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Potential benefits of Waste-to-Energy (WTE) for Turkey

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ABSTRACT

The only proven alternative of landfilling for the management of the post-recycling waste, that means the waste with no value in the market or recovery potential, is thermal treatment for the recovery of energy (waste-to-energy or WTE). The benefits of WTE over landfilling are mainly associated with the complete destruction of pathogens, the volume reduction of the municipal solid waste (MSW) by 90%, the production of about 0.5 MWh of electricity and more than 0.6 MWh of district heating per ton of MSW combusted; the savings of about 0.5 to 1 ton of Greenhouse Gases emissions per ton of MSW, and the preservation of about 1 sq. meter of land for every 10 tons of MSW. However, there is continuing opposition to WTE based on the early history of incineration, and the concern that these technologies will emit harmful pathogens to public health; but, also, due to the high capital costs as compared to landfilling. On top, capacity building is one of the major issues for the deployment of such technologies, especially for countries with no prior expertise. The aim of this study is to provide a snapshot of the current status of waste management in the world, provide evidence on the role of WTE in sustainable waste management, and assess the benefits of such technologies for the case of Turkey. The main finding from the global assessment was that developed nations took several decades to reach their present state of development and achievement in sustainable waste management. On the other hand, developing nations can use the Chinese example and accelerate the phasing out of landfilling or the improper dumping by the massive application of WTE technology. Specifically for the case of Turkey, a nation with high energy dependency on other countries, and with ~70% of MSW landfilled; with the assumption that 50% of the MSW produced in the country will be processed for the production of energy, WTE deployment will be associated with the savings of ~$122 MM per year, by the substitution of natural gas. Also, WTE can contribute up to 2% to the electricity demand of the country, and can lead to the savings of ~ 1.5 million tons of $CO_{2\text{-eq}}$ and ~1.6 million m^2 of land; besides, the aesthetic superiority as compared to landfilling.

Keywords—*Sustainable waste management; Waste-to-Energy; Turkey; energy recovery.*

I. Introduction

An effective waste management is inevitable in order to live in a sustainable, healthy and enjoyable environment. There are several techniques for managing municipal solid waste (MSW) such as recycling, composting, waste-to-energy, landfilling and dumping. Waste-to-energy (WTE) is used for non-landfilling and non-recycling materials. Although recycling is a more desired method among all waste management techniques [1], some materials can not be recycled. If a material can not be recycled, one of the best options is WTE according to the waste management hierarchy [1]. WTE is an effective method for waste management in which energy is recovered from waste. Themelis et. al (2013) states that the reaction of combustion of organic compounds is highly calorific and the theoretical heat of reaction is estimated as 18.5 MJ/kg [2].

Turkey is one of the developing countries with an 11% increase of population between 2008 and 2018 [3] and thus, its energy needs increase steadily, in 2018, Turkey's primary energy consumption was 153.5 million toe [4].

Figure 1 shows that oil, coal and natural gas are the dominant primary energy sources in Turkey with 86% of all energy consumption [4]. Furthermore, 68% of the electricity generation comes from coal and natural gas in the country [4]. Therefore, it can be said that primary energy usage and electricity production mostly dependent on the fossil fuels in Turkey.

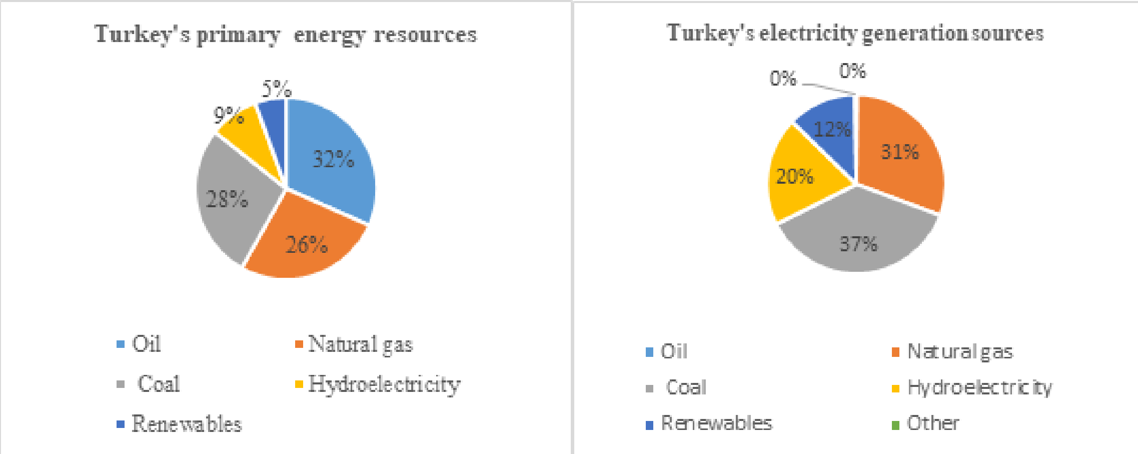

Figure 1. Turkey'sprimary energy consumption (on the left) and electricity generation (on the right) share by resources in 2018 [4].

