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Benefits and Limitations of Waste-to-Energy Conversion in Iran

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Abstract

In the developing countries such as Iran, a massive amount of municipal solid wastes is collected in the form of landfills. These wastes are major sources of soil and water pollutions. Due to the increase in the population of cities and the demand for energy, conversion of waste into energy is one of the most effective tools in waste management and energy generation. In this paper, the process of conversion of waste-to-energy (WTE) in Iran is investigated, and the future situation is estimated. Also the trends of waste management methods and energy production are evaluated. At the end, the benefits of the WTE process in the capital of Iran, i.e. Tehran, are observed. The WTE facilities in waste management are used within 3 regions of 22 metropolitan areas of Tehran serving 950,000 citizens. With manufacturing new WTE plants in Iran, it would be possible to prevent the burning of about 15 million barrels of oil or 255×107 cubic meters of natural gas annually, and use these fossil fuels to produce petrochemicals and export them. The associated overall expenses of WTE are also estimated in different countries at a rate of GDP between 300 and 3,000 $ per ton of MSW. Substituting WTE plants instead of oil basic plants can reduce about 0.13 kg/kWh CO_2 emission, while most of the power plants are gas basic, which will have an increase of CO_2 emissions of about 0.19 kg/kWh, although the cost of producing 1 MWh of electricity by WTE is estimated at around 110 USD. However, the payback period could be between 17 to 20 years.

Keywords: *Waste-to-Energy, Municipal Solid Waste, Incineration, Sustainability, Renewable Energy, Iran.*

1. Introduction

One of the most important problems that many developed and developing countries have encountered in the last decades is Municipal Solid Waste (MSW) [1], [2]. The cost and the problems associated with the disposal of MSW such as finding a suitable site for the landfill, finding the solution for landfill leachates, stinking of MSW deposits and infected soil, and water resources are increasing rapidly [3, 4]. Based on [5], the solid waste production all over the world has been about 2 billion tons per year in the current century. Therefore, respect to the high amount of production, requisiteness of planning, and performing appropriate waste management based on site conditions and climate of areas are important [6, 7].

Generally, the solid waste produced is a threat to the environment, water, soil, and air. Regarding the economic dimensions, recycling is an opportunity in big cities. Evaluation of the stability of the modeling system in the recycling network is important [8]. One of these resources is Waste-To-Energy (WTE). Exploitation of the energy from the wastes is an ongoing and permanent instance for transforming MSWs to a clean and cheap energy. WTE is a beneficial scheme. By increasing the amount of waste produced, the use of earlier waste management methods requires a large area, while the modern methods offer waste processing in a small zone. With regard to heat, electricity, and biogas produced in WTE units, waste can be considered as an opportunity [6]. WTE for MSW can reduce greenhouse gases, while maintaining their economic benefits because it balances energy production and waste consumption as well as obtaining an optimal state. Due to the increase in the waste production in all countries, offering ways to manage these wastes is necessary. Waste management takes place to protect human health

and protection of resources [9, 10]. The existing management solutions are as follow [11–17]:
1. Separation for reuse,
2. Recycling,
3. Composting,
4. Gasification,
5. Pyrolysis,
6. Plasma arc,
7. Landfill,
8. Incineration.

Nowadays, there are more than 800 WTE plants in 40 countries. These plants use 11% of MSW around the world, and they produce 429 TWh. Approximately 10% of these plants are used for electricity generation [18]. In Germany, only 1% of the waste is landfilling, while the share of WTE is 35%, which is 24% higher than the average in European countries [19]. In Sweden, 50% of waste is used to produce energy in the form of heat and electricity from MSW [20].

Technology improvement, reducing costs, and increasing supports and investments by governments will increase the consideration of WTE in the developing countries [8, 21]. In the developing countries, the growth of MSW production has become a risky challenge due to the massive population growth and the lack of proper planning and investment in the waste management sector [22, 23]. In the developing countries, the role of citizens in reducing the efficiency of the waste management system is operational, due to the inadequate separation of waste. Considering the sustainability optimization indices, composite production is one of the worst solutions, while combustion and anaerobic digestion have the best performance [24–27].

In the energy market, bioenergy and biomass have always been a sustainable option in renewable energy [28–30]. In 2010, a report was published about the performance and how to change the WTE power plant in the combined cycle [31]. An integrated model of WTE and gas turbine cycle that is based on the properties of the MSW of Turin in Italy has been introduced. Subsequently, after calculating the thermodynamic properties, the parameters effective in reducing the cost of electricity production have been investigated. These parameters include an evaporator, a condenser, deaerator pressures, temperature at the pinch point, gas turbine outlet temperature, isentropic efficiencies, gas turbine net power, etc. Finally, as a result, the WTE power plant and the combined cycle are compared in terms of net worth and profit ratios. Regarding the market trend, WTE stand-alone is more desirable than integrating the system. However, if the price of natural gas is constant, the combined system would be more appropriate. The thermal efficiency of MSW is 3% more than the thermal efficiency of stand-alone WTE, although the thermal efficiency of the natural gas for a large combustion chamber is the same [32].

Landfills produce a large volume of CH_4 and CO_2, and increase of 54% of greenhouse gases. It is important to pay attention to this problem. Incinerating is an appropriate way to overcome this problem, and the waste generation crisis and a potential source of biodegradable materials by improving the thermal and chemical conversion is considered [33]. The choice of incinerating is considered to be the preferred technology in the generation of electricity and heat. With the arrival of 1000 tons per day, MSW can produce 1430 MWh of heat and 480 MWh of electricity per day; it can reach 287% of economic profit and avoid the production of 2250 tonnes of carbon dioxide per day from fossil fuels. The cost of that is about 450 $ per tonne per day [34].

WTE is one of the most complete ways of incinerating MSW [15]. An amount of 65% to 80% of the energy in the organic matter can be recovered by thermal processes in the WTE power plants; the incinerating efficiency is between 25% and 30% [35]. The energy market between 2006 and 2010 showed that between 3.1 and 5.1 billion US$ was the worth of the incinerating market, which had 10.5% growth per year [36]. The incinerating method with energy recovery is the most widespread way for a lower cost and a more reliable pollution control system among the WTE methods. While incinerating waste with thermal recovery is also economically justifiable, and in terms of compliance with the actual conditions governing waste production and the supply of energy, it is more important than the other employed methods [37]. Innovative research works have been carried out on the potential of the different resources for generating electricity in Isfahan (Iran), and the three main resources are wind, solar, and biomass. According to the system life span, biomass is the most effective in the economic indices and is more reliable [38].

The incinerating method is a common solution for the abovementioned problems [11]. The brilliant aspects of incinerating are as follow [18, 39, 40]:

- This reaction reduces the volume of wastes. The average volume reduction is about 80% to 95%, which can be considered as an averaged 90%. On the other hand, the mass reduction for the ratio of ash to MSW is equal to 25%
- Extensively can increase the life span of landfills and improve their conditions.

- The generated energy can be processed as a useful product, which will be used as an alternative fuel instead of natural gas, oil, and coal.
- Hazardous properties such as flammability, infectious, explosive, toxic or resistant, and chronic are eliminated.
- Perishable materials will be destroyed, and the number of pathogens will be very low.
- Destruction of gases and liquids in waste.

Therefore, by considering the physical benefits of MSW incineration, the comparison is in terms of environmental, economic, and power generation compared to other fuels.

2. Waste in Iran

By increasing the world population, until 2025, it reaches 8.2 billion people. On the other hand, urbanization of metropolises and cities will increase by 1.5%. It will be the cause of increasing energy demand as well as the sake of rising the MSW generation in the world as shown in figures 1 and 2 [36, 41,42].

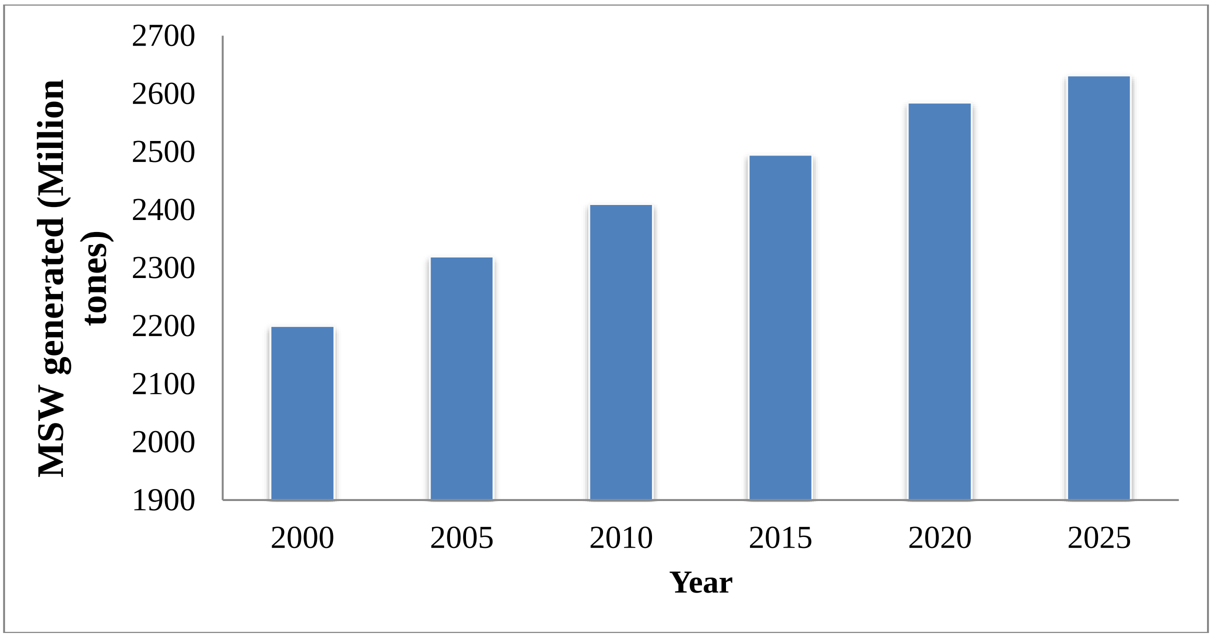

Figure 1. Waste produced in Asia, Europe, and the United States [36].

