous Waste subcategories in Italy*

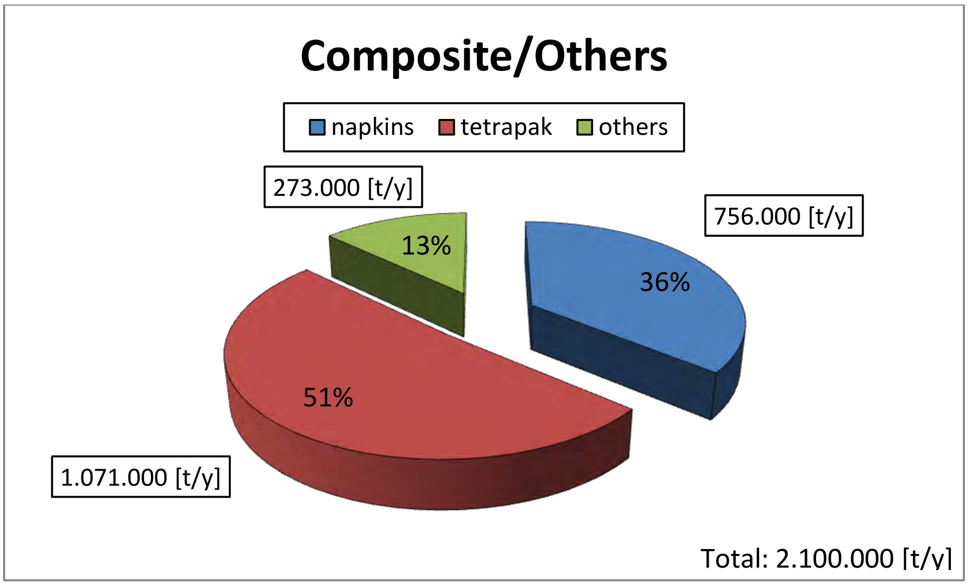


Figure A17: *Composite /Others Waste subcategories in Italy*

ANNEX 4 - Separate Collection amounts per category

This Annex contains the values of separate collected waste in the last years in Germany and in Italy. The values are referred to the different categories used in the separate collection.

1000 tonnes	2002	2003	2004	2005	2006	2007	2008	2009	2010
Glass*	3 106	3 289	3 100	3 572	1 929	2 233	2 480	2 442	2 523
Paper & cardboard	8 590	8 419	7 740	7 895	8 080	8 121	8 528	8 088	8 000
Light packaging	5 654	4 929	4 734	4 601	4 532	4 975	4 885	5 000	5 141
WEEE	105	104	263	291	409	396	469	605	586
Metal, textile etc.	1 313	1 204	1 333	1 274	1 570	1 685	1 842	1 607	1 730
Green kitchen waste from households	3 465	3 447	3 661	3 776	3 757	3 743	3 897	3 882	3 764
Organic food waste from canteens etc.	485	354	578	476	603	668	535	694	726
Garden and park waste	4 163	3 845	4 172	3 924	4 044	4 509	4 421	4 607	4 964

Source: (Statistics Germany, 2012 and Statistics Germany, 2012a).*The decrease of recycled glass is due to a change of the registration principles

Table A2: *Composition of separate collected MSW in Germany from 2002 to 2010 stated in 1000 tons (Deutsches Statistisches Bundesamt, 2014)*

Waste category		Amount of collected waste				
		2009	2010	2011	2012	2013
		(1.000*t)				
Organic fraction (kitchen and garden waste)		3.743,7	4.186,8	4.500,8	4.813,4	5.223,5
Paper and Cardbouard	packaging	1.263,2	1.271,9	1.203,2	952,2	869,3
	other	1.698,9	1.790,8	1.865,7	2.085,4	2.182,7
Glass	packaging	1.173,6	1.480,9	1.426,5	1.407,4	1.430,1
	other	529,0	297,6	273,5	190,7	172,1
Plastic	packaging	505,7	556,7	698,6	849,3	909,8
	other	107,7	91,9	89,3	40,5	35,2
Metal	packaging	166,6	159,4	158,7	98,3	96,9
	other	173,6	158,4	144,3	150,6	143,6
Wood	packaging	201,8	201,1	203,2	199,6	209,9
	other	473,7	490,8	490,1	414,5	425,5
Electronic waste		216,9	253,7	249,3	219,7	209,5
Bulky waste		328,7	315,6	304,3	377,3	397,7
Textile		71,5	80,3	96,7	101,1	110,9
Selective		36,6	37,6	39,9	38,6	39,9
Other		85,5	79,1	103,9	53,7	52,3
Total Separate Collection		**10.776,7**	**11.452,6**	**11.848,0**	**11.992,3**	**12.508,9**

