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POTENTIAL ELECTRICAL ENERGY PRODUCTION USING ESTIMATION OF WASTE COMPOSITION AND REALISTIC MODEL OF WASTE REDUCTION

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Abstract. *One of the important aspects of developing integrated waste management area is the utilization of potential landfills gas to be converted into electrical energy. Significant efforts have been conducted to predict the potential electrical energy from the waste composition method and to analyze the electrical energy output using realistic value of urban waste reduction method based on Intergovernmental Panel on Climate Change (IPCC) model. The IPCC method is utilized to determine the potential electrical energy production from the mitigation of greenhouse gas emission, especially methane gas based on urban waste composition and household waste reduction. The results show that the methane gas emission of solid waste from waste composition with non-realistic approach is estimated to produce electrical energy from 6.9 GWh in 2009 to 10.8 GWh in 2016. Meanwhile, the realistic calculation of methane gas emission by urban waste reduction method yields estimated electrical energy output between 4.6 GWh in 2009 and 6.6 GWh in 2016.*

Keywords: Waste energy, IPCC, Municipal solid waste, Waste reduction, Waste composition

1. **Introduction.** Energy harvesting is one of the main challenges to fulfill the energy demand of society worldwide. Methane gas produced in landfills gas can be utilized as a renewable energy source for electricity generation [1]. However, the methane gas is not easily harvested since the methane gas may evaporate to atmosphere. Utilizing methane gas for useful energy is the important contribution to mitigate the global warming. It is due to the fact that the methane gas in the atmosphere has significant contribution to the global warming effect compared to other typical greenhouse gases. It is predicted that the impact of methane gas is significantly higher than the same volume of carbon dioxide [2]. In other perspectives, the landfills gas is an anaerobic location that produces waste biodegradation, such as methane gas, carbon dioxide gas and other easily evaporated organic compound pollutants.

The Intergovernmental Panel on Climate Change (IPCC) report states that the human activities have been the most dominant factors (95%) of climate change by means of the global warming since the 1950s [3]. Regarding the global warming effects, the methane gas emission is potentially damaging human health, vegetation and crops for the last 20 years. A ton of methane gas causes 72 times higher temperature warming than a ton of carbon dioxide gas [4]. If the municipal solid waste can be utilized systematically, it can be potentially used for the power plants in developing countries [5]. Therefore, the capability to capture methane gas emission will help in reducing the effect of global warming. In this respect, the landfills gas by means of the methane gas can be converted into electrical energy. There are many practical data and scientific estimation of electrical potential of landfills gas. However, to limit the disparity and ambiguity observation and to enable more accurate projection of methane gas in this study, theoretical value and the actual value in the field are compared and derived [6].

International cooperation is very important in mitigating the climate change; therefore, the efforts to reduction of methane gas emission should be constantly promoted. There are many efforts to mitigate the potential methane gas emission in one country and to benefit other countries [7]. The benefits are the improvement of air quality and climate change which might be experienced globally. However, the available data of municipal solid waste and waste to energy conversion in many countries are inconsistent. These problems cause great uncertainty in estimation and reduction of urban waste. Our previous study talks about methane gas estimation method, but the approach is not straightforward to the reduction of urban waste from landfills [8].

The current situation of urban waste in Bontang City of Indonesia has not been analysed to extend the life of municipal final disposal place. Thus, the main objective of this study is to investigate the non-realistic and realistic estimation methods of waste reduction based on waste composition in order to understand the efforts to prolong the life operation of city landfills waste. To achieve this objective, the causal analysis should be taken according to the population projection using the least square method for non-realistic waste reduction method and realistic waste reduction method based on population census data in 2009-2016. In this study, the carbon emissions and waste reduction are investigated using an approach of Intergovernmental Panel on Climate Change (IPCC) [9]. The IPCC method has the default and forecasted values, the determined emissions factor to estimate the potential of electrical energy based on non-realistic and realistic estimation approaches of waste reduction from waste composition. By verifying the parameter relationship, the appropriate strategies can be developed to extend the life of municipal waste disposal location. In addition, the analysis of potential electrical energy conversion from the waste municipal reduction is highly recommended to ensure the benefits of waste landfills utilization.

