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Energy from biomass-based wastes for sustainable energy development

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Abstract
There are three technologies for biomass waste-to-energy; combustion, gasification and biogass. Direct combustion systems may use steam turbines and, if so, are generally used for only the larger applications. Biomass gasification systems produce a synthesis gas, which can be burned in a gas or diesel engine to provide electricity or motive power or burned in a boiler or furnace to provide heat. This possibility of providing motive or productive uses can be a key attraction of gasification systems for off-grid commercial applications. Typical feedstocks include rice husk, sawdust and wood waste and modular systems are increasingly available for off-grid applications. A biogas power system converts biomass feedstock in the form of animal dung, human excreta and leafy plant materials anaerobically digested to produce a combustible biogas. The simplicity and modularity of design, construction and operation and the variety of uses for the biogas product, make this technology well suited for small-scale applications. Municipal solid waste (MSW) is a major environmental problem in Turkey. Problems associated with municipal solid waste are difficult to address, but efforts towards more efficient collection and transportation and environmentally acceptable waste disposal continue in Turkey. This study presents a brief discussion of renewable energy from biomass-based wastes and municipal solid waste management in the world and in Turkey.

Keywords: Waste to energy; municipal solid waste; biomass-based energy; Turkey

1. Introduction

It is the responsibility of the municipalities to handle the waste issues [1]. However, their financing and technical capabilities are limited [2]. Metropolitan municipalities have a higher budget and better access to funds than smaller municipalities. The interest of the private sector in waste projects is increasing, because of the incentives available to the sector. Collection of waste and operation of landfills by private sector is possible on basis of a concession given by the municipality. Some companies are focusing on the rehabilitation of old dumpsites due to their potential for energy recovery from landfill gas [1-3].

The amount of electricity generated and sold to the grid is a major source of income and the projects' cash flow [4]. There is also growing interest in establishing new sanitary landfills in an integrated waste management format, where recycling, composting, energy recovery are all possible. Companies active in this field are interested in developing of new technologies to increase the efficiency of the plants [1]. On the other hand, currently, world cities generate about 1.3 billion tons of solid waste per year. This volume is expected to increase to 2.2 billion tons by 2025. Waste generation rates will more than double over the next twenty years in lower income countries. Globally, solid waste management costs will increase from today's annual $206 billion to about $376 billion in 2025. Cost increases will be most severe in low income countries and lower-middle income countries [6-10].

The global impacts of solid waste are growing fast [5]. Solid waste is a large source of methane, a powerful GHG that is particularly impactful in the short-term [6]. The recycling industry, with more than two million informal waste pickers, is now a global business with international markets and extensive supply and transportation networks. Locally, uncollected solid waste contributes to flooding, air pollution, and public health impacts such as respiratory ailments, diarrhea and dengue

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fever. In lower income country cities solid waste management is usually a city's single largest budgetary item [5-9].

This paper aims to provide a global information about the waste-to-energy potential for electricity generation and in the field of municipal solid waste (MSW) management, with an emphasis on landfills and energy recovery from landfill gas (LFG) [11, 12]. In this attempt, electrical energy potential of these resources has been found by using applicable waste to energy methods, technical and economical parameters. Based on the resources stated; using the biogas and biomass energy values, calculations resulting in primary energy potentials; the installed capacity for gas-motor systems, gas-turbine systems, gas & steam turbine systems and boiler & steam turbine systems have been determined [11-14].

2. Global status of waste-to-energy

Waste-to-energy technologies consist of any waste treatment process that creates energy in the form of electricity, heat or transport fuels from a waste source. These technologies can be applied to several types of waste: from the semi-solid to liquid and gaseous waste. However, the most common application by far is processing the Municipal Solid Waste (MSW) [10-12]. The current most known waste-to-energy technology for MSW processing is incineration in a combined heat and power (CHP) plant [1].

MSW generation rates are influenced by economic development, the degree of industrialisation, public habits, and local climate [5]. As a general trend, the higher the economic development, the higher the amount of MSW generated. Nowadays more than 50% of the entire world's population lives in urban areas. The high rate of population growth, the rapid pace of the global urbanisation and the economic expansion of developing countries are leading to increased and accelerating rates of municipal solid waste production [5, 7, 9].

