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Waste treatment in Greece after the passage of EU Landfill Directive.
Landfill Bioreactor Cell treatment as sustainable solution

Master's Thesis

by

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Abstract

Due to economic growth Greece has experienced a large amount of waste generation during the last twenty years. Landfill has been the predominant waste treatment method which applied so far in the country. A large portion about 90% of the refuse is disposed in Sanitary Landfills and open dumps. European Union concerns for the human health, as well as the environment impose a specific framework for the waste management. The landfill directive places quantitative targets to reduce the landfilling of biodegradable municipal solid waste. Member States must reduce the total amount of BSW to 35% of BSW produced in 1995, until 2016. Greece because is a country with heavy reliance on Landfilling (up to 80%) took a four year extension to attain the targets (2020). Greece has made efforts to treat the biodegradable fraction of waste with composting, but the absence of source separation has as result the low quality of the composting product. Landfill Bioreactor Cell treatment that applied since 1990 in Southern Sweden is a promising case for Greece. The particular treatment method, is a low cost treatment, provides revenues for utilization of energy and nutrients. Energy is extracted as biogas and nutrients are recovered by the leachates. Thus, energy and nutrients enter back to ecocycle and therefore, to society.

Key Words: Landfill site, Biogas, Leachate, Bioreactor Cell, Landfill Directive, Incineration

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TERMS & ACRONYMS

BCR: Bioreactor Cell
CLD: Causal Loop Diagram
EC: European Commission
EEA: European Environmental Agency
EU: European Union
GDP: Gross Domestic Product
JMD: Joint Ministerial Decision
MSW: Municipal Solid Waste
CHP: Combined Heat and Power
BSW: Biodegradable Solid Waste
ACMAR: Association of Communities and Municipalities in the Attica Region
US EPA: US Environmental Protection Agency
RES: Renewable Energy Sources
WFD: Waste Framework Directive

1. INTRODUCTION

1.1 Background

Greek economy has been one of the fastest growing economies both within EU and in the entire world over the last thirty years. The country's economy produces large amounts of goods, products and services for the citizens. Apart from supply, demand also reflects the new unsustainable consumption patterns. Production and consumption always have a feedback relationship. Production of waste is the inevitable measurement of the socioeconomic development. As a result, large amounts of garbage are produced daily in Greece.

Together with the goods there came along 'bads'. The production of large quantities of waste clearly reflects the current unsustainable patterns of production and consumption. These unsustainable activities have reached the limits of the ecosystem's carrying capacity; the ecosystem cannot absorb the waste created by the society. Some authors have ranked waste in the same category as air and water pollution, and named it the "third pollution" (Small 1971). In these circumstances, the importance of waste management becomes clear and vital to society, while the human society has not closed the solid waste loops in production and consumption, moreover, it is impossible to reach a zero waste production level (according to current technology). That's why the solid waste treatment and disposal is a necessity.

Waste is an issue that all countries are concerned about. European Union has developed the legislative framework for the management of waste. Its top priorities are prevention, reuse and recycling, and EU also addresses waste treatment operations and various waste streams with relevant Directives. The member states are free to decide how they will meet EU requirements. EU directives concerning waste policy aim to attain the new framework based on the integrated waste management under the concept of sustainability.

1.2 General purpose, aim and objectives of the thesis

The general purpose of this thesis is to denote the possibilities for an environmentally integrated municipal solid waste management for Greece.
The new European Union policy for the waste sets new standards for an integrated waste management.
There are techniques and treatment methods with both strong and weak points. Some of them are inadequate for economic or technological reasons. Thus, the objective of this thesis is:
To identify and describe a suitable solid waste treatment method for Greece, addressing socioeconomic and environmental aspects.
To demonstrate that the adoption of this treatment is feasible taking into consideration 1) the needs of the country 2) EU legislation and 3) the method's efficiency and performance.

In achieving the above named objectives, this study will identify and describe EU's waste management policy, mainly concerning the final disposal of waste, as expressed by the regulations and directives about waste management; and also describe how the Greek government has adopted these regulations and directives.

The paper also examines the records from waste disposal practices in Filborna Helsiborg Sweden, particularly the Landfill bioreactor cells technique.

1.3 Methodology

The method followed in this study has been based on comprehensive literature review and system analysis.
Literature review provided definitions, theory and knowledge for different issues which were crucial to this study, such as definition of integrated solid waste management and its elements, definition of solid waste, details for the waste treatment methods and their effects, EU legislation framework, Greek legislation framework .

Interviews and Discussions with the representatives of the Authorities (Greek Ministry of the Environment, EDKNA , EPEM, Municipality of Kalamata) were conducted in order to collect data for the study (waste generation rate, waste volume, composition of waste), explain the special characteristics, express the official view, complement and expand the existing literature.

System analysis was used in order to demonstrate the connections and the interactions among the different factors involved in the system. Analysis has used CLD's diagrams to illustrate the cause-effect relationship between the variables.
The study tried to cover more explicitly the sustainable municipal waste management in Greece, under the principles of sustainability as defined in the relevant literature. All results are based on the aforementioned methods.

1.4 Limitations

The study focuses on the municipal solid waste management in Greece. Solid waste refers to municipal solid waste as well as Biodegradable Solid Waste.
The study principally focuses on treatment techniques (end of pipe solution), not on prevention schemes. Although recycling/reuse patterns affect the system, they are considered to be an external factor of the system.
The time frame is a short-term one. Due to lack of information and available data concerning the present year, some figures concern different years or periods.
The data for the Landfill Bioreactor Cell treatment is based on the Filborna solid waste treatment facility in Helsingborg, South Sweden.

2. Literature Review and Explanation of Central Concepts

2.1 Municipal Solid Waste (MSW)

2.1.1 Definition of Solid Waste

Because of the existence of many potential waste materials with variable composition in each category, various attempts at comprehensive definitions of waste have been made in the literature on waste management.

Wagner (1994) defines waste as "any material that has no apparent, obvious, or significant economic or beneficial value to humans". Eduljee & Arthur (1996) define waste as "scrap material or otherwise unwanted surplus substances, or any substance that requires to be disposed of as being broken, worn out, contaminated, or spoiled". Tchobanoglous et al (1993) defines waste as "all the materials arising from human and animal activities that are normally solid and that are discarded as useless or unwanted". European Commission, in the Directive on Waste (1975), defines waste as "any substance or object which the holder disposes of or it required to dispose of pursuant to the provisions of national law in force".

The Eurostat based on Joint OECD/Eurostat Questionnaire summarized the above definitions as "Waste refers to materials that are not prime products (i.e. products produced for the market) for which the generator has no further use for own purpose of production, transformation or consumption, and which he discards, or intends or is required to discard. Waste may be generated during the extraction of raw materials during the processing of raw materials to intermediate and final products, during the consumption of final products, and during any other human activity."

MSW definitions can be found in the Landfill Directive as well as in Individual Member States waste policy legislation. The OECD/Eurostat definition found in the joint Eurostat/OECD questionnaires (1992 - 2002) is:

"Municipal waste is waste collected by or on behalf of municipalities"

The definition also includes waste from the same sources and similar in nature and composition which:

- "are collected directly by the private sector (business or private non-profit institutions) not on behalf of municipalities (mainly separate collection for recovery purposes),
- originate from rural areas not served by a regular waste service, even if they are disposed by the generator".

It also includes:

- Waste originating from households (post-consumption waste), commerce and trade, small businesses, office buildings and institutions (schools, hospitals, government buildings)

- Waste from these sources collected door-to-door or delivered to the same facilities used for municipally collected waste, as well as fractions collected separately for recovery operations (through door-to-door collection and/or through voluntary deposits). It also includes similar waste from rural areas, even if this is disposed of by the generator.

(Eurostat, EEA, 2000)

2.1.2 Municipal Solid Waste Management

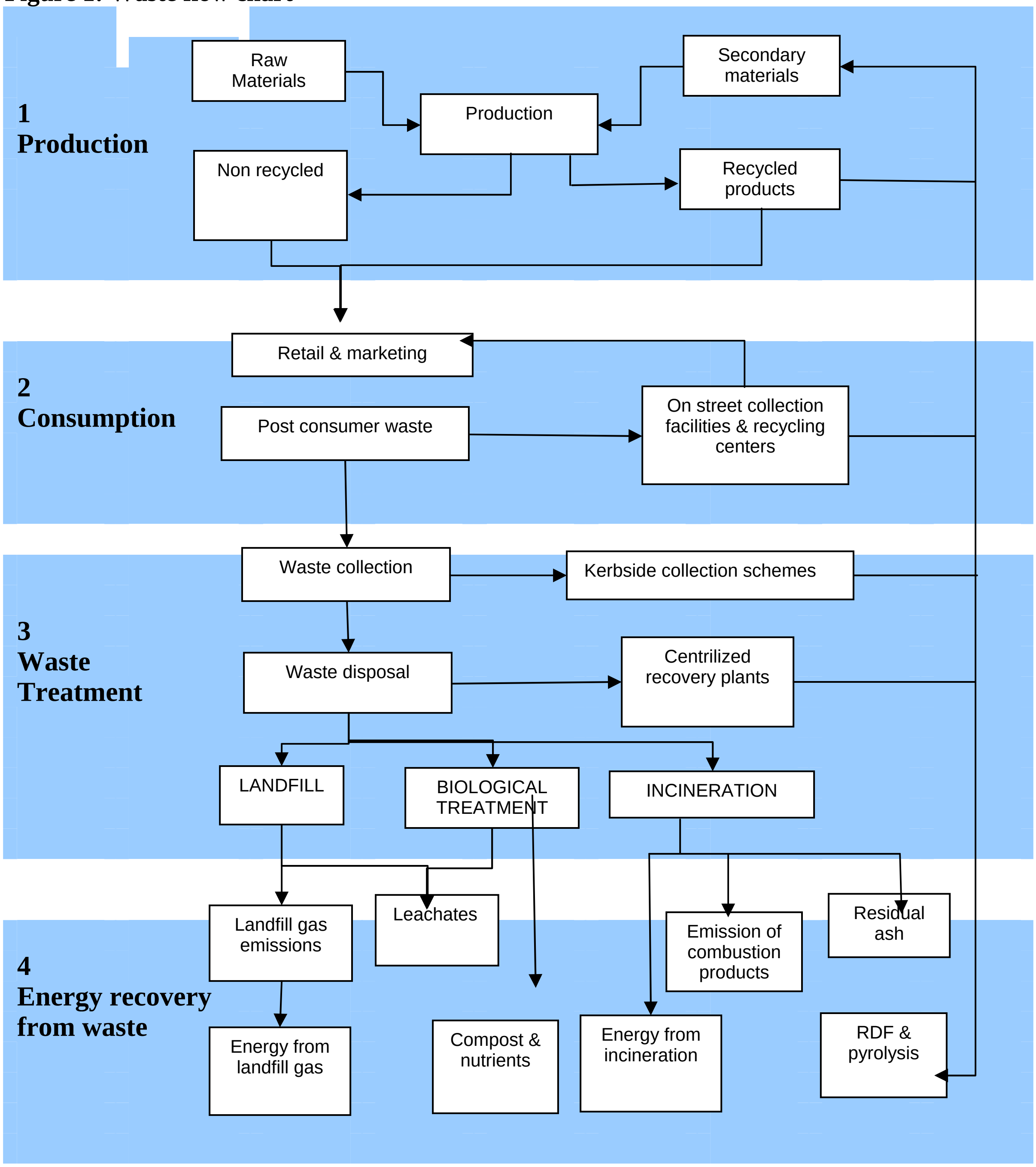
Municipal Solid Waste management is a combination of physical, chemical or/and biological procedures of transformation of the characteristics of the MSW.
The production of large quantities of solid waste reflects the present unsustainable patterns on the production and consumption. Waste production is a burden to society, a difficult problem with lots of parameters and no final solution. Total elimination of waste generation cannot be realized by current technology, and it is financially unfeasible. Moreover, the waste problem is a man-made environmental problem. The causes of the problem are:
-Population (more people, more waste: a linear relationship)
-Consumption (more consumption, more waste)
-Production technology for goods and services (unsustainable patterns and zero - environmental consciousness multiply waste generation).

Factors affecting the quantitative and qualitative characteristics of MSW can be sorted in four levels:
1st level - household: living standards, consuming patterns, lifestyle, the size of the household etc.
2nd level - geographical district: size, tourism, central heating, collection patterns followed by the authorized municipal body etc.
3rd level - Macroeconomics: GDP, income per capita etc.
4th level - Products: raw materials, packaging, expected life circle etc.
(Panagiotakopoulos 2002)

The quantities and components of MSW are expressed in weight. One of the advantages of weight is that it can be easily measured, and it is more reliable than volume measurement. Thus, MSW quantities are expressed in units of weight per capita per day, because in this way it is easy to periodically estimate waste quantities generated by different groups of the population and during different time periods.

Figure 1 demonstrates the flowchart of the entire system for waste generation. It can be divided into four parts, concerning Production, Consumption, Waste management and Final Treatment with or without energy and material recovery. This study focuses mainly on the last part of the model, but it also considers the factors of the other subsystems as external components.

Figure 1: Waste flow chart



Source: Gandy M. (1994)

The flow chart illustrates the Waste Management of the EU members. (Definitely, waste management varies in the different member states, but the chart could give a general view of the system). Production and consumption are the key factors for waste generation. Raw materials enter production, while the output of the process consists of goods for the market and residues/waste. Consumption, on the other hand, after making use of the goods, turns them into waste, too. The uprising product of consumption/production aggravates the problem and increases the need for integrated waste management.

