Waste Management in Greece and Potential for Waste-to-Energy

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Abstract In Greece the daily production of Municipal Solid Waste (MSW) is estimated to be 15,000 tones, which means roughly 5.4 million tons per year, from which 77% is deposited in Landfills, 23% is recycled and composted. The European Union Legislation for Sanitary Landfills (1999/31/EC), imposes the decrease of biodegradable waste that are deposit to sanitary landfills; thus WtE methods of MSW is one of the best, in terms of affordability in a competitive world and environmental friendly, proposed solutions. Waste-to-Energy methods produce steam and/or electricity. Also, the weight of MSW is reduced up to 70–80% and the volume up to 90%, and finally the land area requirements are very small. Our proposal for the WtE technology implementation in Greece is the construction of MSW WtE plants in all major cities operating with an annual capacity of 200,000–400,000 tones. The required land area will be only 4–7 ha. The basic income of such plants is the gate fee, varying from 50 to 80 €/ton. The second income comes from selling of the produced electricity to the Public Power Corporation for 87.85 €/MWh (referring to the biodegradable fraction of MSW), according to the new Greek law for renewable energy sources (L. 3851/2010). Additional income comes from the recovered metals of the bottom ash. Furthermore, there is a considerable prospect for state subsidy of the whole investment, according to the Greek Development Law.

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1 Introduction

Economic development leads to higher consumption rate of goods and services and, thus, there is an increase with regard to the generation of solid wastes. As the rate of waste generation is higher than the rate of economic and population growth; several waste management methods are applied in order to minimize the environmental impact and make it an affordable solution in a competitive world. In the generally accepted waste management hierarchy, the first priority is waste reduction, followed by recycling and composting of clean biodegradable organic wastes as well (food and yard wastes). The EU promotes recycling over other waste treatment methods for recovering materials and energy, the latter either in the form of electricity/heat or production of waste derived fuels. In this way, physical resources are protected since paper, metals, glass, plastics that are recovered from the waste stream demand less resources and energy than the use of “virgin” materials. Also, the energy recovery provides electricity and heat to industrial, commercial and domestic consumers, and also minimizes the volume of wastes to be disposed. The goal of combining these approaches, as well as the additional option of composting, is to minimize the loss of resources to final inert landfill disposal.

Landfilling is the most common method for waste management in many EU Member States and in some cases this dependency exceeds 80%. The EU Landfill Directive of 1999 obliges Member States to progressively reduce the amount of organic waste going to landfill to 35% of the 1995 levels within 15 years aims to reduce such a loss of resources. This clear policy direction has put emphasis on waste management systems that increase and optimize the recovery of resources from waste—whether as materials or as energy. Accordingly, the member states are adopting Waste-to-Energy (WtE) and also mechanical–biological treatment (MBT) methods for the recovery of energy and materials from municipal solid wastes (MSW) and non—hazardous industrial wastes. WtE facilities can combust either as-received MSW (stoker or “mass burn” technology) or pre-processed “refuse-derived” fuels (RDF or SRF). The latter have higher calorific values and can be used both in dedicated WtE plants and as fuel substitutes in cement kilns and coal-fired power plants. In order to protect the environment from the emissions in energy recovery facilities, EU adopted the regulation on emission limits from waste incineration plants (Directive 2000/76/EC), while the regulation on renewable energy sources (RES) (Directive 2001/77/EC), includes the biogenic fraction of wastes [1–3].

Even though there are studies regarding the energy content of MSW and the possibilities for implementing WtE for power generation in Greece, none to our knowledge presents the energy potential for Greece in terms of power generation potential per region. This paper investigates this potential, focusing on electricity production, by examining the application of mass burn and RDF/SRF utilisation options for managing MSW in Greece, in the light of experience gained in E.U. and the U.S., and the National Plan for Waste Management of the Ministry of Environment.

Table 1 Chemical analysis of different waste streams

Waste stream	Content (%)							(MJ/kg)	
	Water	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	HHV	LHV
Food waste	70	48	6.4	37.6	2.6	0.4	5	7.08	3.96
Paper and cartons	6	43.5	6	44	0.3	0.2	6	14.49	13.03
Plastic	2	60	7.2	22.8	0	0	10	26.11	24.48
Textile	10	55	6.6	31.2	4.6	0.2	2.5	20.17	18.47
Wood	20	49.5	6	31.2	4.6	0.2	2.5	15.96	14.16
Garden	60	47.8	6	38	3.4	0.3	4.5	7.94	5.16
Glass	2	0.5	0.1	0.4	0.1	0	98.9	0.23	0.16
Metals	3	4.5	0.6	4.3	0.1	0	90.5	1.55	1.35
Others	20.5	20.91	2.39	12.78	0.4	0.1	42.93	6.72	5.69

Waste can be a major source of renewable energy. The chemical analysis of different waste streams are presented in the Table 1.