Table A3: *Composition of separate collected MSW in Italy from 2009 to 2013 stated in 1000 tons (ISPRA,2014)*

ANNEX 5 - Landfill Simulation Reactor tests on pretreated and untreated MSW

A Landfill Simulation reactor consists in a device which contains one or more waste samples, which are extracted from a landfill body without being mixed. Using a driller the coring procedure can easily be performed. The container is then connected to specific test devices, which allow to evaluate the physical and chemical composition of the waste sample.

Stegmann R., 2013, provided a graphical comparison of the trend of different parameters, both in the case of pretreated MSW and untreated MSW, based on a LSR test. The parameters analyzed are the biogas production, BOD_5, COD, pH and the nitrogen presence. The timescale considered in the graphs is a period of four months.

Figure A18: *Landfill Simulation Reactor (Stegmann R., 2014)*

Comparing the biogas production trends in the two cases, it is notable that in the case of the pretreated waste the maximum biogas production is about ten times lesser (200 l/kg dry matter respect to 25 l/kg dry matter).

The pH value in the pretreated waste sample is very stable (around 7) respect to the one in the untreated waste, which varies between 5.5 and 7.5, due to the acetogenic phase in the methane production.

The values of BOD_5 and COD at the beginning of the sampling are the typical values for untreated waste (about 28.000 and 42.000 mg/l), so very high, and are then reducing in time. In the case of pretreated waste the initial COD is about 2400 mg/l and reduce then in time.

The BOD_5 has at the beginning a value of 1200 mg/l and is very soon reduced to a very low value.

