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THE EVALUATION OF MUNICIPAL SOLID WASTES AS ENERGY SOURCE

ABSTRACT

The waste combustion is a burning method in which wastes are burned under controlled conditions to produce energy under optimal conditions with a reduction in waste volume of 100-1000 times. Although this method is preferred due to the high energy gain, it is criticized in some societies due to the formation of some toxic combustion products and gases and high initial investment cost. The thermal processing or pyrolysis method is a method that brings out innovative technologies and designs around the world because of environmental factors as well as economic improvements. Municipal solid wastes can be disposed by the pyrolysis method which gained popularity in recent years, by producing economical value of the obtained thermal processing liquid and syngas and also the electricity can be produced during the process. In this study, the methods aforementioned in terms of energy production from municipal solid wastes were examined and an evaluation was made for Turkey.

Keywords: Municipal Solid Waste, Energy Recovery, Landfilling, Incineration, Pyrolysis

1. INTRODUCTION

In the recent years, the importance of studies on alternative energies and environmental technologies is increasing. It is aimed to make wastes more economical by using existing resources more efficiently, by developing production technologies that do not harm the environment and by reducing the waste problem with the waste management systems. In this way, it is possible to reduce the effects of environmental pollution and to use these wastes as an energy source. Due to the rapid increase of the urban population, the increasing amount of municipal solid waste should be removed in the most appropriate way [1]. So, the efforts to dispose of municipal solid wastes in a way that does not harm the environment and to use them as an energy source have come to the forefront. In this context, solid waste landfilling, incineration and thermal decomposition of waste (pyrolysis) are the most frequently used technology alternatives. In particular, landfilling of municipal solid wastes is particularly preferred in the world as the necessary experience is acquired at design and operational stages with many applications realized all over the world. The landfill gas (LFG) obtained by this technique can be utilized to produce electricity by burning LFG in suitable gas burners [2 and 3]. However, this technique also has a

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number of drawbacks such as the need for large and sheltered areas, the formation of leachate and undesired harmful gases and the subsequent control and monitoring for a long time after the closure of landfill. Many management systems of solid waste are based on the waste-generation hierarchy. The hierarchy of priorities for solving waste generation problems is as follows: waste minimization, recycling/reuse, treatment and disposal. Unfortunately, these principles are not reflected in the current waste management system. Waste-to-Energy (WtE) technologies includes any waste treatment process creating energy in the form of electricity, heat or transport fuels (e.g. diesel) from a waste source. These technologies can be applied to several types of waste: from the semi-solid (e.g. thickened sludge from effluent treatment plants) to liquid (e.g. domestic sewage) and gaseous (e.g. refinery gases) waste. However, the most common application by far is processing the Municipal Solid Waste (MSW). The current most known WtE technology for MSW processing is incineration in a combined heat and power (CHP) plant [4, 5, 17 and 18]. By analyzing the state of municipal solid waste management in Turkey, it is revealed that MSWM is not yet as developed as in many EU countries. One can observe that Turkey still maintains very high rates of landfilling by reviewing waste treatment methods. Other methods such as composting, recycling and, also incineration are used, but on a negligible scale. Additionally, municipal solid wastes can also be disposed by the pyrolysis technique that gained popularity in recent years, by producing economical value of the obtained thermal processing liquid and syngas. Also the electricity can be produced during the process. In this study, the methods aforementioned in terms of energy production from MSW were examined and an evaluation was made for Turkey.

2. RESEARCH SIGNIFICANCE

In this study, was investigated the evaluation of municipal solid wastes as energy sources. Municipal solid waste produced in Turkey with the general state of waste storage, issues such as municipal solid waste incineration and pyrolysis are described in detail.