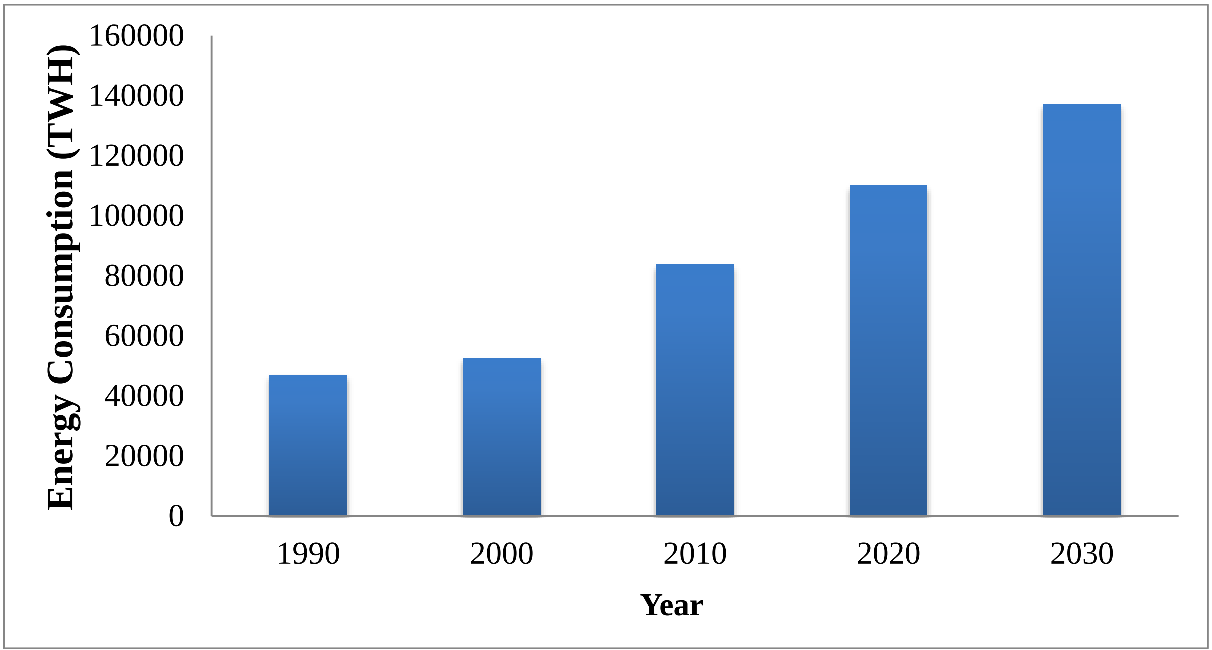

Figure 2. Energy Consumption [36].

In the most metropolises, the organic matter contained in solid waste is destroyed by biological processes [43–45]. The lack of effective solutions in waste management in urban or sub-urban development is the main problem of MSW handling, especially in some developing countries [46]. As shown in figure 3, the primary goal is to reduce waste production, which is only partially possible, and the waste product is associated with the human life. Reuse and recycling are the feasible ways in some conditions but energy recovery is always possible. By the way, the most used solutions are recycling and landfilling [47].

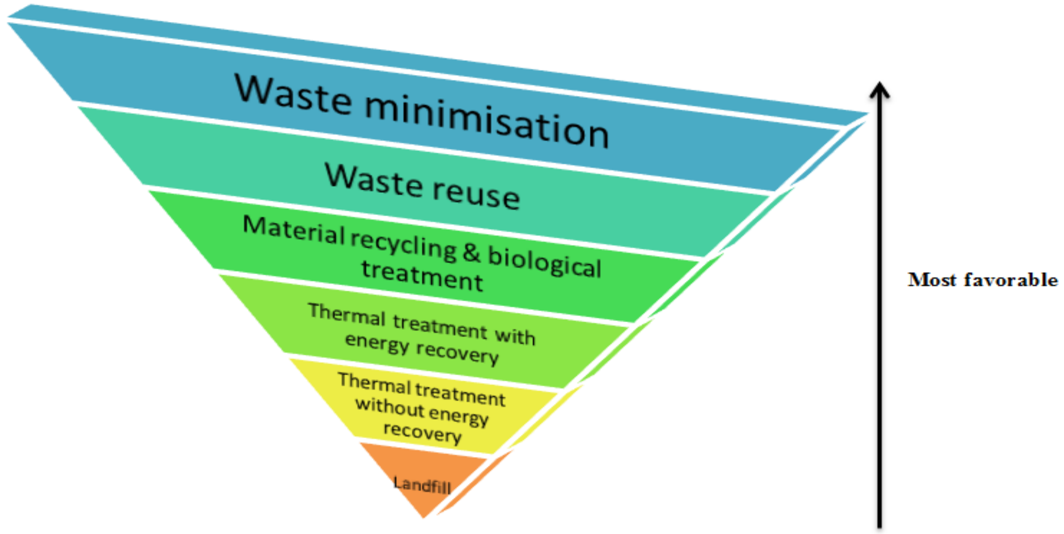

Figure 3. Waste management hierarchy.

In most developing countries, untreated direct landfill and burning without thermal recovery is a quick and inexpensive solution for MSW management [46]. Water pollution, soil toxicity, and environmental degradation are the consequences of non-standard landfill operations in the developing countries [48–50]. Also landfill leachates have significant effects on the human life, soil quality, and underground waters and sight views [51, 52]. New ways to change waste management from the simple landfill to more effective, more profitable, and cleaner methods are being developed [53–57]. These ways are as follow:

1. The electrocoagulation–nanofiltration hybrid system is a new method for refining leachate from the landfill sites. Through this way, by the help of aluminum polymer electrodes, the environmental performance of the site would be increased.
2. The hybrid and anaerobic bioreactor landfill technology is a novel method for consuming the produced methane by MSW.

In these two methods, the amounts of the produced methane would be different.

In the developing countries such as Iran, due to the increased consumerism and weakness in the separation and management of waste from the sources, the amount of waste generated is increasing. Table 1 shows the produced amount of waste in Iran and some developed countries, and provides some considerable differences between them [58].

Table 1. Production of waste in some countries for 2012 and 2025.

Country	2012			Estimated for 2025		
	Total Urban Population	MSW Generation Per Capita (kg/capita/day)	Total MSW Generation (tones/day)	Total Urban Population	MSW Generation Per Capita (kg/capita/day)	Total MSW Generation (tones/day)
Iran	46219250	0.16	7197	66930000	0.6	40158
USA	241972393	2.58	624700	305091000	3.2	701709
Germany	60530216	2.11	127816	61772000	5.2	126633
Canada	21287906	2.33	49616	31445000	2.2	69179
Japan	84330180	1.71	144466	86460000	1.7	146982

Based on a previous research work [59], the average MSW composition in Iran for organic wastes, paper, plastics, glass, metals, and other wastes are 72%, 6.4%, 7.8%, 2%, 2.5%, and 9.3%, respectively. Iran is one of the developing countries facing the problem of waste management, and it is important to note that regarding the lifestyle of people in Iran, most MSW can be recycled with a large contribution to the potential of compost production (about 60%). However, about 8% of all MSWs is recycled in various cities in Iran [60, 61]. Organizing waste management in Iran has a hierarchical structure. The most important government actors are in the ministries or departments of the environment and their affiliated organizations. Local authorities and waste management organizations play the most important role in the local areas. By providing contracts for a duration of 20 years, the Iranian government provides electricity purchases from the private sector producers; waste incineration, anaerobic digestion, and landfill are 0.155, 0.08, and 0.075 US$/kWh, respectively [62]. Producing biomass is dependent on several factors such as the amount and quality of MSW, and farming harvest and agriculture crop residuals; the quality and quantity of these materials are related to conditions of climates and environments [63–65].

Iran has a dry climate and most of it is covered by desert but some regions are forest, covered by trees (about 7%). In the forest area, abundant agricultural production has been created. Also this area has a good potential for biodiesel and bioethanol productions [63]. Generating any kind of wastes in urban and rural areas is equal to 19.6 million tons per year [66, 67]. The resource for producing biomass residues is about 3 million tons of MSWs and 16.5 million tons by farming products and animal wastes [66]. With increasing attention, the amount of biogas production in Iran is increasing, while its amount is about 16146 million cubic meters [68]. In figure 4, the energy potential of biomass resources in Iran has been shown for 2013 [69].

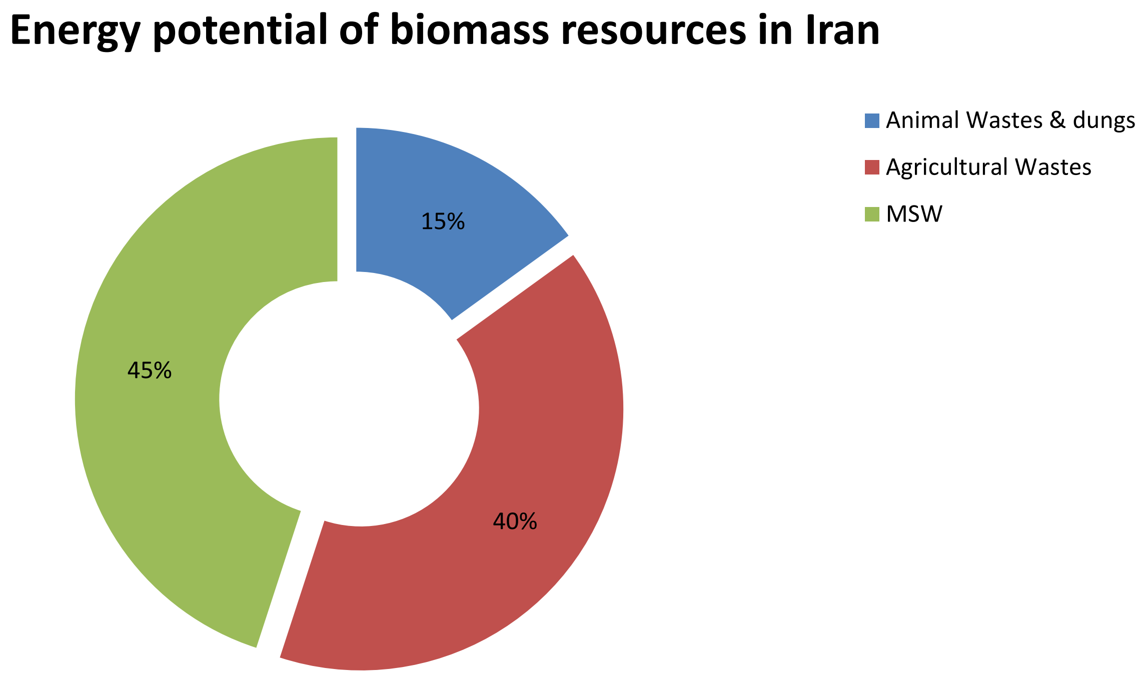

Figure 4. Energy potential of biomass resources in Iran.

It is also interesting to note that in Iran, the rate of producing MSW is between 0.2 to 0.5 kg per person per day. Economic, lifestyle, society, and environment are the main effective factors in changing this data [63], 70], 71]. Tehran is the most populated city in Iran. For residential areas in Tehran, the rate of producing MSW is about 0.88 kg per person per day. Thus the high volume of waste, if not properly managed, causes infectious and contagious problems, and this calls for administrative rules. In Tehran and other cities, most of the wastes are landfilled, while MSW is a good source of energy and biogas. In Iran, about 15 million tons of MSW are produced per year [72]. On average, burning 1000 kilograms of MSW in new and advanced power plants provides a potential for producing 0.6 MW of electrical power. Such a process would prevent the extraction of 1,400 kg of high-quality coal or the equivalent of preventing imports of 1 barrel of oil. This has led the US EPA (Environmental Protection Agency) to consider MSW as a renewable energy source. In a WTE power plant, about $\frac{4}{5}$ of the generated electricity will be send to the electric power distribution, and the rest of it is consumed by the plant facilities [73, 74]. In Iran, 54.4% and 44.1% of energy are consumed by natural gas and oil, respectively. The uses of this energy are in industry, transportation, and households, where transportation has a significant share in the consumption of petroleum and its products, while most of the domestic consumption is in the use of natural gas. The share of non-renewable energy in the world is 81%, and it is 99% in Iran. According to the World Energy Agency (IEA), oil and natural gas have limited resources that will end in 41.8 and 60.3 years, respectively [19, 65, 75]. LHV of natural gas in Iran is about 5.88×10^{-3} BOE, and LHV of crude oil is about 42 MJ/kg. With the aid of BOE (Barrel of oil equivalent), we can examine the behavior of the replacement effect of MSW instead of fossil fuels such as oil or natural gas in the energy market [76, 77].