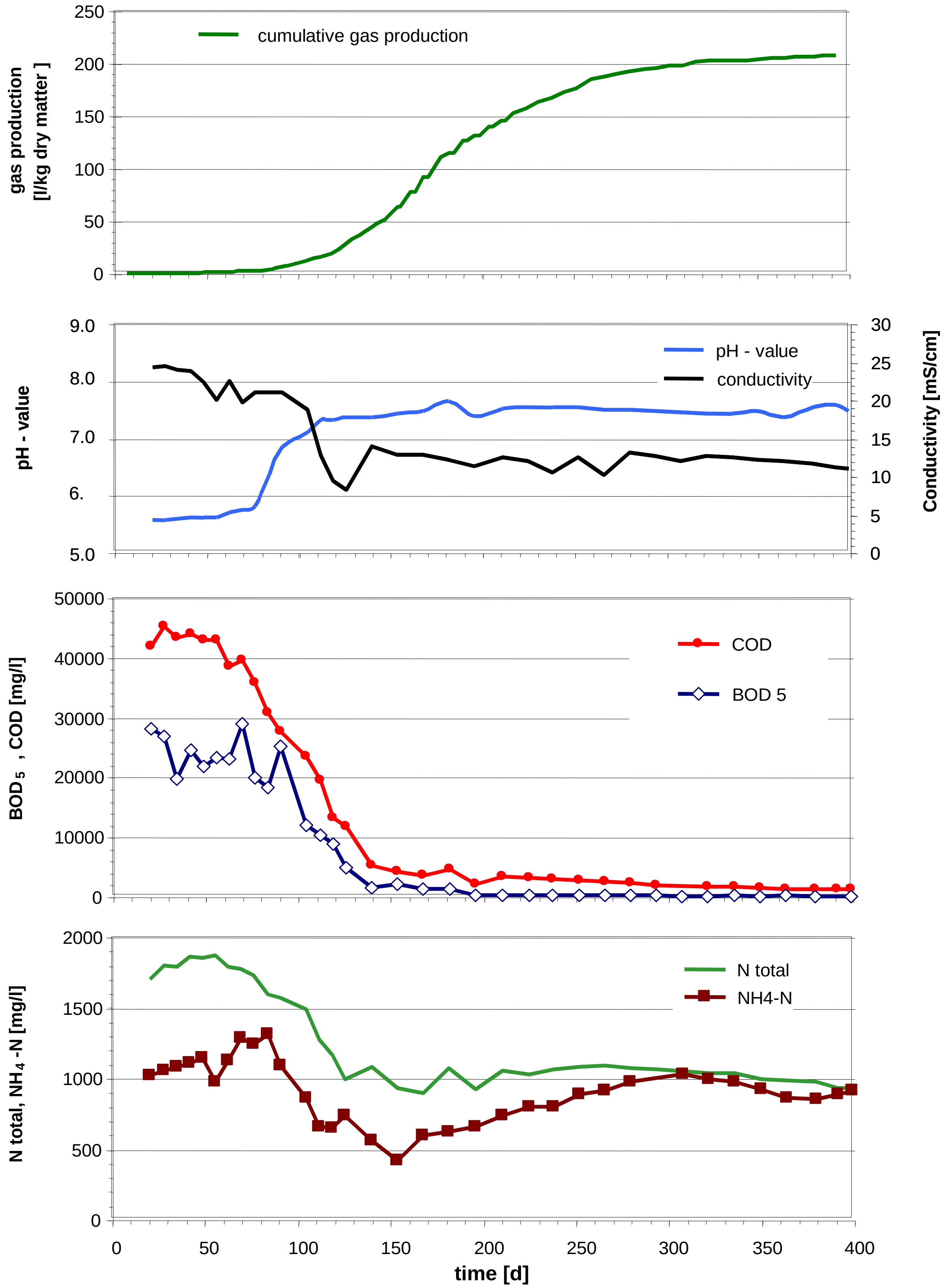


Figure A19: *Untreated MSW sample parameter trend from a LSR test (Stegmann R., 2014)*

Also the total nitrogen and the NH_4 are significantly reduced in the case of the pretreated waste.