3. MUNICIPAL SOLID WASTES AS ENERGY SOURCE

In recent technologically advancements in waste management systems introduce WtE systems such as waste incineration and pyrolysis (gasification) besides landfilling. Waste treatment technology, where applied, is nowadays a highly developed and advanced activity with constant and extensive public control. Specially developed combustors for waste incineration are inevitably needed in every modern and civilized society. Energy from waste offers recovery of energy by conversion of non-recyclable materials through various processes including thermal and non-thermal technologies. Energy that is produced in the form of electricity, heat or fuel using combustion, pyrolization/gasification or anaerobic digestion is clean and renewable energy, with reduced carbon emissions and minimal environmental impact than any other form of energy. In this section, landfilling, waste-incineration and pyrolysis are reviewed for Turkey and possible energy gain from municipal solids wastes produced by per capita of Turkey is depicted.

3.2. Municipal Solid Wastes Produced in Turkey

Municipal solid waste (MSW) is the stream of garbage collected by sanitation services from homes, businesses, and institutions. MSW typically consists of metals, glass, plastics, paper, wood, organics, mixed categories, and composite products. In Turkey, waste statistics given from TurkSTAT covers the statistics for the wastes produced between the years 2001-2016 [6]. In 2016, the municipalities in Turkey collected 31.6 million tones MSW. Solid waste production in kg/day per capita was found to be 1.17kg as shown in Figure 1 with the MSW records for the years 2001-2016.

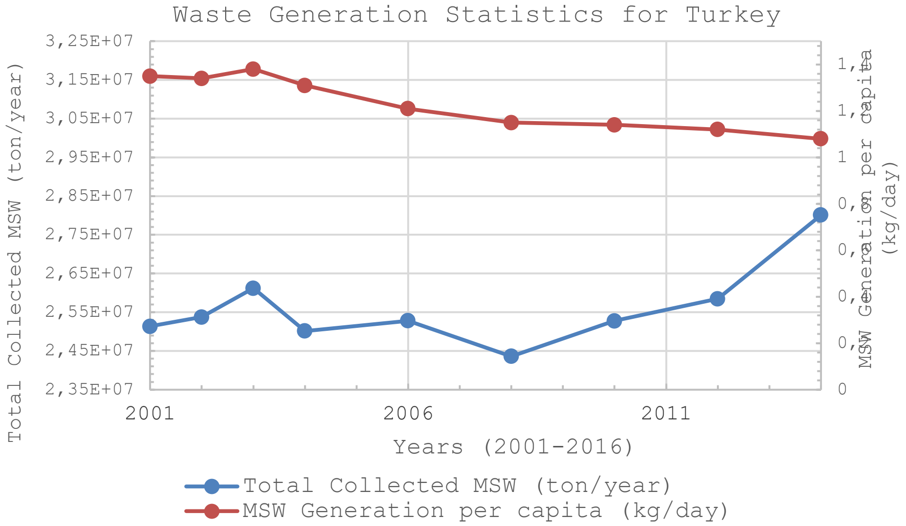

Figure 1. MSW generation statistics for Turkey

A report showed that in the metropolitan cities İstanbul, Ankara and İzmir daily MSW generation for per capita was found to be 1.16kg, 1.10kg and 1.12kg, respectively, in 2014. Additionally, MSW produced by municipalities in Turkey have been disposed by mostly landfilling at a rate of 64%, 35.5% in open dumping, 0.5% by composting and the rest of 0.5% by other methods such as waste incineration. Waste characterization is an important step in waste management. As reported in 2007 by TurkStat, MSW produced in Turkey includes mostly organic wastes such as food and garden wastes. Table 1 shows Turkey's mean MSW composition.

Table 1. Turkey's MSW composition

MSW Type	MSW composition (%)	
	TurkStat	Ministry
Organic wastes	65.45	49
Inert wastes such as ash, rock, stone and soil etc.	22.48	13
Recyclable wastes	12.07	38

Figure 2 shows the most recent MSW rates (in ton/year) by 2016 for the municipalities in Turkey according to Turkish Statistical Institute [22], in which yellow areas fall between 0.10-0.50Mton/year and red areas are in the range of 0.50-8.0MTon/year.