Moreover, Turkey's energy consumption is heavily dependent on the other countries' resources. Figure 2 shows the increasing rate of imported energy for Turkey which reached to 75% in 2015 while it was 12% in 1960 [5]. Figure 2 also shows that the energy use per capita increased from 389 kg toe to 1651 kg toe from 1960 to 2015 [5]. Thus, the reason for the increased energy import rate can be attributed to the dramatic increase of energy use in the country along with the countries' limited fossil fuel reserves which are not sufficient to counterbalance the increase in energy use [6].

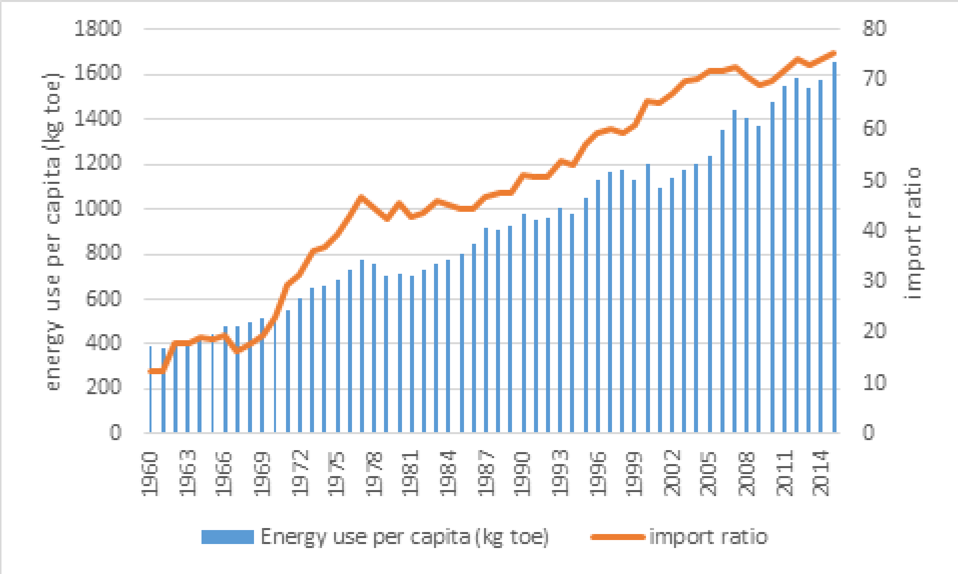

Figure 2. Turkey's energy use and import rate [5].

Therefore, it can be claimed that Turkey needs more clean and national energy resources in order to reduce the environmental impacts of fossil fuels and energy dependence. This study aims to present potential benefits of WTE for Turkey by putting into the perspective of renewable and national character of WTE.

II. WASTE MANAGEMENT AND WASTE-TO-ENERGY TECHNOLOGY IN THE WORLD

A. Literature review for Turkey

There is only a couple of studies focusing on WTE potential of Turkey in the literature. Baran et al (2016) finds that annual 230 GWh of electricity production can be generated by using distributed municipal solid waste [7]. However, they have not estimated economic and environmental benefits of such a potential. Lise (2017) also finds 750 MW capacity of WTE for Turkey [8]. This paper aims to fulfill the gap of more comprehensive approach of potentiality of WTE in Turkey investigating energy production, economical and environmental benefits using local calorific values of municipal solid waste in Turkey.

B. Current Status in the World

WTE technology has been increasingly developed since the beginning of concerns about the landfilling due to the land scarcity, increase of cost and environmental sensitivity [9]. Figure 3 displays the number of WTE plants by the countries [10]. It can be seen that, as of 2018, Japan has the most numbers of WTE plants in the world with 1162 plants followed by China with 299 plants. Among the E.U. countries, France has the highest number of WTE plants with 126 followed by Germany with 121 WTE plants as of 2018 [10]. It is also shown in Figure 3 that there was only 1 WTE plant in Turkey as of 2018 [10].