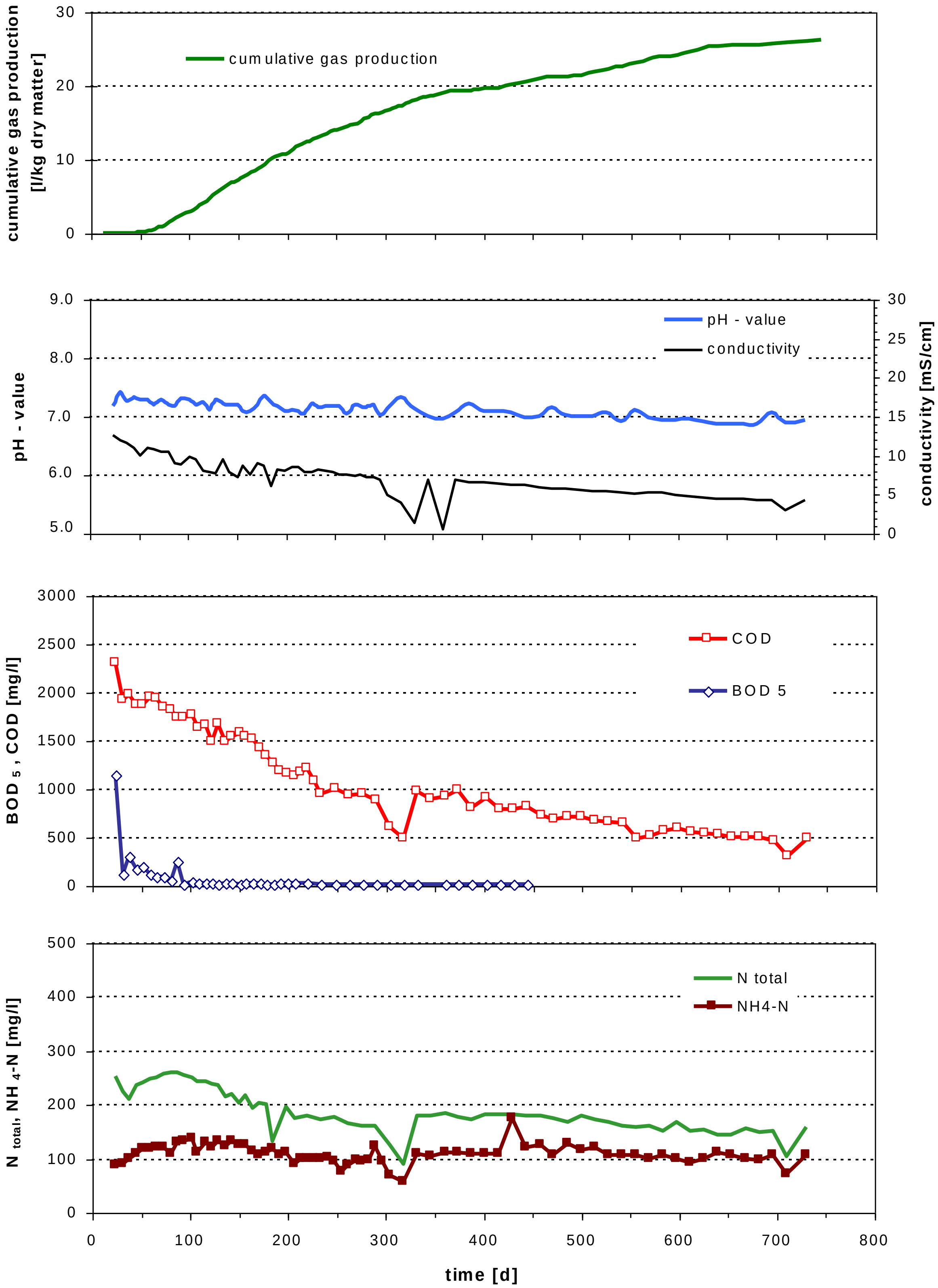


Figure A20: *Pretreated MSW parameter trend from a LSR test (Stegmann R., 2014)*

ANNEX 6 - MBP combinations for different MSW fractions

In Chapter 11 are discussed the most common pretreatment options for MSW. In MRFs very often this treatments are combined, and the waste which enter the facility pass through different treatments, and is from time to time separated and treated.

There is no general way to decide which pretreatment combination have to be used for a particular waste fraction. Every mechanical treatment gives as output different waste fractions, and some impurities. The impurities can't be recycled usually, and go so to the incinerator or landfill.

In this annex there are shown different possibilities for combining mechanical and biological pretreatments in a MRF, for the main MSW categories. This possibilities are proposed by myself, and should not be seen as the only possible way to combine pretreatment technologies, but rather as one of the several possible options.