However, an increasingly demanding set of environmental, economic and technical factors represents a challenge to the development of these Technologies [15]. In fact, although waste-to-energy technologies using MSW as feed are nowadays well developed, the inconsistency of the composition of MSW, the complexity of the design of the treatment facilities, and the air-polluting emissions still represent open issues for this technology. On the other hand, the development of waste-to-energy projects requires a combination of efforts from several different perspectives. Along with future technical developments, including the introduction in the market of alternative processes to incineration, it is nowadays crucial to take into account all the social, economic and environmental issues that may occur in the decision making process of this technology [15-19].

Growing population, increased urbanization rates and economic growth are dramatically changing the landscape of domestic solid waste in terms of generation rates, waste composition and treatment technologies. A recent study estimates that the global MSW generation is approximately 1.3 billion tonnes per year or an average of 1.2 kg/capita/day. It is to be noted however that the per capita waste generation rates would differ across countries and cities depending on the level of urbanization and economic wealth [5].

The amount of municipal solid waste generated is expected to grow faster than urbanization rates in the coming decades, reaching 2.2 billion tons/year by 2025 and 4.2 billion by 2050 [5, 7, 9]. Today, the majority of MSW is generated in developed countries. However, the fastest growth in MSW generation for the coming decade is expected mainly in emerging economies in Asia, Latin America and South Africa. In terms of waste composition, there is a shift towards an increased percentage of plastic and paper in the overall waste composition mainly in the high-income countries [12]. It is expected that both middle- and low-income countries would follow the same trends with the increase of urbanization levels and economic development in these countries [1, 5].

3. Technical and economic considerations

Waste-to-energy technologies are able to convert the energy content of different types of waste into various forms of valuable energy. Power can be produced and distributed through local and national grid systems. Heat can be generated both at high and low temperatures and then distributed for district heating purposes or utilized for specific thermodynamic processes. Several types of biofuels can be extracted from the organic fractions of waste, in order to be then refined and sold on the market. As of today, the most common and well-developed technology is in the form of Combined Heat and Power plants, which treat Municipal Solid Waste through an incineration process. Technical and economic considerations will be therefore limited to this type of plant [1, 5, 7, 9].

By definition, waste incineration is carried out with surplus of air [6, 9]. This process releases energy and produces solid residues as well as a flue gas emitted into the atmosphere. Because of emission and safety concerns, there is a certain temperature range that is demanded for this type of process. In the case of mixed waste, a furnace temperature of 1050 °C is required. A generic description of an incineration process is represented in the Figure 1. As depicted in Figure 1, waste is first deposited and then extracted from a bunker, and then it is processed on a moving grate in order to achieve a correct combustion. Before undergoing the combustion phase, the incoming waste may be exposed to pretreatment, depending on its quality, composition and the selected incineration system [1, 3, 5].

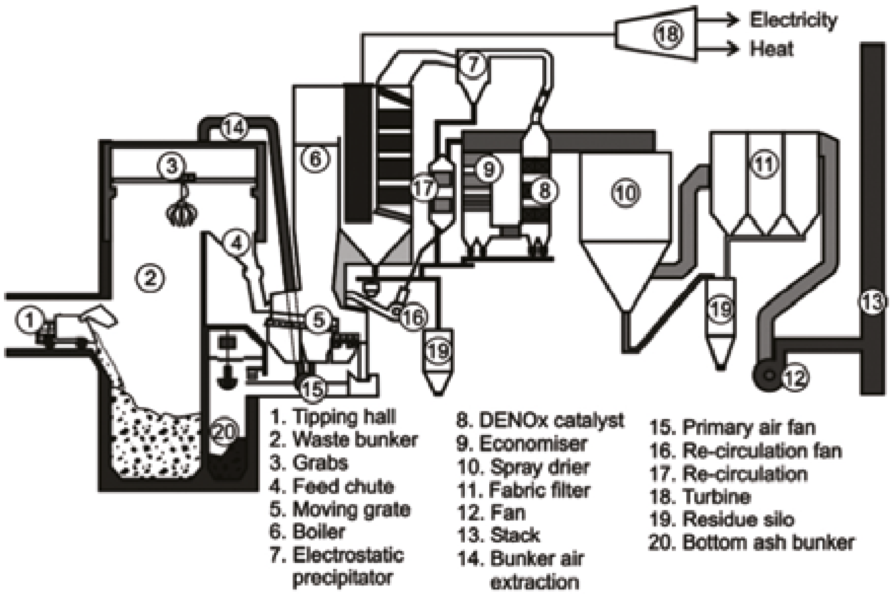

Figure 1. A schematic view of the gasification plant.