In 2019, the average price per barrel of crude oil is 65 USD, and the average price per cubic meter of natural gas is 2.8 USD [78]. Therefore, with manufacturing new WTE plants in Iran, it would be possible to prevent the burning of about 15 million barrels of oil or 255×10^{7} cubic meters of natural gas annually and use these fossil fuels to produce petrochemicals and export them. Therefore, in Iran's internal energy market, about 975 million US $ in the consumption of oil or 7140 million US $ in natural gas consumption is saved. Based on MSW's LHV and the type of system used to generate power, the income by the use of MSW in the power cycle will be different. For example, in the CHP cycle, LHV for MSW is 6MJ/kg, and the income is equal to 28 US$/ton, while for 10 MJ/kg, it is 47 US $/t [79]. Incineration emissions have pollutant materials that have a negative and cost-effective impact on the environment. Estimated emissions of WTE power plants can be calculated as kilowatt hours of net electricity production or by the climate coefficients that are considered for each country. Given that the climate coefficients are less accurate, the calculations are based on the emission factors. Emission factors are average values of CO_2 emissions based on the produced power. CO_2 emissions based on the fuel type are as shown in figure 5 [73, 75, 80].

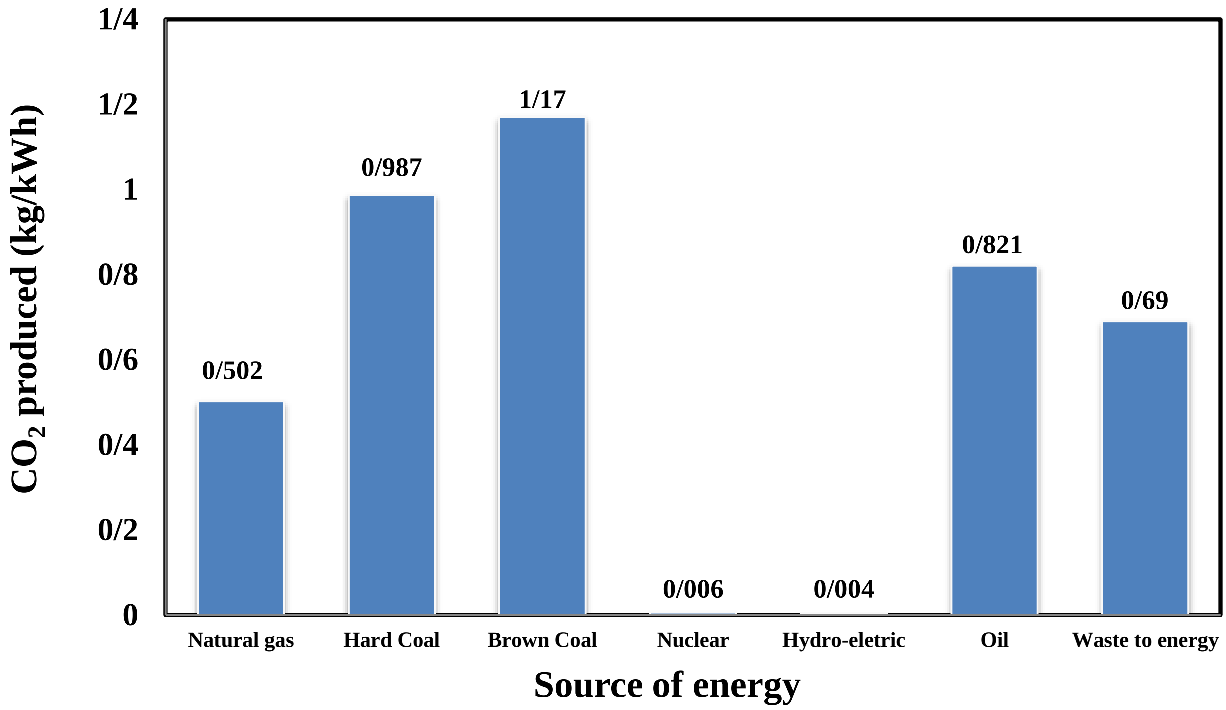

Figure 5. Comparison of amounts of carbon dioxide produced in terms of fuel type at power plants.

On the other hand, it is important to consider the economic situations for the construction of the WTE power plants. The costs associated with the land purchase are based on the size of the land used to build the plant. In this case, the KEZO-WTE power plant in Switzerland is used as a reference, with an estimated reference value of 52,800 square meters. On the other hand, in the European Union,

the cost of land is considered in non-urban areas suitable for the construction of 30 $/m^2 of power plants [81].
Also the costs of equipment and technology used in the WTE power plants, which account for 15% to 40% of the total fixed costs [82]. However, the payback period could be between ۱7 to ۲۰ years [83, 84]. Considering these conditions, the cost for producing 1 MWh electricity is shown in figure 6 [85–88].

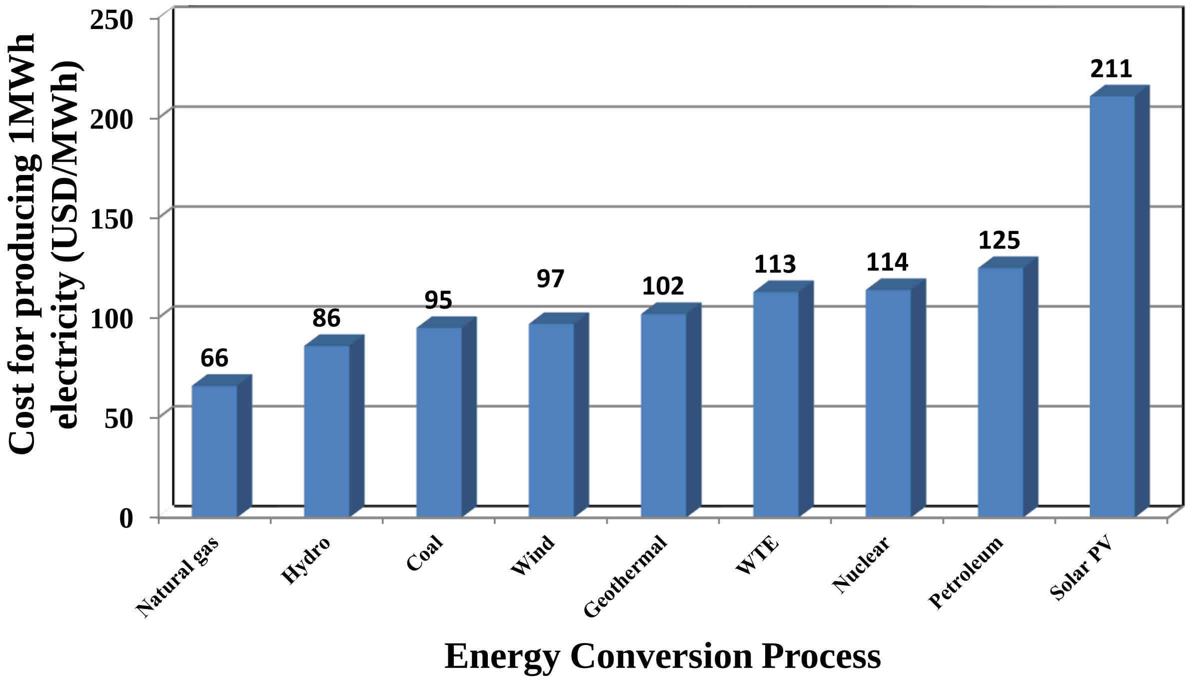

Figure 6. Cost for producing 1 MWh electricity by different sources of energy.

Figure 6 indicates that the cost of generating a certain amount of electricity by WTE is in the middle category and has an acceptable value in terms of its side-benefits. In some cities of Iran, due to the high moisture in MSW, there are preprocesses to reduce the moisture in municipal wastes and increase the heating value before the combustion operation [89]. It is important to note that the heating value is an important indicator for evaluating the energy of waste to energy units [90].

3. Energy in Iran

Iran is a country located in the Middle East and Southwest of Asia. The Latitude and longitude coordinates related to Iran are in the range of 44 to 64 East and 25 to 40 North, respectively. Iran has been ranked 17th and 18th in terms of population and vastity, respectively. Over the past decades, with the rise in urbanization and the progress in technology, industrialization has increased, with energy consumption rising to the top 20 countries in the world [91].
Iran is one of the largest energy resources in the world, ranked 4th and 2nd in terms of oil and gas resources, respectively. These reserves are 9% and 15.8% of global resources, respectively. This has caused fossil fuels to have the biggest proportion of electricity production in Iran. This is clearly illustrated in figure 7 [19]. However, the biggest problem is the release of a large number of pollutants into the air. Iran has a long-term program for reaching the 2030 targets, in which 29% of the country's energy production comes from renewable energy [91].
Iran is one of the countries producing a significant amount of non-renewable energy due to significant fossil resources and the use of natural gas reserves. On the other hand, there is a low cost of fossil fuels and low attention to the sources of renewable resources with lower air pollution. Iran is in a high potential area to produce renewable energy. Iran is capable of reducing the consumption of fossil fuels by using renewable and sustainable energy resources (RESs), and subsequently, reducing pollution caused by that to be from these sources of energy such as biomass, hydropower, wind, solar, and geothermal. Increasing energy consumption in urban areas is much higher than energy consumption in rural areas, the main reason being the increase in the population living in cities and

the increase in energy consumption due to the growing comfort of cities and the use of advanced technologies that increase energy consumption in cities and the villagers are more inclined to migrate to the cities [92].

Energy consumption in the world is basically based on the consumption of electricity. Most of the energy supplied to the world is possible by fossil fuels. Nearly 66% of this energy is required by fossil fuels, namely natural gas, oil, and coal [93]. According to IEA, oil and natural gas has had limited resources; 41.8 and 60.3 years later, these resources will be finished. Therefore, increasing the focus on renewable energy sources and considering the environmental aspects of the international community has led to an increased focus on RSE [19]. WTE systems have a good potential to operate as cogeneration cycles. The combination of energy sources used in Iran is shown in figure 8 [65].