2 Current Waste Management in Greece

Greece is a European country situated in the south-eastern part of it, with population, as of the census of 2001, 10.964.020 inhabitants. Its population is predicted to be 11,295,000 inhabitants in 2011. Administratively, Greece consists of thirteen peripheries, with total land area of 131,621 km^2. The climate of Greece is mostly Mediterranean type, which features mild, wet winters and hot, dry summers. Moreover, the MSW generation in Greece in 2001 was 4,529,585 tones, whereas it is forecasted that in 2011 the generation will be 5,981,290 tones and in 2025 it will be 7,625,648 tones. In 2010, the daily MSW production was around 15,000 tones, which correspond to 5.4 million tones of MSW on an annual basis. Focusing on the Attica region, where Athens, the capital of Greece, is placed, the MSW production reaches the quantity of 6,500 tones daily, which equals to 2.4 million tones of MSW per annum [4].

In general, the waste management in Greece depends especially on dumps and sanitary landfill sites. According to the European Union, uncontrolled disposal sites (dumps) are illegal and have to shut down. The deadline was extended for Greece, until the 1st January of 2011. Nevertheless not all of the dumps have been closed, but new ones have been created, as there is no sustainable waste management plan in Greece. The only exceptions are the five Mechanical and Biological Treatment plants located in Athens, Kalamata, Chania, Heraklio and Kefalonia. On the other hand the products of these plants, such as RDF and compost, have no responding market and as a result in the most cases they are disposed to landfill.

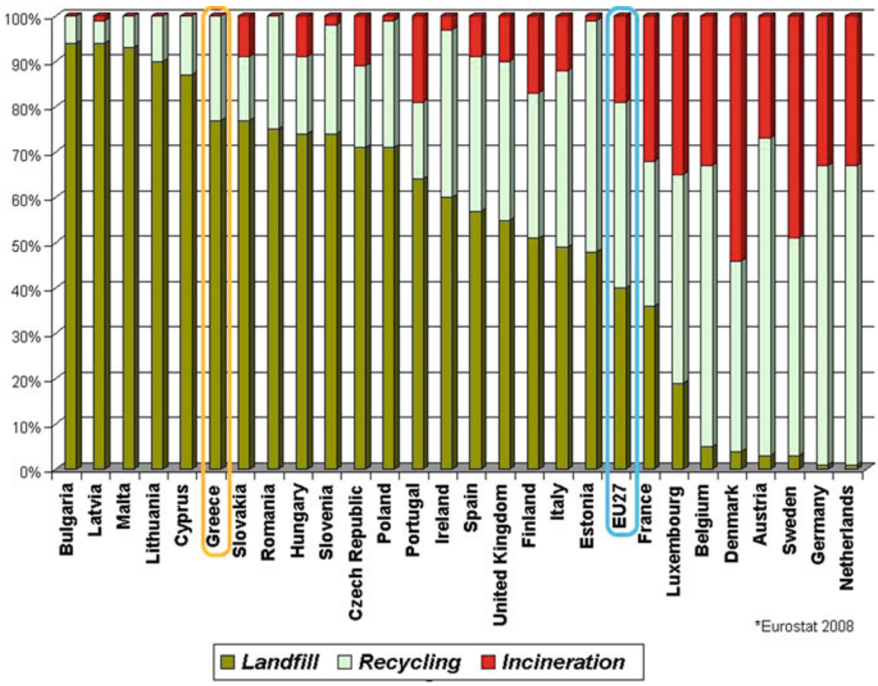

Fig. 1 Waste management statistics across Europe for 2008 (Eurostat)

All the above have driven Greece to the bottom of the European's sustainable waste management gradation. These facts are loudly verified by Eurostat, whose statistics for the year of 2008 for Greece give 77% landfill, 23% recycling and composting. In the Fig. 1 the statistics by Eurostat for the waste management across Europe on 2008 are presented.

The composition of MSW in Greece across the thirteen peripheries of the country is presented in the Fig. 2.

The waste management system is plagued by a number of problems, some of which include inadequate management, lack of technology and human resources, a shortage of transportation vehicles and insufficient funding. In 2010, there are 102 organizations working for the collection, transportation and disposal of residues for the 13 peripheries. Moreover, in Greece there are 25 Waste Transfer Stations, whereas the total WTS that are under construction are 107.

In 2010, the number of sanitary landfills in Greece was 77, for the convenience of 7,861,586 inhabitants, with annually dynamic of 3,031,570 tones. The total sanitary landfills that are under construction or under development are 146. Moreover, there are 3,036 uncontrolled disposal sites located throughout Greece, of which 316 are active, 429 are under reconstruction, and 2,291 are reconstructed. The only Periphery that has not any uncontrolled landfills is West Macedonia.