EPA has defined the intergraded waste management as "the complementary use of a variety of practices to handle municipal solid waste safely and effectively". The uprising waste stream makes waste management indispensable.
Thus, integrated waste management is divided into collection schemes and disposal/recovery action. Waste treatment techniques are an essential part of waste management practices.
Integrated waste management techniques include source reduction, recycling, biological treatment (composting, anaerobic digestion), incineration and landfilling. The final part implies the energy recovery from the treatment methods with their final emissions.

2.2 Treatment Methods

2.2.1 Landfilling and its effects

"Landfilling is the operation of depositing waste on a site, normally engineered and prepared for the storage of waste and including in some cases systems for collection of gaseous and liquid emissions. Landfilling is a managed disposal of waste on land". (EEA, 2004). The definition states clearly that landfilling is not related to open dumping which is a random, not programmed action and does not meet the requirements for a clean environment. The operation of the landfill is advantageous as the sole waste disposal method because the technology is rather simple and the costs are significantly low (in comparison with other techniques).

Landfill is a complex system that encompasses different elements for its operation. The operation creates strong interactions between the environment, society and economy. The major input to landfill is the collected MSW and the final disposal on it. Landfilling is always the final option amongst all the alternative treatment methods.
Landfilling is the unavoidable subsystem of each MSW management system because every treatment method leaves residues which have to be disposed of in a landfill.

The advantages of the use of landfill in comparison with the other methods are:
Simple technology, lower cost for infrastructure and maintenance, land can be reused after the landfill's closure, potential recovery and utilization of biogas.
The exponential waste generation creates severe problems and requires immediate action in waste treatment. The current waste treatment methods have caused lot of direct and indirect problems in the environment, the economy and the society.

Landfill disposal has numerous consequences on the environment. The most important potential environmental effects are:

- The risk of contaminating groundwater and surface water
- The release of gases contributing to global warming
- The risk of explosion (Christiensen and Kjeldsen, 1998)

The aforementioned potential effects are caused by two pressures:
-landfill gas emissions
-leachate emissions

2.2.1.1 Environment

Landfilling remains the predominant waste disposal method in Europe. About 57% of the MSW is landfilled on Sanitary Landfills (ETC/WMF, 2004a).
Although this commonly used, the ongoing disposal of waste creates severe problems. Gas emissions as well as leachate emissions can be characterized as long time effects of landfill disposal, while the existence of the rest (odor, noise etc.) depends on the landfill operation.

Landfill leachate emissions

According to EU, leachate means "any liquid percolating through the deposited waste and emitted from or contained within a landfill" (Art. 2 (i) Council Directive on the landfill of waste). In other words, leachate is the water that has been in contact with waste; after infiltrating through the landfill and mixing with waste, water becomes leachate.

Leachate in landfills is generated from:
-the amount of precipitation filtered through the landfill body
-biochemical process and high moisture content of the deposited MSW (moisture content is very high in Greece; in some cases, it is up to 50%)
-moisture contained on the surface cover of landfill after it is closed. (Panagiotakopoulos, 2002)
As the water runs through the landfill, it washes up dissolved chemical substances and decomposition matter. Hence, the properties of leachate depend on many factors such as waste type, landfill conditions, weather conditions, biochemical decomposition occurring inside the landfill. Other important factors that affect leachate properties are the landfill age, the pH range, and the retained water. (Bilitewski, 1997).
Leachate properties are highly influenced by the anaerobic decomposition at the fermentation stage of waste in the landfill.

Landfill leachate quality and quantity vary with time; hundreds of toxic substances have been found in landfills, such as lead, cadmium, chromium, mercury, toluene, dioxins, organophosphates, and PCBs. Lead and mercury are toxic to living organisms that come into contact with leachate-contaminated water or soil.
Many chemicals (e.g. metals, aliphatics, acyclics, terpenes, and aromatics) have been detected in landfill leachates from domestic, commercial, industrial, and co-disposal sites (El-Fadel et. al.1997).
Their composition is difficult to be identified, but it contains high concentrations of BOD, COD and metals. The most important components of leachate are organic constituents (which give high concentration rates of BOD; COD and TOC[1]) and heavy metals. Organic constituents play crucial role in the procedures within the landfill body. Although it is difficult to generalize with regard to the particular chemical concentration of a leachate, the trend of continually decreasing concentration is a generally observed phenomenon (Panagiotakopoulos, 2002, Skordilis, 2001)

When the leakage of leachates reaches the bottom of the landfill, they must be collected and treated, otherwise the wide range of toxic substances arising from the decomposition of waste may cause contamination of domestic groundwater sources and eutrophication

[1] BOD: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, TOC: Total Organic Carbon

(deterioration of water ecosystems through oxygen depletion) of water sources in the surrounding area.

Table 1: **Chemical Composition of leachate from MSW**

Parameters	**Concentration Range mg/l**	**Parameters**	**Concentration Range mg/l**
Alkalinity (as CaCO3)	0–20 850	Nitrogen (Ammonia)	0–1250
Aluminium	0·5–85·0	Nitrogen (Nitrate)	0–9·8
Antimony	0–3·19	Nitrogen (Nitrite)	0–1·46
Arsenic	0–70·2	Nitrogen (Organic)	0–1000
Barium	0–12·5	Nitrogen (Kjeldahl)	3320
Berylium	0–0·36	Nickel	0-7.5
BOD5	0–1 95 000	Phenol	0·17–6·6
Boron	0·413	Phosphorus (Total)	0-234
Cadmium	0–1·16	Phosphate	0·01–154
Calcium	5–4080	pH	1·5–9·5
Chloride	11 375	Potassium	0·16–3370
Chromium	0–22·5	Selenium	0–1·85
COD	0–89 520	Silver	0–1·96
Conductivity (lmho/cm)	480–72 500	Sodium	0–8000
Copper	0–9·9	Thallium	0–0·32
Cyanide	0–6	Tin	0–016
Fluoride	0·1–1·3	TDS	584–55 000
Hardness (as CaCO3)	0·1–225 000	TSS	140 900
Iron	0–42 000	TOC	335 000
Lead	0–14·2	TVA(as Acetic Acid)	0–19 000
Magnesium	115 600	Turbidity	40–500
Manganese	0·05–1400	Sulfate	0–1850
Mercury	0–3	Zinc	0–1000
Magnesium		30-47	

Source: El-Fadel (1997)

Several studies have shown landfill leachate has been responsible for contaminating ground water supplies and surface water ecosystems. In the USA, more than 75% of the sanitary landfills pollute ground water with leachate (Lee and Jones, 1991). The extent of damage by leachate is largely unknown, given the complexity of leachate flows within landfills, the complex systems of aquifers, which may be affected, and a considerable lack of data. Leachate composition data is only available for the last 30 years and the long term behavior of leachate generation and composition is rather unknown (EEA, 2004). Even the impact of landfills is uncertain, with no suggestion of directly adverse effects on human health; the precautionary principle should apply, given the toxic nature of the materials involved.

Landfill gas emissions

Air emissions from landfills come from landfill gas, generated by the decomposition of refuse in the landfill. Gas generation is the result of biological chemical reactions that take place inside the landfill body. Landfill gas generation reaches a peak after 10 years, and practically ends after 25-30 years (Panagiotakopoulos 2002).

The quantity and the composition of gas depend on the age of the landfill, the composition of the disposed waste, its moisture, the type of disposal (e.g. daily coverage, range of compaction etc). The emitted gas from the landfill is created during the anaerobic biological activity and contains CO_2 (25-50%), CH_4 (30-65%), N2 (5%) with trace constituent of compounds that include volatile organic compounds (VOCs), CO and hazardous air pollutants (HAPs) with a participation of under 0.1 % (ETC/WMF, 2004b).

Landfills are the largest man-made source of methane (a potent greenhouse gas that has 21 times the warming effect of carbon dioxide). Worldwide, methane emissions from landfills and open dumps have been estimated to contribute ~30 teragrams (Tg) per year or 6% of total global methane emissions (Thorneole et al., 1994). It has been estimated that CH_4 contributes by 18% to global warming, 6-13% of which has been produced in landfills; this means that landfills have an annual contribution of about 1-2% to global warming. In Europe, it has been shown that landfills account for 30% of the total anthropogenic CH_4 emissions (ETC/WMF, 2004b).
The quantities of gas generated in a landfill can only be roughly estimated. One tonne of MSW can produce between 120 and 400m^3 landfill gas (Panagiotakopoulos 2002). Landfill gas is emitted to the atmosphere from the top and the sides of the landfill, if there is no gas collection system. On the other hand, landfill gas collection systems do not prevent significant emissions of the harmful greenhouse gas. A ETC/WMF (2004b) study has presented different estimations for different generating and recovery rates, the estimations ranging from 40% (recovered gas while the other emits to atmosphere) to 50%, while US EPA estimate that the recovery rate is between 60% and 80%. The average collected landfill gas seems to be about 60% of the generated quantity (Panagiotakopoulos, 2002). But both quantity and quality are dependent on such factors as composition, waste features, and the technology used.

2.2.1.2 Society

Human Health
Landfill emissions (gas and leachate) contain a number of pollutants which are dangerous for human health. Obviously, workers and the people living near the landfill are the most likely to be contaminated. Pollutants from gas emissions threatening human health are “acrylonitrile, benzene, carbon tetrachloride, methyl ethyl ketone, perchloroethylene, toluene, vinyl chloride, and xylene. Methyl mercury has also been detected at the working face of landfills. Landfill gas emissions also contain Volatile Organic Compounds that contribute to urban smog. There is also concern for emissions of dioxin/furans associated with landfill fires and to a lesser extent with landfill gas combustion” (Thorneloe, 1999). Heavy metals and chemical compounds from leachate are a serious threat to public health.

Vermin Attraction
Landfill is an artificial isolated biotope with its own characteristics. The abundant food, the coverage as well as the high temperatures attract vermins. Birds (seagulls, crows), rats, as well as numerous species of insects (flies, mosquitoes) are potential transmitters of serious illnesses and diseases.

Risk of Explosion/Fire
Methane can explode when mixed with air (under certain conditions). Apart from the risk of explosion, there is always the risk of fire. The inflammability of biodegradable waste is well known. The waste is dumped in layers with venting properties for better management facilitation. Venting properties are potential for fires to erupt into the landfill body, emitting hydrocarbons, carbon monoxide, and soot.

Land use
Landfill disposal needs land that cannot be used before the closure of the landfill. The problem that rises for the prospects of land use is the time required for a landfill to be considered sustainable. A landfill is sustainable if after 30 years it should be stabilized in a final storage quality. If the landfill's expected life is N then sustainability means the land would be released after N+30 years (Panagiotakopoulos, 2002). Hence, as the waste amount increases, pressures and needs for more disposal land are created. Additionally, from an economic point of view, the operation of a landfill deteriorates the area where it is located and always reduces the value of this area.

Odors
When landfill gas reaches the surface of the landfill it releases an unpleasant odor. In general, the gas is diluted, but dilution is not efficient enough to eliminate the odor. Odor is usually created when anaerobic areas of the active landfill body are exposed to the atmosphere. Generally, odors are not noticeable at distances of more than 500m.

Dust
Sources of dust and particulate contamination are the procedures taking place in the surface of the landfill. The concentration of dust depends largely on weather conditions. Annual mean maximum particulate level for Greece is about 200mg/ m^3.

Noise and traffic
Noise is generated in the surface area by delivery vehicles and landfill equipment. It is a nuisance especially to the people living near the landfill. Waste collection can also be annoying for the rest of the inhabitants, because it often causes traffic congestion, especially in the center of the city, mostly during weekends when the traffic is heavy.

2.3 Options for Diverting BMW from Landfill disposal
Available treatment methods and techniques for treating BMW heavily depend on the way in which the waste is collected. Nowadays, the available options for diverting BMW from landfill disposal are three: incineration with energy recovery (bagged waste mainly), central composting (garden waste, food waste) with material recycling (paper and cardboard), anaerobic digestion (food waste, animal fodder). Lately new technologies have become available, such as gasification and pyrolysis – these may play a more significant role in the future, but now the cost is too high. A new technique called Landfill Bioreactor Cell has been operating successfully in Sweden since the late 80s; this is based on the anaerobic procedure inside a common landfill.
Table 2 illustrates the relation between the waste stream and the available options for diverting BMW from landfill disposal.

A key issue when deciding on the proper treatment and its component waste stream is the availability of markets and outlets for the recovered materials or the revenue generation which will maintain their viability.

Greece, according to the EU landfill directive, has to reduce the biodegradable MSW landfilling dramatically in the forthcoming 15 years. The dependence on landfilling is unadvisable, so there must be a diversion to other waste treatment facilities and new schemes.

Table 2: **Available options for diverting BMW from landfill disposal**

Waste stream	Incineration	Gasification	Pyrolysis	Landfill Bioreactor Cell[1]	Composting	Anaerobic digestion	Recycling	Reuse	Manual or mechanical sorting
Wet mixed (bagged waste)	**x**			**x**	**x**	**x**			**x**
Refuse derived fuel (RDF)	**x**	**x**	**x**						
Food & Garden				**x**	**x**	**x**			
Food				**x**	**x**	**x**		**x**	
Garden				**x**	**x**	**x**			
Paper	**x**	**x**		**x**	**x**	**x**	**x**	**x**	
Textiles	**x**	**x**		**x**			**x**	**x**	
Wood	**x**	**x**		**x**			**x**	**x**	

Source: EEA 2002b

2.3.1 Thermal treatment/Incineration

Thermal treatment methods focus on the reduction of the amounts of landfilled waste and secondly on energy recovery. By this process the MSW is transformed into solid, liquid and gaseous emissions with a simultaneous dissipation of heat. Thermal treatment methods are based on the presence of oxygen during the procedure and can therefore be distinguished into three types:
Incineration (combustion in presence of oxygen), Pyrolisis (absence of oxygen), Gasification (in between the previous two) (Panagiotakopoulos, 2002).

