A study on generating bioelectricity from urban waste, a case study of Golestan, Iran

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Abstract: The increasing use of various products and the rise of population and urbanization in the world have led to a significant increase in waste streams, such as environmental pollution, bio waste, and especially greenhouse gas emissions. Therefore, it is important to manage these biowastes effectively. One way to do this is to apply sustainable material management strategies. This study examines the municipal solid waste strategies in detail. The economic analysis was done to estimate the amount of bio-based electricity that can be obtained from municipal solid waste according to the situation of Iran, using the data collected. This study is based on fourteen different cities with different population sizes and growth rates and using the reference amount of municipal solid waste production in the cities of Golestan province. The results show that the population growth has caused an increase in the amount of municipal solid waste. Also, by comparing the average theoretical potential of electricity generation and the average amount of total fossil-based electricity consumption in the Golestan province, it was found that electricity generation from municipal solid waste could cover up to about 8% of the electricity demand in Golestan province. The results also indicate that the population size has a very strong effect on the increase of the studied values, and its changes have a very significant effect on the return on investment through the production of electricity.

Keywords: greenhouse gases, municipal solid waste, electricity generation, population

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1 Introduction

The declining access to fossil fuel sources, along with the increasing use of them in various sectors, has raised many concerns about both global warming and greenhouse gas emissions. Incineration of fossil fuels has also increased CO_2 levels to more than 409 ppm (Tausz-Posch and De Kok 2020; Zhang et al., 2020). Increasing the level of this gas helps to increase the temperature of the earth (Mishra et al., 2019). Due to the increase in energy consumption and limited sources of non-renewable energy sources i.e., oil/gas, all countries in the world are facing the problem of energy supply (Alola et al., 2019). To reduce the above-mentioned emissions, the development of renewable energy is an important part of global energy policy (Azadbakht et al., 2021). Organic wastes e.g., agricultural wastes, municipal sewage sludge, industrial

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wastes, solid wastes, and poultry wastes, fertilizers, can be used for renewable fuels (Dhanya et al., 2020).

In extracting bioenergy from biowaste, several technologies and processes such as degassing, liquefaction, heat decomposition, alcoholic fermentation, photobiological hydrogen production, anaerobic digestion, along with sterilization/microbial photosynthesis of fuel cells are commonly utilized. These technologies lead to the reuse of biobased materials (Lee et al., 2019).

In recent years, due to population growth and increasing urbanization, environmental issues related to the conversion of waste to energy and also value-added products have become essential (Haile, 2014; Sharma et al., 2014; Odetoye et al., 2014). These environmental problems have different aspects. Among these aspects, municipal solid waste (MSW) has become a controversial challenge worldwide (Leme et al., 2014). However, the definition of MSW varies from country to country. But it mainly includes household waste, garden waste/parks/waste and commercial/organizational waste (Rajaeifar et al., 2015). Accordingly, MSW is significantly influenced by consumption habits and patterns affecting societal developments and includes a wide range of substances (Vassanadumrongdee and Kittipongvises, 2018; Kiran et al., 2014). For example, in 2012, around 1.3 milliard tonnes of MSW were produced worldwide, and this is expected to reach about 2.2 milliard tonnes by 2025 (Rajaeifar et al., 2017). This is actually attributed to the resources or energy required at different stages of the life cycle of these goods (Rajaeifar et al., 2015).

In addition, because municipal activities carry the largest amount of waste worldwide (Leme et al., 2014), there are many guidelines and rules to address this growing challenge. Guidelines of the European Parliament (2008/98/EC) and the Council of 19 November 2008 on waste, including the best available reference techniques (BAT), are examples of these rules (Fernández-Nava et al., 2014).

By recycling a certain amount of a given substance, the associated environmental emissions can be prevented. However, the use of efficient recycling systems is essential to maximize both the economic and environmental benefits of recycling (USEPA, 2019). Considering the above-mentioned issues, recycling can bring many benefits, including preventing the emission of large amounts of greenhouse gases and water pollutants, saving energy, further developing green technologies, and providing valuable raw materials for Industry should create jobs, save resources in order to preserve them for future generations and increase the need for new landfills and incinerators (USEPA, 2016; 2019).

Due to the adverse effects of landfill gases and landfill leachates (Jovanov et al., 2018), compost has recently become one of the landfill options due to its recyclable nature. Compost refers to the process of decomposition of residual organic matter. In addition, MSW compost could be used as a soil softener in agriculture and horticulture to restore carbon/nitrogen/phosphorus and other soil elements. However, heavy metals can limit the reuse of compost sludge for agricultural purposes (Wei et al., 2017). Although several processes are used in the combustion process to remove dioxins and heavy metals, such as the use of fabric filters, activated carbon powder injection systems, and scrubbers, the complete removal of these materials is difficult. In recent years, the advantages of the above therapies over their shortcomings have been discussed (Stamou and Antizar-Ladislao, 2016).