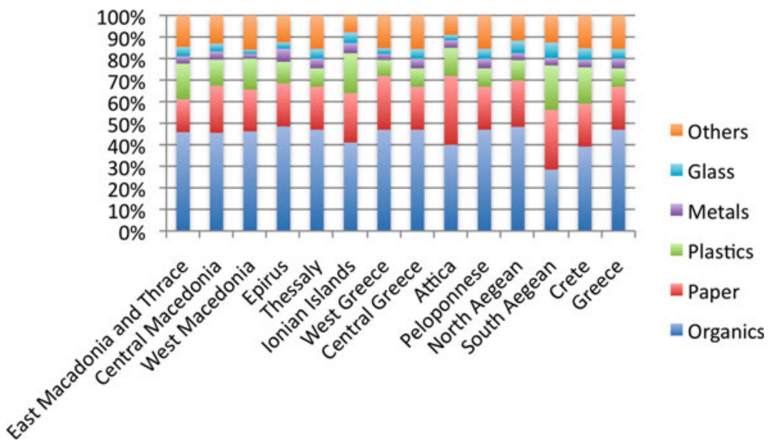

Fig. 2 Composition of Greek MSW

Table 2 Contribution of HE.R.R.Co S.A

Index	2006	2007	2008	2009
Population covered (million)	4.3	6.1	6.6	7.6
Contracted municipalities (#)	337	446	610	648
Sorting centers (#)	12	15	18	22
Recycling bins (#)	25,103	51,602	76,530	98,177
Collection vehicles (#)	95	140	236	327

As regards recycling, communal collection points have been set up in the main towns using 1,100 L containers for glass, paper, cardboard and plastic. These are then emptied by a Refuse Collection Vehicle, in a co-mingled form, and delivered to a materials recovery facility (MRF) for segregation. The system is poor at present as the infrastructure is not in place for regular collection from villages and rural areas. More government promotion is needed to encourage the wider population to recycle, e.g. posters, campaigns, education etc. The Hellenic Recovery Recycling Corporation (HE.R.R.Co S.A.) is responsible for the recycling and reuse of MSW in Greece. It was founded in December 2001 by industrial and commercial enterprises, which, either supply packaged products to the Greek market, or manufacture different packaging items. The Central Union of Municipalities and Communities in Greece (KEDKE) has a shareholding of 35% in the System's capital. In the Table 2 the contribution of HE.R.R.Co S.A. in recycling and reuse of materials is presented [5, 6].

In Greece there are five MBT facilities, which are presented below:

Table 3 Facilities producing energy from biogas recovery

Periphery	Power	Operation
Attica	23.5 MWe, 9.5 MWth	March-01
Thessaly	1.7 MWe	June-08
C. Macedonia	5 MWe	December-06
Crete–Chania	2.3 MWe	2005
Peloponnese–Kalamata		1998–2002. Restarts 2010

- Attica: This MBT plant started its operation in 2004 with a daily capacity of 1200 t and it operates 250 days per annum. The technology that is implemented is mechanical separation and aerobic biological treatment of the biodegradable fraction. The products are the secondary fuel RDF (470 tpd), the compost (120 tpd) and also 23 tpd of ferrous metals and 0.36 tpd of aluminium are recovered. As there is no market for the products of this plant, they are disposed to nearest landfill of Ano Liossia.
- Chania (Crete): This MBT plant started its operation in 2005 with an annual capacity of 70,000 t and it operates 260 days per annum. This plant recovers recyclables (9,000 tpa of paper, 5,200 tpa of plastic, 1,800 tpa of ferrous metals and 600 tpa of aluminium) and also producing 20,000 tpa compost. The 35% residuals are disposed to the nearest landfill.
- Kefalonia (Ionian Islands): This MBT plant started its operation in 2009 with an annual capacity of 25,000 t. The applied technology of this plant is bio-oxidation, through which the overall waste mass is reduced by 36% and the biodegradable fraction is diverted from landfilling by 60%. The product of this plant is used as daily cover material for the nearest landfill.
- Heraklion (Crete): This MBT plant started its operation in January of 2010 with an annual capacity of 75,000 t. The applied technology of this plant is bio-drying, through which the final product is reduced at least by 25% in terms of moisture. Also ferrous metals are recovered.
- Kalamata (Peloponnesus): The MBT plant of Kalamata is the first plant implementing this technology in Greece. The technology that is implemented is mechanical separation and aerobic biological treatment of the biodegradable fraction. It was constructed in 1997, having an operational capacity of 32,000 tpa, nevertheless there were operational difficulties and as a result the plant shut down. There are plans to restart the operation of the plant.

In Greece there are five facilities produce energy from biogas recovery. Concisely, these facilities are presented in the Table 3.