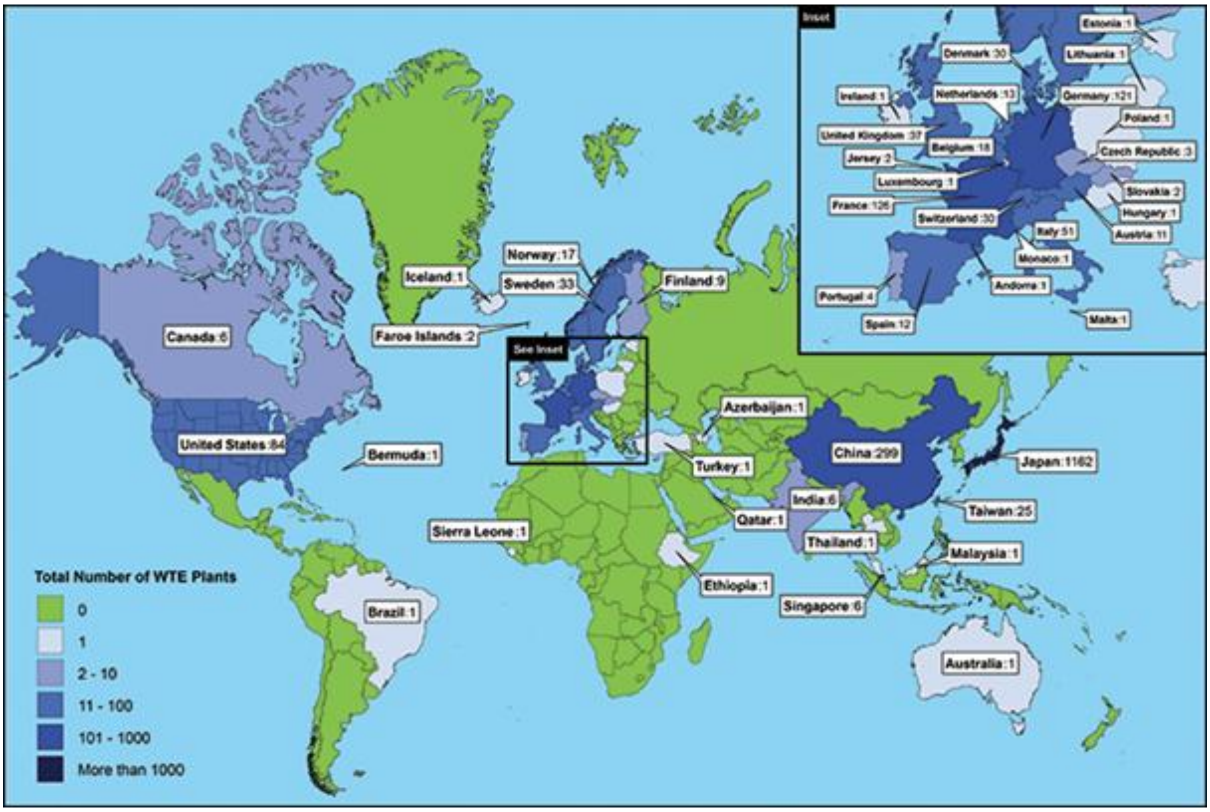

Figure 3. Map of WTE plants in the world by numbers [10].

Although the numbers of WTE plants are relatively lower than the abovementioned E.U. countries (Figure 3); Finland, Sweden and Denmark have the highest percentages of MSW treatment with WTE as a method with 57%, 53% and 51%, respectively as it can be seen in Figure 4 [11]. On the other hand, many countries including a few countries in E.U. have not benefited from WTE yet (Figure 4).

Figure 4 shows the MSW management method shares of E.U. countries. On average, 28% of the MSW is used for WTE in E.U. countries while the highest share of WTE is observed in Finland with 57%. It can also be seen from Figure 4 that recycling and WTE coexist in the urban development. For example, in 2018, Austria achieved 58% recycling with 39% WTE, Sweden 46% recycling and 53% WTE, Denmark 51% recycling and 48% WTE, etc. All these countries had established long term goals to 'move away from landfills' through a combined implementation of recycling and WTE. Turkey, on the other hand, still has 67% sanitary landfilling and 20% uncontrolled dumping as of 2018 [11].