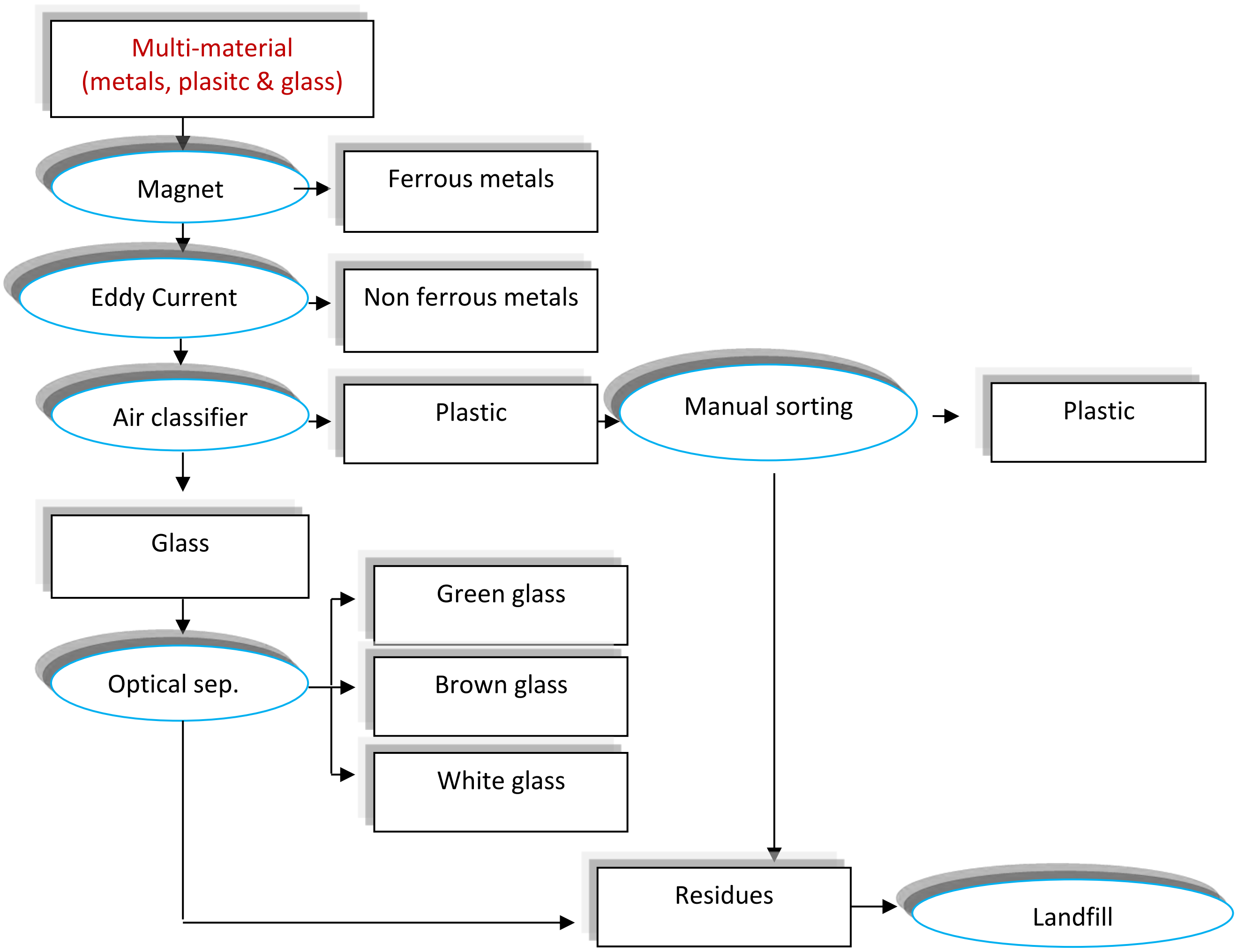


***Figure A21**: Multi-material MP option*

The choice of the combination of pretreatments have to be taken considering different factors, among others the cost of pretreatment technologies, waste characterization, separate collection, amount of impurities and other aspects.

About Figure A18, the waste of this fraction can be easily segregated thanks to the very different properties of each material. The first treatment proposed is a Magnetic and Eddy current separation, so to obtain three fractions: ferrous metals, non-ferrous metals, and the third fraction with plastic, glass and impurities. In metals there are no impurities which can be separated, so they will be directly conferred to a receiving facility. The remaining part will go to an Air classifier, to separate plastic from glass by density. At this point glass will be subdivided with an optical near infrared separator by color, and sent to a receiving facility. Plastic will be cleaned from impurities with manual sorting and sent to receiving facilities too. All the residues of the process are brought to landfill because of their low degradability.