Facilities producing Energy from biogas recovery

In the Fig. 3 is presented the lower heating value (LHV) of Greek MSW

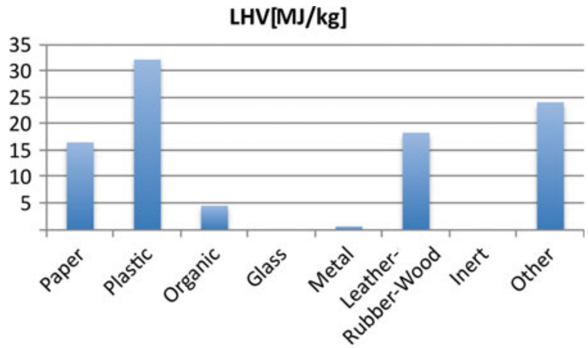

Fig. 3 LHV of Greek MSW (in MJ/kg)

3 Waste-to-Energy Technology

3.1 Introduction-Legislation

The European Union Legislation for Sanitary Landfills (1999/31/EC), imposes the decrease of biodegradable waste fraction which is land filled. Hence, thermal treatment methods of municipal solid waste along with recycling at the source and composting of pre-sorted fraction of waste is almost the only solution to such problems. Additional advantages are the volume and weight reduction of municipal solid waste and the energy production (with the possibility for heat for district heating, industrial heating purposes or for cooling, Waste to Energy Plants/WtE). The Greek legislation for the Incineration of wastes is the Joint Ministry Decision JMD 22912/1117/2005 (in harmonization with the European Union directive for Incineration of Waste 2000/76/EC).

The European Union defined the optimum hierarchy for the waste treatment methods through the 2008/98 EU directive. According to this directive, reduction, reusing and recycling are the first stages, followed by efficient energy recovery methods, which have been upgraded in the hierarchy list [7].

Especially, the European Union, via the directives that it issues, indirectly promotes the application of thermal treatment methods (incineration, gasification and pyrolysis) along with recycling at the source and composting of pre-chosen organic fraction of waste, as an effective method of reducing the quantities of MSW that are deposited in sanitary landfills, while simultaneously producing energy in the form of heat and electricity by exploiting the heating value of MSW. With fossil fuel reserves decreasing dramatically, the utilisation of MSW as fuel looks even more promising [8].

3.2 Waste-to-Energy Technology

Incineration is an old process that includes the development of high temperatures, with the presence of flame for the oxidation of the MSW, (chemical compound with oxygen). The target of this complicated physicochemical operation is the evaporation, degradation and destruction of organic elements in MSW, with the presence of oxygen and also the reduction of the weight and the volume of MSW. The products of the incineration include gaseous compounds (for example CO_2, NO_x, acid gases, PAHs, eje.), which need to be further treated in the state of the art flue-gas cleaning system before the final emission in the atmosphere. The inert solid residues (bottom and fly ash) represent the 20–30% of the incinerator's initial feed (MSW quantity), and possibly contain some important inorganic pollutants, like heavy metals. After stabilization and solidification, the fly ash can disposed in sanitary landfill, while the bottom ash is relative inert and in general can be used for construction applications (roads, earthworks, in mines, etc).

Thermal treatment methods (incineration) with energy recovery represent the majority of waste to energy processes that are in operation across Europe. For the utilisation of produced heat and the recovery of energy, modern incinerators have special boilers for steam production. Then, the produced steam is used either straight for heating applications, or via a suitable steam turbine and generator for the production of electricity. In the following Fig. 4, a typical MSW incineration plant for energy production is presented. The most important process in such an incineration plant is the state of the art flue gas cleaning system, for the chemical cleaning of the produced in the WtE plant gaseous pollutants. The major systems are dry or wet scrubbers, electrostatic filters, fabric bag filters and cyclones, activated carbon filters, chemicals (like NH_3, CaO, Ca $(OH)_2$). The optimum selection of the flue-gas cleaning system is based in the composition of the gaseous pollutants under treatment (depending also on the composition of the feed of MSW) and the emission limits of the plant, according to the directive 2000/76/EC [9–11].

3.3 Emission Levels in Thermal Treatment

The best available antipollution techniques during the whole thermal treatment process of MSW, under the very strict emission limits of the 2000/76/EC directive, and similar in USA and other countries, lead to the environmental acceptance of the MSW incineration plants worldwide, and also promote these incineration methods as friendlier for the environment, even when compared with typical human activities such as using fireplaces or fireworks (see Table 4).