The purpose of this study is to discuss comprehensively MSW generation in Iran, Golestan province. Also, the different waste treatment options for the purpose of bioelectricity production from MSW are investigated. The potentials of green electricity generation from the MSW using different technologies like AD, pyrolysis, also combustion is fully discussed. Besides, information from Golestan province was used as a case study to facilitate the understanding of the potential effects of these strategies. Finally, the potentials of bioelectricity production from those renewables materials were estimated.

2 MSW production in Asia

With 48 countries and more than 4.2 milliard people living (in 2012), Asia is the largest (about 30% of the Earth's surface) and most populous continent. (Kaneda et al., 2015). The average per capita MSW in East Asia was 0.52 kg/person/day (Hoornweg and Bhada-Tata, 2012; Kawai and Tasaki, 2016). About 70% of the waste generated in Asia is done by China. South Asian countries produce approximately 70 million tonnes of MSW per year at an average per capita of 0.45 kg/person/day. In the Middle East and North Africa, the MSW is produced per year at ~63 million tonnes with an average of 1.1 kg/person/day per capita. Figure 1 shows the per capita production of MSW in different parts of Asia (Hoornweg and Bhada-Tata, 2012).

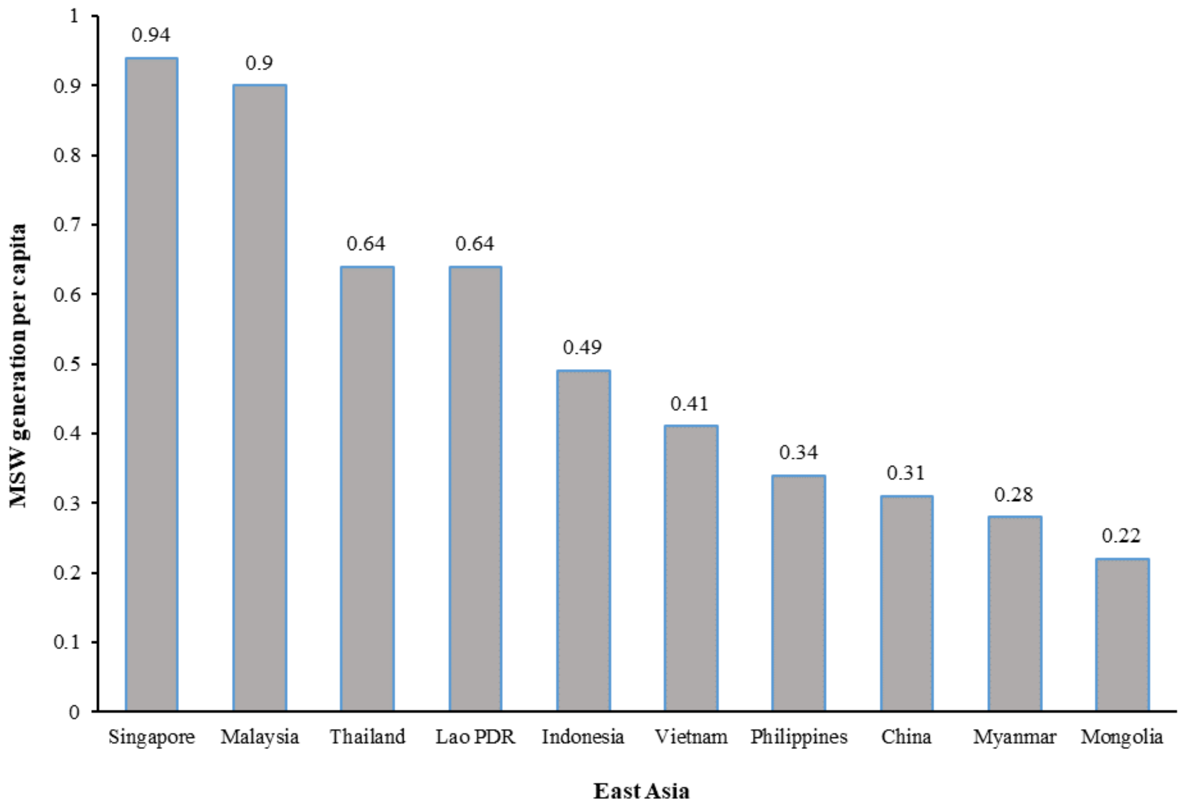

Figure 1 MSW per capita production in different regions of Asia (kg/person/day) (Rajaeifar et al., 2017)

3 MSW production in Iran

Iran, as the third-largest economy in the Middle East country, is one of the developing countries in the world. Iran is facing many environmental problems due to industrialization and increasing urbanization. Figure 2 shows the population (in millions), total production of MSW (in million tons), and per capita production of MSW (kg/person/day) in Iran in 2002, 2007, and 2014. According to Figure 2, in 2014, about 55 million Iranians living in urban areas of the country produced more than 15 million tons of MSW, which was an increase of 50% compared to 2002. Considering the growth of more than 25.1% in the urban population compared to 2002, we saw a significant increase of 50.0% in the amount of MSW. However, it should be noted that in 2007, MSW production peaked at 16 million tons of waste and was 54% and 2.3% higher than in 2002 and 2014, respectively. During the last decade, such fluctuations in MSW production may indicate that disposal of MSW in Iran has not been entirely affected by municipal waste management policies and has not been applied due to inefficiency and weakness in their implementation and has been mainly influenced by other factors such as population growth rate (Rajaeifar et al., 2017).