The combustion products (flue gases) then exchange heat in a boiler, in order to supply energy to a Rankine cycle. This cycle will then provide power and heat by activation of a türbine and by means of a heat exchanger respectively. The choice of the boiler type is strictly related to the choice of the desired final use of the produced energy [19]. Within the incineration plant, the flue gas cleaning system and a series of fans ensure both a correct combustion process and controlled emissions. However, there will be a certain percentage of substances emitted into the atmosphere, depending on the MSW composition and on the type of cleaning systems used. The common pollutant particles in the flue gas are CO_2, N_2O, NO_x, SO_x and NH_3 [15-19].

The most important economic difference between waste-to-energy technologies and other combustion-based energy generation units is strictly related to the nature of the input fuel. Waste has a negative price, which is regulated by prefixed gate-fees, and is usually considered as the main source of income for the waste-to-energy plant owners. In this sense, incineration facilities have the primary purpose of waste treatment. Generation of electricity and heat can be considered as a useful byproduct, with relative additional earnings. Furthermore, the dispatch of power from waste-to-energy units is prioritized over other generation units, thus yielding a guaranteed income form during all operations [1].

Regarding the technology-related costs, the initial investment costs for the construction of the plant play an important role because of the large size of these facilities and of the main installed components. Capital costs, however, can vary significantly as a function of the selected processes for the treatment of flue gases and other produced residues. Operation and maintenance costs have a lower impact on the total expenses of the facility and are mainly related to the amount of treated waste.

4. Market trends and outlook

Despite the recent economic crisis, the global market of waste to energy has registered a significant increase in the past few years and is expected to continue its steady growth till 2016. In 2014, the global market for waste-to-energy technologies was valued at USD 26 billion, an average annual increase of 3% from 2014. The waste to energy market is expected to reach a market size of USD 30 billion by 2015 [1].

The main drivers for this growth could be summarized in an increasing waste generation, high energy costs, growing concerns of environmental issues, and restricted landfilling capacities. Waste-to-energy would help solve these issues by reducing the waste volume and cutting down on greenhouse gas emissions. Moreover, legislative and policy shifts, mainly by European governments, have significantly affected the growth of waste-to-energy market as well as the implementation of advanced technology solutions. The thermal waste-to-energy segment is expected to keep the largest share of the total market. This segment would be expected to increase from 19 to reach USD 26 billion by 2015. The biochemical waste-to-energy segment would witness a rapid growth from USD 1.4 billion to USD 3.2 billion in 2015 [1, 3, 5, 12].

In terms of markets, the Asia-Pacific region is the fastest growing market for waste-to-energy and should witness a significant growth by 2015 with major expansions in China and India. Many of these countries see waste-to-energy as a sustainable alternative to landfills. The European market is expected to expand at an exponential rate for the next decade with European Union’s efforts to replace the existing landfills with waste-to-energy facilities. Moreover, there is a current trend with the private sector actively developing large-scale waste-to-energy projects as opposed to the traditional public sector monopoly. This would influence the future of waste-to-energy as more players would be expected to enter the market which would help decrease prices and increase technological advancements [1].

5. Energy conversion technologies for waste-to-energy

Currently, CHP incineration is the most developed and commercialized technology for waste-to-energy conversion. However, a number of different technological configurations are already available for this purpose and, with a constant R&D, many others are envisioned to become valuable alternatives in the future. The following classification illustrates the possible methodologies which can be used in order to obtain energy from waste.