Even worse, the largest amounts of dioxin emissions are released to the open burning landfills, which is a really common phenomenon in Greece especially on the summer period. According to Dr. Nikolaos Mousiopoulos, Professor of the Aristotle University of Thessaloniki, the uncontrolled fire in Tagarades Landfill

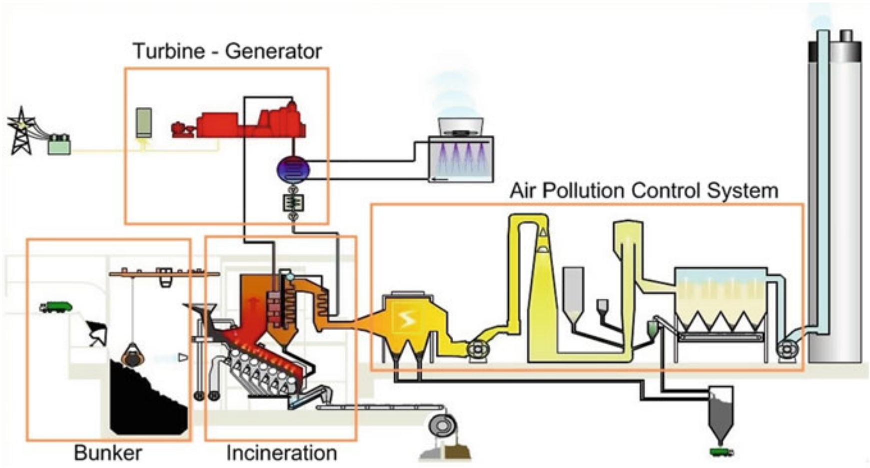

Fig. 4 Typical MSW incineration plant with electricity generation

Table 4 Dioxin emissions

Modern WtE plant	1	0.01 ng/m^3
Modern WtE plant for hazardous waste	1	0.01 ng/m^3
Non controlled incineration (i.e. Fireplaces)	1,000	10 ng/m^3
Fireworks	10,000	100 ng/m^3
Burning landfill	100,000	1,000 ng/m^3

(Thessaloniki) on 2006 summer generated 3 g of toxic dioxins per day. In contrast, the 88 WtE plants operating in USA, which burn more than thirty million tones of waste, release less than 10 g of dioxins at a period of a whole year, as the Emeritus Professor Nikolaos Themelis, director of the Earth Engineering Center of Columbia University, presented in Special Permanent Council for the Environmental Protection of the Greek Parliament on 26 July 2006 [5, 12].

Four years ago, the U.S.A. EPA announced that, MSW incineration plants produced 2800 MW electricity, with smaller emissions compared to any other power plant. MSW incineration plants are more than 800 in all over the world (around 120 WtE facilities have been constructed within the last 10 years). Although in Europe, in U.S.A. and in Japan, the MSW thermal treatment is the most popular technology for the MSW treatment, however, Greece, is almost the only country in the European Union that does not include WtE method in the national waste management plan. Pioneer countries in the application of waste to energy (MSW thermal treatment methods) are Switzerland, Sweden, Netherlands, Denmark, Germany and France, Belgium, Austria and Norway [13, 14].

In Europe, the contribution of dioxin produced in Municipal Solid Waste/WtE Plants is less than 0.7% of the total dioxin production. In Brescia of Italy there is a modern WtE Plant with a nominal capacity of 340,000 tones MSW annually (two

Table 5 Stack emissions from Brescia WtE Plant (All units are in mg/Nm^3)

The values correspond to dry air, normal conditions, 11% O_2	Plant authorization limits 1993	Design plant limits 1994	European union limits 2000	Actual operating data 2005
Particulate matter	10	3	10	0.4
Sulphur Dioxide	150	40	50	6.5
Nitrous Oxides (NO_x)	200	100	200	<80
Hydrochloric Acid (HCl)	30	20	10	3.5
Hydrofluoric Acid (HF)	1	1	1	0.1
Carbon Monoxide	100	40	50	15
Heavy Metals	2	0.5	0.5	0.01
Cadmium (Cd)	0.1	0.02	0.05	0.002
Merucy (Hg)	0.1	0,02	0.05	0.002
Polycyclic Aromatic Hydrocarbon (PAH)	0.05	0.01		0.00001
Dioxin (TCDD Teq)	0.1	0.1	0.1	0.002

lines for the combustion of household waste, went into operation in 1998) and 170,000 tones of biomass, producing 50 MW of electrical power and 100 MW of thermal power for district heating. This plant is only within 300 m distance from the first houses within the city of Brescia (located halfway between Milan and Padua). From the following Table 5 it is well understood that the gaseous emissions from the stack are much lower than the limit values of the European Union directive for Incineration of Waste (2000/76/EC) [2].

3.4 Contribution of MSW Thermal Treatment to Global Warming

The contribution of MSW Waste to energy plants for the reduction of gaseous pollutants in the atmosphere is very important. MSW incineration plants have the obligation to obey to the very strict gaseous emissions according to 2000/76/EC directive, comparing with the emissions of other industrial activities. Problems from the past, such as increased dioxin emissions have now been surpassed, due to the state of the art flue-gas cleaning systems. Of course, the production of various gaseous pollutants depends also in the physicochemical characteristics of the MSW under treatment. The production of the CH_4 and CO_2 in a sanitary landfill varies among cities and countries. According to the Greek literature, the estimated production of CH_4 in Greek sanitary landfills, ranges between 30 and 250 m^3/ton dry MSW, for U.S.A. is around 62 m^3/ton MSW. The estimated production of CO_2 is 1.32 ton/ton MSW in U.S.A. and 1.5 ton/ton MSW in Australia and Israel. However, it is well known that the CH_4 which is produced in the abovementioned significant quantities in sanitary landfills is a very potent greenhouse gas, having a global warming potential of 21 times that of CO_2. The production of CH_4 is avoided with the application of MSW thermal treatment methods [5, 12].