As can be seen in Table 1, the latest available data on urban population, MSW production (tons/day), MSW production per capita (kg/person/day), and the share of each city in the urban population of Iran (%) and the share of each city in MSW production for all provinces of Iran is shown in relation to the total amount of MSW.

Table 1 The population, MSW production (tons/day), MSW per capita production (kg/person/day), and MSW production in Iran (Rajaeifar et al., 2017)

Province	MSW (tons/day)	MSW generation per capita (kg/person/day)	Urban population (%)	MSW generation (%)
Ardabil	695	0.833	1.49	1.62
Alborz	1747	0.770	4.07	4.07
Bushehr	676	0.911	1.31	1.58
Chaharmahal and bakhtiari	424	0.783	0.97	0.99
East Azerbaijan	2066	0.783	4.81	4.82
Esfahan	3674	0.862	7.77	8.57
Fars	2473	0.752	5.79	5.77
Golestan	661	0.694	1.69	1.54
Guilan	1247	0.808	2.79	2.91
Hamadan	967	0.916	1.94	2.25
Hormozgan	661	0.796	1.47	1.54
Ilam	276	0.748	0.67	0.64
Kohgiluyeh and Boyer-Ahmad	186	0.507	0.65	0.43
Kerman	1263	0.715	3.15	2.95
Kermanshah	998	0.722	2.53	2.33
Khuzestan	2411	0.720	6.00	5.62
Kurdistan	819	0.804	1.84	1.91
Lorestan	679	0.618	2.01	1.58
Markazi	798	0.734	1.95	1.86
Mazandaran	1429	0.830	3.14	3.33
North Khorasan	344	0.742	0.83	0.80
Qazvin	705	0.770	1.64	1.64
Qom	691	0.608	2.04	1.61
Razavi Khorasan	3344	0.744	8.04	7.80
Semnan	376	0.745	0.91	0.88
Sistan and Baluchestan	749	0.562	2.32	1.75
South Khorasan	309	0.711	0.69	0.72
Tehran	9713	0.840	21.07	22.65
West Azerbaijan	1565	0.783	3.60	3.65
Yazd	444	0.501	1.66	1.04
Zanjan	493	0.745	1.18	1.15

According to a report provided by the Iranian Renewable Energy Organization (SUNA), the average waste generation in the country was ~ 0.751 kg/person/day. Besides, landfilling is the primary waste treatment strategy in the whole country. The increasing trend was observed, which was from 8.5 million tons in 2002 to 11.1 Million tons increased. Besides, no landfill in Iran (excluding neighborhoods in the metropolitan areas of Mashhad and Shiraz) has met the environmental standards required for leachate recycling and LFG and has created adverse ecological loads in the above-mentioned cities.

4 Golestan province information background

Golestan province is in the north of Iran. This province was a part of Mazandaran province in ancient times, which in 1998 became an independent province called Golestan and Gorgan was chosen as its center. Gorgan is the largest and most populous city. It is in the geographical range of 54 degrees to 56 degrees east longitude and 36.30 to 38.15 north latitude and is located between the provinces of Mazandaran, Semnan and North Khorasan. Golestan is adjacent to Turkmenistan and has 348 km of land border and 90 km of water border with this country. This province has a diverse climate due to its special geographical location (Zakerhaghighi et al., 2016; Kooch et al., 2023).

5 MSW production in province of Golestan and its characteristics

The amount of MSW production trend in Golestan province and its average production in all cities of Golestan province are shown in Figures 2 and 3. According to Figure 2, the total amount of MSW produced in Golestan during 2018 and 2019 was more than 1432 and 1446.5 tons, respectively, and the amount of MSW during this period was 13970 tons.. The results show that the per capita production of MSW in Golestan in 2019 was 1.45 (kg/day). Compared to this amount of MSW per capita production, the per capita production of MSW in China is 1.21 (kg/day) (Fathi et al., 2014) and in Turkey 0.95 (kg/day) (Aslani and Taghipour 2018). Figure 3 shows the average share of each city in Golestan province in MSW production.