5.1. Thermo-chemical conversion

Looking at thermo-chemical conversion processes the energy content of waste is extracted and utilized by performing thermal treatments with high temperatures, the choice of fuel strongly determines the type of process (see Figure 2) [1-6]:

- Incineration: With mixed waste input, simple incineration is often utilized by means of the previously described CHP plant technology.
- Co-combustion: Co-combustion with another fuel such as coal or biomass is an alternative that makes it easier to control the thermal properties of the fuel; in particular the Lower Heating Value. Also, co-combustion is an attractive alternative to simple coal combustion both in terms of costs and emission levels.
- Residual Derived Fuel (RDF) Plant: The possibility to achieve higher energy contents is the main advantage of RDF can be achieved from different kinds of waste fractions. Its high and uniform energy content makes it attractive for energy production, both by mono-combustion and co-combustion with MSW or coal.
- Thermal Gasification: Thermal gasification is a process which is able to convert carbonaceous materials into an energy-rich gas. When it comes to gasification of waste fractions, it is often agreed that this technology is not yet sufficiently developed in comparison to combustion. However, this process could present many favorable characteristics such as an overall higher efficiency, better quality of gaseous outputs and of solid residues and potentially lower facility costs. Thus gasification, with proper future technology developments, could be considered a valuable alternative to combustion of waste.

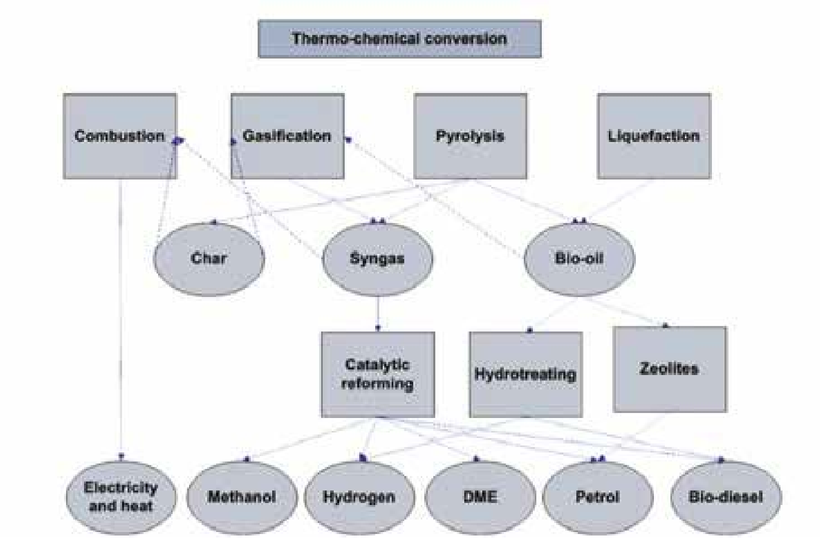

Figure 2. Thermochemical conversion of biomass.

5.2. Bio-chemical conversion

Energy can also be extracted from waste by utilizing bio-chemical processes. The energy content of the primary source can be converted, through bio-decomposition of waste, into energy-rich fuels which can be utilized for different purposes [3-5].

- Bio-ethanol production: Bio-ethanol can be produced by treating a certain range of organic fractions of waste. Different technologies exist involving hydrolysis, fermentation and distillation. Other than bioethanol, it is possible to obtain hydrogen from the use of these technologies is a very useful and promising energy carrier.
- Fermentation: There are two fermentation techniques for producing bio-hydrogen; dark fermentation and photo-fermentation. Dark fermentation and photo-fermentation are techniques that can convert organic substrates into hydrogen with the absence or presence of light, respectively. This is possible because of the processing activity of diverse groups of bacteria. These technologies can be interesting when it comes to researching valuable options for waste water treatment.
- Anaerobic digestion: Anaerobic digestion is a biological conversion process is carried out in the absence of an electron acceptor such as oxygen. The main products of this process are an effluent residue and an energy-rich biogas. The entire conversion chain can be broken down into several stages different groups of microorganisms drive the required chemical reactions. The obtained biogas can be used either to generate power and heat or to produce biofuels. The digest can also be utilized in many different ways depending on its composition. Several technologies utilizing this process have been developed throughout the years but are still considered to be immature and not economically competitive compared to other waste-to-energy technologies.
- Biogas production from landfills: Other than in an anaerobic digester, it is possible to extract biogas directly from landfill sites, because of the natural decomposition of waste. In order to do so, it is necessary to construct appropriate collecting systems for the produced biogas. Biogas in landfills is generally produced by means of complex bio-chemical conversion processes, usually including different phases like initial adjustment, transition phase, acid phase, methane fermentation and maturation phase.