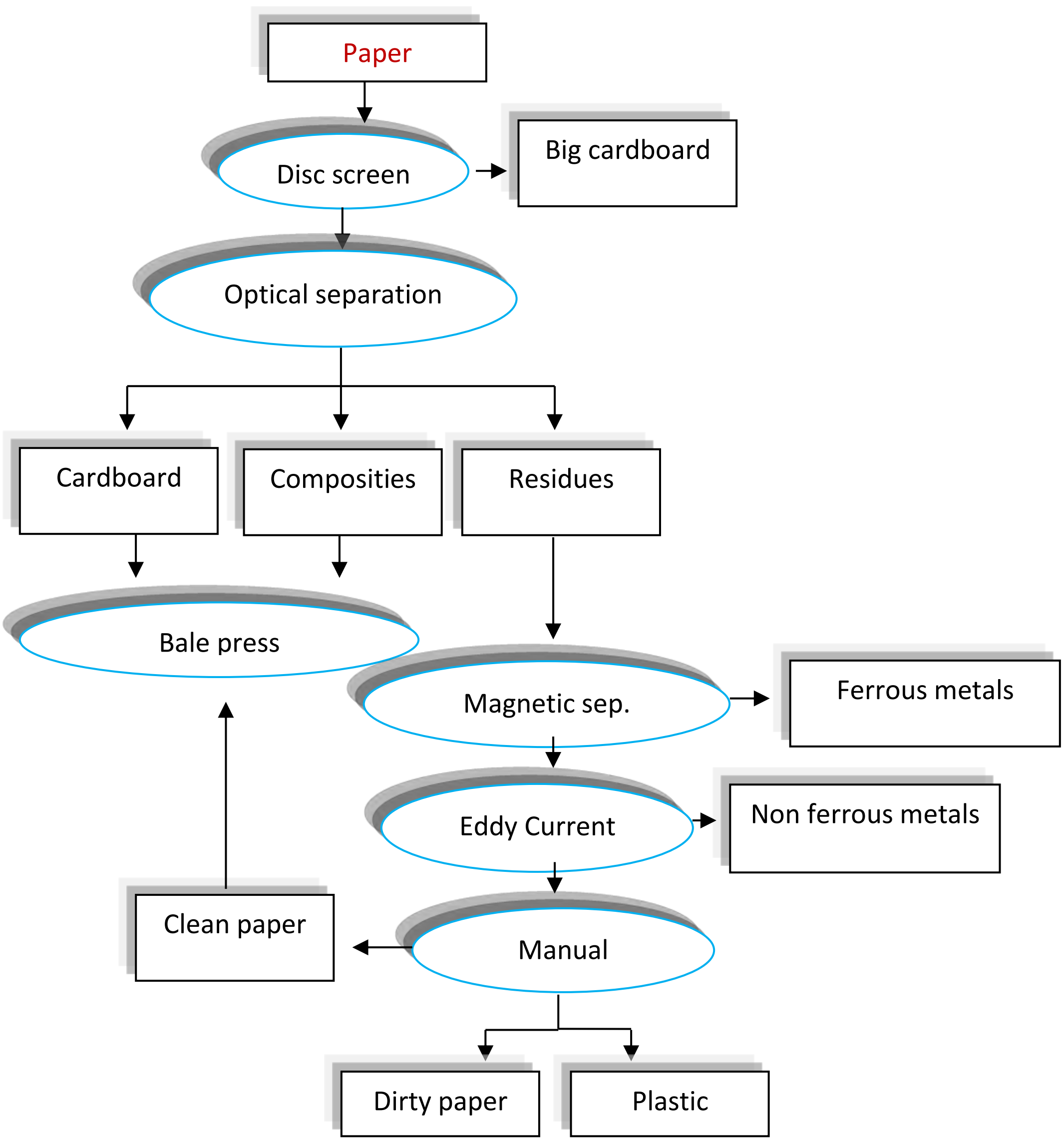
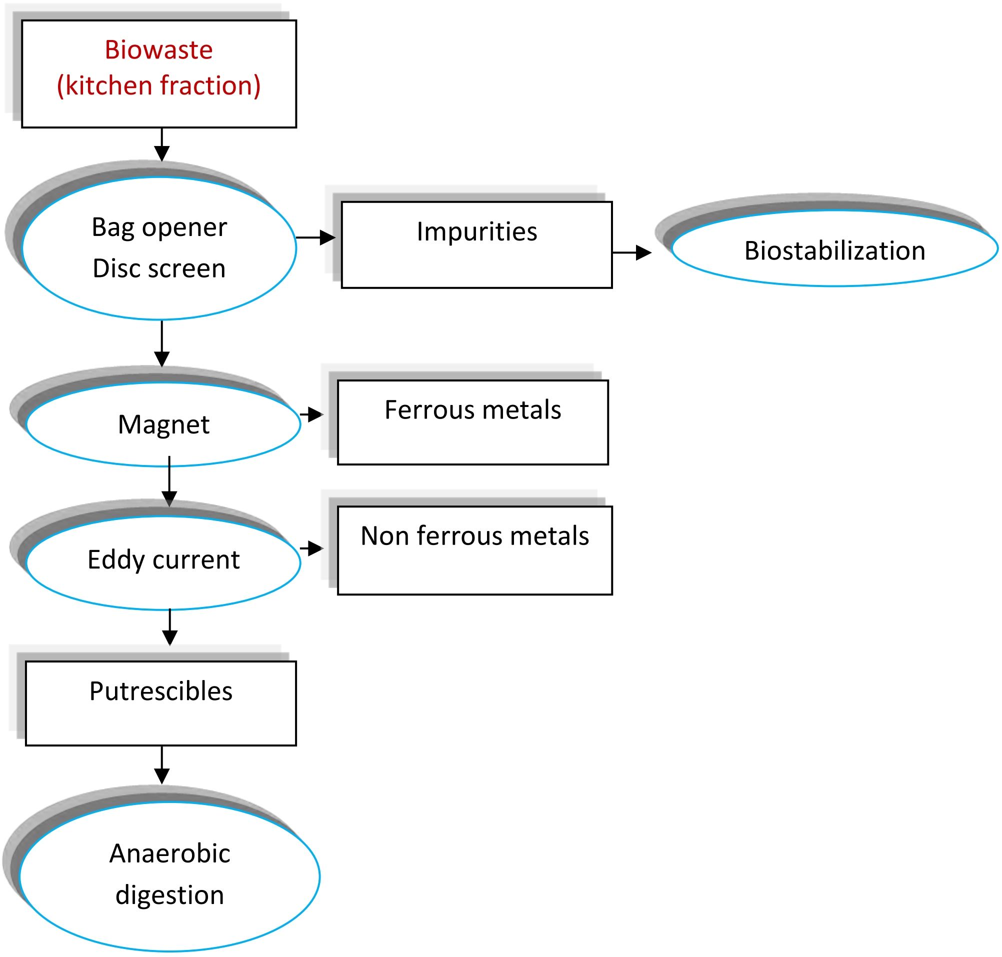