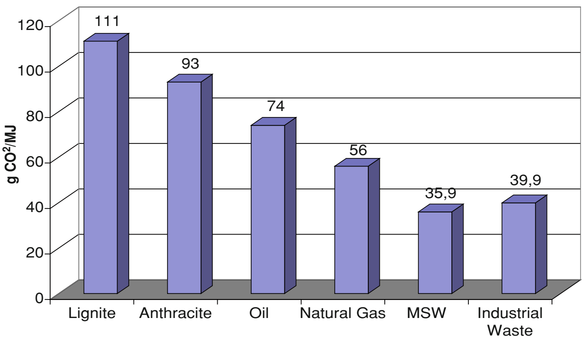

Fig. 5 CO_2 emissions by the combustion of different fuels [1]

In Fig. 5 below, it is well understood that the CO_2 emissions produced during the MSW combustion for energy production, are significantly less than the CO_2 emissions produced from conventional fossil fuels combustion such as lignite, petroleum, anthracite, natural gas. The produced CO_2 during the MSW incineration for energy production is counted as regenerated CO_2, a fact that contributes to the reduction of the production of «protogenic» CO_2 from fossil fuels, such as lignite. So, it contributes to the reduction of «new» inserted quantities of CO_2 to the atmosphere and finally to the Kyoto protocol targets [20]. Simultaneously the cost of mitigating 1 ton CO_2 with the use of MSW as renewable energy source in waste to energy plants, is significantly smaller (7–20 €) in comparison to the cost from other energy production plants which use other biomass forms (80 €), or solar power (photovoltaics, more than 1,000 €, [13]. In conclusion, the waste to energy plants have a significant contribution in the reduction of the atmospheric CO_2. The recovered energy produced from the MSW thermal treatment, reduces the emissions of gases which contribute to the Greenhouse phenomenon in two ways: (1) avoids the methane production and other greenhouse gases produced in sanitary landfills and (2) produces less CO_2 emissions compared to fossil fuels. Taking into consideration the above analysis, the MSW thermal treatment methods (waste to energy), are considered to be among the most efficient methods for solving the municipal solid waste management and treatment problem of Greece and other countries [13, 14].

4 Potential for Waste-to-Energy in Greece

4.1 Introduction

The National Plan of Greece for Waste Management for 2007–2013 (ex-Ministry of Environment, Planning and Public Works), foresees a number of Plants for RDF/SRF production in several areas of Greece, but does not mention the need for RDF-dedicated WtE facilities, because it is assumed that this material would be co-combusted in existing industrial plants. However, if this route does not materialize, as it did not for the MBTC of Ano Liossia, it would be necessary to build combustion plants fuelled by RDF. It must be noted that MSW Processing Plants have also been included in the National Plan for MSW for the Regions of Western Greece, Central Greece, Thessaly, Epirus, East Macedonia and Thrace; however, the number and capacities of such plants have not been defined to this date.

The cases of Attica and Central Macedonia are more complicated due to public acceptance. The quantities of produced MSW are very high and thus, based on international experience, the best method for energy recovery seems to be mass-burn WtE combined with RDF/SRF streams produced at communities far away from the WtE facility. Due to the fact that the major WtE power plants will be close to the consumers (Athens and Thessaloniki), the benefit is even higher due to lower electricity network losses. Combustion with energy recovery will also result in a 90% reduction in the volume of wastes to be landfilled, in case that beneficial uses of WtE ash are not developed. The resulting benefit will be quite high, both in terms of electricity supply and environmental quality in regions that are facing major problems in managing their wastes.

Waste-to-Energy methods produce steam and/or electricity. Also, the weight of MSW is reduced up to 70–80% and the volume up to 90%, and finally the land area requirements are very small. The WtE technology might be implemented in Greece by the construction of MSW WtE plants in all major cities operating with an annual capacity of 200,000–400,000 tones. The required land area will be only 4–7 ha. The basic income of such plants is the gate fee, varying from 50 to 80 €/ton. The second income comes from selling of the produced electricity to the Public Power Corporation for 87.85 €/MWh (referring to the biodegradable fraction of MSW), according to the new Greek law for renewable energy sources (L. 3851/2010). Additional income comes from the recovered metals of the bottom ash. Furthermore, there is a considerable prospect for state subsidy of the whole investment, according to the New Greek Development Law, rated at a 30–40% and depending on the selective site for the plant construction (30% equity and 40% loan). The basic actions required for the preparation of the construction of a MSW waste to energy plant are, in brief [4]:

- Locating the suitable site (land).
- Analytical Preliminary Environmental Study (approved by the Ministry of Environment, Energy and Climate Change).
- Final Environmental Study and all relative papers for the Public Power Corporation (Regulatory Authority for Energy) and the Ministry of Development (for installation, operation, electricity production eje).