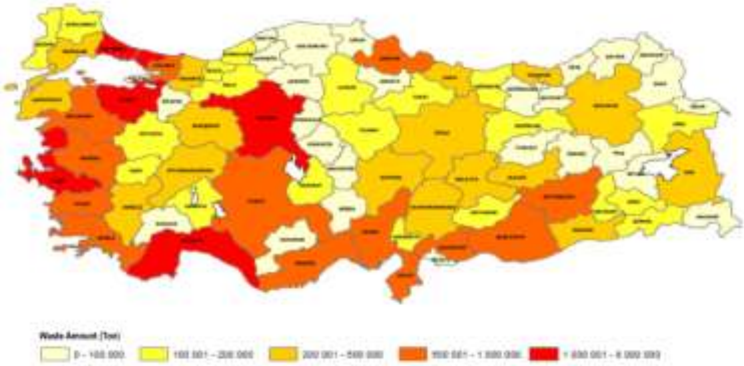

Figure 2. MSW rates of municipalities in Turkey by 2016

3.2. Waste Landfilling

The majority of collected MSW that is not recycled is typically sent to landfills—engineered areas of land where waste is deposited, compacted, and covered (Figure 3). Landfill gas (LFG) is a by-product of the decomposition of organic material in MSW in anaerobic conditions in landfills. LFG contains roughly 50% methane and 50% carbon dioxide, with less than 1% non-methane organic compounds and trace amounts of inorganic compounds. The amount of LFG created primarily depends on the quantity of waste and its composition and moisture content as well as the design and management practices at the site. LFG can be collected and combusted in flares or energy recovery devices to reduce emissions. Some landfills in Turkey installed with the necessary facilities to produce electricity from landfill gas. According to statistics from The Ministry of Environment and Urban (MEU), 103 landfill is operated in Turkey by 2017 (69 landfills for 2015). However, as reported by MEU, waste collection system have been serving 77% of the Turkey’s population currently, which is planned to reach a level of 100% by 2023.

3.3. Municipal Solid Waste Incineration

Municipal solid waste (MSW) incineration plants tend to be among the most expensive solid waste management options, and they require highly skilled personnel and careful maintenance. Hence, controlled waste incineration tends to be a good choice only when other, simpler, and less expensive choices are not available. Incineration is applied to municipal solid waste, hazardous waste and medical waste, which is an efficient way to reduce the waste volume and demand for landfill space. Incineration plants can be located close to the center of gravity of waste generation, thus reducing the cost of waste transportation. Using the ash from MSW incinerators for environmentally appropriate construction not only provides a low cost aggregate but further reduces the need for landfill capacity. In particular, incineration of waste containing heavy metals and so on should be avoided to maintain a suitable slag quality. Several countries in the world, especially in Europe are experimenting with incineration as an alternate means of energy production; USA, Germany and Luxembourg to name a few [5, 9 and 16]. Incineration reduces the mass of the waste from 95% to 96% by thermal combustion with two sequential burners operated at 850-1000°C in rotary kiln namely primary combustion and up to 1250°C in vertical combustor with a residency time of at least two seconds namely secondary combustion, respectively (Figure 4). Mass burn combustors usually range in size from e.g. 45 to 900ton/day. Average combustors are ranged 4 to 130 tones waste/day. Modern incinerators can generate 500kWh electricity by burning 1 ton MSW with producing 700kg flue gas, 250-300kg bottom ash and fly ash (mixed slag) and recycling about 30kg scrap iron.

