AN OVERVIEW OF ENERGY PRODUCTION FROM ANIMAL WASTE DURING IRAN'S ENERGY TRANSITION: IMPLICATION OF MANURE CHEMICAL COMPOSITION

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Abstract. Biogas is a renewable energy source that is generated by the decomposition of organic waste in anaerobic process. The theoretical biogas potential is defined as the possible amount of gas production from biomass. This potential can be evaluated using various calculation methods each of which considers different parameters. The objective of this study was therefore to compare the potential of biogas energy generation from the livestock waste produced from the animal husbandry in Iran using different calculation methods. Using 4 methods of calculation indicated that the amount of 11.82, 5.25, 16.05 and 2.1 million ton of animal waste could be produced in Iran in 2016 with a biogas generation potential of 886.57, 173.36, 745.37 and 565.85 million m^3, energy equivalent of 5.14, 1, 4.32 and 3.28 thousand GWh and electricity generation of 1.59, 0.31, 1.34 and 1.02 thousand GWh. These amounts of electricity generation could provide 2.03%, 1.71%, 0.39% and 1.3% of the electrical energy consumed in household sector in 2016 in Iran, respectively. Furthermore the methane yield potential from the livestock manure with considering the different types of substrate (lipid, lignin, dry matter and cellulose) was evaluated. The highest methane yield was obtained from biochemical methane potential (BMP) value based on lipid and lignin content at 5.27E + 10 NL CH_4 digester^{-1} day^{-1}. The results showed that livestock waste is a low-cost and extensive source of renewable energy in Iran that can be used optimally for biogas energy and electricity generation. Also the treatment of huge amount of livestock manure in anaerobic digestion is helpful for reducing its polluting effects on the environment.
Keywords: *renewable energy, biogas, anaerobic digestion, organic waste, manure livestock*

Introduction

Global demand for energy is increasing rapidly, because of population growth and technological advancements. Use of renewable energy sources is essential due to the limitation of fossil fuel sources and negative environmental effects (International Energy Agency, 2015; United Nations Environment Programme, 2014; Achinas and Euverink, 2016; Abdeshahian et al., 2016; Santos et al., 2018; Chandekar and Debnath, 2018). Biogas is one of the important renewable energy sources which is produced through decomposing organic waste under anaerobic conditions by microorganisms (Travnicek et al., 2018; Scarlat et al., 2018a; Angelidaki et al., 2018). Biogas is mainly composed of CH_4 (60%) and CO_2 (35–40%) (Ilaboya et al., 2010; Sahota et al., 2018). Organic materials such as animal, human and plant wastes are biodegradable and can be converted into biogas (Zareei, 2018; Cu et al., 2015; Ozer, 2017; Yazan et al., 2018). Manure waste obtained from livestock industries are the largest and cheapest source for biogas production in anaerobic process (Comparetti et al., 2012; Ch'ng et al., 2014; Plume et al., 2012; Than, 2005; Cu et al., 2012; Yildirim et al., 2017; Mohammadi Maghanaki et al., 2013). Manure livestock is a type of organic waste which will be

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hazardous to environment if it is not managed suitably. Livestock manure contains residues of some harmful substances such as growth hormones, antibiotics and heavy metals. So, disposal of them contaminates air, soil and water sources and prevalence of the human diseases (Abdeshahian et al., 2016; Pessuto et al., 2016). Anaerobic treatment of manure has the beneficial outcomes of reducing environmental pollution through proper waste management, reduction of unpleasant odors and microbial pathogens with a sustainable production of energy source as biogas (Wyman and Goodman, 1993; Mata-alvarez, 2000; Gebrezgabher et al., 2010; Holm-Nielsen et al., 2009; Wang et al., 2018; Samun et al., 2017; Neshat et al., 2017). Also it can be used for the production of a rich fertilizer which is favorable for the improvement of agricultural lands (De-Vries, 2012; Meyer et al., 2018; Eze and Agbo, 2010).

Considering the importance of animal waste as the enormous raw substances for energy production, many studies have been carried out on assessing the potential of biogas production from livestock waste. For instance, the potential of biogas production from livestock waste was studied in Turkey. The results showed that the amount of 2177.55 million m^3 of biogas can be produced annually in Turkey (Onurbas-Avcioglu and Turker, 2012). Similar studies have also been performed in Finland, Sweden and Denmark to estimate the potential of energy production from livestock waste as evaluated in Turkey. These studies showed that the potential of biogas production is 332.97, 352.09 and 402.1 million m^3 yr^{-1} in mentioned countries, respectively (Abdeshahian et al., 2016; Luostarinen, 2013).

In recent years, the animal husbandry is drastically grown in Iran (Hamzeh et al., 2011; Government of Islamic Republic of Iran and Food and Agriculture Organization, 2012; Tehran Chamber of Commerce, Industries, Mines and Agriculture, 2016; Beldman et al., 2017). Number of industrial cattle farms in Iran based on capacity from 1990-2016 is shown in *Figure 1.*

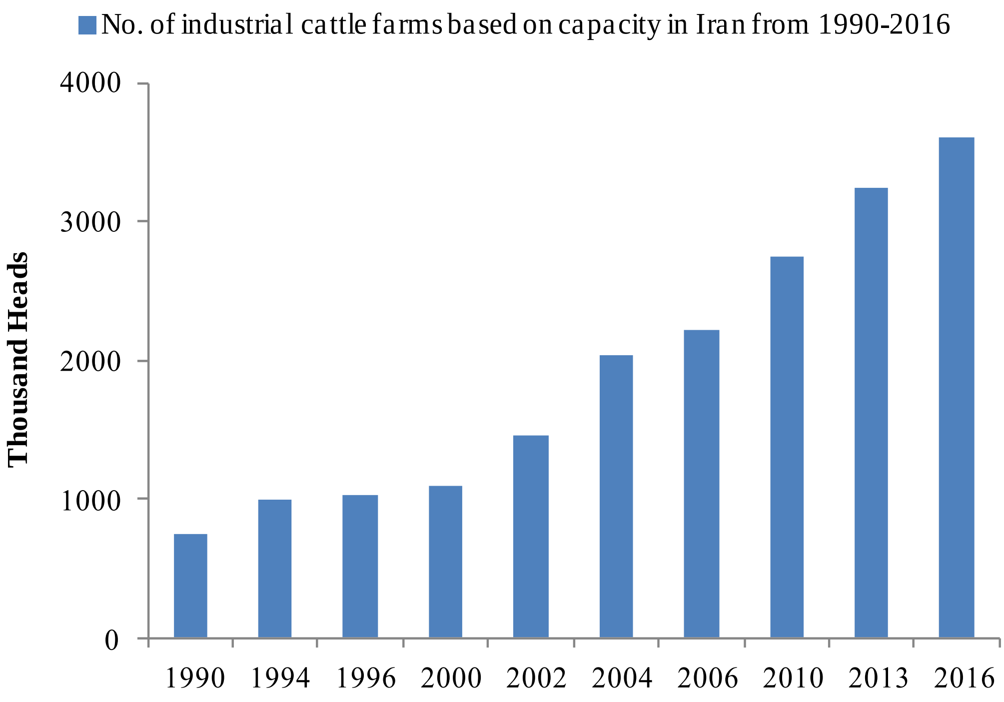

Figure 1. *The increasing capacity of industrial cattle farms in Iran from 1990-2016 (Tehran Chamber of Commerce, Industries, Mines and Agriculture, 2016)*

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As can be seen, industrial cattle farms capacity in Iran has revealed an increasing trend from 1990-2016. The increase population of the livestock has caused an elevated production of livestock waste, resulting in the difficulty with the disposal of a large amount of manure. Unsafe disposal of livestock waste and its accumulation in environment has caused unfavorable conditions due to creating a favorable environment for growth and spread of microbes, in addition to intolerable odor and insects (Zareei, 2018), but could instead be used as a tremendous source for generating biogas energy. A wide variety of calculations exist to evaluate the potential of biogas generation from livestock waste, each of them considers different parameters such as pH, temperature, type, concentration and composition of raw materials and the time remaining in digester (Costa et al., 2016; Abdeshahian et al., 2016; Boysan et al., 2015; Cu et al., 2015; Burg et al., 2018; Zareei, 2018).