4.2 Attica Case

In Attica region (capital of Greece) the daily production of Municipal Solid Waste (MSW) is estimated at 6,500 tones. This means around 2.4 million tones per year, from which 90% is deposited in one Sanitary Landfill, which is almost full. The

Table 6 Power production of the three scenarios for Attica region

Capacity (t/a)	400,000 MSW	700,000 MSW	700,000 MSW + 300,000 RDF
Lower heating value (MJ/kg)	9	9	10.8
Gross power (MW)	32.93	57.63	98.73
Net power (MW)	27.99	48.98	83.92
R1	0.6972	0.6972	0.6979
Net electrical energy (MWh/year)	223,929.08	391,875.90	671,387.41
Number of residents served	141,530	247,677	424,336

European Union Legislation for Sanitary Landfills (1999/31/EC), imposes the decrease of biodegradable waste which are deposit to sanitary landfills, so WtE methods of MSW is almost the only solution to such problems. The Greek legislation for the incineration of wastes is the Joint Ministry Decision 22912/1117/2005 (in harmonization with the European Union directive for Incineration of Waste 2000/76/EC).

For the Attica Region, the Greek Waste-to-Energy Research and Technology Council "SYNERGIA" has suggested the following tree scenarios, through which all the difficulties on the waste management in Attica will be overcome.

Two plants of 400,000 tpa, which is a medium capacity plant. Whether two plants of such capacity were constructed in opposite directions of the Attica Region, the residuals of recycling would be managed by the most environmental friendly method, producing electricity and increasing the lifetime of the landfills.

One plant of 700,000 tpa, which is a large capacity plant, according to the global reference. This kind of plant might be constructed at a site where already waste management facilities exist. Such a place in Attica might be at Ano Liossia Municipality, where the main landfill of Attica and a MBT plant exist.

One co-incineration plant of 700,000 tpa MSW and 300,000 tpa RDF, which is a large capacity plant and also implementing state-of-the-art techniques. This proposal is based on the previous one and also provides a treatment method for the produced RDF of Attica, which otherwise would be landfilled [6].

In the following Table 6 the power production of the three scenarios for Attica are presented.

4.3 Rhodes Case

At the very beginning of In February 2008, the Waste Management Company of Rhodes (DEKR), requested by Themelis Associates and the Earth Engineering Center of Columbia University to conduct a pre-feasibility study setting the following essential conditions to be met in selecting the technology to replace the existing sanitary landfill:

- The technology selected should solve the waste management problem of the island not only for a certain number of years but for generations to come.
- The technology should be proven for several years and be widely accepted in nations that are leading in the global effort for environmental protection.
- The proposed plant should be of capacity that can handle the MSW of all ten municipalities of the island of Rhodes as well as other commercial, light industrial and agricultural residues that cannot be recycled; plus the biosolids produced by the wastewater treatment plants in Rhodes.
- The proposed technology should be environmentally superior to a new Landfill.
- The proposed plant should be economically viable and not impose a very high gate fee, per ton of MSW processed, on the citizens of the island. In particular, it should conserve land by reducing the volume of residuals to be landfilled.

On the basis of the specified conditions by DEKR, the best suited thermal treatment technology for the first WtE facility in Greece is controlled combustion of as-received MSW on a moving grate and recovery of the energy in the combustion gases by means of a boiler and a steam turbine. Furthermore, the municipal waste management company of Rhodes (DEKR) plans to construct an integrated waste-management Environmental Park that will include composting of source-separated organics, recycling of source-separated recyclables (mostly paper, metals and some marketable grades of plastics), combustion of post-recycling MSW, and sanitary landfilling of the WtE ash that is not used beneficially [3].

The proposed WtE plant may consist initially of one line (grate, furnace, boiler, Air Pollution Control system) of annual capacity of 80,000 tones (10 t/h). However, the building size can provide for later expansion to two lines of 160,000 tones capacity. The two-line WtE facility (160,000 tones/year) will generate an estimated 96,000 MWh of net electricity (600 kWh/ton) for the grid. There will also be available another 80,000 MWh of thermal energy which may be utilized by an adjacent industrial operation that can make use of low pressure steam, such as a paper recycling plant. The capital cost of the two-line operation was estimated at €98 million and of the single-line plant €63 million. A preliminary estimate based on the assumptions that [15, 16]:

- The EU grant will amount to 30% of the capital cost of the two-line plant;
- The average price received for the electricity (about 50% of which is biomass energy and therefore renewable) will be €70 per MWh (according to the new Renewable Energy Law L.3851/2010); and the gate fee for the MSW will be €80 per ton of MSW, showed that the projected WtE would be economically viable, during the 25 year period that the capital investment is paid off, and an economic boon to the community thereafter.