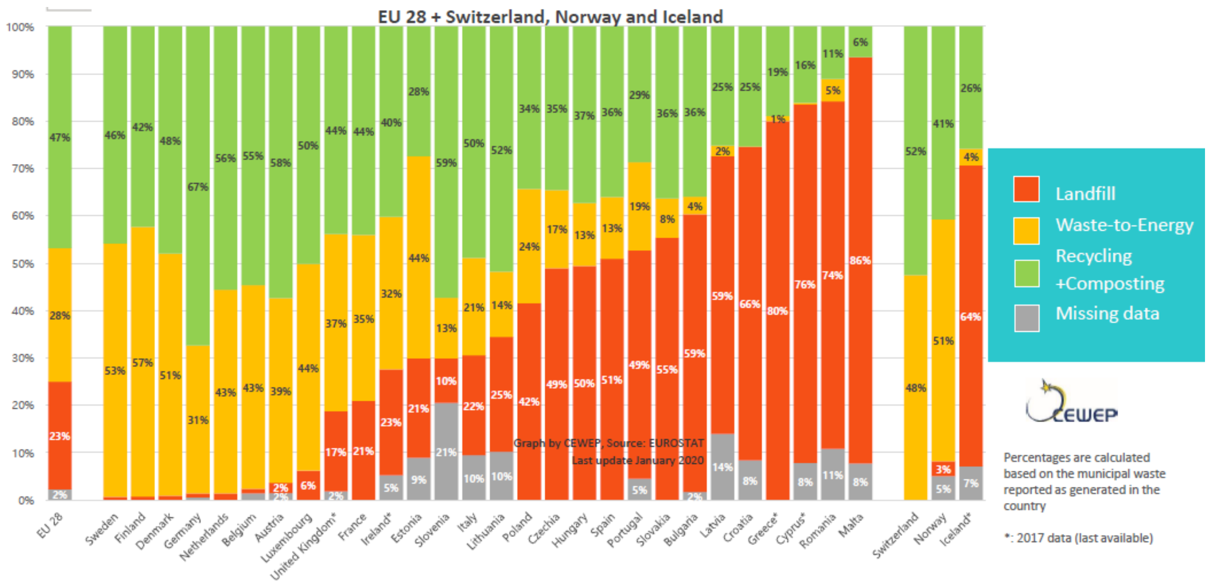

Figure 4. Share of MSW management methods in EU countries [11].

China recognized the problem of the open dumping of wastes and was alarmed by the increasing population and urbanization they faced the recent decades. They introduced WTE technologies to alleviate the problem of waste management. This was also associated with the limited time they had, and few cultural, technical, and regulatory elements of the system that did not provide room for education, and advancement of recycling/composting.

In China, a phenomenal growth is observed with the deployment of thirty to forty WTE plants per year since the beginning of the century, as shown in Figure 5 [12]. A comparison of the capital investment required in several countries of the world is provided in Figure 6 [13]. China has demonstrated that it is possible to reduce the capital cost of WTE plants by means of industrial and academic R&D, and mass production, instead of one plant at the time. In addition, the government was accepting most of the risk of the investment by participating in the equity structure, by providing strong tax and policy incentives, e.g. land permits, disposition of residues, energy credit, etc.; and becoming fully engaged in public education and acceptance of new WTE projects. All these actions were associated with significant reductions in the capital required for WTE. For instance, the WTE plant in Dublin, Ireland was commissioned in the late 1990s, but it was opened in 2018, mainly associated with the public opposition of the project. The capital investment required was ~$1,200/ton, as compared to ~$672/ton of the West Palm Beach plant in the US, and ~$190/ton of the plant in Nanjing, China.

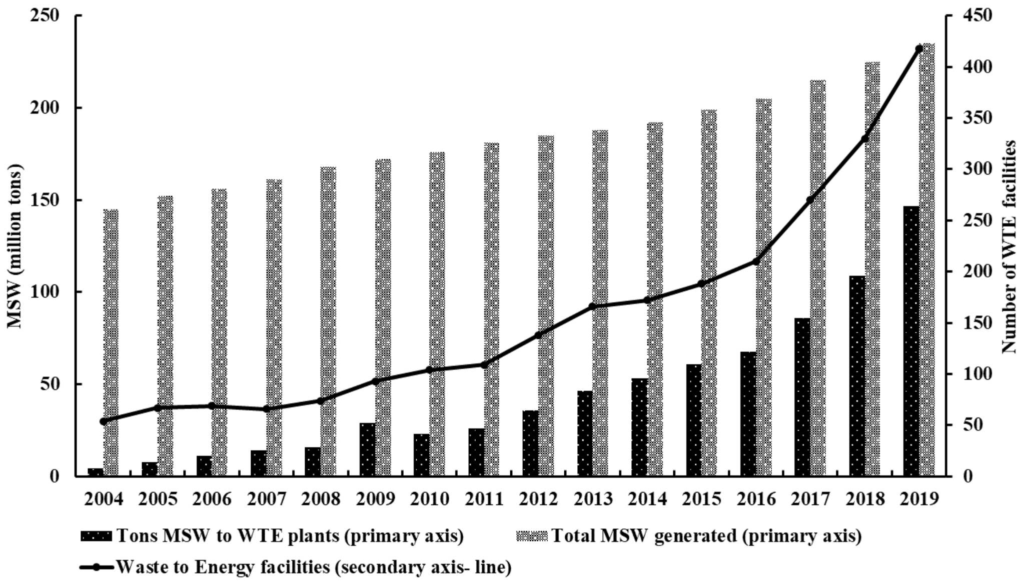

Figure 5. Growth of WTE in China [12].