A wide variety of calculations exist to evaluate the potential of biogas generation from livestock waste. Some studies provide information about the factors that affect the biogas production such as pH, temperature, type, concentration and composition of raw materials and the time remaining in digester (Costa et al., 2016; Abdeshahian et al., 2016; Boysan et al., 2015; Cu et al., 2015; Burg et al., 2018; Zareei, 2018). But variation of quantity of biogas generated from different evaluation methods has rarely been studied in a distinct study. The current study aims to compare the potential of biogas energy generation from the livestock waste produced from the animal husbandry in Iran using different calculation methods.

Materials and methods

Livestock population in Iran

In order to calculate the potential of biogas generation from the livestock manure, initial data was collected from the Statistical Centre of Iran (SCI) (Statistical Centre of Iran, 2017). According to the data reported by SCI, in 2016, Iran had a total of 26061 industrial cattle farms with a capacity of 3619696 heads. In this year 18547 cattle farms were active and the rest were inactive. The total number of cattle was 1439391 heads in Iran in 2016. *Table 1* shows the number of specified groups of cattle population in each province of Iran.

Table 1. *Number of specified groups of cattle population in Iran (Thousand Heads) (Statistical Centre of Iran, 2017)*

Province	Original		Crossbred		Native	Total
	Holstein	Other races	Holstein	Other races		
Azerbaijan, West	21.98	0.52	3.13	2.26	0.45	28.36
Azerbaijan, East	10.83	0.88	0.78	0.16	0.55	13.21
Ardabil	21.48	0	2.99	0.41	0.06	24.95
Isfahan	125.94	1.24	72.95	6.6	0.12	206.87
Alborz	66.77	0.27	3.30	1.19	0.76	72.31
Ilam	5.61	0.10	0.43	0	0	6.15
Bushehr	0.44	0.03	1.88	5.14	2.02	9.52
Tehran	223.55	5.84	14.81	38.31	38.88	321.42
ChaharMahaal and Bakhtiari	28.98	0.10	0.32	0.01	0	29.42
Khorasan, South	8.93	0.03	2.10	0.41	0	11.49

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Table 1 (continued). *Number of specified groups of cattle population in Iran (Thousand Heads) (Statistical Centre of Iran, 2017)*

Province	Original		Crossbred		Native	Total
	Holstein	Other races	Holstein	Other races		
Khorasan, Razavi	92.64	2.75	16.01	1.17	0.03	112.62
Khorasan, North	4.75	0.23	2.46	0.03	0.14	7.62
Khuzestan	4.75	0.37	15.35	2.28	0.43	23.19
Zanjan	14.19	0	2.63	0.04	0.14	17.02
Semnan	16.84	4.06	12.56	23.38	0.78	57.64
Sistan and Baluchestan	2.19	0.23	0.29	0.58	0.79	4.11
Fars	75.65	0.37	17.86	8.21	3.00	105.12
Qazvin	65.59	0.10	5.84	1.05	0	72.59
Qom	28.73	1.13	5.56	16.75	12.65	64.84
Kurdistan	1.85	0.47	0.38	0.31	0.40	3.42
Kerman	29.28	0.26	2.35	0.53	0.75	33.19
Kermanshah	14.74	1.14	0.33	0.06	0.25	16.54
Kohgiluyeh and Boyer-Ahmad	3.13	0	1.28	0.02	0	4.43
Golestan	15.35	1.56	0.98	0.35	0.01	18.26
Gilan	2.31	0.22	0.41	0.10	0.70	3.76
Lorestan	6.35	0	2.21	0.30	1.01	9.89
Mazandaran	10.87	0.82	2.90	6.39	0.66	21.65
Markazi	10.62	0	15.13	33.95	0.34	60.05
Hormozgan	0.24	0.01	0.14	0.52	0.34	1.27
Hamadan	15.34	0.25	1.62	0.29	0	17.52
Yazd	18.35	0.37	38.89	2.96	0.24	60.83
Iran	948.42	23.48	248.02	153.85	65.6	1439.39

Livestock manure production

Livestock waste is composed of the organic matter that can be treated as the potential raw substance for the production of bioenergy (Afazeli et al., 2014; Mathias, 2014). The amount of livestock manure can vary based on the type of animal, feeding methods, animal body size, the type of breeding and keeping time at day or night (Onurbas-Avcioglu and Turker, 2012; Omrani, 1996). Abdeshahian et al., (2016) categorized cattle into the large ruminants and calculated the amount of livestock manure based on the live body weight. The amount of the manure was calculated based on the 9% of body weight for large ruminants. The average live body weight accounted 250 kg for the large ruminants. Accordingly, the average amount of the manure was calculated based on 22.5 kg/day for the large ruminants. This is while that Boysan et al. (2015) calculated the amount of livestock manure production based on 10 kg/day for one cattle. On the other hand, Plume et al. (2012) calculated the manure output from livestock in a year using *Equation 1*.

$$M = \sum_{n=1}^{i} N_i * M_i \qquad \text{(Eq.1)}$$

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where:
M- Livestock manure produced in region (t),
n- Number of specified groups of livestock population in region,
N_i- Average number of livestock present year-round within i[th] group of livestock,
m_i- Manure produced per one head in a year in the i[th] group of livestock (t).

Furthermore Zareei (2018) denoted that the livestock manure production can be calculated using parameters including livestock weight and the ratio of the annual manure generation to livestock weight as shown in *Table 2*.

Table 2. *Coefficient for calculation of manure production from livestock (Zareei, 2018)*

Material type	Livestock weight	The ratio of the annual livestock manure to livestock weight
Cow manure	500-620	2.6

The average weight of livestock was estimated according to the dominant races of the area. As stated in *Table 2,* livestock weight was considered in the range of 500 to 620. The total amount of livestock waste can be calculated by multiplying the waste mass by the population number (Zareei, 2018).

The potential of biogas production from the livestock manure

The biogas produced from the livestock waste is affected by the different factors such as feeding regime, animal type, body weight, the proportion of total solids and the waste availability (United Nations Environment Programme, 2014; Than, 2005). Abdeshahian et al. (2016) considered the total solids of the waste as an important factor for the production of biogas from the livestock waste. They considered the total solids value of livestock manure as 25% for the large ruminants with the quantity of estimated biogas produced per kilogram of the total solids as 0.6 (0.6 m3/kg TS). Also they have pointed that the collection of the manure cannot always be carried out efficiently for the production of biogas and the availability of the manure is varied. Hence, for the calculating of biogas production from the livestock manure the availability coefficient was considered as 50% for large ruminants (Onurbas-Avcioglu and Turker, 2012; Afazeli et al., 2014). By taking into account the mentioned assumptions, the theoretical potential of biogas production from the livestock manure and the potential of electricity generation from the biogas was calculated as shown in *Equations 2* and *3* (Abdeshahian et al., 2016).

$$TPB = M * TS * AC * EB_{TS} \quad \text{(Eq.2)}$$

where:
TPB- Theoretical potential of biogas (m^3 yr^{-1}),
M- Total amount of the manure produced for each region (kg yr^{-1}),
TS- Ratio of the total solids of the animal manure,
AC- Availability coefficient,
EBTS- Quantity of estimated biogas produced per kilogram of the total solids (m^3 kg^{-1} TS).

$$e_{biogas} = E_{biogas} * n \quad \text{(Eq.3)}$$

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where:
e_{biogas}- Quantity of generated electricity (kWh yr^{-1}),
E_{biogas}- Unconverted raw energy in the biogas (kWh yr^{-1}),
n- Overall efficiency of the conversion of biogas to electricity (%). The amount of *n* is varied depending on the power generation plants. The *n* value is considered 35-42% and 25% in the power plants with large turbine system and small generators, respectively (Hosseini and Wahid, 2014; Benito et al., 2015). In this study, the *n* value was assumed as 30%based on Iran power plants characterization (Iran Energy Ministry, 2017).