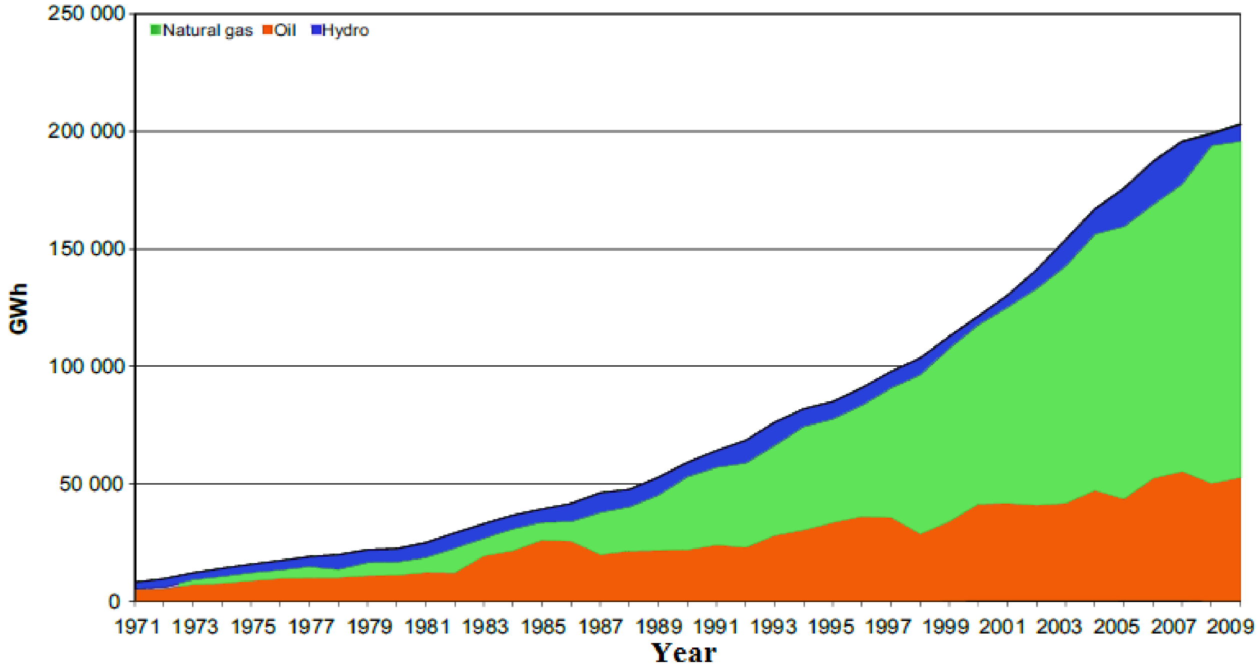

Figure 7. The amount of electricity produced in Iran based on fuels [19].

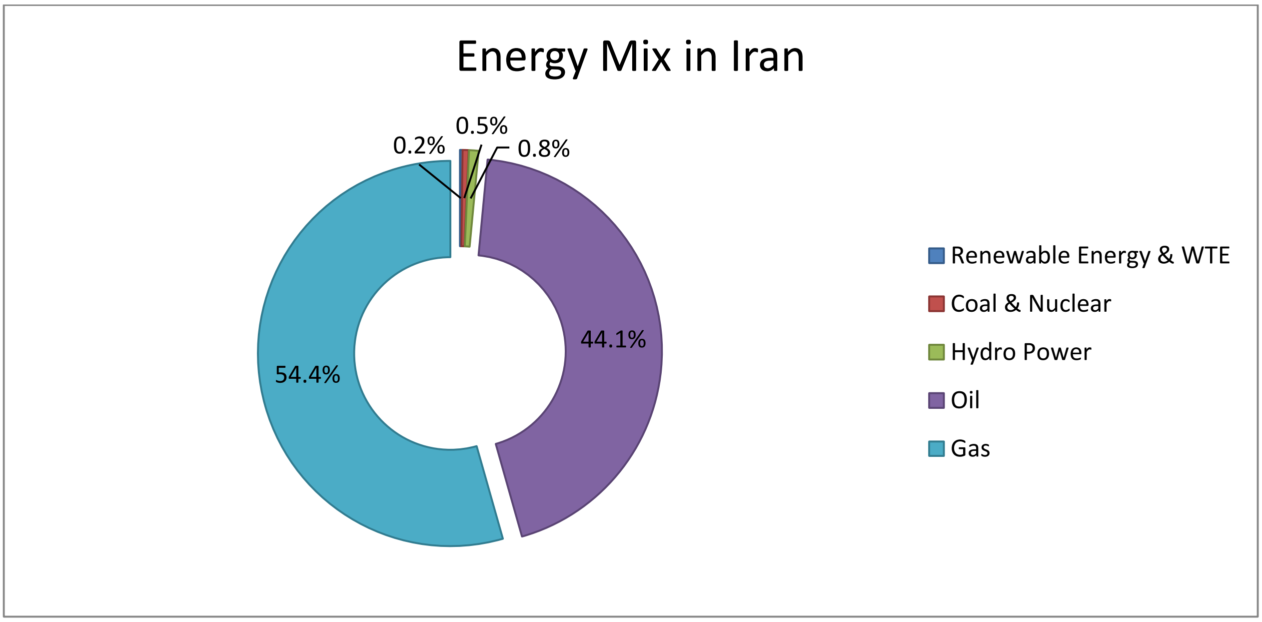

Figure 8. Energy Mix in Iran [65].

Electricity production in Iran has grown dramatically in the recent decades, which has led to an increase in consumption. Figure 9 shows how these two parameters are growing in Iran [19].
In the recent years, the government programs have resulted in a reduction in the electricity generation by fossil fuels and a raise in the proportion of renewable resources. This comprehensive program is focused on the production of oil derivatives and the reduction of fossil product consumption in the country and growing the export of these products. The following is a result of the increase in the local and foreign investment in the renewable energy industry. A glance at figure 10 reveals some considerable information about the produced renewable electricity for a period of time in Iran. The time period from 2005 to 2008 illustrates a significant plunge attributed to the recession and the fall in oil prices in these years.

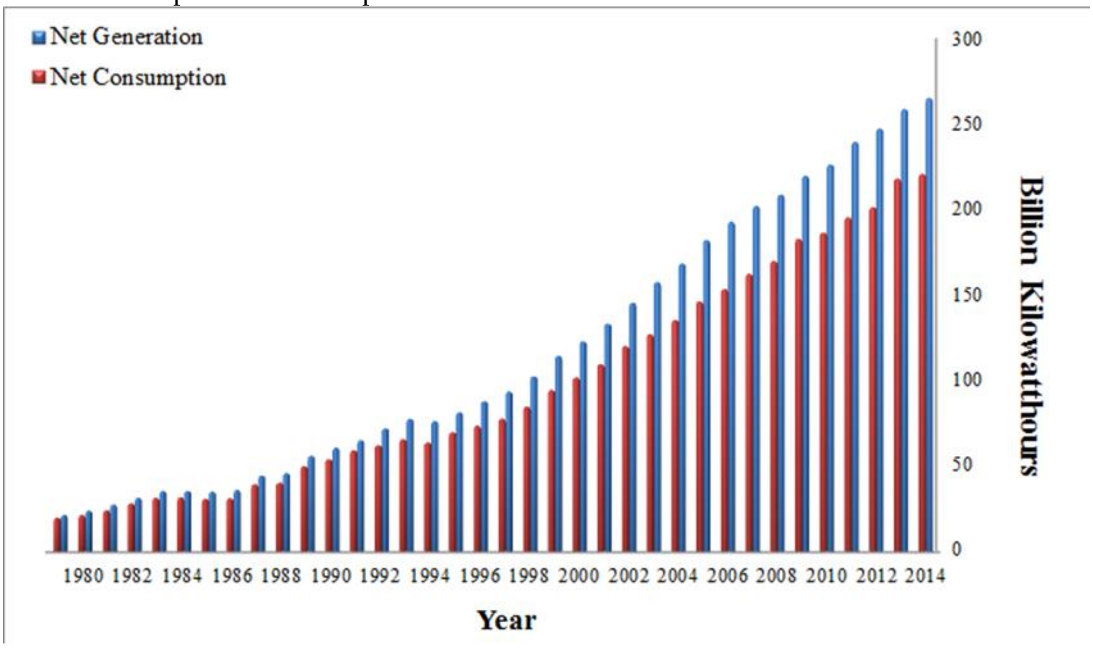

Figure 9. Iran electricity generation and consumption, 1979–2014 [19].

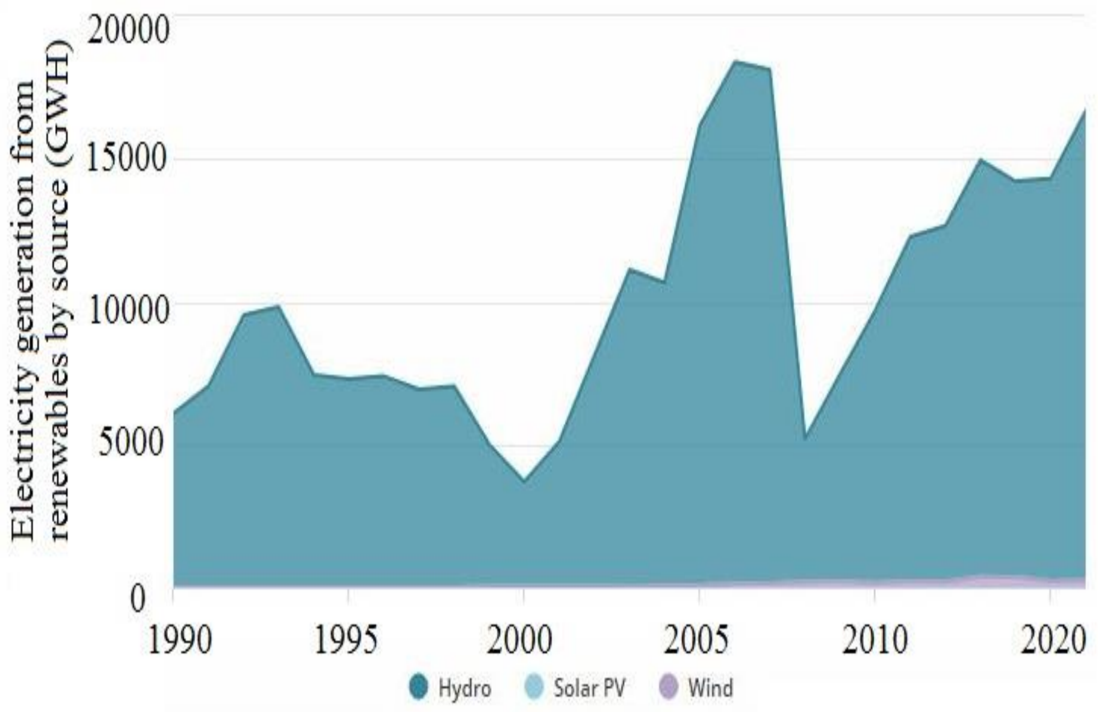

Figure 10. Renewable electricity production in Iran [19].

In the recent years, with increase in investments in the WTE industry, several power plants by the Renewable Energy Institute and the Iran Ministry of Energy in the populated areas have been implemented, as presented in the table 2 [63].

Table 2. The waste-energy units in Iran [63].