Incineration

Incineration is a very common waste treatment method in Western Europe, (e.g. Sweden incinerates 38% of the total waste (RVF, 2004). The waste after their mixture by a crane enters into the incinerator's furnace for combustion. The temperature is 950 C at minimum. The incinerated waste generates thermal energy that can be recovered as heat (hot water/steam) or electric power or combinations of these.

[1] Bramryd

This treatment method has certain advantages: reduction of the volume of waste (90% of the total volume; 70-80% of the weight); the final solid residues are sterile; heat and power can be utilized and provide revenues (In Sweden, almost 95% of this energy produces heat, while the rest produces electricity (EC 2002b)); finally, as can be seen in Table 7, this method is valid for most waste streams (EEA, 2002b). Additionally incineration demands less space compare to landfilling. That is a major benefit especially for countries with limit land resources for landfills such as Denmark with lack of land. The combustion of the waste creates also less need for landfills because as it already mentioned the volume of waste is reduced significantly. Because of there are no leachate emissions the water pollution is avoided and the possibility is rather low.
Although it is a widely used practice, some obstacles are imposed on its adoption, for economic and environmental reasons. The physical characteristics of the waste generation also sometimes constitute a barrier. Generated and collected waste which contains a lot of moisture has low calorific power, thus waste combustion in such cases is not so energy productive procedure.

Environmental effects of incineration
Incineration causes several environmental effects. The MSW enter the plant as an input, while emissions to air, water and soil as well as energy recovery are the potential outputs. The most important effects related mainly to the air emissions and secondly to the production of bottom and fly ash.

More particularly, the contaminants from air emission include particulates, dioxins, heavy metals and their compounds (Cd, Tl and Hg), acid gasses (SO2, HCl, HF), nitrogen oxides (NOx), carbon oxide (CO), volatile organic compounds (VOCs)(*EC 2000a).* Impacts from air emissions can affect humans as well as the ecosystems. Particulates, dioxins, heavy metals VOCs, Sox, CO and SO2 would create adverse health impacts to human organism. Dioxins and heavy metals could also affect the ecosystem negatively. The effects depend on distance from the plant, topography, wind speed and direction etc. (Miller 2002, *EC 2000a)*
Although today the emissions have decreased dramatically after severe restrictions imposed by governments, there are still contaminants in the air from incineration plants. Although incineration decreases the waste by volume almost to 90% there are some residues, bottom ash (slag) as well as fly ash. Bottom ash can be disposed in a conventional landfill while fly ash (because of the toxic nature of the byproduct) must be disposed of in a landfill for hazardous waste (Miller 2002).

2.3.2. Biological treatment methods
Thermal treatment is one way of waste treatment. Biological waste treatment methods are, on the other hand, the competitive treatment method.
The objectives of treating biowaste by biological methods (instead of landfill disposal) can be summarized as the reduction of the waste’s potential to adversely affect human health and environment, recovery of valuable substances, and generation of a useful final product.
Biological waste treatment is based on the biodegradation of organic substances by various microorganisms. Microorganisms break down organic matter such as leaves, food waste, paper and wood in the presence of oxygen (Miller 2002).

The decomposition during composting occurs with air (aerobically) or during biogas processing without air (anaerobically) and the result is the reduction of existing organic matter. The biological waste treatment is an alternative method to incineration, and it can be used as a disposal method, whose goal is material and energy recovery (Bilitewski 1994).

The adoption of BWT reduces the volume of biowaste disposed in landfill. That creates numerous environmental benefits:
- Reduction of uncontrolled gaseous emissions from landfills.
- Reduction of the total amount of greenhouse gases (mostly CH_4).
Moreover, biological ecological waste treatment aims to "resemble natural ecological processes as much as possible and to achieve systems which are as closed as possible" (Bramryd, 2001)

2.3.2.1 Composting
The principle of providing safe and stable end products after a large scale aerobic decomposition of waste is well established in Europe, and many countries support and use this treatment method successfully.

Composting is a classic method of waste treatment. It is an ecologically friendly process because the organic fraction of the waste is returned to the natural circle. During composting microorganisms consume oxygen while feeding on organic matter. Thus, the composting process reduces both the volume and the mass of the raw materials while transforming them into a composted organic material. The composting process "is based on the homogenization and mixing of the waste followed by aeration and often irrigation. This leads to a stabilized dark media, rich in humic substances and nutrients" (EEA 2002b).

Factors Affecting the Composting Process and Quality of Compost
The characteristics and quality of the end products are largely determined by:
- The nature of the feedstock (purity)
- The nature of the feedstock (composition)
- The extent of product maturation.

(European Commission 2003a)

The quality of compost is based on the specific waste stream as well as the separation of the waste. The waste mix must contain only biodegradable organic components such as biowaste, yard and park wastes, household-like commercial waste, organic waste from food industry, and sewage sludge for producing good quality compost (Panagiotakopoulos 2002).

Depending upon the composition of the waste material and the applied method of composting, the compost will be ready after 3 to 18 months, but the time period required to produce a composted organic material is dependent on many factors, including user needs, moisture, temperature, raw materials, and frequency of aeration (Bilitewski 1997, Panagiotakopoulos 2002).
Product quality is determined by process control. This in turn determines the potential market for the product. Products made from cleaner feedstock and having a long maturation period are more likely to reach quality markets (such as horticultural markets)

with larger financial benefits; however, the nature of the feedstock (for example, the relative mix of kitchen and garden waste) will also determine the nature of the product (EEA, 2002b). Although there are plants that accept mixed MSW which rely on manual and mechanical separation to remove other constituents from waste, especially when the source separation rate is significantly low, finally the compost quality is rather low and does not meet the requirements for agricultural use. Compost can be used as fertilizer, soil conditioner (when the quality is high), in quarry restoration, landscape restoration and topsoil cover in the local landfill site.
Composting is a simple, durable and cheap technology which reduces the volumes of waste, produces recycled organic and horticultural products, stabilizes and improves uniformity of waste streams and products, and eliminates weeds and pathogens in the waste material.

On the other hand, disadvantages of composting include:
A large land area is required (the treatment of 30,000t/year requires 30 acres) (Panagiotakopoulos 2002).
Odour emissions, especially when BMW is treated (but lower in comparison with landfill sites)

Although is a simple technique skilled staff needed in order to achieve the high standards for the procedure.
The exploitation of composting requires a developed market for the compost products.
According the compost products the following obstacles must be added:

- Strict requirements according the content in heavy metals and toxic substances
- The farmers prejudice (its difficult they have convinced for using fertilizer from waste)
- The competition of low cost chemical fertilizers

Apart from that composting, is highly suitable as an option for diverting BMW away from landfill. The principal advantages are that a useful and potentially valuable product is being manufactured from waste and that the negative consequences associated with land filling such as the production of landfill gas and leachate is avoided.

2.3.3.2 Landfill Bioreactor Cells
Anaerobic digestion
"Anaerobic digestion is one form of the naturally occurring processes of decomposition and decay, by which organic matter is broken down to its simpler chemical constituents in the absence of dissolved oxygen" (Evans 2001). During decomposition anaerobic bacteria convert organic molecules into methane and carbon dioxide. AD is an artificial accelerated procedure taking place within a digester or a bioreactor cell, in total absence of oxygen. AD can be used to recover both nutrients and energy contained in biodegradable municipal waste. Energy is extracted in the form of biogas while nutrients are recovered through leachates. Additionally, the solid residues generated during the process are stabilized.
Fermentation in a landfill bioreactor cell is an ecologically based technique.
Bioreactor cells are normally constructed within the ordinary landfill area. Landfill bioreactor cells (from now on: bioreactor cells) constitute an integrated system, surrounded by walls made of clay or compressed polyethylene plastics and a layer of low permeability at the bottom, in order to reduce the risk of gas/leachate emissions.

Additionally, each unit has a separate gas and leachate collection system. The size of the cells is determined by the amount of landfilled waste. But for the best results, it should be noted that the bioreactor cell should be filled within 2 years (Bramryd 2001). Hence, in order to avoid disamenity effects from methane transportation and odors, the biogas collection should start during the filling period.
In contrast to other biological treatment methods (composting, anaerobic treatment in a steel reactor), the source separation does not affect the process negatively. Non-easily fermentable materials act like stabilizing materials, hence plastics can help to keep the penetrating air out of the waste and, therefore, contribute to the stabilization of the anaerobic conditions (Bramryd, 2002).

Landfill Bioreactor Cell treatment

The decomposition of the organic matter from MSW produces biogas and nutrients in the form of leachates. More specifically, the process generates gases with a high content of methane and carbon dioxide, and a liquid fraction rich in nutrients. The stabilization of the procedure is essential. The stabilized anaerobic conditions guarantee a high level of methane gas recovery, and the leaching of heavy metals decreases.

Biogas Content

As was mentioned above, the amount of the generating biogas depends on the chemical composition of waste. The produced gas contains methane, carbon dioxide, some inert gases and sulphur compounds.

Table 3: Biogas composition

Component	(%) by volume
Methane	55-70%
Carbon Dioxide	30-45%
Hydrogen Sulphide	200-4000 ppm by vol
Energy content	20-25MJ/ m^3

Source: IEA 1996

The total annual amount of biogas extracted from bioreactor cells is estimated to be 200-250m^3 per tonne of mixed waste. The methane concentrations are about 40% during the first months and after 2 years reach 60-65%. Most of the methane gas will be extracted after a period of 10-15 years (Bramryd, 2002).

Leachates

Leachates are produced in the bioreactor cell at different rates, as they depend on the precipitation and the permeability of the top cover. The composition of waste determines their chemical composition. The leachate fraction must be collected and stored; after a special treatment, leachates could be used in biomass production or recirculate back into the process. They could be used as fertilizers, for instance in energy plantation and forestry, in which case a large portion of the nutrients re-enters the ecological cycle and thus returns to society. (Bramryd 2002). Bioreactor cells can be regarded as an anaerobic filter enabling the separation of the nutrients from the mixed MSW. Throughout anaerobic conditions most heavy metals are immobilized during the mineralization process. As a result, most nutrients will appear in the leachates, while most heavy metals will be immobilized in the fermentation residue and left in the landfill (Bramryd 2002).

A sample of leachate production can be seen in Table 4. The table shows the total quantities of leachates generated from 1995 to 1999 in the Filborna Helsinborg. The average annual generation is 183,856$m^{3.}$

Table 4: Total Leachate Production (m^3/yr)

Year	Quantity
1995	167,406
1996	91,953
1997	70,614
1998	32,217
1999	257,134

Source: Ness 2000

The leachate fraction is rich in nutrients and can, therefore, be used to promote biomass production. On the other hand, when the system from the promotion of biomass is neither adequate nor inapplicable then the leachates can be driven back into cell in order to control the moisture content, C/N ratio, pH, etc(Bramryd, 2002).

CO_2

Landfills can be regarded as the anthropocentric counterpart to natural peatlands and lake sediments accumulating organic carbon. They contribute to balancing the increased atmospheric concentrations of CO_2. The annual accumulation of organic carbon in the world's landfill sites is estimated at about $100x10^6$tonnes (Bramryd, 1999b). Hence bioreactor cells play an important role as moderators of the global CO_2 balance. In the landfill cells of Filborna, 100,000 tonnes of waste per year are treated in bioreactor cells, and a fraction of 7-13000 tonnes of organic carbon will be accumulated in the forthcoming years. This is equal to the total amount that is absorbed from 65 ha of mature spruce or 45 ha of deciduous forest (Bramryd, 1997). The landfilling of products containing organic carbon such as plastic, textiles etc. leads to i) re-routing of organic carbon to a long term accumulation in the ground and ii) an increase in the atmospheric CO_2 concentration (Bramryd 2001). More specifically, 25-40% of the total amount of carbon in the waste can be converted into biogas, while 25-50% of organic carbon will remain the long lived fraction (60% in conventional landfill) (Bramryd, 2001). Therefore, the landfill conforms to the natural CO_2 cycle, since it works as a carbon accumulator to an inarguably positive effect in the minimization of global warming from CO_2 emissions.

Land use

The Bioreactor cell treatment reduces the volume of the waste up to 50%. This is a great advantage, because new bioreactor cells can be built upon the old ones. The bunch bioreactors contraction affects positively the need for land use, and moreover heavy metals and organic carbon will be accumulated for a long time in the landfill.

Benefits

The bioreactor cell technique has a significant performance with various benefits. The most important ones are the following:

- recovered landfill space,
- the generation of large quantities of landfill gas and nutrients is utilized
- decreasing the length of time for the environmental liability of the waste
- treating the whole fraction of BSW

Or, more specifically:

- Demand for less space, as compared to composting (30-50% smaller size)
- Net production of energy from biogas
- Total collection of the generating biogas (contribution to the greenhouse effect)
- No harmful leachates
- Reduced CO_2 emissions by displacement of fossil fuels
- Reduction of the use of chemical fertilizers (for biomass production)
- Revenues from methane utilization for energy recovery and leachates for agriculture purposes.
- Reduction of odours

Disadvantages

Anaerobic digestion in a Landfill Bioreactor Cell is a new technique, so there are no significant studies on the effects of the use of that particular method. The elimination of biogas/leachate emissions minimizes the impacts of conventional landfill. Additionally the fast cover of the top decreases the odour emission as well as the vermin attraction. Hence the effects that the LBC method facing mainly related to disamenity and deterioration of the nearby area and more or less are the same that have already been mentioned for the landfills. They can be addressed such as risk of explosion/fire, land use, noise and dust.