The quantity of E_{biogas} is calculated using *Equation 4* (Abdeshahian, 2016).

$$E_{biogas} = Energycontent_{biogas} * m_{biogas} \quad \text{(Eq.4)}$$

where:
Energy $content_{biogas}$- Calorific value of biogas (kWh m^{-3}). The quantity of the Energy $content_{biogas}$ is assumed as 6 kWh m^{-3} by considering the biogas calorific value as 21.5 MJ per m^3 biogas (1 kWh = 3.6 MJ) (Hosseini and Wahid, 2014; Garcia, 2014).
m_{biogas}- Amount of biogas produced per year (m^3 yr^{-1}).

On the other hand, Boysan et al. (2015) calculated the potential of biogas production from livestock manure based on 0.33 m^3/cattle with considering assumptions including fermenter temperature as 37 °C, 20% mass in manure and waiting time as 30 days. It is while that in the study conducted by Zareei (2018) the biogas production potential per kilogram of cow manure was considered as 0.28-0.28 m^3. Furthermore, Plume et al. (2012) proposed *Equation 5* for calculating the potential of biogas production from livestock manure.

$$V_B = \sum_{n}^{i} N_i * m_i * K_{DMi} * K_{OMi} * v_{Bi} \quad \text{(Eq.5)}$$

where:
V_B- Biogas volume, potentially obtainable from manure biomass in region in a year (m^3),
K_{DMi}- Dry matter content in manure produced by i^{th} group of animals in region,
K_{Omi}- Organic matter content in dry matter of manure produced by i^{th} group of animals in region,
v_{Bi}- Specific biogas output from manure organic matter for i^{th} group of animals in region (m^3 t^{-1}).

The energy of biogas obtainable from manure biomass in region then was calculated according to *Equation 6* (Plume et al., 2012).

$$E_B = \sum_{n=1}^{i} N_i * m_i * K_{DMi} * K_{OMi} * v_{Bi} * e_{Bi} \quad \text{(Eq.6)}$$

where:
E_B- Energy potential obtainable from biogas produced from manure (kWh),
e_{Bi}- Specific heat energy content of biogas obtained from manure produced by i^{th} group of animals (kWh m^{-3}).

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Calculation of methane (CH_4) content of biogas

The biogas obtained from the anaerobic digestion process of livestock manure is composed of 50-70% of methane (Omar et al., 2009; Nasir et al., 2012; Ounnar et al., 2012; Nasir et al., 2013). The methane yield can be calculated based on the original Hashimoto equation (*Eq. 7* below) (Chen and Hashimoto, 1978; Hashimoto et al., 1981).

$$\gamma = \frac{\beta_0 * S_0}{HRT}\left(1 - \frac{K}{HRT * \mu m - 1 + K}\right) \quad \text{(Eq.7)}$$

where:
γ- Methane yield (NL CH_4 digester^{-1} day^{-1}),
β_0- Biochemical methane production (BMP) value of specific substrate (NL CH_4 kg VS^{-1}),
S_0- VS concentration (g kg^{-1}),
HRT- Hydraulic retention time (days),
K- Kinetic constant (K = 0.6 + 0.0206.EXP[0.051.S_0],
μm- Maximum specific growth rate (day^{-1}). µm = 0.013 T – 0.129, for temperature (T) between 20 and 60 °C.

Rennuit and Sommer (2013) extended the Hashimoto equation to calculate the methane yield for a biogas digester. The extended equation takes into account the difference in lowland and highland temperature regimes. It is assumed that the mean monthly air temperature represents the mean monthly digester temperature (Perrigault et al., 2012). Hence, the methane yield for a biogas digester for an air temperature between 15 to 30 °C and 20 to 60 °C is calculated based on *Equations 8* and *9*, respectively (Rennuit and Sommer, 2013).

$$\gamma_{winter}(HRT, \mu m, TD) = \beta_0 * \left[1 - \frac{K}{\mu m(TD) * \left(HRT + \frac{1}{\mu m(TD)}\right) - 1 + K}\right] \quad \text{(Eq.8)}$$

$$\gamma_{summer}(HRT, \mu m, TD) = \beta_0 * \left[1 - \frac{K}{\mu m(TD) * HRT - 1 + K}\right] \quad \text{(Eq.9)}$$

where:
µm(Td)- maximum specific growth rate of the microorganisms at the digester temperature in the temperature interval from 10 to 30 °C (µm[Td] = 0.0039 $e^{0.1188 \cdot (Td)}$ (day^{-1}) and (Td) is the digester temperature which is set to be equal to the average monthly air temperature (°C) represented by region.

In line with this, Cu et al. (2015) suggested that the BMP value (β_0 in the Hashimoto equation) from different types of substrate can be predicted based on their chemical composition. Biogas production is related to the chemical composition of the substrate. Low concentrations of organic matter such as lipids and protein will lead to a low biogas production. However, the high concentration of organic matter in substrates will have a negative effect on biogas production, causing foaming and inhibition if not co-fermented with biomasses low in protein and lipids (Cu et al., 2015; Kougias et al.,

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2013). There is a clear relationship between lipid content of the biomass and biochemical methane potential. Lipid content is the most important factor for biochemical methane potential compared to other components. However, in a biogas technology every component in the substrates affects biogas production. It was found that lipid, lignin, protein, and cellulose contents were the main chemical components of substrates contributing to the variation in the BMP (Cu et al., 2015). Equations to predict BMP are shown in *Table 3*.

Table 3. *Equations to predict BMP for livestock manure (Cu et al., 2015)*

Variables	Equations for BMP
Lipid	57.9+35×lipid
Lipid, lignin	186+30.6×lipid–5.13×lignin
Lipid, lignin, dry matter	167+30.1×lipid–5.43×lignin+1.15×dry matter
Lipid, lignin, cellulose	201+31.5×lipid–3.85×lignin–1.88×cellulose

Results and discussion

Calculation of livestock manure production in Iran

The amount of livestock manure production was calculated for all provinces of Iran based on Abdeshahian, Boysan and Zareei methods. The results are shown in *Table 4*.

Table 4. *The estimated values of livestock manure of different provinces in Iran in 2016 based on different methods*

Manure production (t yr^{-1})							
Province	**Abdeshahian**	**Boysan**	**Zareei**	**Province**	**Abdeshahian**	**Boysan**	**Zareei**
Azerbaijan, West	2.33E+05	1.04E+05	4.13E+04	Fars	8.63E+05	3.84E+05	1.53E+05
Azerbaijan, East	1.08E+05	4.82E+04	1.92E+04	Qazvin	5.96E+05	2.65E+05	1.06E+05
Ardabil	2.05E+05	9.11E+04	3.63E+04	Qom	5.33E+05	2.37E+05	9.44E+04
Isfahan	1.70E+06	7.55E+05	3.01E+05	Kurdistan	2.82E+04	1.25E+04	4.99E+03
Alborz	5.94E+05	2.64E+05	1.05E+05	Kerman	2.73E+05	1.21E+05	4.83E+04
Ilam	5.05E+04	2.25E+04	8.96E+03	Kermanshah	1.36E+05	6.04E+04	2.41E+04
Bushehr	7.82E+04	3.48E+04	1.39E+04	Kohgiluyeh and Boyer-Ahmad	3.64E+04	1.62E+04	6.46E+03
Tehran	2.64E+06	1.17E+06	4.68E+05	Golestan	1.50E+05	6.67E+04	2.66E+04
ChaharMahaal and Bakhtiari	2.42E+05	1.07E+05	4.28E+04	Gilan	3.10E+04	1.38E+04	5.49E+03
Khorasan, South	9.44E+04	4.19E+04	1.67E+04	Lorestan	8.12E+04	3.61E+04	1.44E+04
Khorasan, Razavi	9.25E+05	4.11E+05	1.64E+05	Mazandaran	1.78E+05	7.90E+04	3.15E+04
Khorasan, North	6.26E+04	2.78E+04	1.11E+04	Markazi	4.93E+05	2.19E+05	8.74E+04
Khuzestan	1.90E+05	8.46E+04	3.38E+04	Hormozgan	1.04E+04	4.64E+03	1.85E+03
Zanjan	1.40E+05	6.21E+04	2.48E+04	Hamadan	1.44E+05	6.40E+04	2.55E+04

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Table 4 (continued). *The estimated values of livestock manure of different provinces in Iran in 2016 based on different methods*

Manure production (t yr^{-1})							
Province	**Abdeshahian**	**Boysan**	**Zareei**	**Province**	**Abdeshahian**	**Boysan**	**Zareei**
Semnan	4.73E+05	2.10E+05	8.39E+04	Yazd	5.00E+05	2.22E+05	8.86E+04
Sistan and Baluchestan	3.38E+04	1.50E+04	5.99E+03	Iran	1.18E+07	5.25E+06	2.10E+06

Manure production by livestock in different groups based on Plume et al. (2012) is presented in *Table 5*.