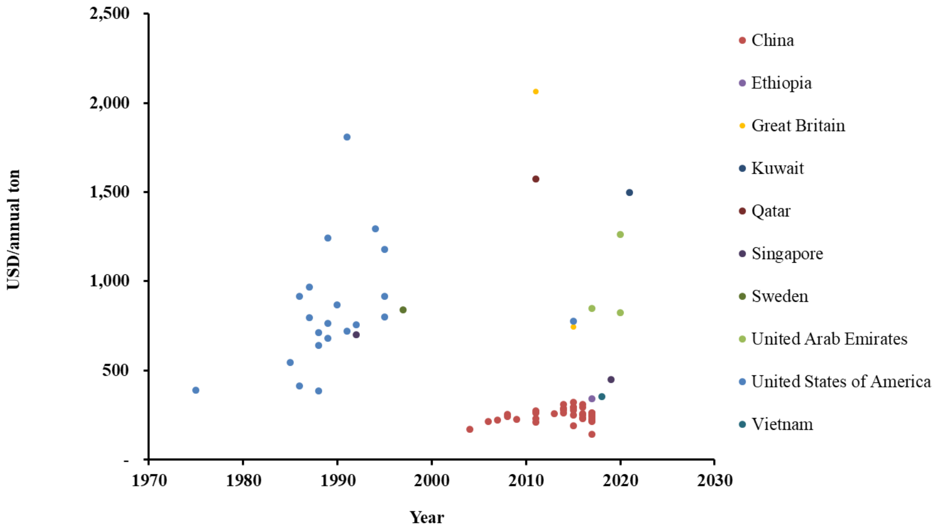

Figure 6. Cost of WTE by country (Adjusted for Exchange Rates and Inflation) [13].

The global experience has shown that two approaches have been used for the advancement of solid waste management (SWM) in communities:

- Developed nations took several decades to reach their present state of development and achievement in sustainable waste management through public education, citizen compliance, and the deployment of sophisticated systems. The integrated systems were designed upon maximum recovery of resources from the recyclable/compostable wastes, and the maximum recovery of energy from the residual wastes;
- China accelerated the phasing out of landfilling or the improper dumping by the massive application of WTE technology.

C. WTE Technologies

There are several technologies to recover energy from the waste such as non-thermal and thermal treatment methods. Anaerobic treatment which is a non-thermal method is good for organic waste treatment where MSW is not accounted for. Thermal treatment methods include incineration, pyrolysis, gasification and plasma gasification. Among the thermal treatment methods moving grate incineration is the most widely used technology in the world with 80% of the WTE plants [2]. Therefore, this study considers moving grate technology for estimating potential benefits of WTE for Turkey.

1) Moving grate technology

The Moving Grate (MG) technology has been in use since the middle of the last century and evolved from coal combustion. MSW is combusted on a grate at 950 to 1100°C with excess air and is presented in Figure 7. The grate moves slowly, in either reverse or forward action and primary air is injected under the grate. Secondary air is also injected to achieve full combustion in the water-cooled furnace.

The heat generated by combustion is transferred through water walls and superheater tubes to the high-pressure steam that drives the turbine generator. The low-pressure steam from the generator exhaust can be used for district heating.

The plants operate with state-of-the-art Air Pollution Control Systems (APCs), and that is why the emissions of all plants are significantly below the stringent nationally established limits. Selective Non-Catalytic Reduction (SNCR) is typically used to reduce NOx emissions by 70%. However, many European, and a few US plants use both SNCR and Selective Catalytic Reduction (SCR) to reduce NOx by >90%. WTE plants use in-bed lime injection able to remove more than 95% of Sulphur, activated carbon injection for the complete destruction of dioxins/furans and bag filters or Electrostatic Precipitators to remove fine particles.