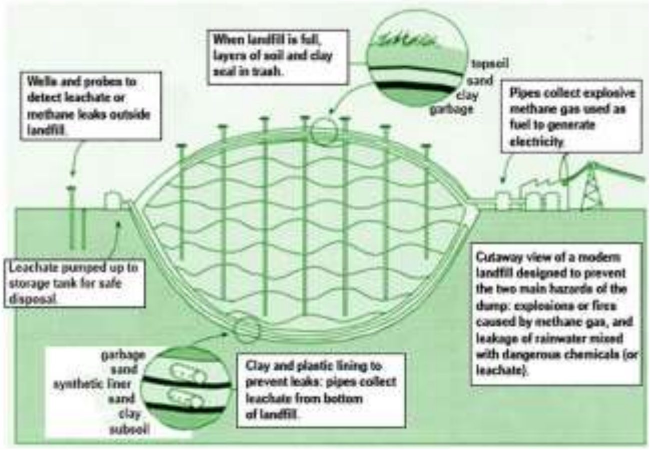

Figure 3. A scheme of solid waste landfilling method

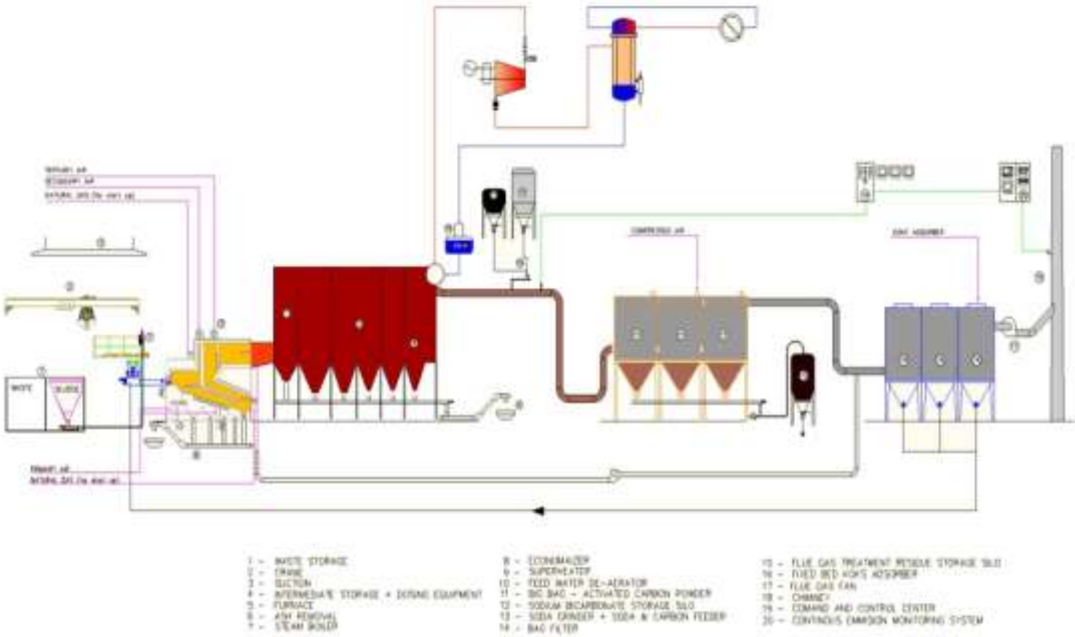

Figure 4. A schematic presentation of WtE plant

3.4. Pyrolysis

Pyrolysis, as a well-known thermochemical process, is an ancient art of producing pyrolytic oil (a mixture of organic chemicals with water), gas, and charcoal [10 and 18]. Several studies on pyrolysis processes of solid waste have already been investigated previously in using several different types of equipments such as fixed bed, cyclone gasifier, fluidized beds and plasma furnace. For convenience, there are two approaches for the conversion technology. One, called as flash or fast pyrolysis, is to maximize the yield of liquid product [11, 17 and 18]. Another, called as conventional or traditional pyrolysis, is to maximum the yield of fuel gas at the preferred conditions of high temperature, low heating rate, long gas resistance time, and in the presence of catalyst, or to enhance the char production at the low temperature and low heating rate. Figure 5 shows a catalytic decomposition of MSW to syngas by using a catalyst, resulting in tar and char. Gas components in syngas were H_2, CO, CO_2, and low molecular hydrocarbon species (CH_4, C_2H_4 and C_2H_6). The syngas term in pyrolysis process stands for the mixture of H_2+CO with a mixing range of 24-36 percent for H_2 and 23-30 percent for CO. The product yield changes by operation temperature that is ranged in 450-900°C. For example, at 750°C and 900°C recovery rates were found to be gas (wt%):43.42, oil (wt%):34.55, char (wt%):18.53, net recovery (wt%):96.50 and gas (wt%):78.87 oil (wt%):5.13, char (wt%):14.92 and net recovery (wt%):98.92, respectively [12 and 17]. This process is an endothermic process in which gas product yield and carbon conversion rate increases by temperature effectively. However, the fuel cost to hold furnace temperature at a constant level also raises by increasing operating temperature. The syngas production with lower heating value (LHV) of 13–14 MJ/N.m^3 also can be directly used as a medium heating value (MHV) (10–16 MJ/N.m^3) fuel.