Table 5. *Manure production by livestock in different groups based on Plume et al. (2012)*

Group characteristics	Manure production per head t yr^{-1})
Dairy cows	$0.0024Y_D+0.447$
Heifers	8
Calves	2.6
Cattle	12

Average values of manure production per one head in a year for all groups of livestock, except dairy cows, are given in *Table 5*. Average manure production per one dairy cow is dependent on cow's milk yield and calculates help by regression *Equation 10* (Plume et al., 2012).

$$m_1 = 0.0024 * Y_d + 0.447 \quad \text{(Eq.10)}$$

where:
m_1- Average manure production per dairy cow in region in a year (t yr^{-1}),
Y_d- Average milk yield per dairy cow in region in a year (kg yr^{-1}).

Aiming to improve accuracy of manure resources evaluation, all the animals was divided in 4 groups (dairy cows, heifers, calves and cattle) according to its manure production capability per one head. The number of livestock within specified groups in each province of Iran in 2016 is presented in *Table 6*.

Table 6. *Number of livestock within specified groups in each province of Iran in 2016*

Province	Dairy cow			Heifers		Calves		Cattle	
	Lactating cow	Dry cow							
		Pregnant	Unpregnant	Pregnant	Unpregnant	Bull	Cow	Breeding cattle	Other
Azerbaijan, West	9085	2197	748	3175	2461	4016	2881	1478	2322
Azerbaijan, East	3804	1069	560	1154	971	2629	1600	940	482
Ardabil	7977	1964	396	2184	1841	4231	4286	389	1688
Isfahan	85333	18747	6047	25458	16938	22081	25890	1615	4766
Alborz	28921	6951	2041	7956	6450	5529	11199	915	2350
Ilam	1552	853	704	315	322	1340	344	438	285

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Table 6 (continued). *Number of livestock within specified groups in each province of Iran in 2016*

Province	Dairy cow			Heifers		Calves		Cattle	
	Lactating cow	Dry cow		Pregnant	Unpregnant	Bull	Cow	Breeding cattle	Other
		Pregnant	Unpregnant						
Bushehr	1026	609	381	346	308	6335	151	53	316
Tehran	93015	25956	10066	25284	24227	104542	28958	6220	3152
ChaharMahaal and Bakhtiari	10136	3738	2031	3230	2535	2896	3848	972	41
Khorasan, South	3451	1109	746	1027	1226	1573	1552	437	371
Khorasan, Razavi	42617	10634	3539	10815	11499	13083	14029	931	5475
Khorasan, North	2290	618	173	691	546	1707	945	592	66
Khuzestan	3881	1480	362	576	1021	11323	1106	676	2767
Zanjan	5984	1752	282	2081	2004	1391	2074	1284	174
Semnan	17947	3811	1592	4081	3311	10407	3722	6540	6233
Sistan and Baluchestan	627	404	136	177	107	1322	256	290	794
Fars	33313	9111	2447	10681	11417	18293	11255	3097	5514
Qazvin	26322	6201	658	7380	5975	11451	10288	596	3722
Qom	9559	2301	745	2928	2470	36488	3770	745	5835
Kurdistan	1090	206	32	278	242	1069	281	130	100
Kerman	10349	3422	1581	3723	2867	4525	3462	2925	338
Kermanshah	5915	1134	978	1785	1701	1445	1973	644	971
Kohgiluyeh and Boyer-Ahmad	1301	358	17	438	471	1243	576	32	0
Golestan	5635	2287	733	2333	2213	2361	2213	393	96
Gilan	1204	310	235	575	241	390	547	250	19
Lorestan	2848	818	116	958	598	2800	1573	29	153
Mazandaran	7544	2354	689	2174	1922	2667	2348	195	1759
Markazi	9822	2133	997	2387	1894	33381	5686	1367	2390
Hormozgan	227	76	32	43	15	298	90	397	92
Hamadan	5878	1999	922	1351	1197	3323	2248	606	0
Yazd	21136	7208	1154	7487	5981	6754	7605	1526	1985
Iran	459789	121810	41140	133071	114971	320893	156756	36702	54256

In line with this, the amount of livestock manure production in different provinces of Iran was calculated based on Plume et al. (2012) and is presented in *Table 7*.

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***Table 7.** The estimated values of livestock manure of different provinces in Iran in 2016 based on Plume et al. (2012)*

Manure production (t yr^{-1})						
Province	**Dairy cows**		**Heifers**	**Calves**	**Cattle**	**Total**
	Lactating cow	**Dry cow**				
Azerbaijan, West	199870	35340	45088	17932	45600	343830
Azerbaijan, East	72276	19548	17000	10995	17064	136883
Ardabil	127632	28320	32200	22144	24924	235220
Isfahan	2218658	297528	339168	124724	76572	3056650
Alborz	607341	107904	115248	43492	39180	913165
Ilam	27936	18684	5096	4378	8676	64770
Bushehr	4104	11880	5232	16863	4428	42507
Tehran	1581255	432264	396088	347100	112464	2869171
ChaharMahaal and Bakhtiari	233128	69228	46120	17534	12156	378166
Khorasan, South	72471	22260	18024	8125	9696	130576
Khorasan, Razavi	980191	170076	178512	70491	76872	1476142
Khorasan, North	48090	9492	9896	6895	7896	82269
Khuzestan	62096	22104	12776	32315	41316	170607
Zanjan	155584	24408	32680	9009	17496	239177
Semnan	287152	64836	59136	36735	153276	601135
Sistan and Baluchestan	8151	6480	2272	4102	13008	34013
Fars	732886	138696	176784	76824	103332	1228522
Qazvin	605406	82308	106840	56521	51816	902891
Qom	248534	36552	43184	104670	78960	511900
Kurdistan	22890	2856	4160	3510	2760	36176
Kerman	196631	60036	52720	20766	39156	369309
Kermanshah	159705	25344	27888	8886	19380	241203
Kohgiluyeh and Boyer-Ahmad	33826	4500	7272	4729	384	50711
Golestan	118335	36240	36368	11892	5868	208703
Gilan	20468	6540	6528	2436	3228	39200
Lorestan	48416	11208	12448	11369	2184	85625
Mazandaran	181056	36516	32768	13039	23448	286827
Markazi	157152	37560	34248	101574	45084	375618
Hormozgan	2043	1296	464	1008	5868	10679
Hamadan	141072	35052	20384	14484	7272	218264
Yazd	422720	100344	107744	37333	42132	710273
Iran	9777075	1955400	1984336	1241875	1091496	16050182

Calculation of the potential of biogas production from the livestock manure in Iran

The biogas production potential from the livestock manure in all provinces of Iran was calculated based on Abdeshahian, Boysan and Zareei methods and is presented in *Table 8.*

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Table 8. *The estimated values of biogas production in all provinces in Iran in 2016 based on different methods*