In Greece, the obstacles are mainly related to the lack of relevant technology and know-how. Additionally, there is no market for liquid fertilizers.

Suitability for diverting BMW away from landfill

The treatment based on the Landfill Bioreactor Cell is fully suitable for the treatment of the fraction of the MSW. The main characteristic is that the bioreactor cell can accept mixed waste instead of composting and Anaerobic Digestion. Bioreactor cells produce biogas that can be used for heating or combined heat and power production. Alternatively, the gas can be used to power public transport vehicles such as public buses. The liquid fertilizer, slurry, is optimally used for biomass production, which also increases the revenues. From an ecological viewpoint, Landfill Bioreactor Cells treatment is very important, as it closes the nutrient cycle by bringing the mineral nutrients back to the producing ecosystems and thereby obtaining sustainable resource utilization. From an economic point of view, the cost of establishing such a treatment is not very high, so it is a feasible and attractive option meeting EU requirements and at the same time reducing the negative effects of landfilling

3. EU POLICY FOR WASTE

3.1 Generation of Waste in EU

Waste generation has been recognized as one of the most severe problems within European Union. Waste generation threats human health and environmental balance and, moreover, constitutes a huge loss of valuable resources and material. Total waste generation continues to increase in EU members: about 1.3 billion tonnes are generated annually (excluding agricultural waste), approximately 3.5 tonnes per capita per year (European Commission, 2003b).
European Environment Agency (EEA) has indicated five major waste streams that contribute to the total waste generation in EU: manufacturing waste (26%), mining and quarrying waste (29%), construction and demolition waste (C&DW) (22%) and municipal solid waste (MSW) (14%), (agricultural and forestry waste excluded). 2% of this waste is hazardous waste, i.e. about 27 million tonnes (EC, 2003b).
Total waste quantities will continue to increase in most European countries over the next years. The Organization for Economic Co-operation and Development (OECD) estimates that MSW generation in the OECD region will increase by 43% from 1995 to 2020, reaching 640 kg per capita at the end of this period. (OECD, 2002)

Intergraded waste management has been recognized as one of the crucial factors for future action internationally. As agreed in the World Summit on Sustainable Development and suggested in Agenda 21, the aim is to "prevent and minimize waste and maximize reuse, recycling and use of environmentally friendly alternative materials, with the participation of government authorities and all stakeholders, in order to minimize adverse effects on the environment and improve resource efficiency" (UN 2002).
Furthermore, European Commission proposed for EU's sustainable development strategy the need for decoupling the GDP from the use of the resources and the forthcoming waste generation. The aforementioned subjects have been included in the European Community's 6th Environmental Action Programme (6EAP) "Our future, Our choice" which presents the environmental agenda for the period 2002-2010. The overall aim is to attain "better resource efficiency and resource and waste management to bring about more sustainable production and consumption patterns, thereby decoupling the use of resources and the generation of waste from the rate of economic growth and aiming to ensure that the consumption of renewable and non-renewable resources does not exceed the carrying capacity of the environment." This overall aim will be addressed in the context of the thematic strategy on the sustainable use and management of resources ("the resources strategy"[1]).
Complementarily the thematic strategies from 6EAP are also addressing soil protection, protection and conservation of the marine environment, sustainable use of pesticides, air pollution, urban environment, sustainable use and management of resources and waste recycling.

[1] Decision N° 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme.

3.2 European Community Legislation for waste

European Union, recognizing the importance of sustainable use and management of resources, has adopted a hierarchy of preferred waste management options based on the principles of sustainable development and Agenda 21. The most common definition of sustainability is the one provided by the Brundtland Report (World Commission on Environment and Development, 1989), which describes sustainability as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

The waste management hierarchy encompasses the following objectives:

- Prevention/ Reduction on the source
- Reuse
- Material recovery
- Energy recovery
- Final disposal

The first two objectives focus on the avoidance of waste generation while the next two focus on the utilization of generating waste. Final disposal is the inevitable result of production and consumption. It must be mentioned that zero point disposal of waste is impossible with the use of current technology.

Moreover, there are two principles governing the aforementioned objectives of EU integrated waste management policy:

- Reducing the amount of generated waste and its potential impact on the environment
- Endeavouring to recognize and reform the remaining waste into a resource.

(EEA, 2000)

Material flow is the starting point for the analysis of the relation between economy and environment. Products and goods become waste when their utilization has been accomplished. So it can be said that waste generation is an integral part of industrial metabolism.

3.3 Regulations and directives

EU has established a set of principles, regulations and directives in order to protect primarily human health as well as the environment. Waste treatment is only one of the ways in which environmental problems are created.

European Union's waste legislation can be divided into three main categories:

– horizontal legislation;

– legislation on waste treatment operations;

– legislation on specific waste streams.

3.3.1 Horizontal legislation

Horizontal legislation establishes the overall framework for the management of waste; the objective is to set the overall requirements covering all waste management operations, e.g. permitting of waste treatment facilities, and providing the "common vocabulary" necessary to allow a uniform implementation of waste legislation across the Union. However, due to its broad nature, horizontal legislation can take into account the specificity of neither all waste management operations nor all waste materials.

3.3.2 Council directive 75/442/EEC of 15 July 1975 on waste

The "waste framework directive" or (WFD) establishes the overall framework for the management of waste including definitions and general principles. (It was revised in 1991 and 1996). Following the goal of sustainable use and management of resources, the European Commission sets out a hierarchy of preferred waste management options. The waste management hierarchy is a concept that promotes waste avoidance, focusing on prevention at source rather than end-of-pipe responses. The hierarchy is as follows: prevention, reduction of waste, recycling, reuse, reclamation (material recovery), energy recovery, and landfilling as the least preferred disposal option.

Moreover, WFD has established the principles upon which EU waste management strategy is based and can be addressed as follows:

- Secure the conservation of nature and resources, waste generation must be minimized and avoided where possible (waste hierarchy)
- Secure a reduction of the impact from waste to human health and the environment
- Make sure that those who generate or contaminate the environment should pay the full costs of their actions (polluter pays and producer responsibility principles)
- Secure an adequate infrastructure by establishing an integrated and adequate network of disposal facilities (proximity and self-sufficiency principles)

(European Commission, 2003c)

The requirements of the horizontal legislation are complemented by more detailed legislation in two areas: legislation concerning waste treatment including disposal, and legislation concerning specific waste streams. For this study the focus is on the waste treatment techniques.

3.3.3 Legislation on specific waste streams

The legislation on specific waste streams set quantitative targets focusing on material recovery and recycling (Packaging and Packaging Waste Directive 94/62/EC), avoidance and prevention of impacts of hazardous waste, Waste Electric and Electronic Equipment (WEEE) Directive 2002/96/EC, Directive on Batteries and Accumulators 91/157/EEC, amended by 98/101/EC.

3.3.4 Waste treatment operations

The third category of the legal framework on waste concerns waste treatment operations, including landfilling.

3.3.4.1 Incineration Directive

The objective of the Incineration Directive 2000/76/EC is to prevent or reduce as far as possible air, water and soil pollution caused by incineration or co-incineration of waste.

3.3.4.2 Directive on the landfill of waste

Municipal waste is defined by Article 2 of the landfill directive as follows: ‘Municipal waste’ means waste from households, as well as other waste, which because of its nature and composition is similar to waste from households.

Landfill directive by same Article has also defined the Biodegradable waste as follows: 'Biodegradable waste' means any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard.

There is no specific definition provided for biodegradable municipal waste, the subject of the targets set by Article 5 of the Directive. However, combining the above definitions provides the following definition: "Biodegradable municipal waste' means biodegradable waste from households, as well as other biodegradable waste, which because of its nature and composition is similar to biodegradable waste from households". (EEA, 2002b)

Directive 1999/31/EC of 26 April 1999 on the landfill of waste ("the landfill directive") "sets out a number of administrative requirements, including permit conditions, technical requirements and environmental standards applying to landfills accepting various categories of waste (inert, non-hazardous and hazardous waste)" (European commission 2003b). Furthermore, the directive contains a number of targets concerning the reduction of biodegradable waste disposed of in landfills and bans for landfilling certain types of waste, (liquid wastes, infectious waste, car tyres).

The implementation of the landfill directive is expected to be a major driver for the development of waste management policies at national level during the current decade. Directive places targets on Member states to reduce the quantities of biodegradable municipal waste (BMW) going to landfill.

The targets by the landfill directive are set on article 5 and require the following:

- "Not later than 16 July 2006, biodegradable municipal solid waste (BMW) going to landfill must be reduced to 75% of the total amount by weight of BMW produced in 1995 or the latest year before 1995 for which standardized Eurostat data is available.

- Not later than 16 July 2009, biodegradable municipal solid waste (BMW) going to landfill must be reduced to 50% of the total amount by weight of BMW produced in 1995 or the latest year before 1995 for which standardized Eurostat data is available.

- Not later than 16 July 2016, biodegradable municipal solid waste (BMW) going to landfill must be reduced to 35% of the total amount by weight of BMW produced in 1995 or the latest year before 1995 for which standardized Eurostat data is available.

Member states which in 1995 put more than 80% of their collected municipal waste to landfill may postpone the attainment of the targets for four more years. The first target can therefore be extended to 2010, the second to 2013 and the third to 2020". The countries with heavy traditional reliance on landfill are Greece, UK, Spain, Portugal and Eire.

Landfill directive seeks to prevent or reduce the possible negative impact on the environment by landfilling of biodegradable waste. The directive's aim is to promote the diversion of waste towards material recovery and biological/thermal treatment).

Although the landfilling rate of municipal waste has decreased in EU countries from 67% in 1995 to 57% in 1999 (mostly due to high recycling rates and composting) there are still great differences concerning waste management in EU member countries: 1/3 of EU countries disposed of more than 2/3 of MSW, while another 1/3 disposed of 1/3 of the MSW. (European Topic Centre on Waste and Material Flows, 2004)

The Landfill Directive has set detailed targets for the reduction of landfilling of biodegradable waste in EU Member States, BSW generation must be reduced from the ceiling of 69 million tonnes in 1995 to 37 million tonnes by 2016.

In conjunction with the landfill directive, the Integrated Pollution Prevention and Control (IPPC) 96/61/EC imposes on to the operator to characterize and quantify each waste stream, describe in advance the proposed measures for its recovery or disposal and where it has to be disposed, to explain why recovery is technically and financially unfeasible.

4. GREECE

The solid waste management in Greece has been remarkably upgraded during the last decade. While it is still generally considered a major problem, now it is increasingly becoming a well-structured, organized and environmentally responsible activity with specific goals, mostly in urban areas. A significant improvement can be seen in the development of treatment facilities, collection and recycling. At the same time, it is obvious that management of MSW in Greece needs a continuous improvement; a considerable management reorganization is also required in order to achieve EC goals.

4.1 Domestic waste generation

The overall quantity of MSW in Greece increased rapidly over the last 20 years, from 3 million tonnes in 1990 to 3,600mt in 1996 and to 4,640 mt in 2002 (about 45%). A comprehensive look at MSW generation during the last 25 years clearly shows the increasing generation from 1980 to 2002.

Table 5: National generation of MSW (in thousand tones)

1980	**1990**	**1997**	**1998**	**1999**	**2001**	**2002**
2,499	3,000	3,900	4,082	4,264	4,559	4,640

Source: (JMD 50910/2727/2003)

The increasing generation is primarily based on the improvement of living standards and the change of consumption patterns which clearly reflect the rapid development of the Greek economy as it is obvious from the uprising GDP figures. Waste generation has positive income elasticity (generation grows as income grows). The quantity of municipal waste reached almost 4.7 million tonnes in 2002, having increased by 45% compared to 1990 levels while at the same time the GDP increased 125%.

Table 6: Gross Domestic Product, (million Euros, in current prices)

1980	**1990**	**1997**	**1998**	**1999**	**2001**	**2002**
35018.2	66167.8	107,103	108977.3	117849.5	131341.2	141502.4

Source: Eurostat 2004

4.2 Population

The population in Greece, according to the 2001 census, is about 11,275,312 and each inhabitant generates 411.5 kg of municipal waste per year or 1,12kg per day. (JMD 50910/2727/2003) Although the birth rate is low (about 0.5%), urbanization and immigration have contributed to an increase in the population density, mostly in the urban centers of Athens and Thessalonica. Almost half of the country's population lives in these two cities (the biggest in Greece). Population is a waste generating contributor and has a great impact on the production of MSW. Commercial and institute's waste has also a contribution to the total amount of waste. Additionally, in order that one understands the Greek reality, one has to know that a large part of the country consists of small populated islands (more than 100) and mountainous areas with thousands of communities of 200-300 inhabitants. Panagiotakopoulos, (2002) has estimated the connection between population and MSW generation in Greece.