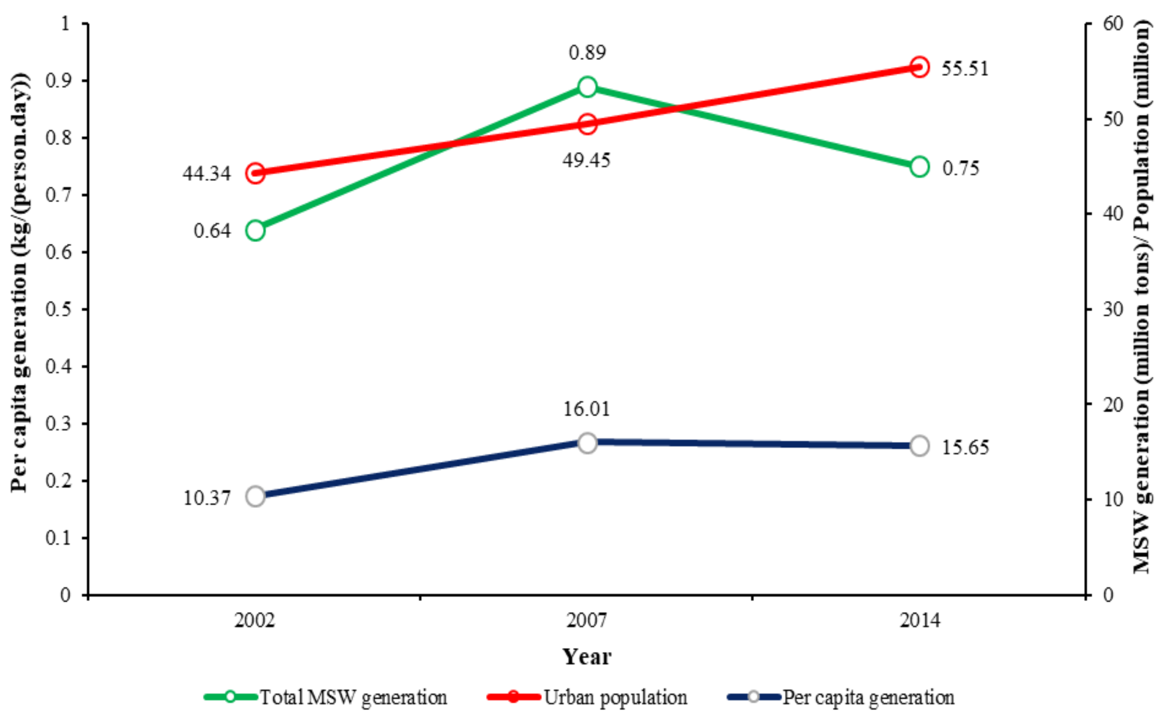

Figure 2 Population (in million), total production of MSW (in million tons) and per capita production of MSW (kg/person/day) in Iran (Rajaeifar et al., 2017)

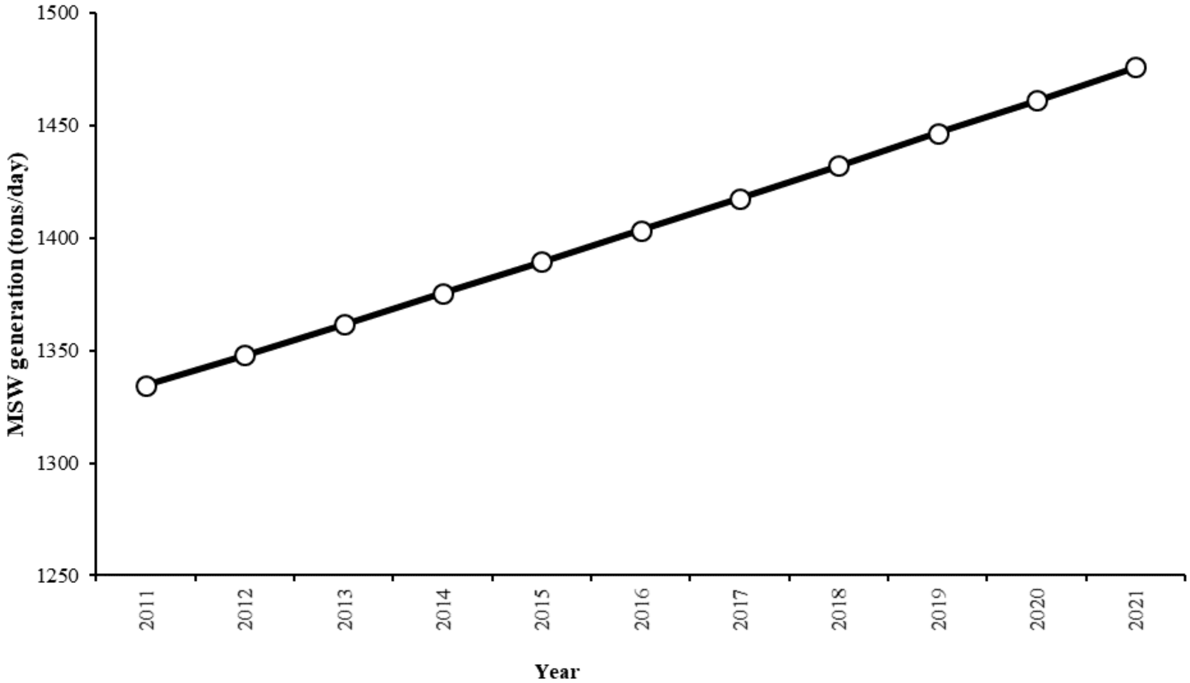

Figure 3 Total production of MSW in Golestan province from 2011 to 2021

According to Figure 4, Gorgan has the highest and Bandar-e-Gaz has the lowest MSW production in Golestan province. Gorgan is the most populous city in Golestan province and by nature has 24.77% of the total amount of MSW produced in the province and has a difference of 6.78% with the second city, Gonbad-Qaboos.