Number	State	Capacity (MW)	Processing capacity (ton/day)	Type
1	Tehran	3	200	Pyrolysis & Gasification + mass burner
2	Mazandaran	4	400	Gasification
3	Mazandaran	2	200	Gasification
4	Tehran	1.9	-	landfill with a gas recovery system
5	Fars	1.06	150	landfill with a gas recovery system
6	Razavi Khorasan	0.66	-	landfill with a gas recovery system
7	Tehran	3	400	landfill with a gas recovery system
8	Isfahan	1.2	300	landfill with a gas recovery system
9	Tehran	4	473000 (m^3/day)	Anaerobic digestion (wastewater and sludge)
10	Isfahan	1.2	135000 (m^3/day)	Anaerobic digestion (wastewater and sludge)

The dispersal of these power plants is such that they are located throughout the country and near the high population areas (high MSW production). In figure 11, the dispersion of WTE power plants in Iran is shown. It is clear that the locations of these power plants are in populated areas [94].

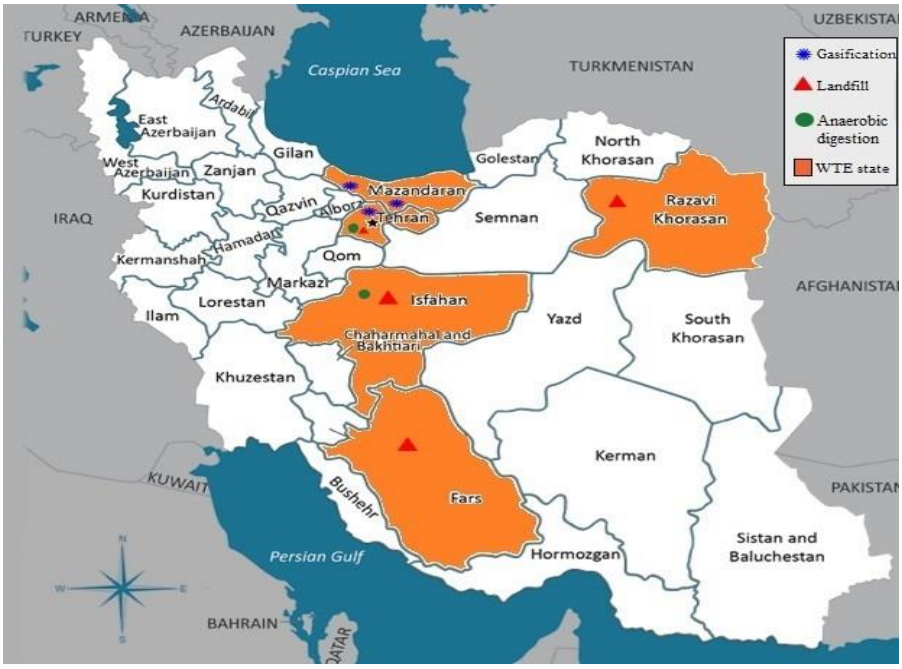

Figure 11. The dispersion of waste-to-energy power plants in Iran [94].

A particularly striking fact is that the government has long-term plans for developing the facilities to exploit energy from the wastes, and constructs the units for producing biomass in the cities with a high population. For example, in the future, the 0.6 MW power plant in Saveh will be constructed [63].

4. Tehran case study

The basic point in the investigation of MSW generated in Iran is the increasing trend in the recent years, which is accelerating with increasing population density, economic prosperity, and social conditions. As an example, as shown in figure 12, the statistic shows the amount of waste produced in the largest city in Iran, Tehran, between 1991 and 2008 [70].

The most important reasons for the increase in the growth rate of waste products are the strong increase in production and the growth of the activities in private sectors. In this period, urban services have changed from the governmental to the private sector, and contractors are remunerated based on the amount of waste they have collected. As a result, the contractors tend to record higher and unrealistic amounts of collected waste in order to increase their income [70]. In Tehran, 86% of the waste is landfilled directly, and only 5.3% of MSW is used in the 3MW Kahrizak WTE power plant (figure 13). The WTE power plant consumes 150,000 tons of solid waste each year as fuel to provide super-heated steam for generating electricity. The waste composition used in the WTE plant is presented in table 3 [26].

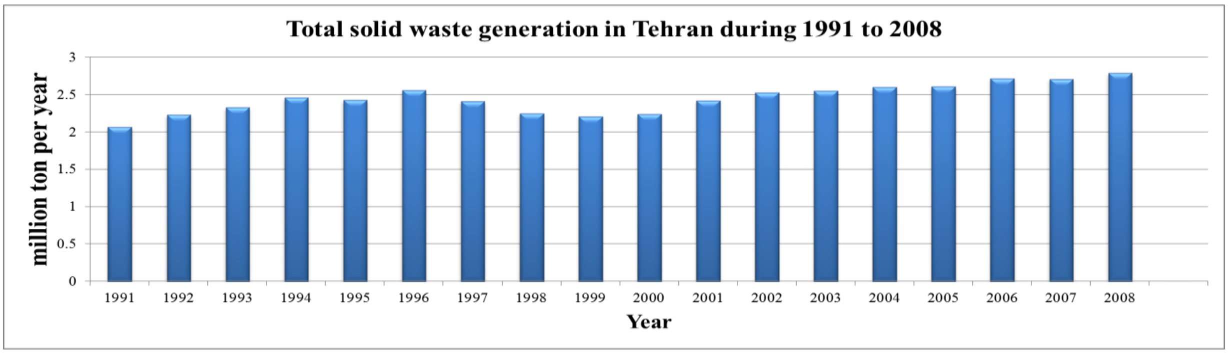

Figure 12. Produced waste in Tehran between 1991 and 2008 [70].

Figure 13. Kahrizak WTE power plant.

Table 3. MSW composition for Kahrizak Power Plant [26].

Components in the MSW	Dry	C	H	O	N	S	Ash	Overall
Paper	2.87	1.27	0.17	1.27	0.01	0.01	0.015	3.32
Plastic	15.43	1.54	1.31	2.68	0.35	0.03	1.54	16.41
Wood	1.64	0.82	0.1	0.69	0.00	0.00	0.02	2.11
Cellulosic Material	3.6	1.88	0.28	1.36	0.01	0.00	0.07	4.5
Textile	7.85	4.08	0.49	2.81	0.25	0.01	0.2	9.81
Others	2.18	0.1	0.01	0.08	0.00	0.00	1.99	2.27
Small Material	3.89	1.02	0.21	1.19	0.1	0.01	1.36	5.56
Organic Material	16.81	8.07	1.01	5.71	0.37	0.05	1.6	56.02

The low heating value (LHV) of MSW can be used with the aid of the Dulong equation for estimating the thermal value (Eq. 1) [95]. HHV, on the other hand, can be calculated by Eq. 2 [96], while C, H, O, N, S, and H_2O are the weight percent of the constituents.

$$LHV_{waste} = 337C + 1428 \left(H - \frac{O}{8} - \frac{Cl}{35.5}\right) + 9S \quad (1)$$

$$HHV_{waste} = \left(1 - \frac{H_2O}{100}\right)(-0.3578C - 1.1357H + 0.0845O - 0.0594N - 0.1119S) \quad (2)$$

The WTE power plant of Kahrizak has a net power capacity equal to 3 MW. The waste incinerator has a capacity equal to 6.5 kg/s of MSW and approximated LHV is 8700 kJ/kg in the relevant Rankine cycle that produces superheated steam with a 40 bar pressure and a 640 K temperature. The annual operating hours of the plant is 6000 h. In figure 14, the typical flow diagram of the Kahrizak WTE power plant indicates the process. In the incinerating MSW, Activated Carbon Enhanced Lime is used to reduce dioxins, mercury, and acid gases [97]. In figure 15, the typical scheme of the WTE power plant is displayed. MSWs stay in an incinerator for 2 seconds, and the flue gas temperature is maintained at about 1120 K to prevent the production of dioxin [2, 26].

Due to the high value of LHV for MSW, an evaporator wall is used in the furnace to cool it. Ultimately, the heat of the flue gas is transferred in heat recovery steam generator (HRSG) to pressurize waterto change it to superheated steam. HRSG includes three parts, i.e. economizer, evaporator, and superheater. In HRSG, an economizer is used to reduce costs and increase the system efficiency. The evaporator is used to prevent the production of HCL at high temperatures, and consequently, corrosion of metals [2, 98]. After reducing the gas temperature, the flow of combustion products is transferred to the electrostatic pepcepiator (ESP) to collect the combustion products in the range of 0.1-10 micrometers and baghouses to clean up the submicron size material [1].

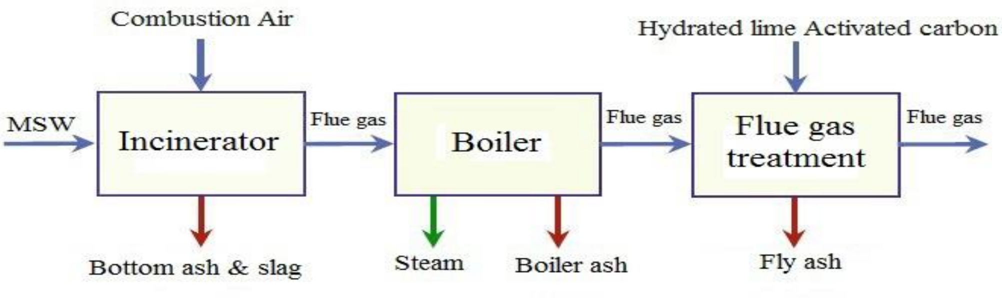

Figure 14. Flow diagram of Kahrizak WTE power plant.

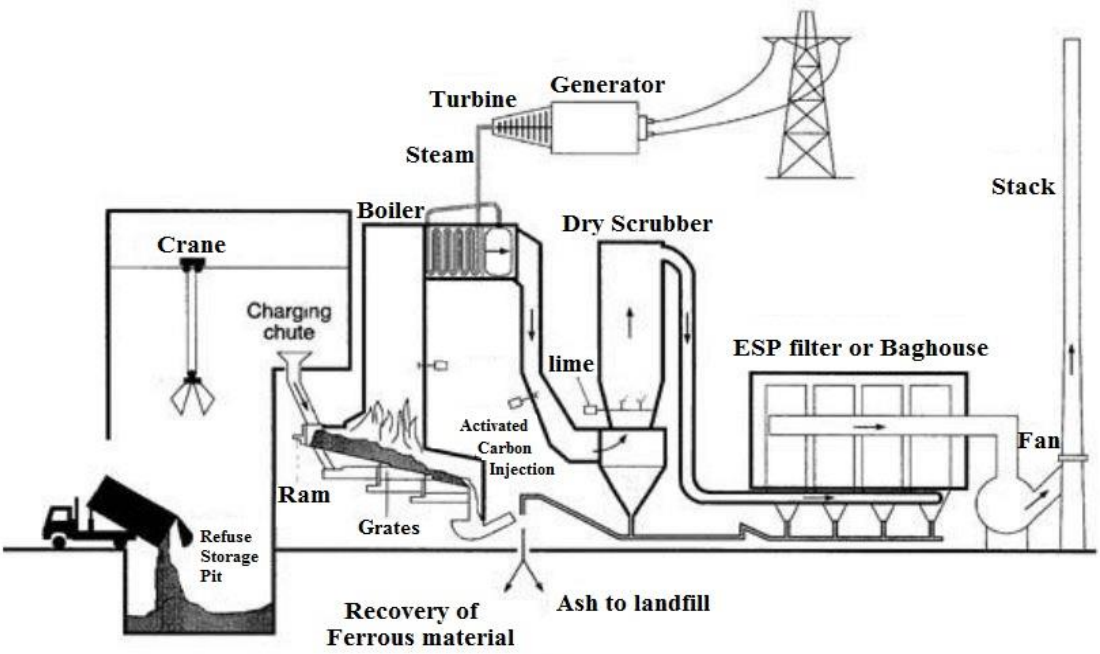

Figure 15. A typical scheme for WTE power plant [2, 99]