Table 7: MSW Generation in Greece

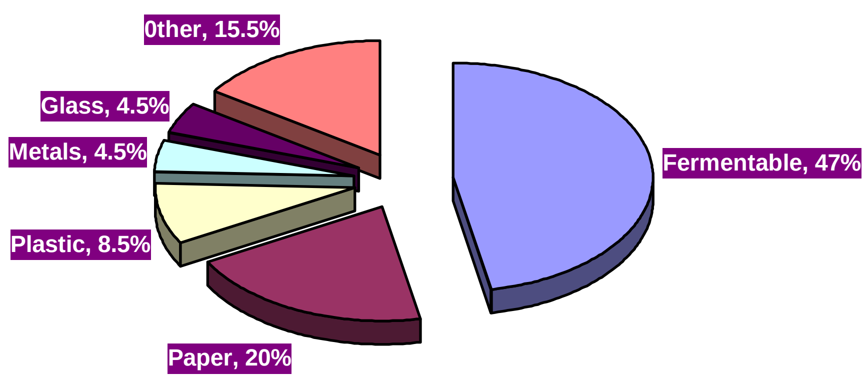
Population	Household wastes (In Kg)	Commercial and institute wastes (In Kg)	Total (In Kg)
<2,000	0.5	0.2	0.7
2,000-10,000	0.7	0.2	0.9
10,000-100,000	0.7	0.3	1.0
>100,000	0.8	0.5	1.3

Source: Panagiotakopoulos, 2002

4.3 Composition of MSW

The composition and the amount of the generated waste quantities differs: i) from place to place; different areas have different waste generation (urban places and big cities have more materialistic consuming patterns than rural areas, composition and generation are different even in different districts within the same city. ii) From time to time, waste generation varies in the same area (waste generation differs monthly and seasonally in the same city as wastes is a reflection of the societal trends and habits.
Greece has great differences in the generating amounts as well as in the composition of MSW compared to other EU members. Apart from the understandable differences in the GDP and lifestyle, which affect the consumption patterns, there are also significant disparities in MSW management. Some difficulties have been encountered in monitoring MSW composition due to seasonally different MSW production (the influence of tourism on waste production i.e.).
Waste is composed of Fermentable waste (47%), paper 20%, plastics 8.5%, metals 4.5%, glass 4.5%, other 15.5%. (JMD 50910/2727/2003).

Figure 2: Composition of MSW in Greece as %



Source: (JMD 50910/2727/2003)

Even though the generation of large quantities of solid waste has rapidly increased, there is still a differentiation between EU and Greek average quantities. In the late 90's, the Greek average waste production was 27% lower than the European average one. But lower consumption does not eliminate or reduce the problem. On the contrary, over the last decade, the problem has deteriorated more severely in Greece than in the other EU members. The domestic problem is mostly related to the inadequate solid waste management practices that have been applied so far. The weak management is connected to organizational infrastructure inefficiencies, as well as to the continually changing lifestyle patterns imposed by rapid economic development. Apart from the irregularity of MSW management, the proportion of the population served by a regular collection system has increased from 70% in the mid 90's to 90% in 2003, while in numerous small islands and distant villages waste collection was poorly organized (Ministry of Environment, 2004).

4.4 Current Municipal Waste Management in Greece

4.4.1 Waste Disposal

In Greece 91.2% (4,233 thousand tones in 2002 figures) of the municipal solid waste is collected and disposed of in landfills (56%), and in 1260 open dumps (44%) while 8.8% (375,000t) is recycled. Open dumping is implemented on small islands and distant mountainous and insular areas with inadequate systems of collection and waste management. From the organic fraction of the waste 98.5% is disposed of in landfills, while 1.5% is composted (in 2002 32,000t composted) (JMD 50910/2727/2003, Eurostat 2004).

Until 1994 waste management was carried out in thousands of dumpsites (about 4,850 were recorded officially), 70% of which were uncontrolled (corresponding to 35% of the total waste quantities applied to small municipalities and small islands). Nowadays, 30 Landfills operate in Greece, most of which can be classified as Sanitary landfills and serve about 55% of the population. In the meantime, around 10 new landfills are now being constructed (Greek Ministry of environment 2004, Eurostat/OECD Joint Questionnaire 2002).

4.4.2 Recycling

As mentioned above, Greek recycling rates have improved significantly, but the recycled waste quantities are very low in comparison with those of other EU members. The private sector has a significant participation in this effort, with measurable results. The overall recovery rate for recyclable material (plastic, paper, glass) is estimated at 21% and the diversion rate at 8.8%. (JMD 50910/2727/2003)

4.4.3 Composting

Greek has shown an obvious preference for biological waste treatment. Composting has been officially adopted, and many composting facilities have already been established or will soon be established. In 2002, as was mentioned above, the composting treatment method has made its first steps, with an insignificant contribution to waste treatment (less than 2%), (Eurostat, 2004). Since then, serious efforts have been made in order to promote biological treatment facilities. Treatment facilities of mechanical separation and organic treatment have been operating in Athens with a capacity of 1200t/day or 360,000

tonnes per year, 240,000t/year in Thessalonica, 70,000t/year in Chania and 32,000t/year in Kalamata. (Panagiotakopoulos, 2002). The total treatment capacity of those facilities can be roughly estimated at 700,000t/year. More treatment projects are under preparation and will start operating in the forthcoming years. Mechanical separation is completely necessary in order to purify the feedstock. Compost product quality is based on the composition of the waste.
These efforts have increased recycling rates and it is certain that these rates will continue to increase. According to the Joint Ministerial Decision 14312/1302/FEK 723/9-6-2000 it is estimated that over the next 5 years 70% of the generated MSW will be disposed of in Sanitary landfills, while 30% will be recycled and composted.

4.4.4 Sanitary Landfill Disposal

"Landfilling is the operation of depositing waste on a site, normally engineered and prepared for the storage of waste and including in some cases systems for collection of gaseous and liquid emissions. Landfilling is a managed disposal of waste on land" (EEA, 2004). The definition states clearly that landfilling is not related to open dumping which is a random, not programmed action and does not meet the requirements for a clean environment. Landfill is the most predominant end of pipe solution for waste management in Greece. The operation of the landfill is advantageous as the sole waste disposal method because the technology is rather simple and the costs are significantly low (in comparison with other techniques).

Landfill is a complex system that encompasses different elements for its operation. The operation creates strong interactions between the environment, society and economy. The major input to landfill is the collected MSW and the final disposal on it. Landfilling is always the final option amongst all the alternative treatment methods.
Landfilling is the unavoidable subsystem of each MSW management system because every treatment method leaves residues which have to be disposed of in a landfill.

The advantages of the use of landfill in comparison with the other methods are:
Simple technology, lower cost for infrastructure and maintenance, land can be reused after the landfill's closure, potential recovery and utilization of biogas.

The significant increase in waste generation, the need for disposal and treatment, has a severe impact on the country. This is reflected in direct and indirect problems in the environmental, economic as well as social performance of the country.

4.5 Waste Management Administration and Policies

Waste management in Greece can be divided into three levels: local, regional and national.
On the first level Municipalities and local authorities are mainly responsible for waste collection and disposal, as well as aspects of planning. In 1998, the Greek parliament implemented the merge of 5,600 communities and 360 municipalities into less than 1,000, with considerable benefits for waste management planning (Ministry of Interior, 2004).

The second level consists of 51 Prefectural authorities. The development of solid waste management master plan, the approval of relevant waste operations by municipalities, is under the jurisdiction of these authorities. The latter are further under the jurisdiction of 13 regional authorities consisting of representatives of the relevant ministries.

At the national level, the Ministry of Environment, Physical Planning and Public Works is responsible for policy making, national planning, technical matters, as well as licensing and regulating the financing of large waste treatment and disposal facilities. The ministry also has the responsibility for preparing the sectoral waste management strategies to ensure compliance with the EU legislation (Ministry of environment, 2004, Ministry of Interior, 2004).

EU legislation (Council Directive 75/442/EEC on waste) requires each Member State to draw up one or more waste management plans in accordance with relevant EU directives. Each individual Member State has the duty to apply the principles of these directives when implementing a national waste management system. In order to implement the existing legal framework and to develop the action plan for waste management on the national level, the 1st 'National Planning for the Integrated and Alternative Management of Solid Waste' was elaborated during 1997-1999, in order to ensure the sustainable use of natural resources, the protection of environmental quality and thus the sustainable development of the country.

The establishment of such an approach was an obligation stemming not only from the Greek Constitution and Law 1650/86 for the "protection of the Environment" but also from the obligations of Greece as a European Union Member State. The National Planning took into account all the existing management schemes on Regional and Prefectural level, as well as the works that have already been implemented in the framework of national and European funding. The Planning of a uniform national strategy for waste management was based on the following main principles, as set by JMD 113944/101/97:

- Prevention or minimization of waste production (quantitative minimization) as well as the minimization of the waste content in hazardous substances (qualitative minimization);
- Utilization of waste (recycling and energy recovering);
- Safe final disposal of residues;
- Proximity of disposal sites to the sites/sources of waste generation;
- Rehabilitation of disposal sites so that they could easily be incorporated, after the termination of their use, into the surrounding natural environment;
- The "polluter pays" principle.

Moreover, the Waste Framework Directive has been implemented into Greek legislation through three Joint Ministerial Decisions, which define the terms and measures for solid waste management; provide detailed technical specifications for solid waste management facilities, equipment and procedures; and give the general directions of solid waste management policy in Greece.

The Landfill directive has also been implemented by the JMD29407/3508/2002 measures and terms for sanitary disposal (harmonization with the EU Directive 99/31/EC); JMD 50910/2727/2003 providing measures and terms for solid waste management, National and Regional Planning Management, in compliance with the European Waste Framework Directive 91/156/EEC.

The Council Directive for Landfilling places aims at a decrease in the biodegradable quantities going for landfill disposal. Greece has taken advantage of the 4 year extension (allowed for those members which disposed of more than 80% of their waste in 1995 in landfills). According to the aforementioned policy, Greece is required to reduce the landfilling of biodegradable municipal solid waste to

75% by 2010
50% by 2013
35% by 2020

4.5.1 Taxation

There is not a specific fee related to waste generation. Fees for waste collection and treatment are part of the Municipal Fees system; the tax is not related to the generated quantity of waste, but is based on the surface area (m^2) of professional and residential buildings (and is included in the electricity bill). The fee's level is set by the municipal council and it varies from city to city. In most cases, the fees for waste management are a fixed amount of money related to the services provided by the municipality. Because of that the revenues from the fees are not used only for waste management but also for other municipal services. The fee is usually set to such a level, as to cover the expenses for all the services provided by the municipality. Thus, municipalities very rarely differentiate between waste management expenses and other services, since they mainly aim to balance the projected overall municipal expenses (Ministry of National Economy, 2000)

4.5.2 MSW management Cost

In 2002 estimations for the annual expenses for municipal solid waste management reached $300x10^6$ euros all over the country. Recent studies have shown that the operational cost of a sanitary landfill is about 10% of the total cost, while the collection and transportation cost is about 50-70% of the total cost (Panagiotakopoulos, 2002).

5. ANALYSIS AND DISCUSSIONS

5.1 Why Does Greece Need Immediate Action?

Greece has already faced the challenge for the reconstruction of the existing MSW management schemes according to the new EC directives. The adopted hierarchy leads to a new policy until 2020. According to the Landfill directive, the targets that have to be attained are:

1. High rates of diversion of BMW away from landfill.
2. High rates of recovery, in particular material recovery, of BMW diverted away from landfill.

Undoubtedly, the existence of composting treatment meets all the criteria for an effective biological waste treatment. But it cannot adequately correspond to the pressure exerted by the increasing waste generation. Moreover, although the aerobic digestion treatment covers the obligation for diverting the BSW fraction from the landfill, (because of the lack of source separation) it does not meet the requirements as a valuable component of the integrated waste management system. Although Greece has strictly determined the quantity of heavy metals and toxic substances contained in the compost, the composting treatment method still faces some problems. The current situation in Greece can be summarized as:

- No sorting schemes are in place for the organic fraction of MSW (with the exception of green waste), so the production quality is rather low.
- All the facilities produce compost from mixed MSW, as source separation rates are low.
- Standards on compost quality refer solely to mixed MSW compost.

(Ministry for the Environment 2001)

Although most facilities use Mechanical Separation, the sorting schemes do not provide a "clean" organic fraction without mixtures. If composting aims only at the reduction/diversion of the MSW entering the Landfill, then low quality does not matter. It can be used for quarry restoration, amenity sites and landfill cover. But the low quality of compost cannot provide revenues. Additionally, the absence of an organized market for composting products hinders the progress of the efforts.

5.2 Estimation of BMW quantities

The second pressure is related to the increase in waste generation. Greece has followed the general European pattern as far as generation of MSW is concerned. Several methods of estimating waste generation have been applied so far. EEA (2002) has developed a model for estimating waste quantities which is based on the annual increase of waste generation, while the other methods are based on the connection between GDP, consumption and waste generation. Greek GDP presented a constant increase over the last decade, but estimations for the future are not easy. Despite last year's dynamism, the Greek economy seems to be following EU towards a period of uncertainty. For this reason, it is much more reliable to use waste generation as the basis of the estimation. The three scenarios assume different growth rates in waste production:

1st scenario: Waste grows by 1% yearly – "Optimistic" scenario
2nd scenario: Waste grows by 35% in the 20-year period 2001-2020 – "Realistic" scenario
3rd scenario: Waste grows by 3% yearly – "Pessimistic" scenario

The second scenario is closer to the Greek reality. If one considers that the generation of waste increased by 47% over the last decade, then the 35% scenario can be called realistic. It is assumed that, as population increases, waste generation per capita tends to be constant or increase slightly.
In order to analyze the problem in greater detail, it is essential to determine the composition of waste.