Microbial fuel cell: A microbial fuel cell is a device that is able to produce electricity by converting the chemical energy content of organic matter. This is done through catalytic reaction of microorganisms and bacteria that are present in nature. This technology could be used for power generation in combination with a waste water treatment facility.

5.3. Esterification

The chemical process of esterification occurs when an alcohol and an acid react to form an ester. If applying this process to waste-to-energy treatment, it is possible to obtain various types of biofuels from waste [1-5].

5.4. Life cycle analysis (LCA) for waste-to-energy ssytems

In the development of waste-to-energy projects, the consideration of the environmental implications is playing an increasingly important role [10, 11]. The LCA approach is more and more used as a support tool in strategic planning and decision-making process of waste-to-energy projects. However, dealing with a general LCA for MSW waste-to-energy systems could be a challenging task. The inputs and outputs of the waste-to-energy systems could markedly vary from project to project: in fact, the composition and cost of the waste strongly depend on the location of the project. Efficiencies and emissions can vary significantly by the waste-to-energy plant design and waste composition; so does the size of the markets for products derived from waste-to-energy facilities [11-18].

The cradle-to-grave life cycle of a waste-to-energy technology (Figure 3) begins with the waste generation e.g. when the owner of a product discards it in the waste collection trash cans. Then, depending on the country and/or regional laws, the waste is collected either via mixed-waste bags or via separate collection; in both cases a dedicated infrastructure for the collection is required. The next stage is the transportation of the collected waste to the waste treatment facility: the mixed-waste bag reaches the waste-to-energy facility/plant. The next stage of the life cycle is then the processing of the waste inside the waste-to-energy plant: energy in the form of heat, electricity and fuels are produced, as well as residues and ashes.

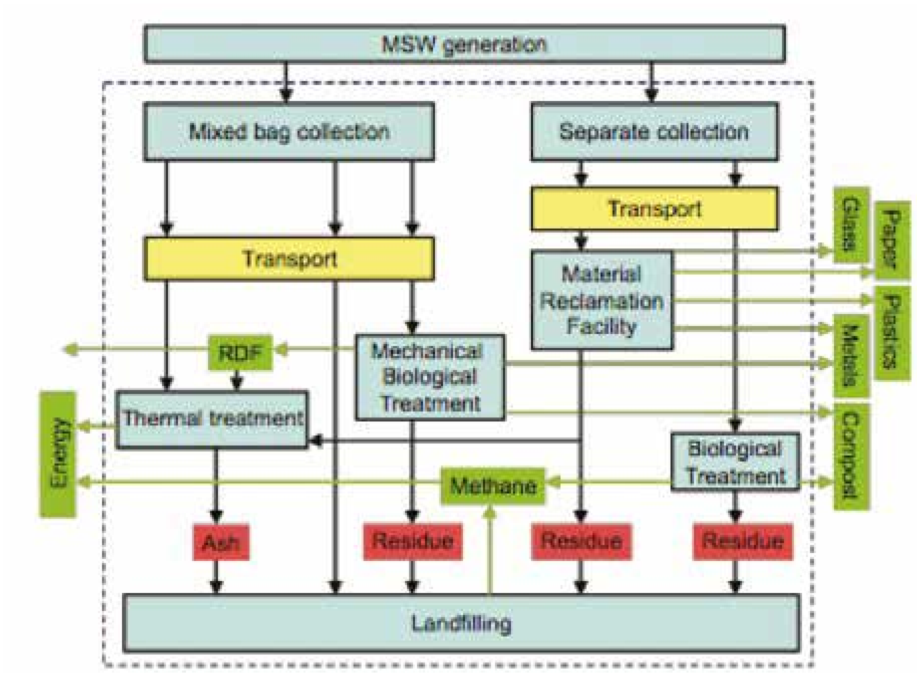

Figure 3. Municipal solid waste generation flow sheet.

Regarding the collection, storage and transportation of the MSW, LCA studies show that the door-to-door collection system has a higher environmental impact than the multi-container collection system. Moreover, the bring systems, although widely used in modern waste collection schemes, have higher overall environmental impacts than the curbside collection, where the collection of waste is centralised. Eventually, it is believed that using bigger high-density polyethylene (HDPE) bins in the collection systems will yield a lower environmental impact than if using smaller HDPE bins [11, 13]. The costs associated with the collection and disposal of the MSW depend, of course, on the considered country. An overview of the estimated solid waste management costs by disposal method is shown in Table 1 [5].