The bottom ashes of the incineration process will bury in the landfills, whereas in the recent years, the focus has been on the use of bottom ash in concrete production and road construction [100]. The MSW combustion fly ash contains about 25% lime and some materials including silicates and aluminosilicates, which provide the suitable potential for cement production [101, 102]. By using bottom ash instead of gravel and mixing that with cement, cracking occurs in concrete due to the presence of aluminum. Therefore, the processing of ash by sodium hydroxide can prevent this reaction and increase the durability of the resulting concrete [103,104]. After combustion, the metals are unburned in the residual ash, which is used as a building material for concrete and road construction. The maximum amount of recycled metal in the ash is about 50-100 kg per year, which is 1-2% of the original source substitutes for the existing materials such as iron, stainless steel, aluminum, copper, and brass. These materials can be separated in various ways such as magnetic separation [105]. One of the common methods available for the separation of bottom ash is the use of fixed elements at the end of the grates, in which ash is separated and cooled down by the water pool and stored in ash reservoirs. The mechanical processing of ash is performed by screening the material in it through the processing of ashes, and extracts of products such as silicates and metal compounds [106]. The properties of the obtained metals show that it is not possible to consider the existing metals merely as a combination of metals or a pure metal [107]. Particles larger than 1 mm are considered to be continuous, and the detection and displacement of a combination of spectral and pneumatic/mechanical separators are done [107].

The production of MSW in Tehran is increasing day by day as a result of an increase in the population (an average of 6650 tone/day in 2014). MSW is made up of a variety of materials, which have a high volume of plastic, glass, organic material, metal, and paper. The responsibility for collecting this high volume of MSW is by the centers embedded in each of the 22 regions [108]. By incinerating this amount of MSW, it produces about 1500 tons per day of bottom ash, which has the good potential to be used in the mentioned cases.

Regarding the LHV of MSW, which has a major role in WTE systems, it is the LHV of the plastic and paper in the range of 28-35 GJ/tone and 14-15 GJ/tone, respectively, so according to investigations carried out in the 22 districts of Tehran, districts 4, 13, 14, 15, 16, 17, 18, 19, 20, and 21 have a higher volume than other regions in the production of these materials. Therefore, LHV of MSW from these districts will be higher [8, 109]. The location of the MSW collection centers and WTE facilities are shown in figure 16 [108].

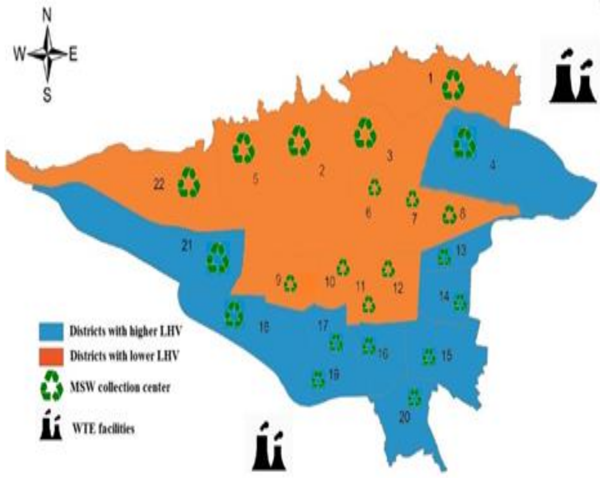

Figure 16. Location of the MSW collection centers and WTE facilities in Tehran.

By using this amount of MSW in WTE industries instead of burying them in the landfill sites can prevent burning 6650 barrel of oil or 113×10^4 cubic meters of natural gas daily. On the other hand, the economic benefit of this action is 317×10^4 US$ per day. Based on the Tehran waste management organization, about 46% of the MSW collects from the districts by higher LHV that cause a suitable situation for constructing WTE units near these districts [108]. Income from heat generation, electricity generation or CHP from MSW depends directly on its heat value. In table 4, these values are presented.

Table 4. Energy Income based on heat value of MSW.

Heat Value (MJ/kg)	Electricity Income (US$/Ton)	Heat Income (US$/Ton)	CHP Income (US$/Ton)
6	20	20	28
7	24	23	33
8	27	27	37
9	31	30	42
10	34	33	47

The MSW management fee is included between 0.2% and 0.4% of GDP for each country. The cost of burning is estimated at around 100 US$ per ton of MSW. The associated overall expenses of WTE is also estimated in different countries at a rate of GDP between 300 and 3,000 $ per ton of MSW [110]. However, the cost of constructing a new WTE power plant in Europe is about 58.6 US$/PJ; the cost of O&M is 7% of the investment [40]. By considering figures 5 and 6 for Tehran, it can be noted that due to the low cost of natural gas in Iran, WTE will have more pollution and higher costs compared to natural gas but considering the environmental aspects of waste management, using this method is justifiable. By comparing the CO_2 generated by WTE, natural gas and oil, it can be seen that WTE has a CO_2 emission rate of 0.69 kg/kWh, while for oil and natural gas, it is 0.821 kg/kWh and 0.502 kg/kWh, respectively, indicating that the order of WTE is among these two energy sources. On the other hand, by examining the cost of producing 1 MWh of electricity, it is clear that the cost of WTE is 113 US$, while it is priced at 66 US$ for natural gas.

According to the Tehran municipality report, the consumption of natural gas in Tehran is about 30,000 million cubics per year. On the other hand, 77.2% of the amount of electricity produced in Tehran is based on natural gas, which represents a significant share of natural gas in electricity generation and consumption in Tehran [71]. Today's efforts are aimed at directing the complete recycling of the end hexadecimal by extraction of metals and the upgrading of the remaining fractions as building materials.

In modern countries, the amount of available waste is about 5% of energy demand. The effective operation of this energy can reduce the demand for other energy carriers such as fossil fuels.

5. Conclusion

In Iran, with an increasing population in metropolises, producing MSW and demand for energy are increasing. WTE is a cheap and desirable way to manage MSW. With increase in investments in this sector and the government's focus on the guaranteed purchasing of electricity by private investors at a price of 0.2 $ per kilowatt in a 20-year contract, it is necessary to spread the WTE power plants all over Iran. Manufacturing the new WTE power plants in Iran, it would be possible to prevent the burning of about 15 million barrels of oil or 255×107 cubic meters of natural gas annually and use these fossil fuels to produce petrochemicals and export them. Therefore, in Iran's internal energy market, about 7140 million US$ in natural gas consumption is saved. WTE has a CO_2 emission rate of 0.69 kg/kWh, while for oil and natural gas, it is 0.821 kg/kWh and 0.502 kg/kWh, respectively, indicating that the order of WTE is among these two energy sources. Also the cost of producing 1 MWh of electricity by WTE is 113 US$, while by natural gas, it is at 66 US$. However, the consumption of natural gas in Tehran is about 30,000 million cubics per year. In addition, 77.2% of the amount of electricity produced in Tehran is by natural gas, which represents a high impact of natural gas in electricity generation in Tehran. LHV of natural gas in Iran is about 5.88×10^{-3} BOE (barrel of oil equivalent) and LHV of crude oil is about 42 MJ/kg. By considering the heating value of MSW, investigation of the MSW potential instead of oil or natural gas in the energy market has been done. The main points of review of WTE facilities in Iran and the capital of Iran (Tehran) are as follow:

- The production of MSW in Tehran is increasing day by day as a result of an increase in population, and has an average of 6650 t/d in 2014.
- By using this amount of MSW in WTE industries, instead of burying them in the landfill sites can prevent burning 113×10^4 cubic meters of natural gas daily for Tehran.
- Based on the Tehran waste management organization, about 46% of the MSW collects from the districts by higher LHV that cause a suitable situation for constructing WTE units near these districts.
- The cost of burning is estimated at around 100 US$ per ton of MSW. The associated overall expenses of WTE is also estimated in different countries at a rate of GDP between 300 and 3,000 $ per ton of MSW
- WTE facilities for waste management are used within 3 regions of 22 metropolitan areas in Tehran and serve 950000 inhabitants.
- Increasing government support will increase the interest and increase the produced power of MSW.
- By incinerating this amount of MSW, it produces about 1500 tons per day of bottom ash, which has a good potential to be used as the construction materials, transport infrastructure and miscellaneous. Reuse of the bottom ash in other industries will increase the profitability of the WTE industry.

Nomenclature

LHV	Lower heating value (kJ/kg)
HHV	Higher heating value (kJ/kg)
MSW	Municipal solid waste
WTE	Waste-to-energy

References

[1] A. J. Chandler et al., Municipal solid waste incinerator residues, Vol. 67. Elsevier, 1997.

[2] L. Branchini, Waste-to-energy: advanced cycles and new design concepts for efficient power plants. Springer, 2015.

[3] A. Nabavi-pelesaraei, R. Bayat, and H. Hosseinzadeh-bandbafha, "Modeling of energy consumption and environmental life cycle assessment for incineration and land fi ll systems of municipal solid waste management-A case study in Tehran Metropolis of Iran," J. Clean. Prod., Vol. 148, pp. 427–440, 2017.

[4] A. Nabavi-pelesaraei, R. Bayat, and H. Hosseinzadeh-bandbafha, "Prognostication of energy use and environmental impacts for recycle system of municipal solid waste management," J. Clean. Prod., Vol. 154, pp. 602–613, 2017.

[5] K. Perkins, A. Vincent, F. White, S. Vernon-Gerstenfeld, I. Bar-On, and I. E. R. González, "Evaluation and solid waste management plan for El Cuerpo de Bomberos." Worcester, MA: Worcester Polytechnic Institute, 2008.

[6] E. Kuznetsova, M. Cardin, M. Diao, and S. Zhang, "Integrated decision-support methodology for combined centralized- decentralized waste-to-energy management systems design," Renew. Sustain. Energy Rev., Vol. 103, no. January, pp. 477–500, 2019.

[7] M. Touš, M. Pavlas, O. Putna, P. Stehlík, and L. Crha, "Combined heat and power production planning in a waste-to-energy plant on a short-term basis," Energy, vol. 90, pp. 137–147, 2015.

[8] A. Mirdar, S. Mansour, B. Karimi, and C. Lee, "Multi-period sustainable and integrated recycling network for municipal solid waste A case study in Tehran," J. Clean. Prod., Vol. 151, pp. 96–108, 2017.

[9] P. H. Brunner and H. Rechberger, "Waste to energy - key element for sustainable waste management," Waste Manag., Vol. 37, pp. 3–12, 2015.