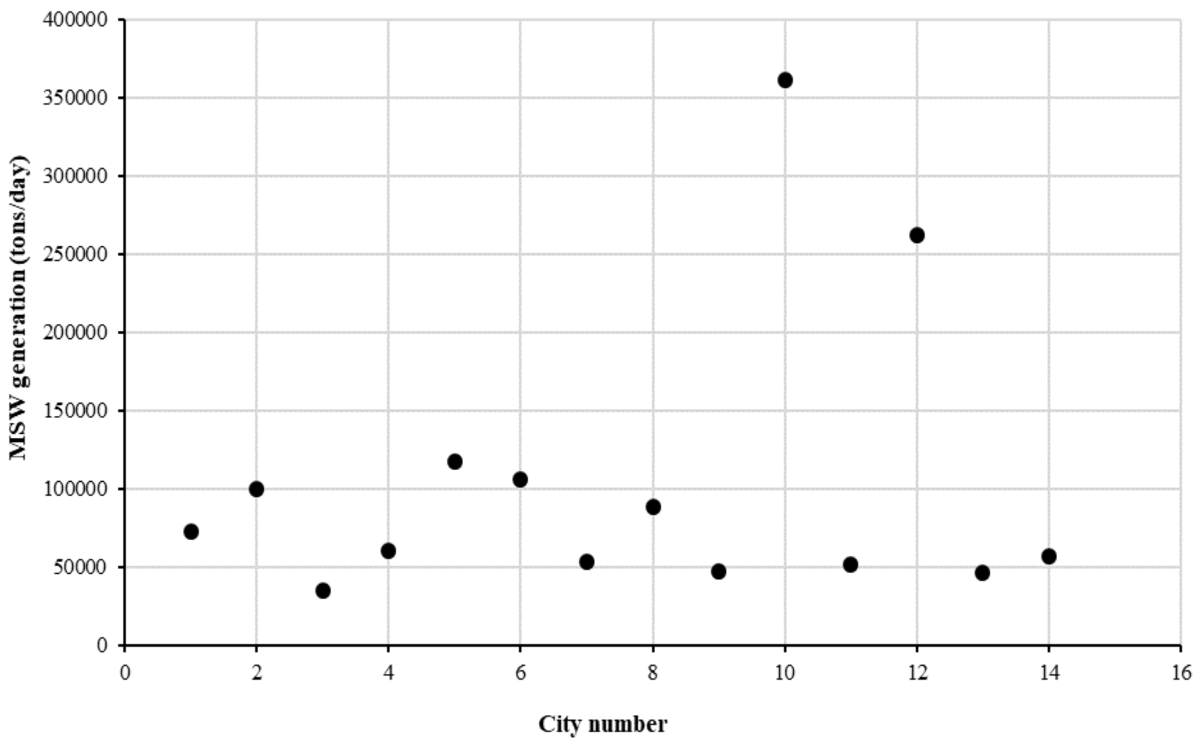

Figure 4 Average share of each city of Golestan province in MSW production (ton/day)

Table 2 also shows the amount of MSW production in different years by city. According to Table 2 and reviewing the last 5 years, the highest amount of MSW production is related to the three cities of Gorgan, Gonbad-Qaboos and Aliabad, respectively.

Table 2 The amount of MSW production(tons/day) for each city of Golestan province

		Year										
City number	City	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1	Azadshahr	68917.017	69657.5	70405.5	71161.8	71926.3	72699.1	73480.1	74269.4	75067	75873.5	76688.4
2	Aqqala	93262.935	94512.6	95779.5	97063	98364.5	99682.5	101019	102373	103745	105135	106544
3	Bandar-e Gaz	34782.565	34754.8	34727	34699.2	34671.4	34643.6	34615.8	34588.1	34560.3	34533.2	34505.4
4	Torkaman	54675.053	55712.9	56769.6	57847.3	58945.2	60063.5	61203.5	62364.5	63548.1	64754.2	65982.9
5	Ramian	64078.324	64210.5	64343.4	64477.1	645884	64743.7	64877.4	65011.8	65146.2	65280.7	65415.9
6	Aliabad	99700.507	100868	102047	103242	104450	105672	106909	108161	109426	110706	112002
7	Kordkuy	52753.244	52906.4	53060.4	53214.4	53369.1	53523.8	53679.2	53835.4	53991.6	54148.6	54305.6
8	Kalaleh	82965.223	83968.6	84984.7	86012.8	87053.7	88106.6	89172.2	90251.4	91343.4	92448.1	93566.3
9	Galikash	45041.225	45511.4	45986.7	46467.4	46952.5	47442.9	47938.6	48438.7	48944.9	49456.4	49973
10	Gorgan	347303.71	349979	352674	355390	358128	360886	363666	366467	369289	372134	375000
11	Gomishan	47648.697	48423	49210	50009.8	50822.4	51648.5	52488.1	53341.3	54207.9	55088.9	55984
12	Gonbad-e Qabus	244667.54	248022	251423	254870	258364	261907	265498	269138	272828	276569	280360
13	Maraveh Tappeh	41921.571	42665.8	43422.8	44193.3	44977.4	45775.7	46588.3	47415.1	48256.3	49112.4	49984.3
14	Minudasht	56819.909	56793.6	56767.3	56740.3	56714	56687.7	56661.4	56635.2	56608.9	56581.8	56555.6
	Golestan	1334537.5	1347986	1361601	1375389	1970622	1403483	1417796	1432289	1446962	1461822	1476867