Table 1. An overview of the estimated solid waste management costs by disposal method [5]

	Low Income Countries	Lower Mid Income Countries	Upper Mid Income Countries	High Income Countries
Income (GNI/capita)	$876	$876-3465	$3466-10725	
Waste generation (tons/capita/yr)	0.22	0.29	0.42	0.78
Collection efficiency	43%	68%	85%	98%
Cost of Collection and Disposal (US$/tonne)				
Collection	20-50	30-75	40-90	85-250
Sanitary Landfill	10-30	15-40	25-65	40-100
Open Dumping	2-8	3-10	NA	NA
Composting	5-30	10-40	20-75	35-90
Waste-to-energy incineration	NA	40-100	60-150	70-200
Anaerobic Digestion	NA	20-80	50-100	65-150

6. A case study in Turkey

6.1. Energy production and consumption

Turkey’s total primary energy supply (TPES) was 120 Million tons of oil equivalent (Mtoe) while the total primary energy production (TPEP) was 32 Mtoe in 2014 as shown in Table 2. Fossil fuels are accounted for 90% of TPES while renewable energy sources provided the remaining 10% in 2014. Since 2000, the increase in TPES can be attributed to the growing use of just two fuels: natural gas, up by 20 Mtoe, and coal, up by close to 7.4 Mtoe. The other primary energy sources remained practically unchanged with the exception of traditional biomass (firewood), the use of which inevitably declines as the economy develops [20].

Table 2.Turkey’s energy situation in 2014 (Mtoe) [20]

Energy source	Production	Consumption
Hard coal	990	17 692
Lignite	13 973	13 182
Asphaltite	488	416
Oil	2 485	33 896
Natural gas	443	37 628
Hydropower	5 110	5 110
Geothermal (electric)	1 173	1 173
Geothermal (heat)	1 463	1 463
Animal & plant wastes	1 666	1 666
Wood	2 707	2 707
Wind	650	650
Solar	795	795
Total	31 944	120 290

As regards energy source, oil provided 35% of TFC in 2014, electricity and natural gas 17% each, coal 19%, biomass and waste 7% and the other sources 3%. The share of natural gas has increased significantly since 1990, and that of electricity has grown markedly from 10% in the mid-1990s. Reflecting the diversification of the energy mix, oil has lost ground, down from 50% in the early 1990s. Traditional biomass is also declining. In its projections made before the economic downturn, the government foresaw TFC more than doubling from 2014 to 240 Mtoe in 2030, with most growth coming from the use of coal, oil and electricity.

In 2014, renewable sources provided 47.8 TWh of electricity, or 19.6% of the total power generation in Turkey. Hydropower accounted for 95% of this total and wind power for 4%. The remaining 1% came from biomass and geothermal energy. Biomass energy includes agricultural residues, municipal wastes, fuelwood, animal wastes and other fuel derived from biological sources. The total recoverable bioenergy potential is estimated to be about 17.6 Mtoe [20]. The estimate is based on the recoverable energy potential from main agricultural residues, livestock farming wastes, forestry and wood processing residues and municipal wastes. Firewood is the largest source of heat from renewable sources. In 2014, 5.1 Mtoe of firewood was used for residential heating in rural areas. Other forms of biomass are negligible [20, 22, 23-26].

6.2. Turkey municipal solid waste management

In 1983, the Ministry of Environment in Turkey published Environmental Law 2872 as the first stage in order to improve the environmental situation in the country. However, there was no consensus on the best option for MSW management in the law. In 1991, the Solid Waste Control Regulation came into force in order to manage solid waste. The regulation played a fundamental role in solid waste collection, storage, transport, and disposal. The regulation has been continuously updated. In addition, Turkey developed regulations for medical waste in 1993 and for hazardous waste in 1995. The Medical Waste Control Regulation established a basic action line for medical waste management based on the collection, storage, transport, and disposal or reuse of the waste by its owner. Some types of waste, such as radioactive wastes, were excluded from that law. The Hazardous Waste Control Regulation set the criteria for the collection, transport, and final disposal of hazardous waste, including options for landfi lling or incineration, as well as the design criteria and the operational rules for sanitary landfills and incinerators. The regulation also focuses on the minimization of hazardous waste and encouragement of recycling [21, 23].