[10] A. Heidari, A. Hajinezhad, and A. Aslani, "A Sustainable Power Supply System , Iran ' s Opportunities via Bioenergy," 2018.

[11] P. H. Brunner and H. Rechberger, "Waste to energy–key element for sustainable waste management," Waste Manag., Vol. 37, pp. 3–12, 2015.

[12] X. Li, "Recycling and reuse of waste concrete in China: Part I. Material behaviour of recycled aggregate concrete," Resour. Conserv. Recycl., Vol. 53, No. 1, pp. 36–44, 2008.

[13] B. Wens, R. Gillner, K. Hornsby, and T. Pretz, "Environmental Impacts of NF-Metal Recycling–MSW as a Resource "," in ISWA World Congress, 2010.

[14] U. Arena, "Process and technological aspects of municipal solid waste gasification. A review," Waste Manag., Vol. 32, No. 4, pp. 625–639, 2012.

[15] U. Arena, "From waste-to-energy to waste-to-resources: the new role of thermal treatments of solid waste in the Recycling Society," Waste Manag., Vol. 37, pp. 1–3, 2015.

[16] M. Pourali, "Application of plasma gasification technology in waste to energy-challenges and opportunities," IEEE Trans. Sustain. Energy, Vol. 1, No. 3, pp. 125–130, 2010.

[17] M. Shaygan, M. A. Ehyaei, A. Ahmadi, M. E. H. Assad, and J. L. Silveira, "Energy, exergy, advanced exergy and economic analyses of hybrid polymer electrolyte membrane (PEM) fuel cell and photovoltaic cells to produce hydrogen and electricity," J. Clean. Prod., Vol. 234, pp. 1082–1093, 2019.

[18] S. T. Tan, C. T. Lee, H. Hashim, W. S. Ho, and J. S. Lim, "Optimal process network for municipal solid waste management in Iskandar Malaysia," J. Clean. Prod., Vol. 71, pp. 48–58, 2014.

[19] "IEA," 2010.

[20] "Swedish Waste Management," 2018. [Online]. Available: https://www.avfallsverige.se/fileadmin/user_upload/Publikationer/Avfallshantering_2017_eng_low.pdf.

[21] F. Habibi, E. Asadi, S. J. Sadjadi, and F. Barzinpour, "A multi-objective robust optimization model for site-selection and capacity allocation of municipal solid waste facilities : A case study in Tehran," J. Clean. Prod., Vol. 166, pp. 816–834, 2017.

[22] J. Jara-Samaniego et al., "Composting as sustainable strategy for municipal solid waste management in the Chimborazo Region, Ecuador: Suitability of the obtained composts for seedling production," J. Clean. Prod., Vol. 141, pp. 1349–1358, 2017.

[23] D. A. Turner, I. D. Williams, and S. Kemp, "Combined material flow analysis and life cycle assessment as a support tool for solid waste management decision making," J. Clean. Prod., Vol. 129, pp. 234–248, 2016.

[24] R. Heidari, R. Yazdanparast, and A. Jabbarzadeh, "Sustainable design of a municipal solid waste management system considering waste separators : A real-world application," Sustain. Cities Soc., Vol. 47, No. February, p. 101457, 2019.

[25] M. A. Edalatpour, S. M. J. M. Al-e-hashem, B. Karimi, and B. Bahli, "Investigation on a novel sustainable model for waste management in megacities :

A case study in tehran municipality," Sustain. Cities Soc., Vol. 36, No. May 2017, pp. 286–301, 2018.

[26] S. Azami, M. Taheri, O. Pourali, and F. Torabi, "Energy and exergy analyses of a mass-fired boiler for a proposed waste-to-energy power plant in Tehran," Appl. Therm. Eng., Vol. 140, pp. 520–530, 2018.

[27] P. Nojedehi, M. Heidari, A. Ataei, M. Nedaei, and E. Kurdestani, "Environmental assessment of energy production from landfill gas plants by using Long-range Energy Alternative Planning (LEAP) and IPCC methane estimation methods: A case study of Tehran," Sustain. Energy Technol. Assessments, Vol. 16, pp. 33–42, 2016.

[28] R. B. Hiremath, B. Kumar, P. Balachandra, and N. H. Ravindranath, "Decentralized sustainable energy planning of Tumkur district, India," Environ. Prog. Sustain. Energy, Vol. 30, No. 2, pp. 248–258, 2011.

[29] B. Amuzu-Sefordzi, J. Huang, D. M. A. Sowa, and T. D. Baddoo, "Biomass-derived hydrogen energy potential in A frica," Environ. Prog. Sustain. Energy, Vol. 35, No. 1, pp. 289–297, 2016.

[30] S. I. Ahmed et al., "Optimal landfill gas utilization for renewable energy production," Environ. Prog. Sustain. Energy, Vol. 34, No. 1, pp. 289–296, 2015.

[31] C. Poma, V. Verda, and S. Consonni, "Design and performance evaluation of a waste-to-energy plant integrated with a combined cycle," Energy, Vol. 35, No. 2, pp. 786–793, 2010.

[32] C. Poma, V. Verda, and S. Consonni, "Design and performance evaluation of a waste-to-energy plant integrated with a combined cycle," Energy, Vol. 35, No. 2, pp. 786–793, 2010.

[33] R. Johri, K. V Rajeshwari, and A. N. Mullick, "Technological options for municipal solid waste management," Wealth from Waste, p. 341, 2011.

[34] S. Tan, H. Hashim, C. Lee, M. R. Taib, and J. Yan, "Economical and environmental impact of waste-to-energy (WTE) alternatives for waste incineration, landfill and anaerobic digestion," Energy procedia, Vol. 61, pp. 704–708, 2014.

[35] C. S. Kirby and J. D. Rimstidt, "Mineralogy and surface properties of municipal solid waste ash," Environ. Sci. Technol., Vol. 27, No. 4, pp. 652–660, 1993.

[36] O. K. M. Ouda, S. A. Raza, A. S. Nizami, M. Rehan, R. Al-Waked, and N. E. Korres, "Waste to energy potential: a case study of Saudi Arabia," Renew. Sustain. Energy Rev., Vol. 61, pp. 328–340, 2016.

[37] A. Björklund and G. Finnveden, "Recycling revisited - Life cycle comparisons of global warming impact and total energy use of waste management strategies," Resour. Conserv. Recycl., Vol. 44, No. 4, pp. 309–317, 2005.

[38] A. R. Ariae, M. Jahangiri, M. H. Fakhr, and A. A. Shamsabadi, "Simulation of Biogas Utilization Effect on The Economic Efficiency and Greenhouse Gas Emission: A Case Study in Isfahan, Iran.," Int. J. Renew. Energy Dev., Vol. 8, No. 2, 2019.

[39] C. Vadenbo, S. Hellweg, and G. Guillén-Gosálbez, "Multi-objective optimization of waste and resource management in industrial networks–Part I: Model description," Resour. Conserv. Recycl., vol. 89, pp. 52–63, 2014.

[40] M. Münster and H. Lund, "Comparing Waste-to-Energy technologies by applying energy system analysis," Waste Manag., Vol. 30, No. 7, pp. 1251–1263, 2010.

[41] M. A. Ehyaei, A. Ahmadi, M. E. H. Assad, and T. Salameh, "Optimization of parabolic through collector (PTC) with multi objective swarm optimization (MOPSO) and energy, exergy and economic analyses," J. Clean. Prod., 2019.

[42] M. A. Ehyaei, A. Ahmadi, M. E. H. Assad, A. A. Hachicha, and Z. Said, "Energy, exergy and economic analyses for the selection of working fluid and metal oxide nanofluids in a parabolic trough collector," Sol. Energy, Vol. 187, pp. 175–184, 2019.

[43] C. Montejo, D. Tonini, M. del Carmen Márquez, and T. F. Astrup, "Mechanical–biological treatment: Performance and potentials. An LCA of 8 MBT plants including waste characterization," J. Environ. Manage., Vol. 128, pp. 661–673, 2013.

[44] A. Ra et al., "The impact of various festivals and events on recycling potential of municipal solid waste in Tehran , Iran," Vol. 183, pp. 77–86, 2018.

[45] M. Rasapoor, M. Adl, and B. Pourazizi, "Comparative evaluation of aeration methods for municipal solid waste composting from the perspective of resource management : A practical case study in Tehran , Iran," J. Environ. Manage., Vol. 184, pp. 528–534, 2016.

[46] N. Ferronato, V. Torretta, M. Ragazzi, and E. C. Rada, "Waste mismanagement in developing countries: A case study of environmental contamination," UPB Sci. Bull, Vol. 79, pp. 185–196, 2017.

[47] R. Chandrappa and D. B. Das, "Materials Recovery and Recycling," in Solid Waste Management, Springer, 2012, pp. 81–115.

[48] M. A. Alanbari, N. Al-Ansari, and H. K. Jasim, "GIS and Multicriteria Decision Analysis for Landfill Site Selection in AL-HashimyahQadaa," Nat. Sci., Vol. 6, No. 5, pp. 282–304, 2014.

[49] S. Kapilan and K. Elangovan, "Potential landfill site selection for solid waste disposal using GIS and multi-criteria decision analysis (MCDA)," J. Cent. South Univ., Vol. 25, No. 3, pp. 570–585, 2018.

[50] H. K. S. Amiri and J. H. A. Karimi, "Integrating GIS and multi - criteria decision analysis for landfill site selection , case study : Javanrood County in Iran," Int. J. Environ. Sci. Technol., No. 0123456789, 2018.

[51] S. Shu, W. Zhu, S. Wang, C. W. W. Ng, Y. Chen, and A. C. F. Chiu, "Leachate breakthrough mechanism and key pollutant indicator of municipal solid waste landfill barrier systems: Centrifuge and numerical modeling approach," Sci. Total Environ., Vol. 612, pp. 1123–1131, 2018.

[52] H. Pasalari, M. Farzadkia, M. Gholami, and M. M. Emamjomeh, "Management of landfill leachate in Iran: valorization, characteristics, and environmental approaches," Environ. Chem. Lett., pp. 1–14, 2018.

[53] Y. Chi, J. Dong, Y. Tang, Q. Huang, and M. Ni, "Life cycle assessment of municipal solid waste source-separated collection and integrated waste management systems in Hangzhou, China," J. Mater. Cycles Waste Manag., Vol. 17, No. 4, pp. 695–706, 2015.

[54] H. Taghipour, M. Alizadeh, R. Dehghanzadeh, M. R. Farshchian, M. Ganbari, and M. Shakerkhatibi, "Performance of on-site Medical waste disinfection equipment in hospitals of Tabriz, Iran," Heal. Promot. Perspect., Vol. 6, No. 4, p. 202, 2016.

[55] Q. Xu, X. Jin, Z. Ma, H. Tao, and J. H. Ko, "Methane production in simulated hybrid bioreactor landfill," Bioresour. Technol., Vol. 168, pp. 92–96, 2014.

[56] R. Cossu, L. Morello, R. Raga, and G. Cerminara, "Biogas production enhancement using semi-aerobic pre-aeration in a hybrid bioreactor landfill," Waste Manag., Vol. 55, pp. 83–92, 2016.