Biogas production potential (million m^3 yr^{-1})							
Province	**Abdeshahian**	**Boysan**	**Zareei**	**Province**	**Abdeshahian**	**Boysan**	**Zareei**
Azerbaijan, West	17.46	3.41	11.15	Fars	64.75	12.66	41.32
Azerbaijan, East	8.13	1.59	5.19	Qazvin	44.71	8.74	28.53
Ardabil	15.37	3.00	9.81	Qom	39.93	7.80	25.49
Isfahan	127.42	24.91	81.32	Kurdistan	2.11	0.41	1.34
Alborz	44.53	8.70	28.4269	Kerman	20.44	3.99	13.04
Ilam	3.78	0.74	2.41	Kermanshah	10.19	1.99	6.50
Bushehr	5.86	1.14	3.74	Kohgiluyeh and Boyer-Ahmad	2.73	0.53	1.74
Tehran	197.97	38.71	126.35	Golestan	11.24	2.19	7.17
ChaharMahaal and Bakhtiari	18.12	3.54	11.56	Gilan	2.32	0.45	1.48
Khorasan, South	7.07	1.38	4.51	Lorestan	6.09	1.19	3.88
Khorasan, Razavi	69.36	13.56	44.27	Mazandaran	13.33	2.60	8.51
Khorasan, North	4.69	0.91	2.99	Markazi	36.99	7.23	23.60
Khuzestan	14.28	2.79	9.11	Hormozgan	0.78	0.15	0.49
Zanjan	10.48	2.05	6.69	Hamadan	10.79	2.11	6.88
Semnan	35.50	6.94	22.66	Yazd	37.47	7.32	23.91
Sistan and Baluchestan	2.53	0.49	1.61	Iran	886.57	173.36	565.85

The manure and biogas characteristics for calculating the potential of biogas production from the livestock manure based on Plume et al. (2012) such as dry matter content, organic matter content in dry matter, biogas output from manure and heat energy of biogas are shown in *Table 9*.

Table 9. *Manure and biogas characteristics in different groups of livestock based on Plume et al. (2012)*

Groups of livestock	**Dairy cows, heifers, calves, cattle**
Dry matter content	0.18
Organic matter content in dry matter	0.86
Biogas output from manure (m^3 t^{-1})	300
Heat energy of biogas (kWh m^{-3})	5.8

The biogas production potential of livestock manure from the different groups of livestock in Iran was calculated based on Plume et al. (2012) using *Equation 5* and is presented in *Table 10*.

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Table 10. *The estimated values of biogas production of different provinces in Iran in 2016 based on Plume et al. (2012)*

Biogas production (million m^3 yr^{-1})						
Province	**Dairy cows**		**Heifers**	**Calves**	**Cattle**	**Total**
	Lactating cow	**Dry cow**				
Azerbaijan, West	9.28	1.64	2.09	0.83	2.11	15.96
Azerbaijan, East	3.35	0.90	0.78	0.51	0.79	6.35
Ardabil	5.92	1.31	1.49	1.02	1.15	10.92
Isfahan	103.03	13.81	15.75	5.79	3.55	141.95
Alborz	28.20	5.01	5.35	2.01	1.81	42.40
Ilam	1.29	0.86	0.23	0.20	0.40	3.00
Bushehr	0.19	0.55	0.24	0.78	0.20	1.97
Tehran	73.43	20.07	18.39	16.11	5.22	133.24
ChaharMahaal and Bakhtiari	10.82	3.21	2.14	0.81	0.56	17.56
Khorasan, South	3.36	1.03	0.83	0.37	0.45	6.06
Khorasan, Razavi	45.52	7.89	8.29	3.27	3.56	68.55
Khorasan, North	2.23	0.44	0.45	0.32	0.36	3.82
Khuzestan	2.88	1.02	0.59	1.50	1.91	7.92
Zanjan	7.22	1.13	1.51	0.41	0.81	11.10
Semnan	13.33	3.01	2.74	1.70	7.11	27.91
Sistan and Baluchestan	0.37	0.30	0.10	0.19	0.60	1.57
Fars	34.03	6.44	8.20	3.56	4.79	57.05
Qazvin	28.11	3.82	4.96	2.62	2.40	41.93
Qom	11.54	1.69	2.00	4.86	3.66	23.77
Kurdistan	1.06	0.13	0.19	0.16	0.12	1.68
Kerman	9.13	2.78	2.44	0.96	1.81	17.15
Kermanshah	7.41	1.17	1.29	0.41	0.90	11.20
Kohgiluyeh and Boyer-Ahmad	1.57	0.20	0.33	0.21	0.01	2.35
Golestan	5.49	1.68	1.68	0.55	0.27	9.69
Gilan	0.95	0.30	0.30	0.11	0.14	1.82
Lorestan	2.24	0.52	0.57	0.52	0.10	3.97
Mazandaran	8.40	1.69	1.52	0.60	1.08	13.32
Markazi	7.29	1.74	1.59	4.71	2.09	17.44
Hormozgan	0.09	0.06	0.02	0.04	0.27	0.49
Hamadan	6.55	1.62	0.94	0.67	0.33	10.13
Yazd	19.63	4.65	5.00	1.73	1.95	32.981
Iran	454.04	90.80	92.15	57.67	50.68	745.37

Calculation of the potential of electricity generation from the livestock manure in Iran

The potential of electricity generation from the biogas obtainable from livestock manure calculated based on Abdeshahian, Boysan, Zareei and Plume methods was estimated for all provinces of Iran according to *Equations 3* and *4* and is presented in *Table 11*.

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Table 11. *The estimated values of the potential of electricity generation from livestock manure based on different methods in all provinces of Iran in 2016*

Electricity generation potential (kWh yr^{-1})									
Province	**Abdeshahian**	**Boysan**	**Zareei**	**Plume**	**Province**	**Abdeshahian**	**Boysan**	**Zareei**	**Plume**
Azerbaijan, West	3.14E+07	6.15E+06	2.01E+07	2.87E+07	Fars	1.17E+08	2.28E+07	7.44E+07	1.03E+08
Azerbaijan, East	1.46E+07	2.86E+06	9.35E+06	1.14E+07	Qazvin	8.05E+07	1.57E+07	5.14E+07	7.55E+07
Ardabil	2.77E+07	5.41E+06	1.77E+07	1.97E+07	Qom	7.19E+07	1.41E+07	4.59E+07	4.28E+07
Isfahan	2.29E+08	4.49E+07	1.46E+08	2.56E+08	Kurdistan	3.80E+06	7.43E+05	2.43E+06	3.02E+06
Alborz	8.02E+07	1.57E+07	5.12E+07	7.63E+07	Kerman	3.68E+07	7.20E+06	2.35E+07	3.09E+07
Ilam	6.82E+06	1.33E+06	4.35E+06	5.41E+06	Kermanshah	1.83E+07	3.59E+06	1.17E+07	2.02E+07
Bushehr	1.06E+07	2.06E+06	6.74E+06	3.55E+06	Kohgiluyeh and Boyer-Ahmad	4.92E+06	9.61E+05	3.14E+06	4.24E+06
Tehran	3.56E+08	6.97E+07	2.27E+08	2.40E+08	Golestan	2.02E+07	3.96E+06	1.29E+07	1.74E+07
ChaharMahaal and Bakhtiari	3.26E+07	6.38E+06	2.08E+07	3.16E+07	Gilan	4.18E+06	8.17E+05	2.67E+06	3.28E+06
Khorasan, South	1.27E+07	2.49E+06	8.13E+06	1.09E+07	Lorestan	1.10E+07	2.14E+06	7.00E+06	7.16E+06
Khorasan, Razavi	1.25E+08	2.44E+07	7.97E+07	1.23E+08	Mazandaran	2.40E+07	4.69E+06	1.53E+07	2.40E+07
Khorasan, North	8.46E+06	1.65E+06	5.40E+06	6.88E+06	Markazi	6.66E+07	1.30E+07	4.25E+07	3.14E+07
Khuzestan	2.57E+07	5.03E+06	1.64E+07	1.43E+07	Hormozgan	1.41E+06	2.75E+05	8.99E+05	8.93E+05
Zanjan	1.89E+07	3.69E+06	1.20E+07	2.00E+07	Hamadan	1.94E+07	3.80E+06	1.24E+07	1.82E+07
Semnan	6.39E+07	1.25E+07	4.08E+07	5.03E+07	Yazd	6.74E+07	1.32E+07	4.30E+07	5.94E+07
Sistan and Baluchestan	4.56E+06	8.92E+05	2.91E+06	2.84E+06	Iran	1.60E+09	3.12E+08	1.02E+09	1.34E+09

Calculation of the potential of energy of biogas from the livestock manure in Iran

The potential of energy of biogas obtainable from manure biomass calculated based on Abdeshahina, Boysan, Zareei and Plume Methods in all provinces of Iran was estimated using *Equation 6* and is presented in *Table 12*.