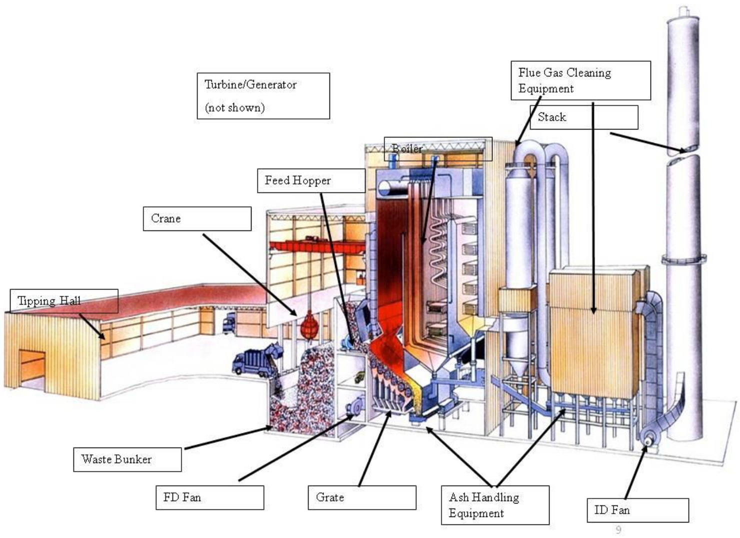

Figure 7. Parts of a moving grate WTE facility [2].

2) Sitting of WTE plants

The perception that WTE facilities are undesirable neighbors from an esthetic viewpoint has also been an obstacle to the development of WTE. However, modern WTE facilities operating in the U.S., Europe, Japan, and other nations have been designed with this concern in mind. WTE plants located in the center of architecturally sensitive cities, such as Vienna, Osaka, and Paris, have shown that designs can be made compatible with local esthetic requirements. An analysis of primary data estimated that the average distance of WTE plants from the city center that these plants are serving is ~five kilometers, as presented in Figure 8 [14]. Most of the plants in Japan, and EU are located close to the city centers. Most of the outliners were plants located in the US.

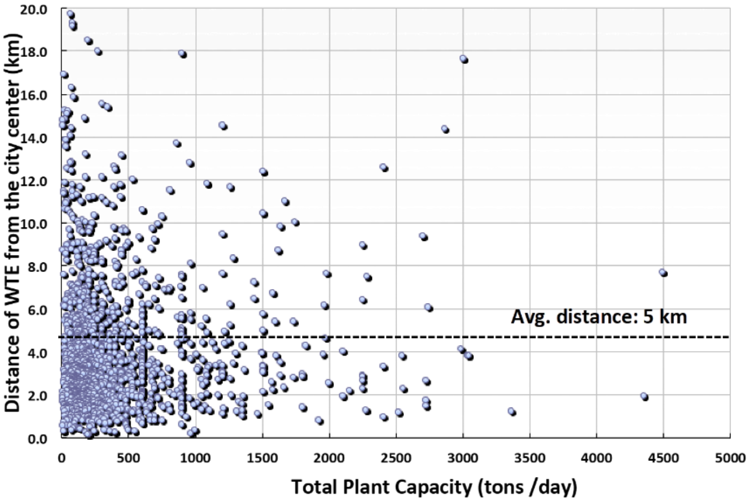

Figure 8. WTE capacity (x-axis) vs. distance of WTE from city center (y-axis). The analysis represents all the ~1000 WTE plants of the world. [14].

III. WASTE MANAGEMENT IN TURKEY

Municipalities are responsible for municipal solid waste management in Turkey. The total amount of MSW was around 25 million tons in 2001, with a 28% increase in 17 years it reached around 32 million tons in 2018 [15]. As it can be seen from Figure 9, dumping was the dominant MSW treatment method in 2001 for the country whereas sanitary landfilling became the most dominant MSW treatment method in years. Also, material and energy recovery which is summed up by the data supllier from MSW is developing recently in the country.