[57] M. Ebrahimi and S. A. Jazayeri, "Effect of hydrogen addition on RCCI combustion of a heavy duty diesel engine fueled with landfill gas and diesel oil," Int. J. Hydrogen Energy, 2019.

[58] D. Hoornweg and P. Bhada-Tata, "What a waste: a global review of solid waste management," 2012.

[59] M. S. Hassanvand, R. Nabizadeh, and M. Heidari, "Municipal solid waste analysis in Iran," Iran. J. Heal. Environ., Vol. 1, No. 1, pp. 9–18, 2008.

[60] M. R. A. Moghadam, N. Mokhtarani, and B. Mokhtarani, "Municipal solid waste management in Rasht City, Iran," Waste Manag., Vol. 29, No. 1, pp. 485–489, 2009.

[61] A. Jamshidi, F. Taghizadeh, and D. Ata, "Sustainable municipal solid waste management (case study: Sarab County, Iran)," Ann. Environ. Sci., Vol. 5, No. 1, p. 7, 2011.

[62] Dashti.B, "Biomass & Bioenergy in Iran, Ministry of Energy, Renewable Energy Organization of IRAN (SUNA), Department of Biomass, Biomass Energy Office Manager, Tehran, February," Dashti, B. (2016). Biomass Bioenergy Iran, Minist. Energy, Renew. Energy Organ. IRAN (SUNA), Dep. Biomass, Biomass Enery Off. Manag. Tehran, February, 2016.

[63] S. E. Hosseini, A. M. Andwari, M. A. Wahid, and G. Bagheri, "A review on green energy potentials in Iran," Renew. Sustain. Energy Rev., Vol. 27, pp. 533–545, 2013.

[64] M. S. Ardebili, B. Ghobadian, G. Najafi, and A. Chegeni, "Biodiesel production potential from edible oil seeds in Iran," Renew. Sustain. Energy Rev., Vol. 15, No. 6, pp. 3041–3044, 2011.

[65] B. Ghobadian, "Liquid biofuels potential and outlook in Iran," Renew. Sustain. Energy Rev., Vol. 16, No. 7, pp. 4379–4384, 2012.

[66] S. Kim and B. E. Dale, "Global potential bioethanol production from wasted crops and crop residues," Biomass and bioenergy, Vol. 26, No. 4, pp. 361–375, 2004.

[67] Agricultural Ministry of Iran., "In:Statisticalbookof2008,vol.1,part 1. Availableat: ⟨http://maj.ir/portal/Home/Default.aspx?CategoryID=20ad5e49- c727-4bc9-9254-de648a5f4d52⟩," 2008.

[68] L. Rafati, M. RahmaniBoldaji, and M. Khodadadi, "Waste to Energy: Challenges and Opportunities in Iran," J Env. Heal. Sustain Dev, Vol. 1, No. 3, pp. 163–172, 2016.

[69] "British Petroleum Statistical Review of World energy," 2013.

[70] M. A. Abduli and E. Azimi, "Municipal waste reduction potential and related strategies in Tehran," Int. J. Environ. Res., Vol. 4, No. 4, pp. 901–912, 2010.

[71] Municipality of Tehran, "Municipality, Center for Studies and Planning of Tehran," 2014.

[72] S. E. Hosseini, A. M. Andwari, M. A. Wahid, and G. Bagheri, "A review on green energy potentials in Iran," Renew. Sustain. Energy Rev., Vol. 27, pp. 533–545, 2013.

[73] IPCC, "Intergovernmental Panel on Climate Change, (IPCC), <www.ipcc.ch>," 2019.

[74] C. S. Psomopoulos, A. Bourka, and N. J. Themelis, "Waste-to-energy: A review of the status and benefits in USA," Waste Manag., Vol. 29, No. 5, pp. 1718–1724, 2009.

[75] M. Mohammadnejad, M. Ghazvini, T. M. I. Mahlia, and A. Andriyana, "A review on energy scenario and sustainable energy in Iran," Renew. Sustain. Energy Rev., Vol. 15, No. 9, pp. 4652–4658, 2011.

[76] A. L. Ahmad, N. H. M. Yasin, C. J. C. Derek, and J. K. Lim, "Microalgae as a sustainable energy source for biodiesel production: a review," Renew. Sustain. Energy Rev., Vol. 15, No. 1, pp. 584–593, 2011.

[77] G. Najafi, B. Ghobadian, and T. F. Yusaf, "Algae as a sustainable energy source for biofuel production in Iran: a case study," Renew. Sustain. Energy Rev., Vol. 15, No. 8, pp. 3870–3876, 2011.

[78] OPEC, "The Organization of the Petroleum Exporting Countries," 2019.

[79] The World Bank, "Municipal Solid Waste Incineration," 2000.

[80] J.Penman et al., "good practice guidance and uncertainty management in national greenhouse gas inventories," 2001.

[81] J. Tang, "A Cost-Benefit Analysis of Waste Incineration with Advanced Bottom Ash Separation Technology for a Chinese Municipality–Guanghan," No. September, p. 79, 2012.

[82] A. Bejan and G. Tsatsaronis, Thermal design and optimization. John Wiley & Sons, 1996.

[83] M. Rodriguez, "Cost-benefit analysis of a waste to energy plant for Montevideo; and waste to energy in small islands," Columbia Univ. 2015 Feb. 27, 2011.

[84] A. Karagiannidis, Waste to energy. Springer, 2012.

[85] M. Bilek, M. Lenzen, C. Hardy, and C. Dey, "Life-cycle energy and greenhouse gas emissions of nuclear power in Australia," Univ. Sydney, Vol. 181, 2006.

[86] U. S. EIA, "Energy Information Administration (2014b),'Annual Energy Outlook 2014 with projections to 2040', p," MT-23, 2016.

[87] H. Hondo, "Life cycle GHG emission analysis of power generation systems: Japanese case," Energy, Vol. 30, No. 11–12, pp. 2042–2056, 2005.

[88] A. Evans, V. Strezov, and T. J. Evans, "Assessment of sustainability indicators for renewable energy technologies," Vol. 13, pp. 1082–1088, 2009.

[89] K. Zoroufchi, B. A. Safaiyan, D. F. F. Khalili, N. M. Shakerkhatibi, and H. H. G. H. Safari, "Municipal solid waste characterization and household waste behaviors in a megacity in the northwest of Iran," Int. J. Environ. Sci. Technol., 2018.

[90] H. Zhou, A. Meng, Y. Long, Q. Li, and Y. Zhang, "An overview of characteristics of municipal solid waste fuel in China: physical, chemical composition and heating value," Renew. Sustain. Energy Rev., Vol. 36, pp. 107–122, 2014.

[91] A. H. Ghorashi and A. Rahimi, "Renewable and non-renewable energy status in Iran: Art of know-how and technology-gaps," Renew. Sustain. Energy Rev., Vol. 15, No. 1, pp. 729–736, 2011.

[92] H. Bakhoda, M. Almassi, N. Moharamnejad, R. Moghaddasi, and M. Azkia, "Energy production trend in Iran and its effect on sustainable development," Renew. Sustain. Energy Rev., Vol. 16, No. 2, pp. 1335–1339, 2012.

[93] M. Heshmatzadeh, "Iran and oil sociology of political sociology of oil in Iran," Tehran Recognit. Cent. Islam Iran's, 2000.

[94] "Renewable Energy and Energy Efficiency Organization of the Ministry of Energy," 2017. [Online]. Available: http://www.satba.gov.ir/en/home.

[95] C. D. Cooper, B. Kim, and J. MacDonald, "Estimating the lower heating values of hazardous and solid wastes," J. Air Waste Manage. Assoc., Vol. 49, No. 4, pp. 471–476, 1999.

[96] L. Meraz, M. Oropeza, and A. Dominguez, "Prediction of the combustion enthalpy of municipal solid waste," Chem. Educ., Vol. 7, No. 2, pp. 66–70, 2002.

[97] A. Licata, M. Babu, and W. Carlson, "The application of activated carbon enhanced lime for controlling acid gases, mercury, and dioxins from MWCS," Prepr. Pap. Am. Chem. Soc. Div. Fuel Chem., Vol. 41, No. CONF-960376, 1996.

[98] S. Azami, M. Taheri, O. Pourali, and F. Torabi, "Energy and exergy analyses of a mass-fired boiler for a proposed waste-to-energy power plant in Tehran," Appl. Therm. Eng., Vol. 140, pp. 520–530, 2018.

[99] T. Rand, J. Haukohl, and U. Marxen, Municipal solid waste incineration: requirements for a successful project, Vol. 462. World Bank Publications, 2000.

[100] C. Ferreira, A. Ribeiro, and L. Ottosen, "Possible applications for municipal solid waste fly ash," J. Hazard. Mater., Vol. 96, No. 2–3, pp. 201–216, 2003.

[101] T. Mangialardi, A. E. Paolini, A. Polettini, and P. Sirini, "Optimization of the solidification/stabilization process of MSW fly ash in cementitious matrices," J. Hazard. Mater., Vol. 70, No. 1–2, pp. 53–70, 1999.

[102] X.-G. Li, Y. Lv, B.-G. Ma, Q.-B. Chen, X.-B. Yin, and S.-W. Jian, "Utilization of municipal solid waste incineration bottom ash in blended cement," J. Clean. Prod., Vol. 32, pp. 96–100, 2012.

[103] J. Pera, L. Coutaz, J. Ambroise, and M. Chababbet, "Use of incinerator bottom ash in concrete," Cem. Concr. Res., Vol. 27, No. 1, pp. 1–5, 1997.

[104] H.-K. Kim and H.-K. Lee, "Use of power plant bottom ash as fine and coarse aggregates in high-strength concrete," Constr. Build. Mater., Vol. 25, No. 2, pp. 1115–1122, 2011.

[105] G. Mitterbauer, S. Skutan, and H. Rechberger, "Charakterisierung der Rostasche der MVA Dürnrohr im Hinblick auf die Rückgewinnung von Metallen (Projekt ChaRo)," Bericht für AVN–Abfallverwertung Niederösterreich Ges. mbH, Österreich, S, Vol. 151, 2009.

[106] H. Rechberger, "WTE: Decreasing the Entropy of Solid Wastes and Increasing Metal Recovery," Recover. Mater. Energy from Urban Wastes A Vol. Encycl. Sustain. Sci. Technol. Second Ed., pp. 183–196, 2019.

[107] S. Skutan and H. Rechberger, "Bestimmung von Stoffbilanzen und Transferkoeffizienten für die Linie II der MVA Wels. Final Report," Inst. Water Qual. Resour. Waste Manag. Vienna Univ. Technol., 2007.

[108] TWMO, "Statistics Report on 2013. Tehran Waste Management Organization, Tehran Municipality, Iran," 2014.

[109] N. B. Klinghoffer, N. J. Themelis, and M. J. Castaldi, “Waste to energy (WTE): an introduction,” in Waste to Energy Conversion Technology, Elsevier, 2013, pp. 3–14.

[110] P. H. Brunner and J. Fellner, “Setting priorities for waste management strategies in developing countries,” Waste Manag. Res., Vol. 25, No. 3, pp. 234–240, 2007.