Table 12. *The estimated values of the biogas energy obtainable from manure biomass based on different methods in all provinces of Iran in 2016*

The potential of biogas energy obtainable from manure (kWh)									
Province	**Abdeshahian**	**Boysan**	**Zareei**	**Plume**	**Province**	**Abdeshahian**	**Boysan**	**Zareei**	**Plume**
Azerbaijan, West	1.01E+08	1.98E+07	6.47E+07	9.26E+07	Fars	3.76E+08	7.34E+07	2.40E+08	3.31E+08
Azerbaijan, East	4.72E+07	9.23E+06	3.01E+07	3.69E+07	Qazvin	2.59E+08	5.07E+07	1.65E+08	2.43E+08
Ardabil	8.92E+07	1.74E+07	5.69E+07	6.34E+07	Qom	2.32E+08	4.53E+07	1.48E+08	1.38E+08
Isfahan	7.39E+08	1.45E+08	4.72E+08	8.23E+08	Kurdistan	1.22E+07	2.39E+06	7.77E+06	9.74E+06
Alborz	2.58E+08	5.05E+07	1.65E+08	2.46E+08	Kerman	1.19E+08	2.32E+07	7.56E+07	9.95E+07
Ilam	2.20E+07	4.30E+06	1.40E+07	1.74E+07	Kermanshah	5.91E+07	1.16E+07	3.77E+07	6.50E+07

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***Table 12 (continued).** The estimated values of the biogas energy obtainable from manure biomass based on different methods in all provinces of Iran in 2016*

The potential of biogas energy obtainable from manure (kWh)									
Province	**Abdeshahian**	**Boysan**	**Zareei**	**Plume**	**Province**	**Abdeshahian**	**Boysan**	**Zareei**	**Plume**
Bushehr	3.40E+07	6.65E+06	2.17E+07	1.14E+07	Kohgiluyeh and Boyer-Ahmad	1.58E+07	3.10E+06	1.01E+07	1.37E+07
Tehran	1.15E+09	2.25E+08	7.33E+08	7.73E+08	Golestan	6.52E+07	1.28E+07	4.16E+07	5.62E+07
ChaharMahaal and Bakhtiari	1.05E+08	2.06E+07	6.70E+07	1.02E+08	Gilan	1.35E+07	2.63E+06	8.58E+06	1.06E+07
Khorasan, South	4.11E+07	8.03E+06	2.62E+07	3.52E+07	Lorestan	3.53E+07	6.91E+06	2.25E+07	2.31E+07
Khorasan, Razavi	4.02E+08	7.87E+07	2.57E+08	3.98E+08	Mazandaran	7.73E+07	1.51E+07	4.94E+07	7.73E+07
Khorasan, North	2.72E+07	5.33E+06	1.73E+07	2.22E+07	Markazi	2.15E+08	4.20E+07	1.37E+08	1.01E+08
Khuzestan	8.28E+07	1.62E+07	5.28E+07	4.60E+07	Hormozgan	4.54E+06	8.87E+05	2.84E+06	2.88E+06
Zanjan	6.08E+07	1.19E+07	3.88E+07	6.44E+07	Hamadan	6.26E+07	1.22E+07	3.99E+07	5.88E+07
Semnan	2.06E+08	4.03E+07	1.31E+08	1.62E+08	Yazd	2.17E+08	4.25E+07	1.39E+08	1.91E+08
Sistan and Baluchestan	1.47E+07	2.87E+06	9.34E+06	9.16E+06	Iran	5.14E+09	1.01E+09	3.28E+09	4.32E+09

Calculation of methane (CH_4) content of biogas from manure livestock in Iran

The chemical composition of the livestock manure which is required to calculate the biochemical methane potential based on Cu et al. (2015) including dry matter, volatile solid, protein, lipid, cellulose and lignin are shown in *Table 13*.

***Table 13.** Chemical composition of livestock manure based on Cu et al. (2015)*

Substrates	Animal manure group
Dry matter	10.94
Volatile solid[1]	73.01
Protein[1]	7.55
Lipid[1]	3.63
Cellulose[1]	17.59
Lignin[1]	10.41

[1]% in dry matter

The BMP value based on chemical composition of the substrate was calculated according to chemical composition of the livestock manure (*Table 13*) and equations to predict BMP (*Table 3*) and is presented in *Table 14*.

***Table 14.** The estimated values of BMP based on chemical composition of the substrate*

Variables	BMP
Lipid	184.95
Lipid, lignin	243.67
Lipid, lignin, dry matter	232.31
Lipid, lignin, cellulose	242.34

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The methane yield was calculated in different provinces of Iran according to the BMP value (β_o in the extended Hashimoto equation by Rennuit and Sommer (2013)) from different types of substrate based on chemical composition (*Table 14*) and is presented in *Tables 15–18*.

Table 15. *The estimated values of methane yield (NL CH_4 digester^{-1} day^{-1}) based on the BMP value of specific substrate (lipid)*

Province	Methane yield	Province	Methane yield	Province	Methane yield	Province	Methane yield
Azerbaijan, West	5.64E+08	ChaharMahaal and Bakhtiari	3.13E+08	Fars	3.19E+09	Gilan	7.90E+07
Azerbaijan, East	1.72E+08	Khorasan, South	2.89E+08	Qazvin	1.45E+09	Lorestan	2.60E+08
Ardabil	1.41E+08	Khorasan, Razavi	2.65E+09	Qom	2.20E+09	Mazandaran	5.53E+08
Isfahan	5.94E+09	Khorasan, North	1.33E+08	Kurdistan	7.02E+07	Markazi	1.29E+09
Alborz	1.70E+09	Khuzestan	1.24E+09	Kerman	8.38E+08	Hormozgan	7.31E+07
Ilam	1.52E+08	Zanjan	2.33E+08	Kermanshah	3.73E+08	Hamadan	2.67E+08
Bushehr	4.98E+08	Semnan	2.00E+09	Kohgiluyeh and Boyer-Ahmad	7.68E+07	Yazd	2.28E+09
Tehran	1.05E+10	Sistan and Baluchestan	1.32E+08	Golestan	4.71E+08	Iran	4.01E+10

Table 16. *The estimated values of methane yield (NL CH_4 digester^{-1} day^{-1}) based on the BMP value of specific substrate (lipid and lignin)*

Province	Methane yield	Province	Methane yield	Province	Methane yield	Province	Methane yield
Azerbaijan, West	7.42E+08	ChaharMahaal and Bakhtiari	4.12E+08	Fars	4.2E+09	Gilan	1.04E+08
Azerbaijan, East	2.26E+08	Khorasan, South	3.81E+08	Qazvin	1.9E+09	Lorestan	3.43E+08
Ardabil	1.85E+08	Khorasan, Razavi	3.49E+09	Qom	2.9E+09	Mazandaran	7.27E+08
Isfahan	7.82E+09	Khorasan, North	1.75E+08	Kurdistan	92446950	Markazi	1.7E+09
Alborz	2.23E+09	Khuzestan	1.64E+09	Kerman	1.1E+09	Hormozgan	97949190
Ilam	1.99E+08	Zanjan	3.07E+08	Kermanshah	4.9E+08	Hamadan	3.51E+08
Bushehr	6.57E+08	Semnan	2.63E+09	Kohgiluyeh and Boyer-Ahmad	1.02E+08	Yazd	3E+09
Tehran	1.38E+10	Sistan and Baluchestan	1.74E+08	Golestan	6.2E+08	Iran	5.27E+10