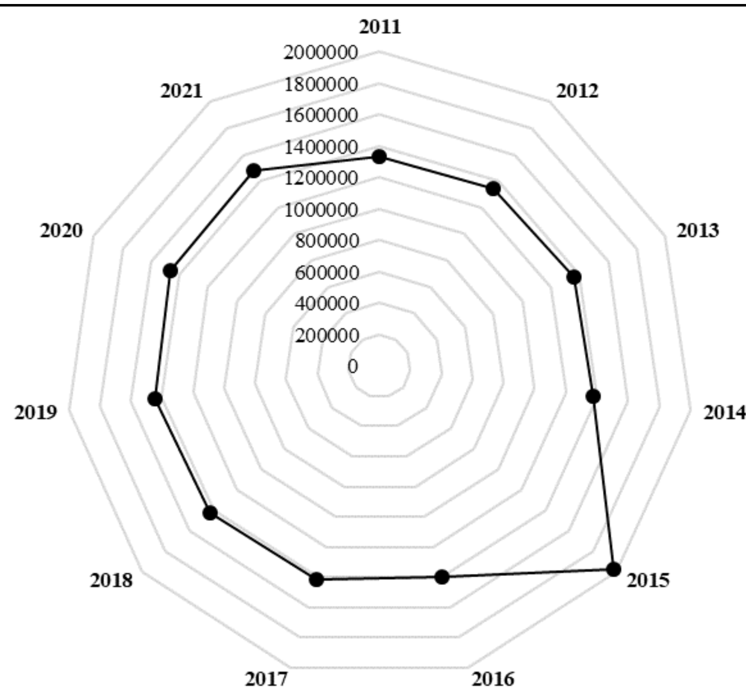

Figure 5 The amount of MSW production (tons/day) for the cities of Golestan province by year

There are many types of MSW in Golestan: Solid waste generated by homes and centers such as restaurants; medical centers and industrial centers .

Figure 5 shows the different values of MSW for different cities of Golestan province by different years. As shown in Figure 5, it is clear that the amount of MSW produced in 2015 reached its peak. Also, the amount of MSW in the study years fluctuated in a relatively constant range and did not exceed the average of 1.5 million (tons/day). In 2015, MSW production reached nearly 2 million (tons/day). Because the population of each city affects the amount of MSW generated., this significant increase could be due to the sudden increase in population of Ramyan in 2015.

In order to evaluate the capacity to generate electricity from MSW, it was necessary to separate the components of MSW. For this purpose, according to Figure 6, the various components of MSW in Golestan Province include organic matter, plastics, polyethylene terephthalate (PET), glass, fabric and ferrous metals. Of the total amount of MSW, about 1261 tons were related to organic matter and 19 tons were related to polyethylene terephthalate. Then, in order to perform calculations related to electricity generation capacity measurement, the data of organic matter section in MSW were used. This section includes 65% of the total amount of MSW produced in the last 9 years in Golestan province.

6 Components of MSW

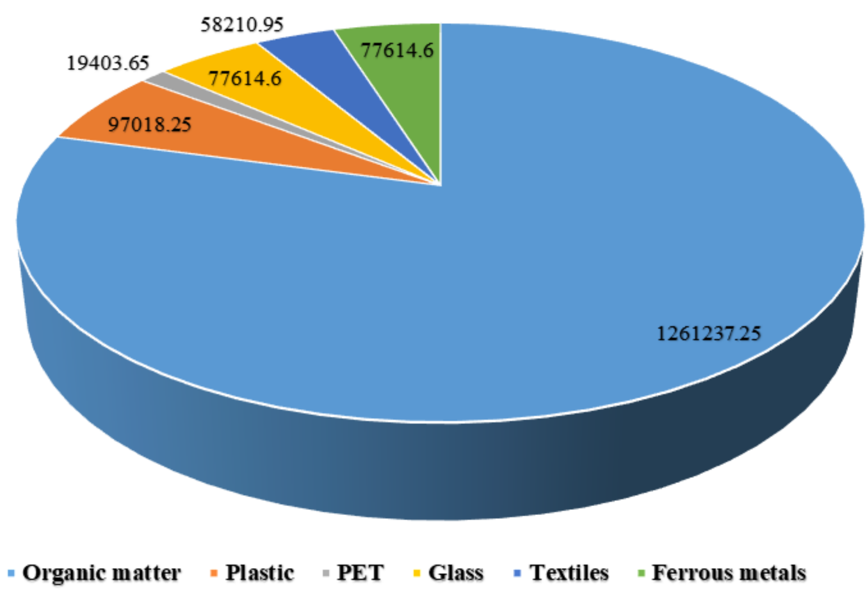

Figure 6 Types of waste produced from MSW (kg/year) for all cities of Golestan province

7 Possibility of generating electricity from MSW ($P_{theoritical}$)

$P_{theoritical}$ is the maximum power generation capacity of an MSW proprietary waste treatment technology.According to this theory, the electricity generated by MSW is the energy received from mixed organic and combustible MSW compounds. Figure 7 shows the block diagram used as $P_{theoritical}$. According to Figure 7, the entire metal and glass part is removed from burning or decomposition by heating-gasification; because they have a negative impact on this process. In the next section, parts of glass and metal that are recyclable are separated and other parts that are non-recyclable are buried.. In addition, in the recycling phase, recyclable parts of PET, plastic, cardboard and paper are separated and other non-recyclable parts are burned or decomposed.. Because the use of energy in the form of heat is highly dependent on spatial properties, only the potential for electricity generation was considered (Rajaeifar et al., 2017).