By legal definition, municipal solid waste includes all the waste arising from human activities that are normally solid and that are discarded as useless or unwanted. Municipal solid waste generally consists of waste generated from residential to commercial areas, industries, parks, and streets. In Turkey, community initiatives in solid waste management are currently being supported by the municipal authorities, who guide their activities according to the legislation and policies dictated by the Ministry of Environment and Urbanization (MEU). The framework of responsibility and management of MSW in Turkey is important and the MSW comes from commercial services, industries, healthcare facilities, and citizens in Turkey. Some private enterprises are responsible for the collection and transport of solid waste and for the sorting of separately collected packaging waste. After sorting, the packaging waste is directed towards the recycling industry [21, 23].

Until 2000, there were only estimates of MSW generation in Turkey because of the predominance of open dumping and the difficulty of recording MSW generation. The absence of reliable data and statistics for waste generation and composition makes a regional and national evaluation of MSW management difficult. The Turkish State Statistical Institute (TUIK) [22] has compiled statistics about MSW management since 2000 [23]. In the 1990s, 10–20 million ton of municipal solid waste per year was generated in Turkey. However, according to the TUIK’s 2010 database, approximately 50 million ton of MSW was generated annually. Increasing population levels, rapid economic growth, and the rise in community living standards will accelerate the future solid waste generation rate in Turkey [22].

In 2015, 78 million people live in Turkey, with quite different socioeconomic and demographic characteristics and dietary habits. Urbanization in Turkey is a response to a rapid population increase and migration from rural areas to cities. The quantities of solid waste generated by various population groups in Turkey are given in Table 3. The rate of waste generation is highly influenced by the population of the community. The rate of waste generation in the areas with the lowest population is 1.74 kg/cap/day, while in the areas with the highest population it is 1.37 kg/cap/day. As can be seen, solid waste generation is reduced when the population of the area increases.

Table 3. MSW generation based on population of communities in Turkey [22]

Population groups	Waste generation (kg/cap/day)	Waste generation (tons/year)	Percent of waste generation (%)
<100,000	1.74	87,924	0.32
100,000-500,000	1.54	4,764,834	13.44
500,000-1,000,000	1.47	6,685,356	23.22
1,000,000-2,000,000	1.34	7,124,643	24.62
>2,000,000	1.37	11,234,564	38.42

The typical composition of municipal solid waste in Turkey is shown in Table 4. As can be seen, organic waste is the main component of MSW. Between 7% and 24% of the material is denoted as “other”, which mainly includes construction and demolition debris, coal ash, and hazardous waste. The high concentration of biodegradable matter and inert material results in a high waste density (weight-to-volume ratio) and high moisture content. In the summer season, the MSW densities are relatively high in the high income region because of the higher quantities of organic waste compared to the low income regions. In low income regions, organic waste is fed to animals, used as soil conditioner, or used as fuel for ovens.

Table 4. Composition of MSW in Turkey [22]

Components	Range (%) in weight
Organics	40-60
Paper/carboard	10-20
Plastics	10-20
Metal	4-10
Glass	4-8
Others	10-30

7. Conclusions

The waste-to-energy market is continuously under development and other new Technologies are likely to play an important role in the near future, as long as they can prove to be sufficiently competitive with the more traditional Incineration process from a technical, economic and environmental perspective. Other methods of electricity generation that differ from MSW- gas - gas motor are described in this article. Incineration method and other electricity generation technologies have been used to define electrical energy potentials.

Although various forms of incineration are widely used for waste management, there has been increased public debate in the last several decades over the expected benefits and the potential risk to human health that might result from the emission of pollutants generated by the incineration process. Currently, electricity production from waste incineration is rather low in Turkey. This is because several of incineration plants lack the capacity to produce electricity.

In Turkey, as in many developing countries, there is a lack of organization and planning in MSW management due to insufficient information about regulations and due to financial restrictions. In the short term, the best policy might be to leave disposal methods without any controls, and use the resources available to upgrade them with environmental protection systems. In the long term, the construction of new sanitary landfill areas, composting, and incineration facilities could be planned. Public participation and awareness are also important issues in achieving the goals of the suggested management system, but it is difficult and takes a long time to make people aware of the importance and of the principles of the proposed management system and to effect their participation.

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