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Table 17. *The estimated values of methane yield (NL CH_4 digester^{-1} day^{-1}) based on the BMP value of specific substrate (lipid, lignin and dry matter)*

Province	Methane yield	Province	Methane yield	Province	Methane yield	Province	Methane yield
Azerbaijan, West	7.08E+08	ChaharMahaal and Bakhtiari	3.93E+08	Fars	4.01E+09	Gilan	9.90E+07
Azerbaijan, East	2.15E+08	Khorasan, South	3.63E+08	Qazvin	1.81E+09	Lorestan	3.27E+08
Ardabil	1.77E+08	Khorasan, Razavi	3.33E+09	Qom	2.77E+09	Mazandaran	6.93E+08
Isfahan	7.46E+09	Khorasan, North	1.66E+08	Kurdistan	8.81E+07	Markazi	1.62E+09
Alborz	2.13E+09	Khuzestan	1.56E+09	Kerman	1.05E+09	Hormozgan	9.17E+07
Ilam	1.9E+08	Zanjan	2.93E+08	Kermanshah	4.68E+08	Hamadan	3.34E+08
Bushehr	6.26E+08	Semnan	2.5E+09	Kohgiluyeh and Boyer-Ahmad	9.71E+07	Yazd	2.86E+09
Tehran	1.31E+10	Sistan and Baluchestan	1.66E+08	Golestan	5.91E+08	Iran	5.03E+10

Table 18. *The estimated values of methane yield (NL CH_4 digester^{-1} day^{-1}) based on the BMP value of specific substrate (lipid, lignin and cellulose)*

Province	Methane yield	Province	Methane yield	Province	Methane yield	Province	Methane yield
Azerbaijan, West	7.38E+08	ChaharMahaal and Bakhtiari	4.09E+08	Fars	4.18E+09	Gilan	1.03E+08
Azerbaijan, East	2.25E+08	Khorasan, South	3.79E+08	Qazvin	1.89E+09	Lorestan	3.41E+08
Ardabil	1.84E+08	Khorasan, Razavi	3.47E+09	Qom	2.89E+09	Mazandaran	7.23E+08
Isfahan	7.78E+09	Khorasan, North	1.74E+08	Kurdistan	91942230	Markazi	1.69E+09
Alborz	2.22E+09	Khuzestan	1.63E+09	Kerman	1.1E+09	Hormozgan	95695200
Ilam	1.98E+08	Zanjan	3.05E+08	Kermanshah	4.88E+08	Hamadan	3.49E+08
Bushehr	6.53E+08	Semnan	2.61E+09	Kohgiluyeh and Boyer-Ahmad	1.01E+08	Yazd	2.98E+09
Tehran	1.37E+10	Sistan and Baluchestan	1.73E+08	Golestan	6.16E+08	Iran	5.25E+10

The potential of livestock manure production, biogas, electricity and energy obtainable from livestock manure and methane yield of biogas were calculated for all provinces in Iran in order to compare the results between provinces and determine which of them has the least and most potential. The amount of livestock manure production in different provinces in Iran based on Abdeshahian, Boysan and Zareei methods (*Table 4*), shows that the higher amount of the manure was produced in Tehran while the lowest amount of the manure is related to Hormozgan and it is because of this

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that Tehran and Hormozgan have the highest and the lowest number of livestock, respectively, compared to that other provinces of Iran. On the other hand, the amount of livestock manure based on Plume method (*Table 7*) shows that the higher amount of the manure was produced in Isfahan. This is due to considering the different manure production for each group of livestock (dairy cows, heifers, calves and cattle) in this method. The lowest amount of manure production still belongs to Hormozgan.

Figure 2 shows the potential of livestock manure production in Iran according to 4 different methods. It is shown that the higher amount of the manure was produced in Plume method with the annual manure production of 16.05 million ton followed by Abdeshahian, Boysan and Zareei methods with a manure production of 11.82, 5.25 and 2.1 tons, respectively. As can be seen, the amount of livestock manure produced using Zareei method was much less compared to that from Plume, Abdeshahian and Boysan methods. This is due to the fact that the lowest coefficient of manure production was considered in this method (the ratio of the annual livestock manure to livestock weight = 2.6).

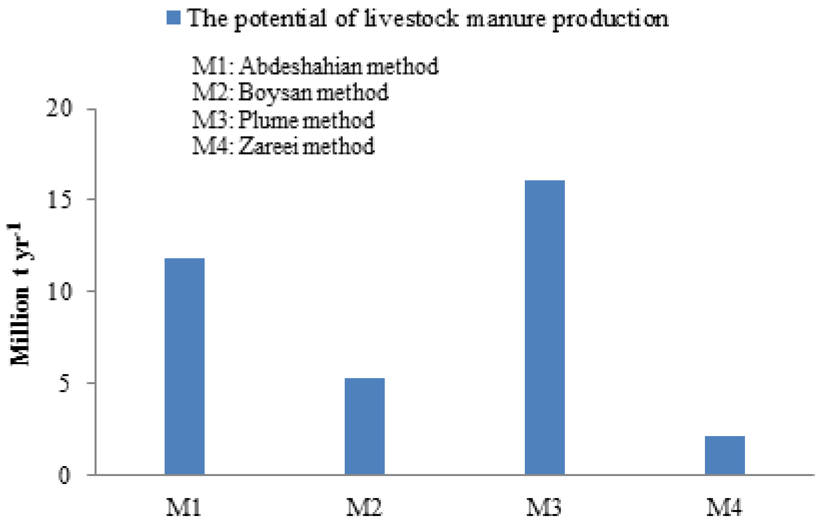

Figure 2. *Comparison the estimated values of the manure production potential in Iran using 4 different calculation methods*

The comparison of the biogas production potential in different provinces of Iran (*Tables 8* and *10*) revealed that Tehran had the highest potential of biogas evolution based on Abdeshahian, Zareei and Boysan methods, while Isfahan had the highest potential of biogas evolution based on Plume method. Hormozgan had the lowest amount of biogas production potential in each method.

The biogas production potential from the livestock manure based on 4 mentioned methods is shown in *Figure 3*. It is found that the highest potential of biogas from the manure is obtained from Abdeshahian method with the biogas production potential of 886.57 million m^3 yr^{-1}, followed by Plume, Zareei and Boysan methods with a biogas generation potential of 745.37, 565.85 and 173.36 million m^3 yr^{-1}, respectively.

This study showed that the cattle manure can be considered as the good source for the generation of biogas in an AD process. Similar observations were reported by other studies. For instance, it has been reported that Vietnam has the potential of generation

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of 16878 TJ y^{-1} biogas in 2014 from the cattle manure (Roubik et al., 2017). The study on the Nigeria biogas potential has revealed that Nigeria biogas potential from livestock manure represents a minimum of 1.62×109 m^3 of biogas per annum (Adeoti et al., 2014).