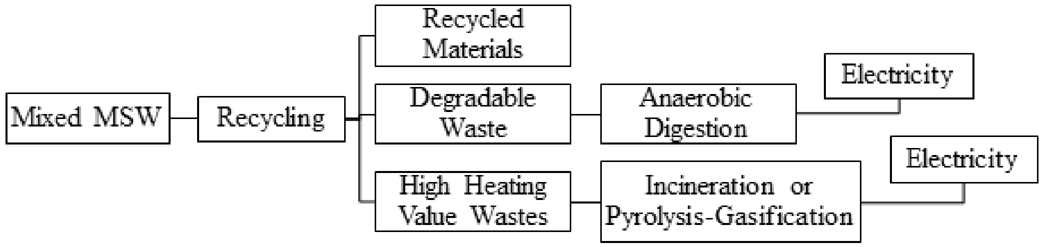

Figure 7 The block diagram used as $P_{theoritical}$

$P_{theoritical}$ in electricity generation from MSW consists of two main parts as shown in Equation 1:

$$P_{theoretical}(MW)=P_{degradable}+P_{dry} \quad (1)$$

Where, $P_{degradable}$ is the potential for degradable fraction (MW); and is high heat potential part (MW), which means dry part with the exception of glass and iron (Rajaeifar et al., 2017).

The degradable fraction potential (or AD theory) was calculated by considering Equation 2 (Rajaeifar et al., 2017).

$$P_{degradable}(MW)=P_{bio}\times150\times0.6\times38000\times1.157\times10^{-8} \quad (2)$$

where, $P_{degradable}$ is the potential for degradable fraction (MW), R_{bio} represents the rate of degradable waste production (tons day^{-1}), 150 is constant rate of biogas production (m^3 ton^{-1}), 0.6 is methane concentration in biogas produced, 38000 High Heat (HHV) methane (kJ m^{-3}) and 1.157×10^{-8} is the constant factor.

The potential fraction with a high heating value for combustion was calculated using Equation 3 (Rajaeifar et al., 2017).

$$P_{dry\text{-}inc(MW)}=R_{HHV}\times HV\times11.57\times10^{-6} \quad (3)$$

where, $P_{dry\text{-}inc}$ is the equation of dry potential with high heating value for incineration (MW), R_{HHV} stands for deduction of high heating waste rate (tons day^{-1}), HV is heating value of MSW (kJ kg^{-1}), and 11.57×10^{-6} is the constant factor of the equation.

The dry potential fraction with high heating value for heating-gasification decomposition was calculated using Equation 4 (Rajaeifar et al., 2017).

$$P_{dry\text{-}pg}(MW)=R_{HHV}\times HV\times15.1\times10^{-6} \quad (4)$$

Where, $P_{dry\text{-}pg}$ is the fraction of dry potential with high heating value for production due to heating-gasification (MW), R_{HHV} indicates the amount of waste production in dry section with high heating value (tons day^{-1}), HV is the heat value of MSW (kJ kg^{-1}), and11.57 $\times10^{-6}$ is a constant factor. Because the efficiency of the power generation systems used is not considered in the calculations, P_theoretical does not represent the actual amount of power generation from MSW. Figure 8 shows the average amount of electricity production in each city of Golestan province. According to the figure, it can be seen that city number 10 (Gorgan city) has the largest share of total electricity production in terms of (MW). The amount of this production is 25% of the whole value of electricity produced. This is while the amount of MSW produced in Gorgan is 24.77% of the total amount of waste. Also, the three large and densely populated cities of Gorgan, Gonbad-Qaboos and Aliabad can produce 50% of the total amount of electricity produced.

8 Comparison of electricity generation from MSW and the amount of municipal electricity consumption

Figure 9 shows the average amount of electricity generation (MW) in the last 9 years in Golestan province. According to the figure, it was observed that 2015 has the potential to generate more electricity than any other year. One of the reasons for this is the increase in the population of cities in Golestan province in 2015, and as a result, the increase in the amount of waste produced per day, per capita..On the other hand, Figure 9 also shows the average amount of electricity consumption (MW) in the last 9 years in Golestan province. The figure shows that the highest amount of electricity consumption is related to 2019. Comparing the information in these two diagrams, it can be seen that the theoretical potential of electricity generation can compensate by 8.02% of the total amount of electricity consumed in the last 9 years in Golestan province.