The plant will most likely be financed as a Public Private Partnership. A special problem in Rhodes and other popular tourist destinations is that during the summer months the generation of MSW nearly doubles. To overcome this problem, the Rhodes authorities are considering the importation of MSW from other islands in the area, to complement the feedstock to the WtE plant; or the storage and use of industrial wastes from Rhodes and other places.

The high capital cost of the plant is explained by the fact that in addition to eliminate the need for landfilling on the island, it will utilize the heat of combustion to generate an appreciable amount of electricity for the island [17]. Also, it will include state of the art gas cleaning equipment consisting of dry scrubber (HCl and SO_2 removal), activated carbon non-catalytic selective reduction (for NO_x), activated carbon injection (for volatile metals and dioxins/furans), and fabric filter baghouse (for particulate matter). As a result of the highly sophisticated Air Pollution Control system, the projected emissions will be at lower levels than the E.U. stringent standards that are applied in nations like Denmark, Germany, France, the Netherlands, Sweden, and Switzerland. For example, the projected total emissions of dioxins and furans from the combustion of 160,000 tones of MSW annually will be 0.05 g TEQ. Efforts are also under way to attract industrial or commercial users who can use the low-pressure steam, which remains after generating electricity in the steam turbine, to heat or cool facilities that may be built within a few kilometers of the Eco-Park site [18].

The preliminary technical and environmental studies have been completed and the projected environmental impacts of this installation have been submitted to the Ministry of the Environment, Energy and Climate Change (YPECA). The chosen site for this project is on the northern part of the island and is adjacent to the existing regulation landfill that is now serving most of the population of Rhodes but is scheduled to fill up in less than three years. According to the present plan of Rhodes, in addition to a state-of-the-art waste-to-energy plant which, at the beginning, will process an estimated 300 tones of MSW per day, the Environmental Park that will be created at that site will include an aerobic composting plant for the production of soil conditioning compost, a Center for Recovery of Recyclable Materials (KDAY of Rhodes)., and a new monofill cell that will be used for disposal of the WtE ash that cannot be used beneficially on the island, as has been done in the island of Bermuda and many other nations [19].

5 Conclusion

The waste management plan in Greece has to be changed rapidly in order to be conformed to the European directives. Many efforts should be made in order to inform and persuade the society and the policy makers of Greece that modern waste to energy technology is the demanded step after recycling and composting at the source, in order to be severed by the landfill sites and the illegal dumps.

The research conducted on the existent MSW management system in Greece led to the conclusion that it has several assets and numerous liabilities. Currently, the MSW generated in Greece are mainly transferred either directly or indirectly through Waste Transfer Stations (WTSs), to sanitary landfills; also, some are disposed at illegal Uncontrolled Waste Disposal Sites (UWDSs). To alleviate this situation, the construction of Integrated Waste Management Facilities (IWMFs) has been planned, but not yet implemented. The above reasons render the study for an alternative SWM system obligatory.

In the search for long-term solutions to the existing problem, the advantages and disadvantages of the SWM system currently practiced were taken into consideration in order to develop an effective MSW management plan, which will greatly improve the quality of life in the Region of Attica and Rhodes.

Therefore, a preliminary assessment of WtE as a possible solution to the MSW issue in the Regions of Attica and Rhodes was carried out in this study. This alternative was chosen, because of its demonstrated environmental and economic viability throughout Europe and other nations. It is a well proven means of environmentally sound treatment of solid wastes that also generates renewable electricity and heat. Controlled combustion of as received MSW on moving grates allied with stringent Air Pollution Control (APC) technologies can consistently and reliably process not only untreated MSW, but also post recycling/composting waste residues in an environmentally safe fashion with minimal impact on the environment. Additionally, the volume of waste to be landfilled is reduced by 90%, resulting in alleviation of traffic congestion and the reduction of air pollution caused by trucks. Finally, the electrical and thermal energy produced by the processing of waste (replacing fossil fuels) is a major source of profit and also can be used for the operation and for cooling/heating of the WtE plant and/or neighboring facilities. For all these reasons, WtE is considered to be a long-term solution to the waste problem situated in Greece.

To sum up, the integration of WtE in Greece's Regional Plan for SWM will lead not only to compliance of the Region with the EU targets (Directive 2008/98) towards Sustainable Development, but also to the final solution of the MSW problem of the Region with the simultaneously production of renewable energy (reducing GHGs comparing with fossil fuels, Directive 20–20–20 and the relative new Greek Law 3851/2010) [20].

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