Figure A22: *Paper MP option*

The paper fraction represented in Figure A19 can be separated firstly based on the size, with a Disc screen with a sieve of 50 cm, so that mainly cardboard is removed. Then an optical separator subdivide cardboard and composites from the residues. After, metals are removed with a magnet and an Eddy current separator, so that only plastic and some dirty paper remain to remove, by manual sorting. The last step in the paper treatment will be the pressing to bales or briquettes by which the volume of paper and cardboard is reduced, and then the fraction is sent to receiving facilities. Metals and plastic obtained are very clean, so they are sent to receiving facility with metals and plastic from the multi-material treatment.



***FigureA23**: Biowaste MBP option*

Figure A20 shows that the organic fraction can be treated with an anaerobic digestion process for instance. To achieve the best efficiency possible in this process the substrate should be degradable and smaller than 80 mm, so the pretreatment has the aid to remove the not degradable fraction and impurities bigger than the threshold dimension.

Putrescible waste is mostly disposed in bins closed in bags. For this reason the first proposed treatment is a bag opener.

This can be done with a Trommel screen, which performs even the screening in order to immediately remove bags and impurities like plastic films, paper, napkins, which will undergo bio-stabilization. After the Trommel, waste is disposed on a conveyor belt, and with a magnet and an Eddy current system ferrous and non-ferrous metals are removed. Putrescible waste is then ready to be degraded in the anaerobic digester.

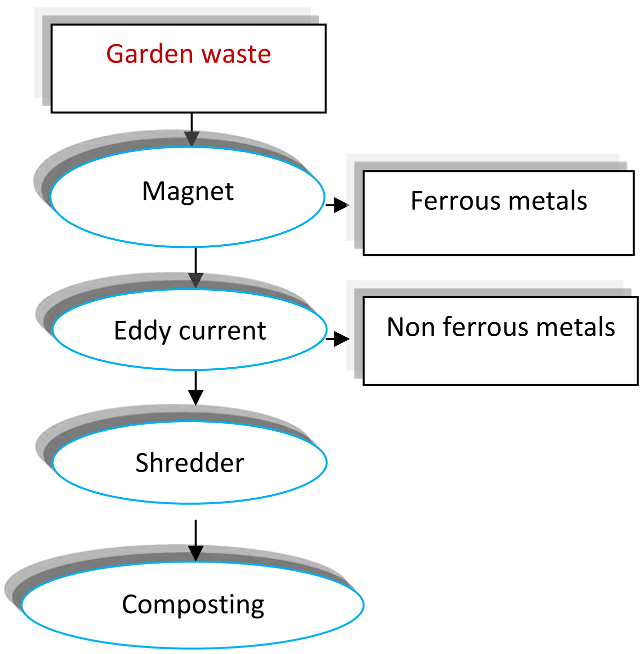


***Figure A24**: Garden waste MBP option*

Garden residues (Figure A21) can be disposed in bins both close in shoppers or free. The amount of metals require the provision of an adequate treatment, so that they are removed with a magnet and an Eddy current separator. Branches are then shredded in small pieces, and will be mixed with the putrescible fraction in order to reach an optimal nutrients ratio for the digestion in a composting plant.