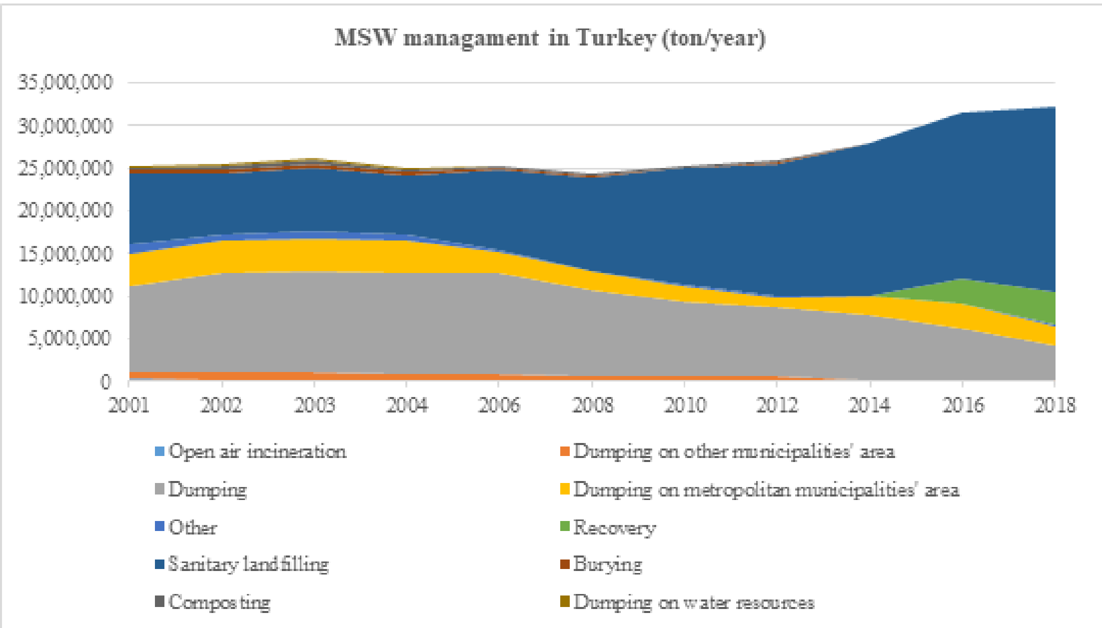

Figure 9.Amount of MSW by treatment methods between 2001-2018 in Turkey[15].

Figure 10 shows the share of MSW amount by the treatment methods in Turkey in 2018. It can be seen from Figure 10 that sanitary landfilling and dumping treated 87% of all MSW in the country while energy and material recovery was gained from 12% of MSW. Composting was applied to only 1% of the MSW in the country.

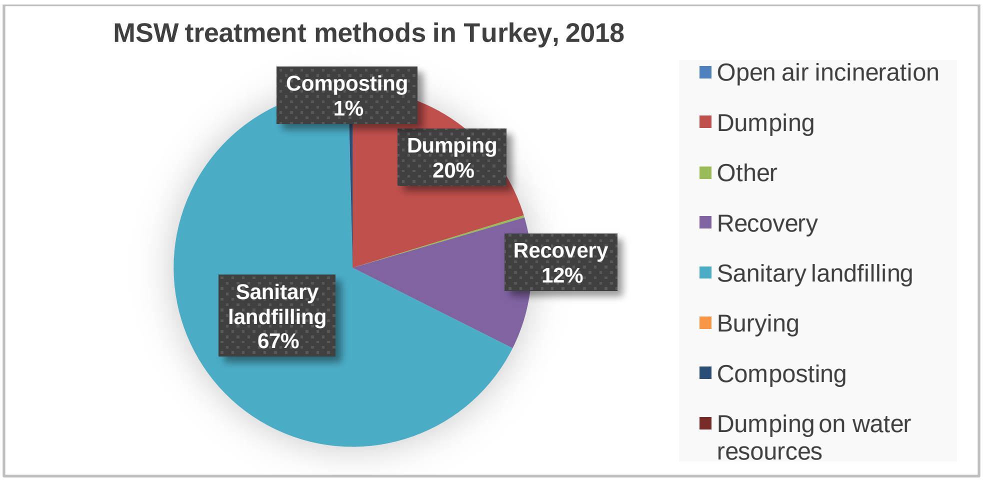

Figure 10. Share of MSW managed by different methods [15].

IV. POTENTIAL BENEFITS OF WASTE-TO-ENERGY FOR TURKEY

In this study, we consider three scenarios which consist low, medium and high landfilling scenarios for WTE integration to the current status of Turkey's MSW management. In the first scenario, it is assumed that 10% of MSW is managed by the WTE method; in the second scenario it is assumed that 30% of MSW is managed by WTE; and in the high end-scenario it is assumed that 50% of MSW is treated by WTE.

A. Benefits to electricity mix

Calixto (2017) estimated calorific value for Chilean MSW as 8.73 MJ/kg which corresponds to net gained electricity of 0.56 MWh/ton considering all losses [16]. However, Yildiz et al. (2012) determined average calorific value of MSW for Istanbul is estimated as 6 MJ/kg [17]. Considering Istanbul is the biggest metropolitan of Turkey which hosts almost one fifth of all population in Turkey, the calorific value for MSW of Istanbul is adopted for this study. Using the same efficiencies that Calixto (2016) assumed, net gained electricity from collected waste in Turkey is determined as 0.38 MWh/t for this study [16].

Table 1 summarizes expected electricity generation from WTE and its share in electricity mix based on 2018 data. For the calculations in Table 1, the total amount of produced energy in 2018 is taken as 304.8 TWh [18]. Results of the calculations show that if 50% of the MSW in Turkey is used in WTE plants to produce electricity 2% of the countries' electricity would be supplied from the solid waste.

Table 1. Annual expected electricity generation from WTE and its share in the electricity mix.