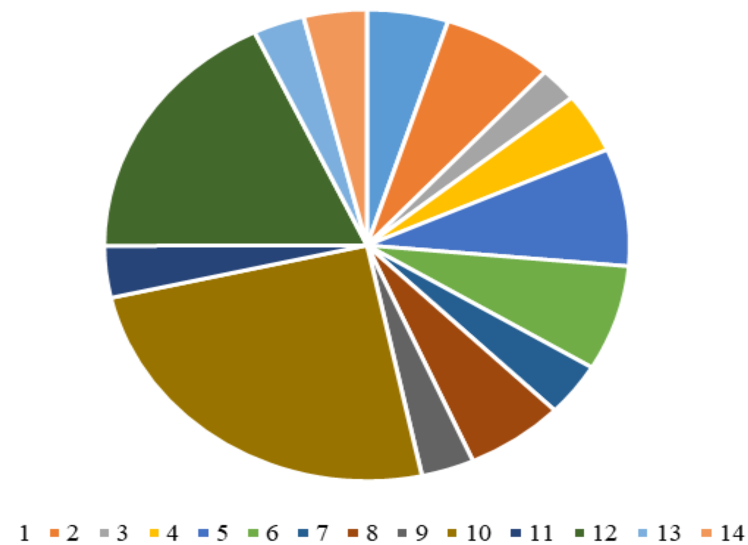

Figure 8 Average amount of electricity production (MW) in each city of Golestan province

Considering the maximum amount of electricity consumption in 2019, it can be seen that the theoretical potential of electricity generation from MSW can reduce the amount of electricity consumption in Golestan province by 4.17%. Also, in the maximum amount of theoretical potential of electricity generation in 2015, it was observed that electricity generation from MSW can reduce the amount of 17.32% of the average amount of electricity consumption in Golestan province.

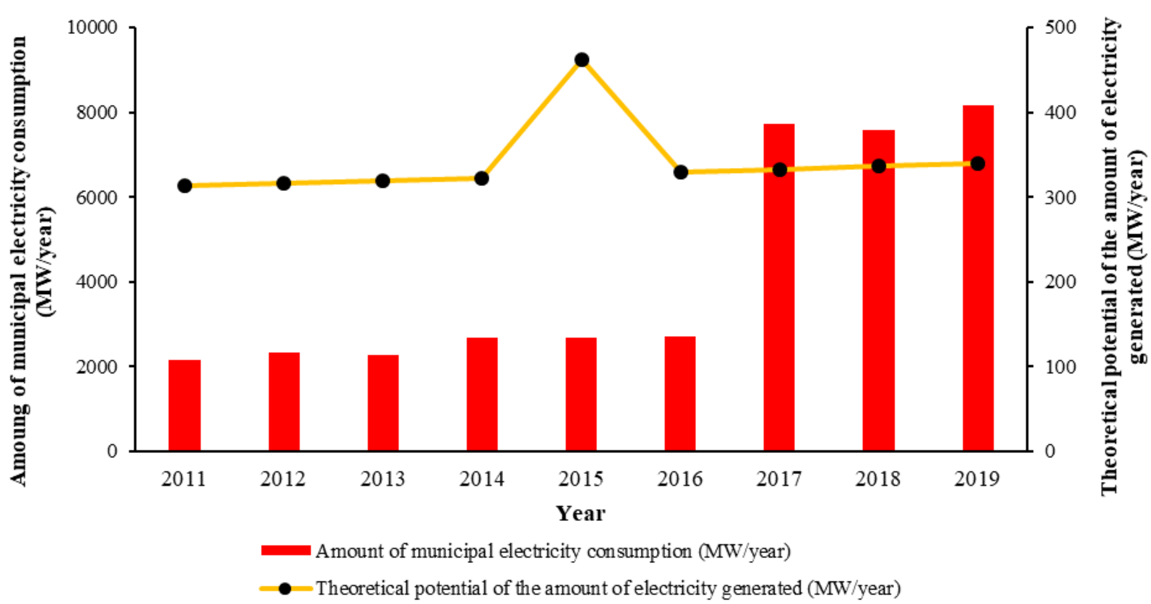

Figure 9 Mean theoretical potential of electricity generation (MW) from MSW and average electricity consumption in the last 9 years in Golestan province (GPEDC, 2017)

9 Conclusions

Economic evaluation was performed to recover the amount of electricity generation from MSW according to the conditions of Iran, using the collected data. This study is based on fourteen different urban centers with different number of residents and using the reference amount of MSW production in the cities of Golestan province. According to the results, it was shown that the population factor is very important to increase electricity generation in a project. In other words, when the population increased, the MSW increase was also confirmed. The analysis was performed for the main economic factors and they included the amount of population, the amount of MSW produced per day, the amount of organic power generated by MSW and the electricity generated per year. Also, by comparing the average theoretical potential of electricity generation and the average amount of electricity consumption, it can be concluded that generating electricity from MSW can compensate up to about 8% of the amount of electricity consumed in Golestan province.. Finally, the evaluation results showed that the increase in population is very effective in increasing the values studied and its changes have a good effect on maintaining capital through energy production (electricity).

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