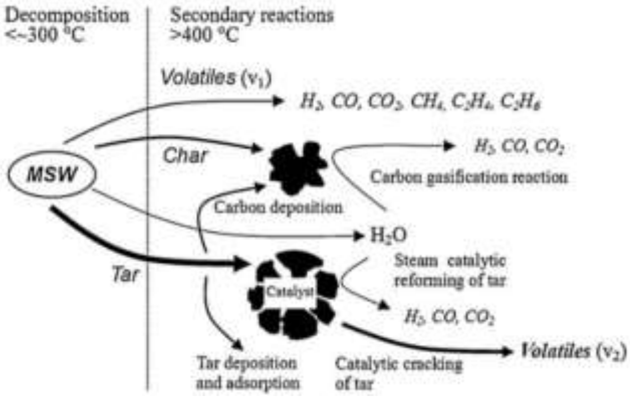

Figure 5. Schematic presentation of MSW pyrolysis

4. FINDINGS AND DISCUSSIONS

4.1. LFG Energy Conversion

With growing economy and increasing population, Turkey requires much more energy year-after-year. Parallel to increase in its population, it is generated much more municipal solid wastes in 81 cities in Turkey which may be an effective energy source for electricity production besides preferred renewable energy sources in recent years. An integrated approach has been practiced to manage municipal solid wastes produced in Turkey, including all necessary parts of such a system such as collecting, separating and disposing. However, as our problem is energy recovery from MSW, Turkey has no such great scores. As it is mentioned before in landfilling of MSW, Turkey prefers controlled landfilling at first when disposing MSW. Integrated MSW management approach use the waste as an energy source by introduced Wte technologies. So, landfill sites were planned with waste incineration plant with advanced air pollution control units, and LFG to electricity conversion system namely, combined heat and power (CHP) plants. As shown in Figure 6, 103 operated landfills serving to dispose produced MSW in municipalities in Turkey by 2016 in addition to planned ones for near future. However, reported numbers indicates that only 25 landfills out of 103 produce electricity from LFG produced in these landfills as shown Figure 7. Total energy capacity of these landfills reported as 151.7MW. The biggest LFG energy station is Odayeri LFG conversion station in Istanbul with an installed capacity of 34MW. The current trends in LFG investments shows that Turkey plans to reach 123 landfills up to 2023 with a full capacity of 100% MSW collection and landfilling, which will considerably contribute to Turkey's installed energy capacity by LFG energy conversion predicted up to 1000MW.

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4.3. Energy Recovery by MSW Incineration

MSW produced in Turkey have been analyzed in terms of suitability for waste incineration and energy recovery. Table 2 summarizes current and near future amounts of MSW generated in some big cities in Turkey and their approximate calorific values in kcal/kg [13]. As showed in Table 2 and Table 3, MSWs produced in Turkey includes combustible components at a rate of %45, so it is reasonable to examine the combustibility of MSW for energy recovery. As a tomb of rule, the waste is theoretically feasible for combustion without auxiliary fuel when: moisture of raw waste<50%, ash content<6% and combustible organic fraction>25%. Additionally, the waste calorific value should be at least 2000-2500kcal/kg for energy production, and 1500-1600kcal/kg for the combustion without additional fuel. If the heating value is below 1200kcal/kg, it is understood that the solid waste cannot be economically burned. Considering LHV of MSW given in Table 3 and a report prepared by MEU shows that MSW produced in the biggest cities in Turkey is suitable to incineration for energy production with an average calorific value about 2000kcal/kg (8374kJ/kg) [13, 15 and 19]. The total installed power capacity from MSW incineration is about 1000 tones MSW/day facility with 20 MW power production capacity, which is much lower than recoverable effective capacity. Theoretically, about 20% of the city's electricity need can be met by burning the MSW generated. Moreover, when the entire country is treated with energy recovery by thermal methods, it is possible to recover a renewable energy with 5-10% of total energy needs in Turkey, which approximately indicates an extra power capacity of 7800MW. Currently, Turkey has about 467MW total installed power capacity by