Composition scenario: The biodegradable fraction is 67% of the collected waste (47% organics and 20% paper) minus recycled paper. The percentage of recycled paper is considered to remain constant at 67%.
In order to estimate the waste production in the target years the present value fraction is used. $PV=A/(1+r)^{t,}$ where A is the 2002 generated quantity of waste, r is the waste rate and t is the time.

Table 8: Targets on diverting BSW away for landfill disposal

Targets on landfilling and diversion of BSW	2010 (thousand t/y)	2013 (thousand t/y)	2020 (thousand t/y)
Max BMW that allowed to be land filled	1959	1306	900
Scenario 1[1]: Min BMW that should be diverted	968	1712	2324
Scenario 2[2]: Min BMW that should be diverted	1100	1900	2700
Scenario 3[3]: Min BMW that should be diverted	1468	2432	3705

Scenario 2 is closer to the Greek reality, because the increase of 35% in waste during the 2002-2020 period is constituent to the previous decade pattern (47%), (population increased slightly and waste production per capita tended to be constant).

Scenario 2 analysis:
Greece has been facing a great challenge in order to reduce BSW landfilling in the forthcoming years. BSW management is a top EU priority for both environmental and economic reasons. Greece has already implemented the waste management hierarchy which prioritizes the principles of waste management as prevention-reduction-reuse-recycling-material and energy recovery-final disposal. The overall aim is to reduce the effects of harmful emissions from waste on human health and the environment, and to recover the materials that have been lost during waste disposal.

[1] Waste generation rate is 1% per annum
[2] Waste generation rate is 35% for the 2002-2020 period
[3] Waste generation rate is 3% per annum

Greece has produced 4640 thousand tonnes of MSW in 2002, of which 3109 were biodegradable (47% putrescibles, 20% paper). Recycled paper accounted for 404 thousand tonnes (67%). Therefore, 2705 thousand tonnes of BSW were landfilled.

The estimations for the forthcoming years show an increased quantity of generated BSW that have to be treated away from the landfill: in 2010, 1110 thousand tonnes; in 2013, 1900 thousand tonnes; in 2020, 2700 thousand tonnes.

5.3 Composting Capacity

As was already mentioned, the total capacity of the 4 composting plants is almost 700,000 tonnes per year. Until 2010, (1100-700 =) 400 thousand tonnes of BSW there must additionally be diverted. If one insists on using composting treatment facilities, new ones must be created which could treat the additional 400,000 tonnes of waste. In the Greek case, this sort of treatment is inefficient on both economic and environmental grounds. Environmentally, the system cannot close the loop and let the composted product be used in agriculture as a sustainable resource because of the low quality. Additionally, it consumes energy. Economically, it is not efficient because the product of composting cannot offer any revenue, again because of the low quality.

5.4 The Systems Dynamics analysis

The overall analysis for the current situation of MSW disposal in Greece, and the lively impacts of various waste treatment options are demonstrated in the following Causal Loop Diagrams.

5.4.1 Landfill Disposal CLD

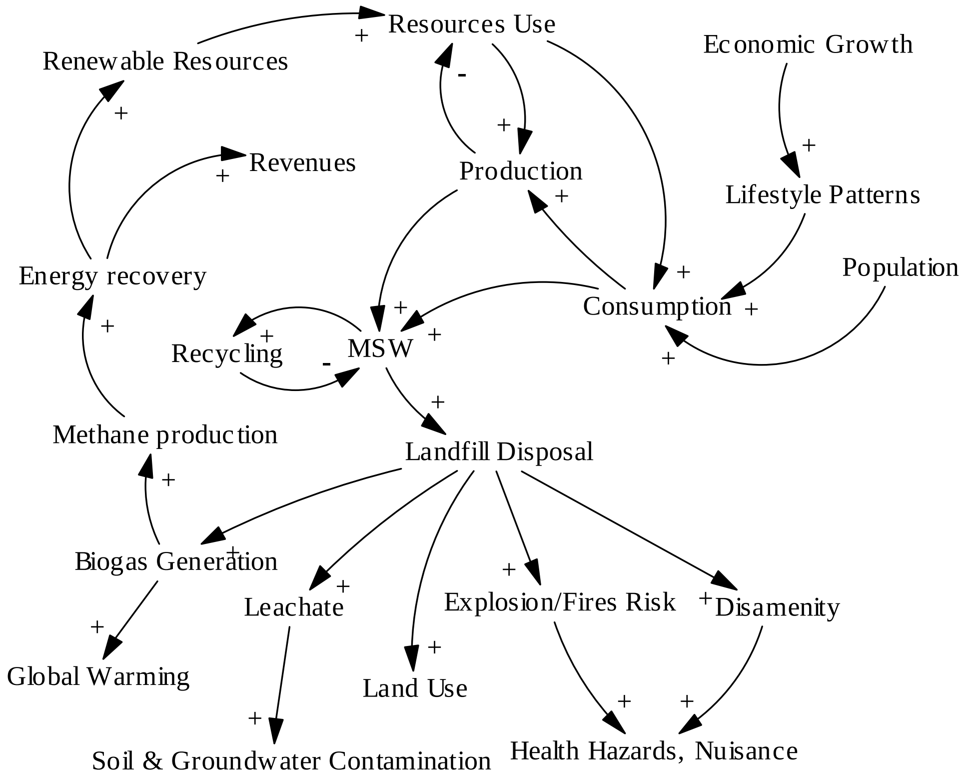
The CLD below presents the waste flow with a twofold environmental challenge. All waste has to be recovered or disposed through operations which unavoidably have environmental effects and economic costs. Waste can also be a symptom of inefficient consumption and production patterns, in the sense that materials may be used unnecessarily. These materials do not only create waste but also cause a wide range of effects during their production and use phase

The CLD could be divided into three systems. The first system (up right) is the mechanism behind the generation of the MSW while the second system (center) is related to the treatment method, in that case the landfill disposal that has been applied in Greece. The central one shows the relevant effects of the landfill operation. The increasing MSW quantities have a positive relationship with the environmental effects of the treatment. The last system (left) denotes the utilization of landfill biogas to renewable resources with the revenues gained of the produced energy.

The main factor affecting the MSW generation is production, and consumption is the primary factor that increases the generation of MSW. Consumption is the result of the increasing living standards (based on the economic growth) and the population. The push on the level of demand also affects production (goods, services etc), and total production increases the total generating MSW quantities.
The fraction of the MSW is diminished by the recycling rate. Larger amounts of MSW increase the recycled quantities. On the contrary, high recycling rates decrease the fraction of the MSW disposed of in landfills. The quantities that are not recycled go to

the landfill for disposal. Hence the recycling rate affects the amount of the final disposal, but recycling has not yet developed in Greece as sufficiently as in Western Europe.

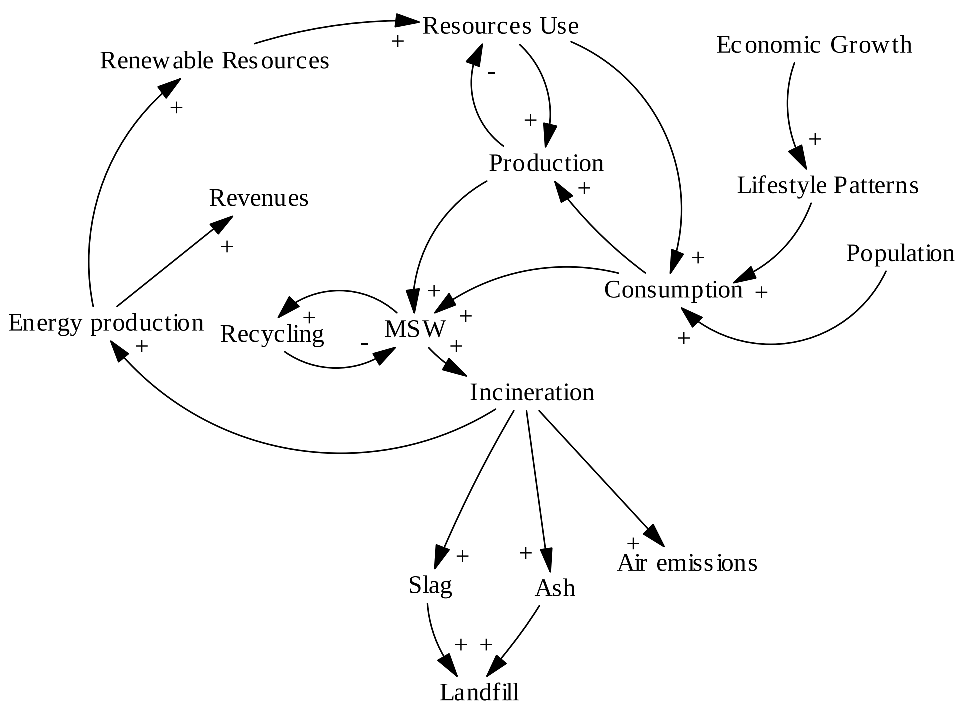
Figure 3: Landfill Disposal CLD



MSW disposal has a serious impact on the environmental economic and social life of the country. As already noted, landfill disposal is a burden to the sustainability concept, because it has a severe environmental impact and it constitutes a loss of resources. The major effects are related to Greenhouse gas emissions and groundwater contamination. The increase in methane emissions in Greece is mainly attributable to the waste sector, which saw a 42% increase over the time period 1990–2000. Moreover, methane emissions from solid waste disposal on land increased from 2811kt CO_2 eq in 1990 to 4767kt CO_2 eq in 2000. In the year 2000, waste accounted for 4% of methane emissions at national level (Ministry for Environment 2002). Furthermore, methane is an explosive inflammable gas, so there is always the risk of explosion or fire. Leachate emission is related to the contamination of soil and groundwater by heavy metals and chemical compounds. Although it is difficult to establish their actual effects, because their composition and production is constantly changing, leachates are a threat to both nature and humans. The large production of MSW means that landfills require larger and larger land areas in order to receive the accumulating incoming quantities. The establishment of a new landfill has severe effects on the value of the land (negative relation) and on the use of the land (for more than 30 years, the land will exclusively serve disposal purposes). Moreover, the continuous waste generation means always the

same demand for land use as landfill. Thus people living nearby express the not-in-my-back-yard (NIMBY) syndrome. The operation of the landfill is seen as a nuisance, especially by the people living nearby. Nuisance includes odor, noise, dust, health hazards because of vermin attraction.
On the other hand, gas generation is a challenge for collection, and utilization. CH_4 generated within the landfill's body has been recognized as a renewable energy resource. CH_4 can be collected and, after a special treatment, it can be used for electricity generation, heating purposes, and as a fuel for local cars or busses. The utilization of gas contributes to the RES reserve and comes back either to consumption or to production. But at the same time the biogas provides revenues from the biogas production, thus decreasing the net cost of the facility.

Figure 4: CLD of incineration

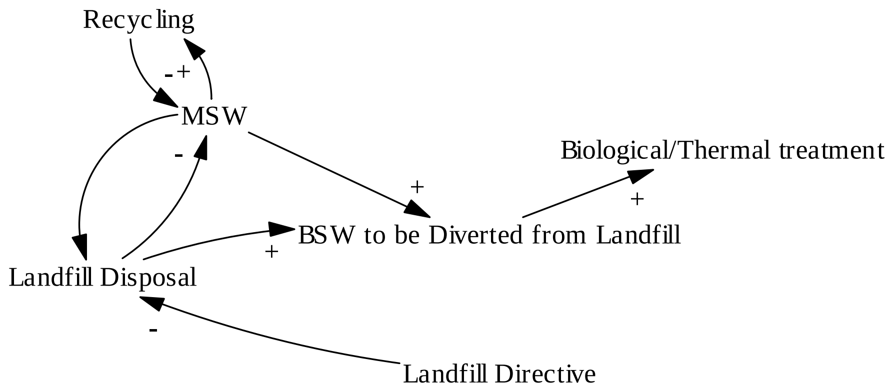


The CLD of incineration follows the same pattern as the Landfill CLD. But instead of landfilling the treatment is switched to incineration. The combustion of waste has outputs air emissions, ash and energy. The energy provides revenues and at the same time contributes the RES reserve. Nutrients and organic constitutes are destroyed during the combustion. Slag must be disposed in a landfill for hazardous waste as it contains high concentrations of toxic elements.

5.4.2 EU Landfill Directive CLD

EU has set the landfill directive which shows the reduction of the biodegradable MSW with specific quantitative targets in a specific time frame.

Figure 5: CLD EU Landfill Directive



The implementation of the landfill directive by the Greek Government has changed the Greek MSW management. The treatment technique applied must take into account materials and energy recovery, and at the same time be able to meet the viability requirements.

The directive has set specific targets for the minimization of biodegradable waste disposed of in landfills. As can be seen in the above CLD, the landfill directive affects the amount of disposed waste negatively, as the fraction of organic waste must be reduced to 35% of the 1995 figure. Therefore, the major quantity of biodegradables must be treated with different techniques. The diversion of landfill to other treatment methods does not mean that landfilling is not valid anymore. But the decreased biodegradable material, especially the organic fraction, is diminishing the effects of landfill disposal.