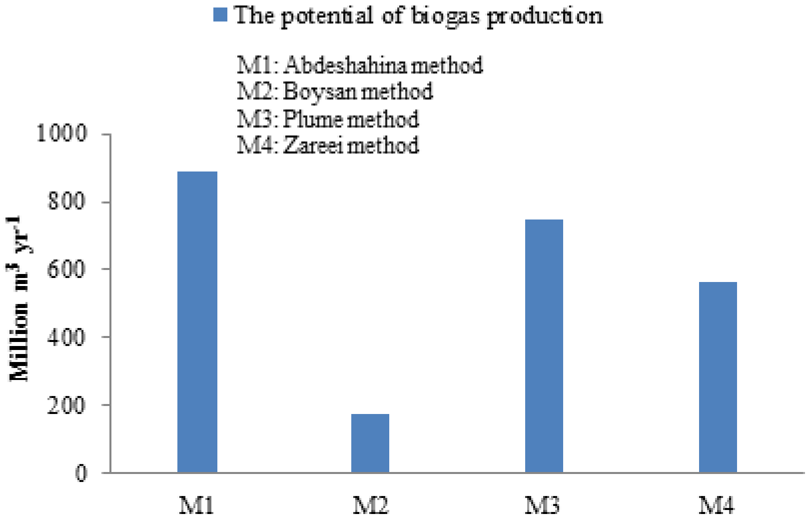

Figure 3. *Comparison the estimated values of the biogas production potential in Iran using 4 different calculation methods*

Figure 4 depicts the energy and electricity potential from livestock manure in Iran based on 4 calculation methods. As can be seen, the biogas produced from the livestock manure based on Abdeshahian, Boysan, Plume and Zareei methods was potentially able to provide the heat energy with the value of 5.14, 1, 4.32 and 3.28 thousand GWh yr^{-1}, respectively. The results shown in *Figure 4* also indicated that the total amount of electricity generation estimated in Iran based on Abdeshahian, Boysan, Plume and Zareei methods was 1.59, 0.31, 1.34 and 1.02 thousand GWh yr^{-1}, respectively. These estimated values could provide the 0.67%, 0.56%, 0.13% and 0.42% of the total electrical energy consumed in Iran in 2016 with the total electricity consumption of 237.4 billion kWh (Iran Energy Ministry, 2017). It should be noted that the electricity consumption with the value of 237.4 billion kWh was related to household, public, agricultural, industrial and other uses of the electrical energy consumed. The share of electrical energy consumption in household sector in Iran in 2016 was mainly for lightning, electrical household appliances and cooling systems with amount of 33% of the total electricity consumption. Hence, the electricity generation from livestock manure based on Abdeshahian, Plume, Boysan and Zareei methods could provide the 2.03%, 1.71%, 0.39% and 1.3% of the total electrical energy consumed in household sector in Iran in 2016, respectively, with the total electricity consumption of 78378 million kWh.

In this regard, the investigation on the potential of electricity generation from livestock manure in Malaysia showed that the total amount of electricity generation was 6.85E + 09 kWh yr^{-1} (Abdeshahian et al., 2016). Also the study on the potential for electricity generation from biogas in South Africa showed that the potential of electricity production from cattle manure was 2098553 MWh (Laks, 2017).

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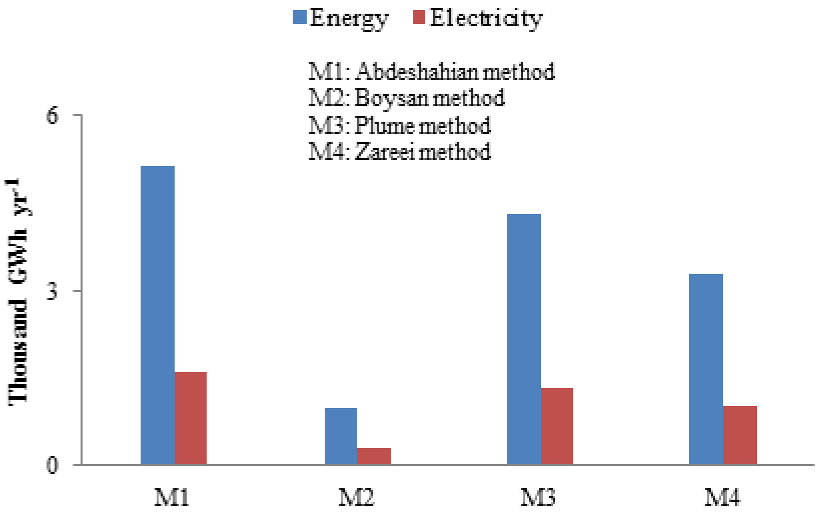

Figure 4. *Comparison the estimated values of the energy and electricity potential from livestock manure in Iran using 4 different calculation methods*

The methane production potential from the livestock manure in Iran with considering the different types of substrate (lipid, lignin, dry matter and cellulose) is shown in *Figure 5*. As can be observed, the highest potential of methane yield is related to the BMP value of lipid and lignin content at 5.27E + 10 NL CH_4 digester^{-1} day^{-1} followed by BMP value of lipid, lignin and cellulose, BMP value of lipid, lignin and dry matter and BPM value of lipid, at, respectively, 5.25E + 10, 5.03E + 10 and 4.01E + 10 NL CH_4 digester^{-1} day^{-1}.

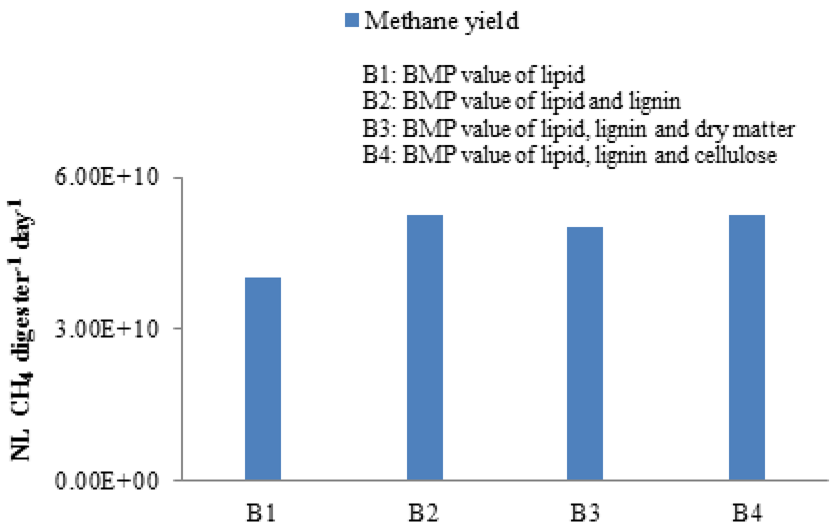

Figure 5. *Comparison the estimated values of the methane production potential from livestock manure in Iran considering the BMP value of specific substrate*

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Study fulfilled by Scarlat et al. (2018b) revealed that the potential of methane production from livestock manure in Belgium, Germany, Ireland, Spain and France is 556, 2907, 893, 2298, 3952 million m^3, respectively. These results reflect the lower methane potential in mentioned countries than Iran. This discrepancy could be related to the variation in the biotransformation rate of manure into methane and different amount of the livestock waste produced.

Conclusion

Present study focuses on the evaluation of the different methods for estimating biogas production potential from livestock manure in Iran. Biogas generation from animal wastes has rarely been assessed based on their chemical structure and the findings of this research reveal the significance of manure chemical properties to be considered or the estimation of biogas production in husbandry industry. As a result of the calculations made, the manure production was estimated as 11.82, 5.25, 16.05 and 2.1 million ton yr^{-1} based on Abdeshahin, Boysan, Plume and Zareei methods with a biogas generation potential of 886.57, 173.36, 745.37 and 565.85 million m^3 yr^{-1}, energy equivalent of 5.14, 1, 4.32 and 3.28 thousand GWh yr^{-1}, and electricity generation potential of 1.59, 0.31, 1.34 and 1.02 thousand GWh yr^{-1}, respectively. The electrical energy values could provide the 2.03%, 1.71%, 0.39% and 1.3% of the total electrical energy consumed in household sector in Iran in 2016, respectively. Furthermore the methane yield potential from the livestock manure with considering the different types of substrate (lipid, lignin, dry matter and cellulose) was evaluated. The highest methane yield was obtained from BMP value based on lipid and lignin content at 5.27E + 10 NL CH_4 $digester^{-1}$ day^{-1}. This study shows that the treatment of the livestock manure by the anaerobic digestion process is helpful for producing the huge amounts of renewable energy as biogas. In addition, anaerobic digestion of livestock waste reduces their deleterious impacts on the environment and the treated organic matters could be used for the improvement of crops growth in the agriculture land. For future studies it is recommended to develop new applicable models based on chemical composition of animal wastes to further reveal the contribution of animal waste composition in generation of biochar and precisely estimate biogas production potential from such wastes.

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