utilizing MSW, biogas, waste-steam energy and pyrolytic oil energy out of an installed total power capacity of 78500MW, as shown in Figure 8.

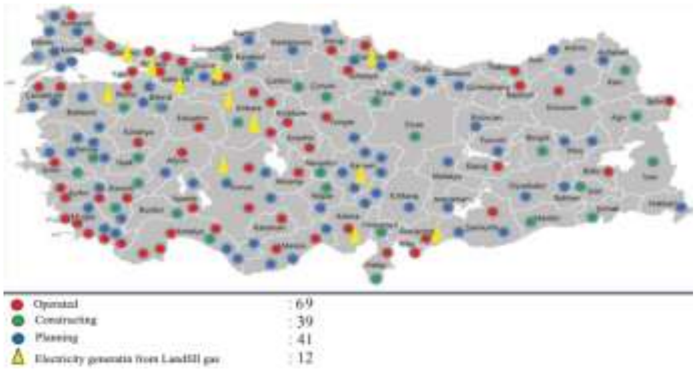

Figure 6. Municipalities with landfill sites in Turkey

Figure 7. Municipalities with LFG energy conversion facilities

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Table 2. Recent and near future waste amounts and calorific values of MSW for metropoles in Turkey

Metropole cities	Waste Amount by years, ton/year		LHV (kcal/kg)	
	2015	2025	2020	2030
İstanbul, İzmir	7695117	11063179	1700	2000
Bursa, Kocaeli, Sakarya	2074941	2928548	1700	2000
Ankara	2140002	3077952	1700	2000
Antalya, Mersin	1487418	2081057	1700	2000
Adana, Eskişehir, Kayseri, Konya, Samsun	2888399	4071234	1400	1700
Artvin, Giresun, Ordu, Rize, Trabzon	794716	1118017	1400	1700
Gaziantep	715387	1089208	1700	2000
Total	17795979	25429195	Avg:1700	Avg:2000