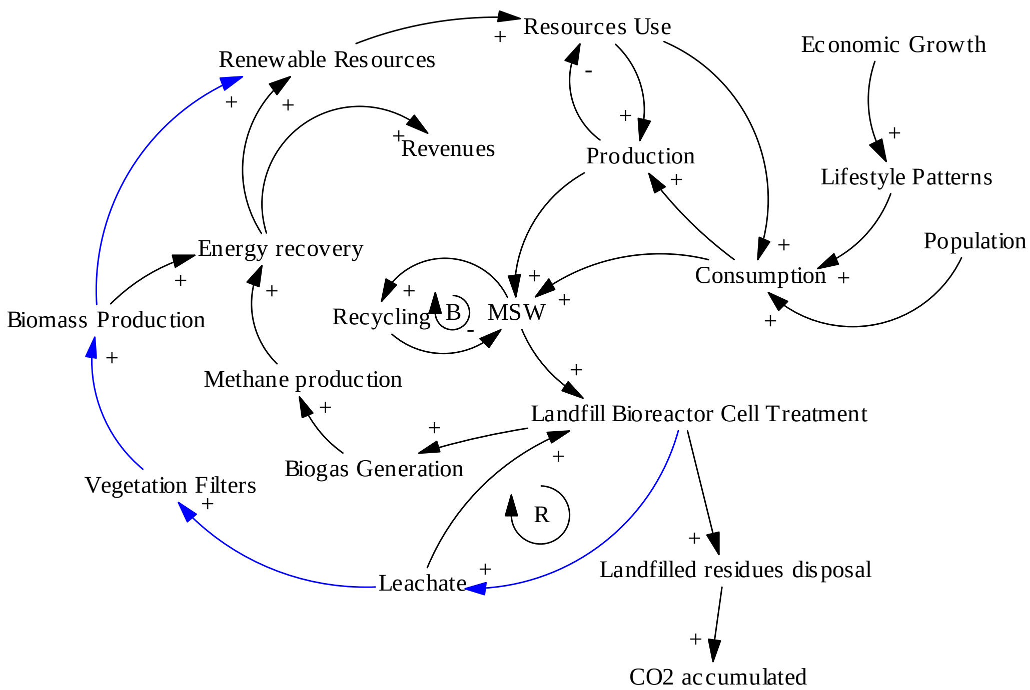
The passage of the landfill directive by EU was stormy and the final adoption by the Council of Ministers represents the strong will to reduce, in the forthcoming ten years, the biodegradable material entering landfills.

5.4.3 CLD Landfill Bioreactor Cell Treatment

The system follows the same pattern as the landfill CLD. Human consumption affects the generation of MSW, while recycling decreases the quantity of treated waste. The MSW minus the recycled material goes to landfill bioreactor cells for treatment. The products of the digesting process are methane as well as nutrients from leachates which are potential revenue contributors. The methane accumulated in the bioreactor is all collected and the production can be used for energy recovery, electricity or biogas production for car fuel. So methane increases the Renewable energy sources and, at the same time, it offers significant revenues. The leachates, on the other hand, as main components of the process, are stored and distributed. “Heavy metals are immobilized through the process into fermentation residues” (Bramryd 1997) while leachates recover the nutrients from the waste. Thus, with the use of vegetation filters, leachates can be used as fertilizers, for example in energy plantations and forestry. This constitutes another potential contribution to the revenue maximization. In Filborna the produced leachates are

collected in ponds and used for the irrigation of a mixed forest of European birch (*Betula pendula*) and Colorado spruce (*Picea pungens*), the birch being the dominating species. On the other hand, nutrients can be brought back into the ecological circle.
A landfill bioreactor cell extracts all the quantity of methane in 10-15 years. During this period the volume of waste has decreased by about 50%. This is quite beneficial to the land use, since it is possible to build another bioreactor over the old one, which saves 50% of the land needed for a conventional landfill. Finally, it must be mentioned that there are always residues that have been disposed of in the landfill and remain there as fermentation residues. Because of that the landfill plays a vital role for the global CO_2 balance, since it works as a CO_2 accumulator. This negatively affects the global warming problem.

Figure 6: Landfill Bioreactor Cell CLD



5.4.3 CLD of the Solution

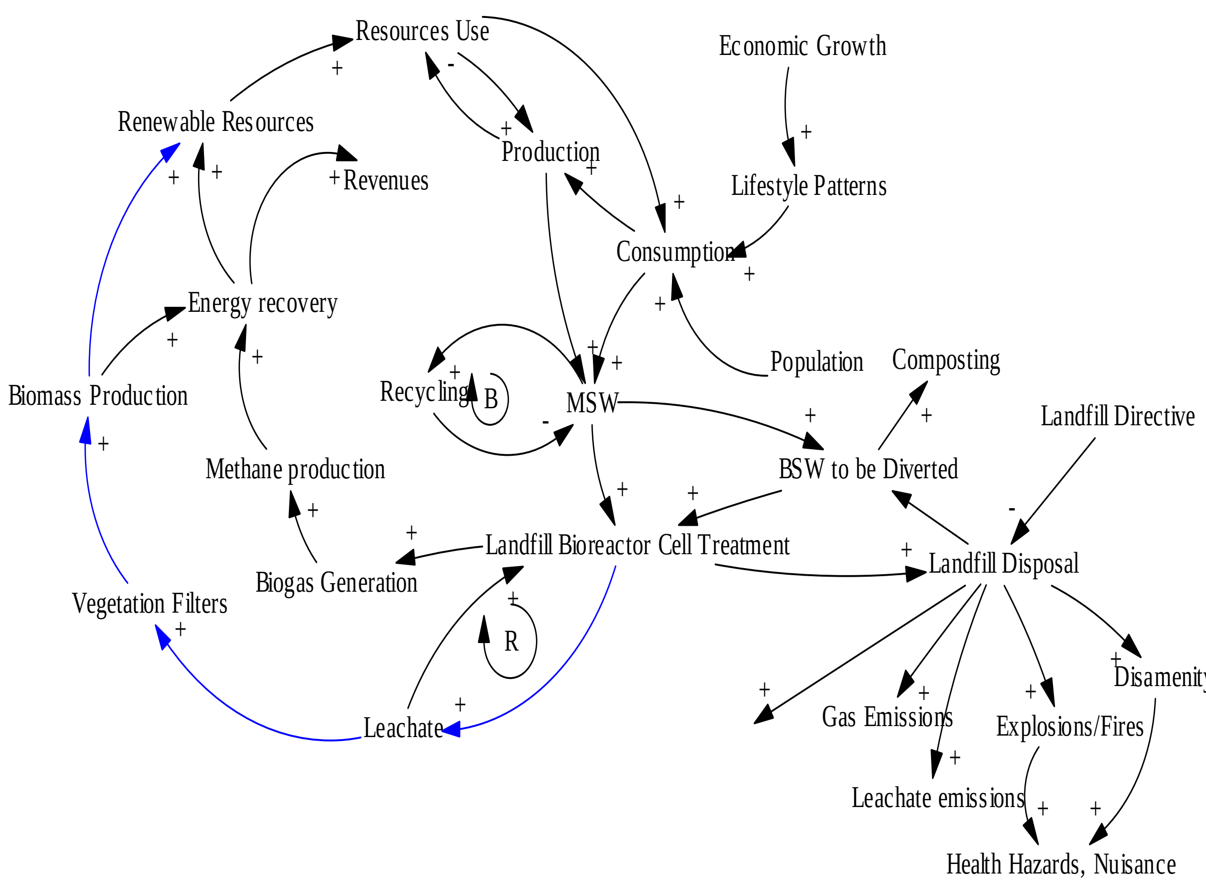
As was suggested earlier, landfilling is not a proper method for waste management, since it causes serious environmental and socioeconomic problems. Composting is a preferable option, and Greece has shown a preference to this biological way of treatment. However, composting is not efficient from an economic and environmental point of view. The establishment of Filborna landfill bioreactor cell treatment has created a new dynamic element in the waste treatment facilities. Taking into account the low costs, the acceptance of mixed waste, the full utilization of biogas, the utilization of leachates (even without biomass production, the recirculation of the leachates is beneficial for the fermentation process), LBC is a promising solution (Bramryd 2001).

Figure 6 demonstrates the CLD of the system. It follows the patterns that have already been mentioned. In short, the generated waste must be treated.

Until now the common practice is the landfilling of wastes in Sanitary Landfills. But after the Landfill Directive, the BSW must be diverted from the landfill, following the restrictions and the quantitative targets. Thus, the introduction of the LBC treatment works complementarily to the composting and enhances the reliance on the biological treatment of waste. The construction and operation of the BRC results in the utilization of all the generated methane which can be used for energy recovery (heating, electricity or car fuel), thus offering considerable revenues. The leachates, on the other hand, with recirculation can enter again into BRC, helping the stabilization of the anaerobic procedures. Obviously, the landfill is not out of the system. The reasons are various and can be counted as follows.

Landfills are an essential part of the Greek waste management system. First of all, the BRC are located in a Landfill but now, without the biodegradable waste, the impact of landfilling is rather limited. As already mentioned, year after year, the landfill is restored and the relevant area is returned to the public. At that particular point, the nutrients from lechates can be used. The restored parts of the landfill can be used for cultivating energy forestry, such as willow plantation for biomass production. So the nutrients come back to society and the ecological circle closes. Nevertheless, composting is a vital part of the system; the role it plays in the whole process is a supporting one, since it involves a low source separation. Composting products can only be used for quarry restoration, amenity sites and landfill covering at least in the short-term period.

Figure 7: Landfill Bioreactor Cell CLD of the possibilities



5.4.6 Economic Analysis

5.4.6.1 Landfill sites

The construction and operation cost of a Sanitary landfill is demonstrated on the table 9

Table 9: C&O cost for Landfill Site

Acres	**Capacity (10^3 m$^{3)}$**	**Served population**	**Construction cost (10^3 Euro)**	**Operational cost (Euro/tonne)**
53-80	5,00	55,000	2-2.3	5.2-5.8
80-130	1,000	110,000	3.3-3.6	4.1-4.6
110-165	1,500	165,000	7.3-8.3	5.8-6.5
170-260	3,000	330,000	12-13.5	4.8-5.4
270-410	6,000	660,000	19.6-22.1	3.9-4.4
425-645	12,000	1,320,000	32-36.2	3.2-3.6

Source: (Panagiotakopoulos 2002)

In the cost does not included land cost, pre constructional works, post closure and restoration costs.
Except the costs that related to the performance of the facility there is another cost the external cost.

Environmental externalities of disposal on landfill sites

According to ExternE study (1995) externalities can be defined as “the costs and benefits which arise when the social or economic activities of one group of people have an impact on another, and when the first group fails to fully account for their impact.” Landfill disposal have both direct and indirect effects on the environment. Indirect cost can be defined as external cost from landfill. Numerous difficulties arise when someone tries to evaluate these external effects. Time is a crucial parameter as many of the potential effects of landfills do not occur immediately but over a prolonged time frame. The specific characteristics of the disposed waste change with time and territory. That means the air and leachate emissions are difficult to evaluate. Another effect is related to the time period during which a landfill is used: a landfill may cause emissions even after 30 years from its closure.
Externalities are damages or benefits, which are not paid for by the polluter or beneficiary under normal market conditions. They can be split into fixed (independent of the quantity of waste) or variable (depending on the quantity of waste) costs and benefits. Most waste externalities such as emissions to air, water and soil are variable external costs (European Commission 2000a).
Hence the effects of landfilling on society and environment can be shown by economic figures. The external costs from landfill disposal are distinguished into:

- external costs related to greenhouse gases causing climate change;
- external costs of conventional air pollutants and some airborne toxic substances causing e.g. health effects;
- external costs of leachate to soil and water;
- external costs of disamenity effects of the facilities, e.g. visual effects, noise, smell and litter; (European Commission 2000a)

Unfortunately there is lack of reliable data, so there are a lot different estimations for the external cost of the landfill disposal externalities.
The following example is taken from a European Commission study (2000a). It reflects the different technological standards and level of energy recovery. The example is as follows:

• **L1.** The landfill is a modern containment landfill that fulfils the demands of the landfill directive (EC/31/1999). The landfill has a leachate collection and treatment system. Furthermore, the landfill gas is collected to generate electricity and heat (CHP).
• **L2.** The landfill is an old site without a liner and landfill gas is not collected. (European Commission 2000)

Table 5 illustrates the different external costs for each landfill. Definitely the L1 is better from an environmental point of view. As it is obvious, the disamenity cost (usually, a fixed cost) and global warming (mainly methane emissions) are the most significant contributors. Leachate emissions affect the neighboring area. The problem is aggravated when there are cultivations nearby that could be contaminated by the leachates. In L1 there is an insignificant cost based on the use of the landfill gas while in the L2 there is no such facility.

Table 10: Summary of external costs for landfill disposal of waste in examples L1 and L2 (EURO/tonne waste disposed at landfill)

	L1	**L2**
Global warming[1]	5 (1 – 14)	8 (2 – 23)
Damage from air pollution	0.1 (0.02 – 0.2)	0 (-)
Damage from leachate	0 (0 – 1)	1.5 (1 – 2)
Disamenity	10 (6 – 19)	10 (6 – 19)
Total external costs	**15** **(7 – 34)**	**20** **(9 – 44)**
Pollution displacement[2]	-4 (-10 – -1)	0 (-)
Net external costs	**11** **(6 – 24)**	**20** **(9 – 44)**

[1] The main part of these costs is related to CH_4.
[2] The main part of these benefits is related to NOx and SO2.

Limitations for the example

To begin with, the disamenity cost estimations are based on US studies and probably they are not suitable for Europe.

Secondly, the cost of leachate is based on very few studies and does not reflect the cost of each substance in the leachate but regards emission of leachate as one component based on clean-up costs. It is therefore uncertain whether this reflects the true external costs.