Scenarios	Expected annual electricity generation	Share in electricity mix
Scenario 1 (10%)	$0.38*(32*10^6)*0.1$= 1.2 TWh	1.2/304.8 = 0.4%

Scenario 2 (30%)	$0.38*(32*10^6)*0.3=$ 3.6 TWh	3.6/304.8 = 1.2%
Scenario 3 (50%)	$0.38*(32*10^6)*0.5=$ 6 TWh	6/304.8 = 2%

B. Benefits to the economy

In this study, WTE is assumed to replace natural gas power plants since natural gas is mostly imported in Turkey and it is wanted to be reduced to minimize dependency on other countries as well as reducing the budget deficit. The economic benefits are estimated for the third scenario of using 50% of the MSW in WTE plants. Capital cost of WTE plants are estimated as 305.3$ per ton of MSW and operational cost is estimated as 12.82 $ per ton per year whereas gate fee is taken as 18 $/ton per year [16]. On the other hand, Kocaoglu (2009) stated that capital cost of a natural gas power plant and operational expenditures are 650$/kW and 0.03 $/kWh, respectively [19]. Table 2 shows the comparison of costs of investing on WTE and natural gas plants. It can be seen from Table 2 that annual cost for WTE and natural gas plants are 79.9 MM$ and 201.7 MM$, respectively, which corresponds to 121.8 MM$ per year of savings for the country.

Table 2. Cost comparison between WTE and natural gas power plants

Expenses & Revenues	**3rd scenario (6 TWh annual energy production)**	
	WTE (1280 MW) - 30 year lifetime [17]	Nat. Gas (1000 MW) - 30 year lifetime [20]
Capex	305.3 $/ton	650 $/kW
Opex	12.82 $/ton per year	0.03 $/kWh
Gate fee	18 $/ton per year	-
Total cost ($ per year)	79.9 $ MM	201.7 $ MM

C. Benefits to the environment

Psumopoulos et al. (2009) stated that landfilling requires 30 times more area than using WTE for waste management method [20]. Therefore, considering the scenario of 50% of the waste which is 16 million tons of MSW being treated by WTE, the required land use is estimated as 1.6 million m2 where this area would be needed if landfilling is in use per year. Therefore, it is estimated that 46.4 million m2 area would be saved from landfilling in the 30 years lifetime of WTE plants which corresponds to 1.55 million m2 area per year.

Moreover, CO2 emissions from WTE plants is asserted to be lower than natural gas power plants [21]. O'brien (2006) states that a WTE plant emits 379.66 kg CO2 per MWh whereas a natural gas power plant emits 514.83 kg CO2 per MWh. Therefore, considering the scenario of 50% of the MSW which is 6 TWh electricity production being generated, WTE plants could reduce 135.2 ton CO2 emissions per year replacing natural gas power plants. On the other hand, landfilling of 16 million tons of MSW contributes to 1.54 million tons of CO2 and 571,424 tons of methane emission which could be eliminated if treated by WTE plants [21].

V. CONCLUSION

The aim of this study is to provide a snapshot of the current status of waste management in the world, provide evidence on the role of WTE in sustainable waste management, and assess the benefits of such technologies for the case of Turkey.

The global experience has shown that two approaches have been used for the advancement of solid waste management in communities:

- Developed nations took several decades to reach their present state of development and achievement in sustainable waste management through public education, citizen compliance, and the deployment of sophisticated systems. The integrated systems were designed upon maximum recovery of resources from the recyclable/compostable wastes, and the maximum recovery of energy from the residual waste.

- China accelerated the phasing out of landfilling or the improper dumping by the massive application of WTE technology.

The general benefits of WTE can be summarized below:

1. Produces energy from waste that cannot be recycled, and it is typically landfilled. Recycling processes themselves inherently generate wastes and residues. WTE can help recover energy from these residues.
2. Successful examples of the world have proved that recycling goes hand in hand with WTE.
3. WTE is key to remove hazardous materials out of the economy.
4. Allows recovery of metals and minerals from non-recyclables.
5. Saves land (1 m^2/ 10 tons of MSW) and GHG (1 ton of $CO_{2\text{-eq}}$/ton of MSW) over landfilling that emit methane.
6. the "turns" or "cycles" in an economy need energy that can be provided by WTE.

For the case of Turkey, WTE deployment will be associated with the savings of ~$122 MM per year. Also, WTE can contribute up to 2% to the electricity demand of the country, and can lead to the savings of ~ 1.5 million tons of $CO_{2\text{-eq}}$ and ~1.6 million m^2 of land; besides, the aesthetic superiority as compared to the only alternative, which is landfilling.

ACKNOWLEDGMENT *(Heading 5)*

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