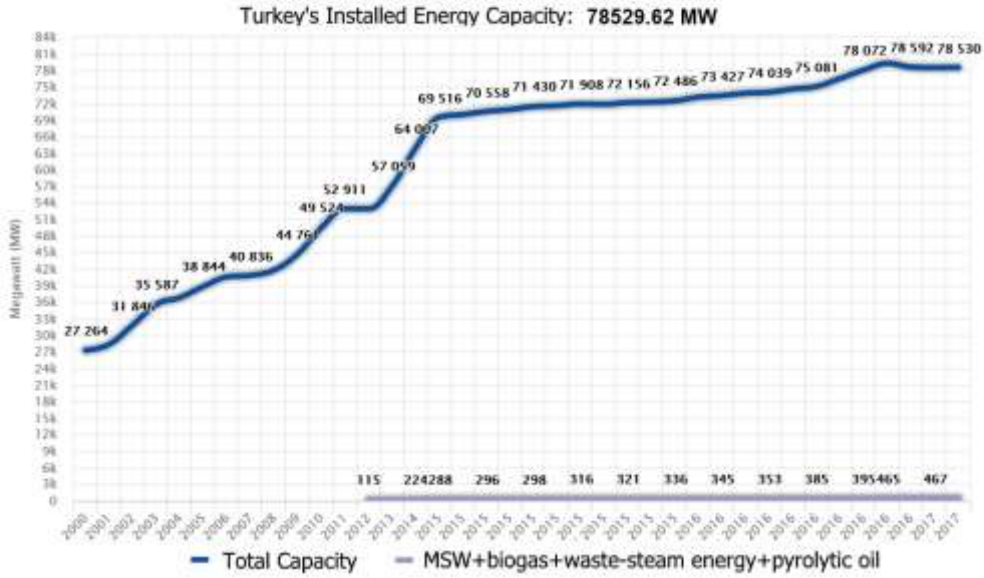

Figure 8. Turkey's energy capacity with other sources

Table 3 gives summarized information for energy recovery potential from MSW generated in Turkey for current and near future. According to energy reports, a renewable energy potential of 11550-26300MWh/day and an installed power capacity of 480-1100MW can be recovered by utilizing thermal disposal of MSWs in Turkey [13, 15, 19 and 21].

Table 3. Turkey's projected energy potential from MSW

Information	Energy Recovery Potential		
	Years		
	2015	2020	2025
Thermally Disposed MSW (1000ton/day)	23.1	35.4	52.6
Electricity Energy Potential (MW/day)	11550	17700	26300
Thermal Energy Potential (MWh_T/day)	15000	23000	34000

5. CONCLUSION AND RECOMMENDATIONS

Municipal solid wastes are considered recoverable energy sources by developing technologies in waste management systems. Conventional landfilling, MSW incineration and pyrolysis are applied methods in treating MSW. Landfilling was successfully established by 103 plants in Turkey, because of having great experience and ease of installation of these plants in contrast to MSW incineration and pyrolysis plants. Most of local MSW characterization analysis showed that MSWs have mostly organic wastes at about 50-60%, parallel to this; combustible wastes were at a fraction of 45% of total MSW produced in Turkey. Hence, LFG energy conversion and thermal MSW disposing methods may be the most an efficient ways to recover energy from MSW in Turkey. The current trends in LFG investments shows that Turkey plans to reach a target number of 123 landfills in total up to 2023 with a full capacity of 100% MSW collection service and landfilling, which will considerably contribute to Turkey's installed energy capacity by LFG energy conversion predicted up to 1000MW. However, a current contribution to Turkey's energy capacity of LFG energy conversion is reported about 150MW which means that Turkey should establish more LFG energy conversion stations, namely CHP plants, besides operated 25 landfills with CHP plants out of 103. On the other hand, the total installed energy capacity from MSW incineration is about 20MW, which is much lower than recoverable energy capacity from MSW incineration.

Turkey has about 467MW total installed power capacity utilizing MSW, biogas, waste-steam energy and pyrolytic oil energy out of an installed total energy capacity of 78500MW in 2017. When the entire country is treated with energy recovery by thermal methods, it is possible to recover a renewable energy up to 10% of total energy needs in Turkey, approximately adding an extra power capacity of 7800MW. This shows that Turkey should invest in controlled incineration of MSW by establishing high-tech incineration plants and also strictly planning use of other alternative energy sources to achieve horizon-2020 targets by utilizing and increasing renewable energy investments much more than today. In contrast to landfilling and MSW incineration, pyrolysis energy conversion plants are very limited in Turkey that they are either pilot scale plants for academic studies and experiments or mostly used for waste-tire recycling. Apparently, Turkey has no mid-level plants for MSW energy recovery currently. Therefore, pyrolysis energy conversion from MSW should be considered and invested in particular regions in Turkey such as for areas with high industrial waste potential, besides MSW incineration plants. On this route up to 2023, it's concluded that Turkey has to plan establishing WtE plants such as MSW incineration and pyrolysis plants at suitable parts of Turkey by exploiting local and global MSW analysis and considering geographical information systems in location determination and MSW disposing method selection.

NOTICE

This study was presented as an oral presentation at the I. International Scientific and Vocational Studies Congress (BILMES 2017) in Nevşehir/Ürgüp between 5-8 October 2017.

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