The last proposed pretreatment combination regards the unsorted MSW fraction (mixed waste), and is represented in Figure A22. In this fraction waste is very heterogeneous, and recoverable material has low quality due to putrescible residues attached on it, but metals and putrescible waste can be recovered anyway. At first bags need to be opened, so the garbage has to pass through a bag opener Trommel. Then metals are removed with a magnet and an Eddy current separator. At the end a fine fraction with a diameter smaller than 50 mm is obtained thanks to a Disc screen and sent to bio-stabilization.

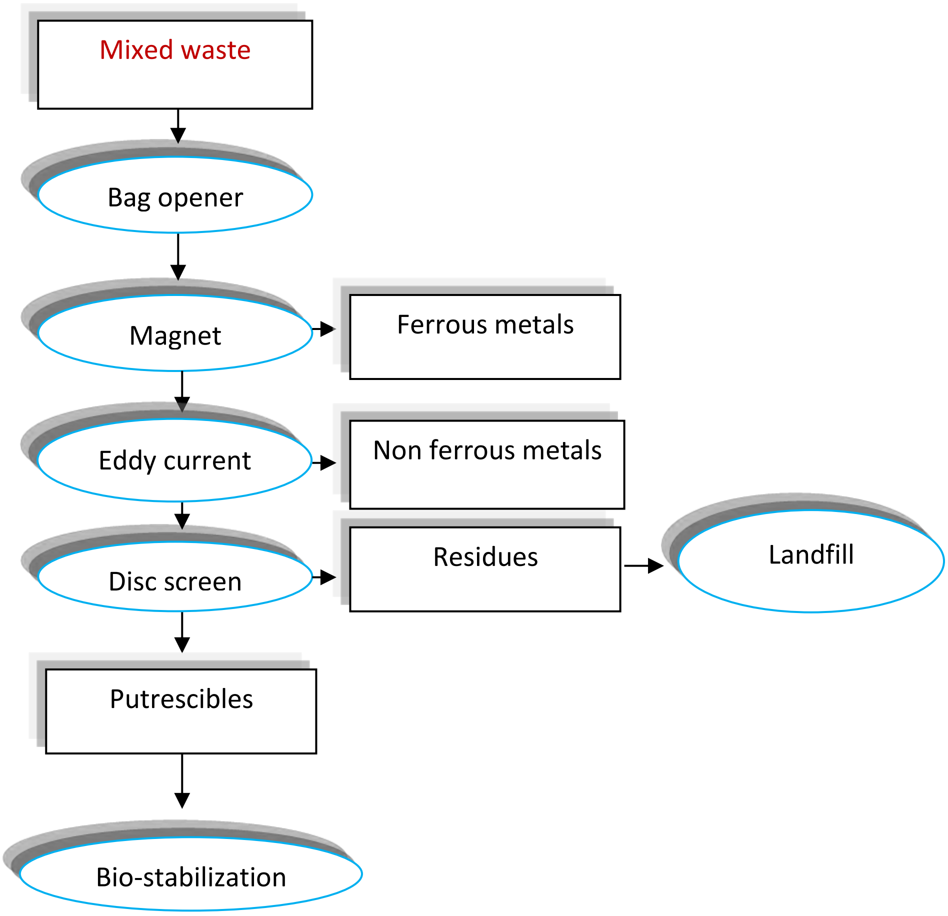


Figure A25: *Mixed waste MBP option*

Thanks

I want to thank my German supervisor Dr. Christoph Wünsch for his advices and his help in the writing and the correction of this work, and my Italian supervisor Prof. Raffaello Cossu for his support and his teachings in this years.