5.4.6.2 Landfill Bioreactor Cell treatment cost

The cost estimation for bioreactor cells is based on the Filborna in Helsiborg. This is a central waste treatment and recycling plant for the district of Northwest Scania, with a population of approximately 220,000 people. The facility is owned by the Northwest Scania Recycling Company, NSR, established by six municipalities in the area. The incoming waste is a mixture of domestic, commercial and light industrial waste and originates from the cities of Helsingborg, Ängelholm and Höganäs and the communities of Bjuv, Båstad and Åstorp. The total amount of recycled and treated waste products is about 330,000 tons per year (Bramryd, 2001)

Table 11: Construction and operational cost for the BRC facility (in Euros in 2000 prices[1]).

Bioreactor liner cost	388,888 (3.5 MSEK)
Cell walls, gas/leachate piping	166,666 (1.5 MSEK)
Pretreatment Plant	16,666 (0.15 MSEK)
Pretreatment Equipment	266,666 (2.4 MSEK)
Bioreactor Equipment	88,888 (0.8 MSEK)
Staff	444,444 (4.0 MSEK)
Infrastructure	133,333 (1.2 MSEK)
Overhead	222,222 (2.0 MSEK)
Total	**1,722,222 (15.5 MSEK)**

Source: Ness 2000

The cost can be divided into three sections: construction cost, methane and leachate collection system, and expenses for the filling and covering of the cell. Construction cost contributes by 47% to the total cost, while collection system accounts for 29% and filling 24% of the total cost (Ness, 2000)

On the basis of the treatment cost, it is easy to estimate the cost per tonne. The incoming waste was 110,000t, so the cost per tonne is 1,722,222/110,000, approximately 15.7 euros per tonne.

In the cost fraction, the cost of the post closure care must also be calculated. Post closure contains the top covering of the cell, cost for monitoring (mostly leachates, since, as was mentioned above, methane is exhausted after 10-15 years). Methane and leachate extraction also adds to the overall cost.

Table 12: Costs for some specific measures (In Euros)

Cell Cover Cost	31 euros per m^3
Leachate	0.5 Euro per tonne
Gas extraction	0.5 Euro per tonne
Monitoring	0.2 Euro per tonne

Source: Ness 2000

[1] The convert rate is considered 1 euro=9 SEK

The new cost is not fixed and depends on the incoming waste quantity treated. In Filborna the cell area is 1.2 hectares, so the cost is 31 euros X 12,000m^2 or 372,000 euros for 110,000t. That adds 3.4 euros per tonne and the final cost including the leachate gas extraction and monitoring cost reaches 15.7+3.4+1.2= 20.3 euro/tonne. To get the final cost, the leachate treatment cost must finally be added; for Filborma LBC it was 1.2 euros (11 SEK)/tonne[1]. That increases the total cost to 21.5 euros/tonne.
The aforementioned cost does not include the cost for the leachate vegetation system. According to Ness study the establishment of vegetation filters reduces the treatment cost from 183,856m^3 x 0.72 euros/ m^3 = 132,376.32 euros/year to 2,441 euros/year for 20 hectares vegetation. The treatment cost for this particular area based on the vegetation filters is 0.072 euros or 0.65 SEK per m^3.
External cost for the LBC can be addressed as external costs of facility disamenity effects, e.g. visual effects, noise, smell and litter;

5.4.6.3 The incineration cost
The cost of an incinerating plant is very high in comparison with the biological treatment cost. Thus the high construction cost constitutes a significant barrier. (In Sweden the SYSAV incineration unit, with a capacity of 200,000 t/year, had a construction cost of more than 85 million euros in 2000 (Ness 2000); in Brescia, Italy, the construction cost for an incineration unit with a capacity of 1600t/day was160million euros in 1998) (Panagiotakopoulos, 2002). The need for such a great investment has a large payback period (of up to 15 years) (*EC 2002b)*.
It must be added that the facility's life expectancy is about 20 years (EC 2002b).
The operational cost (capital cost and revenues from energy excluded) ranges from 20 to 50 euros (depending on the size of the plant).

The incineration Unit in Malmö Sweden is operated by SYSAV and incinerates 205,000 tonnes of waste annually or its operating 8,200hr per year. The cost can be divided as follows:

Construction cost	85 million euros (800 million SEK)
Operational cost	36 euros/t (300 -350 SEK/t)

Taking into consideration that the treatment plant has a life expectancy of 20 years, then the treatment cost is about 57 (21+36) euros per tonne.

Waste incineration produces energy which can be sold, so the waste is transformed into energy, but unlike the BRC the nutrients are lost in the ash and disposed of without a closure of the ecological circle.

Besides the conventional cost, incineration generates significant external costs. A study for the European Commission demonstrated large benefits for the switch from incineration to composting (in the order of €12 - €25 per tonne) and even larger ones (€13 - €29 per tone) when switching from incineration to anaerobic digestion *(EC 2003a).*

[1] Leachate treatment cost is 0.72 euros or 6.5 SEK per tonne (Ness 2000).

Additionally, the incineration directive sets requirements and restrictions for the treatment of residues (flue gas, bottom/fly ash). Cost does not include the expenses for ash treatment/disposal.

Incineration/BRC, Revenues and Total Cost

BRC technique as well as incineration provides significant revenues for the utilization of the output of their operation.
Bioreactor Cells gain revenues from the production of biogas and the use of leachates as fertilizers for biomass production (in Filborna the forest plantation gain revenues from selling woodchips).
The SYSAV's Incineration plant, on the other hand, has gained revenues from the recovery of produced energy.
To illustrate the system, the revenues must be added to the system to indicate the total cost of each method (Costs – Revenues).

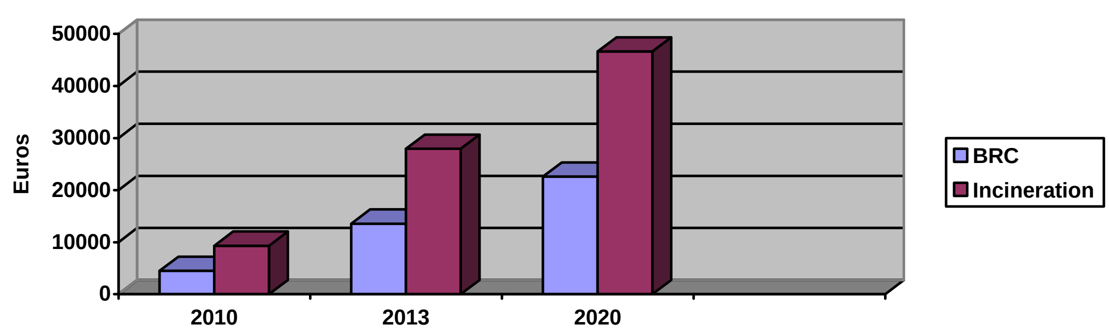
Table 13: Total treatment cost (Euros/tonne)

	BRC w/o veg. filter	BRC with veg. filter	Incineration[1]
Treatment Cost	22 (198 SEK)	20.8 (187 SEK)	57 (513 SEK)
Energy Revenues	10.7 (97 SEK)	10.8 (98 SEK)	33.3 (300 SEK)
Total Cost	11.3 (101 SEK)	10 (89 SEK)	23.3 (213 SEK)

According to table 13 there are three scenarios that estimate the generation of the BMW for Greece over the next 15 years. Scenario 2 is chosen as the realistic scenario approaching the 2% annual increase.
In this approach, it is assumed that the composting facilities treat 700,000 tonnes per year (the present capacity).

The diverted quantity of BMW is (in thousand tonnes)
2010: 1,100 - 700 = 400
2013: 1,900 - 700 = 1,200
2020: 2,700 - 700 = 2,000

Figure 8: Cost of Bioreactor Cell/Incineration treatment for Scenario #2



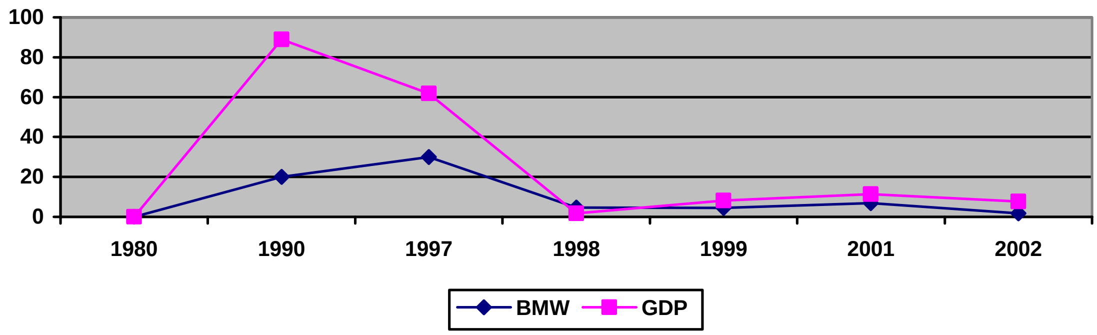
[1] Energy recovery is 615,918 MWh/year. Payment is 11.1 euro/MWh (100 SEK/MWh) (Ness, 2000)

6. Discussion

6.1 Waste generation

The scenarios concerning the projections for Greek waste generation were based on the assumption of an EU study (EEA, 2002c). In this study, instead of EU's 2nd scenario with an annual growth rate of 2%, a 35% growth rate has been chosen for the 2001-2020 period.

Figure 9: BMW and GDP growth rates within Greece 1980-2002



Although there is a trend for decoupling the GDP and the generating MSW, it is clear waste generation follows the GDP trend. Because the elasticity is between 0 and 1, waste generation is less than the increase in GDP.

A strategy for treating the BMW fraction, meeting the targets set out in the landfill directive needs a comprehensive understanding of the BMW quantities being produced within the country, as well as their future. As with all projections considering future trends, the results must be treated with a degree of caution; however, they give an indication of the challenges that Greece might face in the forthcoming years.

Table 6 presents an overview of projected quantities for Greece during the targeted years, 2009 to the year 2020, based on the assumption that BMW quantities will grow in line with projected growth in private consumption (as expressed in GDP).
Obviously, any increase in BMW generation during the time frame of the Landfill Directive (2009-2020) will have a considerable effect on the requirement for treatment routes other than landfill.
Thus it is essential for the Greek waste management strategy to examine a comprehensive analysis of future trends in BMW generation between now and 2020, in order to ensure that adequate capacity can be planned well in advance of directive's requirements.
The National strategy for waste will also need to be sufficiently flexible in order to successfully respond to changes (such as economic and demographic changes) that may affect the generating BMW quantities.

6.2 Market issues

Despite the absence of a market for products of composting, there is a well organized market for power and heat production. In Ano Liosia landfill (collecting the waste of the Attica periphery) a CHP plant has successfully operated since 2001. About 110 GWh of electricity is produced annually. The electricity is sold to the national electricity company. Moreover, the remaining thermal energy from flue gasses is utilized for heating

purposes (steam and hot water production). The total capacity of heat production is approximately 16.5 MWth. (ACMAR, 2004).
Given the fact that the aforementioned production of energy has been based on the extraction of 4.5 m^3/t of waste, and then the extraction of the total amount of biogas from a landfill bioreactor cell would multiply the revenues from methane utilization.
Thus, the construction and operation of a CHP plant is essential when the aim is the maximization of revenues. As was often mentioned, the biogas, CH_4 utilization from landfills contributes to the RES, and also meets the requirements of the EU hierarchy for energy recovery, simultaneously providing revenues to the owner of the facility.

The utilization of leachates for biomass production has been based on the Swedish system. The energy forest is located near the treatment facility and its 20ha. The revenues are provided by the burn of woodchip. The absence of such a system in Greece is a fact, but a novel practice like that is a challenge for both economic and environmental reasons. The energy forests can be created on the restored landfills. In the case of Athens, the Ano Liosia landfill has covered a land area of 250 ha and is approaching its carrying capacity. The new landfill will be created near the old one. Hence a forest for future utilization of biomass energy can be established.

6.3 Taxation

The introduction of a tax on landfill waste surely affects the MSW management system. An environmental tax means there is some external additional cost that is not reflected on the market price. In Greece there is no direct taxation for waste generation. A tax on landfilling could help decrease waste volume; promote reuse and recycling, according to the EU waste hierarchy. Many member states have imposed taxes on landfilling (The Swedish government has imposed a tax of 250 SEK (28 euro)/tonne of waste.) Taxation is an economic tool for policy-making. For instance, in Sweden the implementation of the landfill tax has created problems to the financial performance of the LBC, which have been classified as conventional landfills and are therefore taxed by 250SEK. In the Greek case, there is no evidence of such a policy yet. Apart from that, another important issue for implementing such a measure is the willingness of the public to accept it. The Greek economy has been fluctuating after the Olympic Games, so the introduction of a landfill tax could create many political and economic problems at this particular moment. Although there is no clear evidence of a landfill implementation, at least in the short term, a well-structured plan should consider the possibility of future landfill taxation. Taxation on landfill will affect any kind of chosen treatment method, whether it is BRC or incineration.

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7. CONCLUSIONS

Waste production is a threat to public health, as well as a loss of valuable resources. The current waste management system in Greece does not respect these two principles.
The findings of this study have established that Landfilling as a predominant waste treatment method (without gas and leachate collection) could create a lot of socioeconomic and environmental problems.

EU policy for waste, especially the implementation of the waste directive, has created a new reality in waste management across member states.

Composting, due to the lack of sorting schemes, especially the small portion of source separation of the waste stream, leads to low quality products.

Landfill Bioreactor Cell treatment is a sustainable solution, since it minimizes the effects of conventional landfill and at the same time it provides economic benefits to the system, mainly through biogas utilization and production. Moreover, methane and nutrients enters back to society, thus closing the loop.

The Landfill bioreactor cell is a new waste treatment technique which is much more economical compared to incineration.

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