The outline of the paper is presented as follows. It begins with the importance study of the potential landfills gas utilization into electrical energy including the objective of this study. Then, the methodology based on population projection that contributes to potential methane gas production in the study location is described. Later, some scenarios of results and discussion are presented. The conclusion including the main challenge of municipal waste management is denoted in the end.

2. Methodology.

The research methodology to analyze the effects of landfills gas emission and the mitigation of waste reduction to be converted into potential electrical energy is conducted based on the projection of city population and modeling of methane gas production from landfills gas. The more detailed explanation regarding the methodology is described as follows.

2.1. Projection of population of Bontang City of Indonesia.

According to Indonesia National Law No. 18 of 2008 about the waste management, the processed waste is the waste from household and waste similar to household waste. Household waste is derived from daily activities of people excluding feces and specific waste. Waste similar to household waste is from commercial, industrial and special locations, social & public facilities, and/or other facilities [10]. The data of waste volume is obtained from garbage heap, waste composition and reduction of waste method is from the garbage bank activities, integrated landfills, composting, waste in company areas. For this reasons, the number of population has the significant contribution to the daily waste volume and the municipal waste management. In this study, the projection of city population is calculated with the least square method as in Equation (1) as follows.

$$\widehat{Y} = a + bX \tag{1}$$

$$a = \frac{\sum y \sum x^2 - \sum x \sum y}{n \sum x^2 - \left(\sum x\right)^2} \tag{2}$$

$$b = \frac{n \sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2} \tag{3}$$

where $\widehat{Y}$ is the variable value according to the regression line. In this study, this variable is the population projection of the year. X is the independent variable which is the year calculation. n is the year of data population. a in Equation (2) and b in Equation (3) are the constant and the direction coefficient of linear regression, respectively.

2.2. **Models of methane gas production from landfills.** The research method to calculate the carbon gas emission and waste processing reduction is the Intergovernmental Panel on Climate Change (IPCC) method. The IPCC method is used for the reasons of the availability information of default and estimation values including the emission factor set by IPCC. Using this technique, the methane gas emission is calculated in Equation (4) as follows.

$$ME = \left(\frac{MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times 16}{12} - R\right)(1 - OX) \tag{4}$$

where ME is the methane gas emission in Gg/year, MSW_T is the garbage heap entering the processing or landfills area in Ton/year, MSW_F is the percentage of waste entering processing or landfills area compared with waste production, MCF is methane gas correction factor. In this case, Indonesia does not currently own gas processing equipment in landfills; therefore, $MCF = 0.4$ is selected for the calculation, DOC is the carbon organic degradation based on IPCC, DOC_F is the DOC fraction which is 0.77, F is the fraction based on methane gas volume in landfills where the value of IPCC is 0.5, R is the methane gas stored in the gas processing instrument. Indonesia does not have gas processing instrument; therefore, the methane gas stored from garbage heap cannot be measured (R is set to be 0). The last variable is OX which is the oxidation factor where the standard IPCC value is 0.1.

In addition, the approach to calculating the potential electrical energy production, the gas volume in m^3 is converted to electrical energy unit in kWh where 1 m^3 of methane gas equals 11.17 kWh, while 1 kWh equals 3.6×10^7 J. Therefore, the methane gas in 1 m^3 potentially produces 402.12 MJ of electrical energy [11].

3. **Case Study.** The study is conducted in waste municipal landfills area in Bontang City as a part of East Kalimantan Province, Indonesia. The waste volume in this city is highly influenced from the number of population. The increased population may produce the significant amount of garbage heaps [12]. About 70.4% of the waste produced by the people of Bontang City is sent and transported to Bontang Lestari landfills. The waste management in Bontang Lestari Landfills utilizes sanitary landfills method which is alternating waste management between soil layers as cover material. The landfills area utilization is about 10 h.a and planned to be 16 m high. The calculation of landfills capacity is based on planned garbage heap which will affect the life of landfills utilization [12,13]. The Bontang Lestari landfills will be able to dump up to 960.000 m^3 of waste. The layout of landfills area including the surrounded facilities is shown in Figure 1.

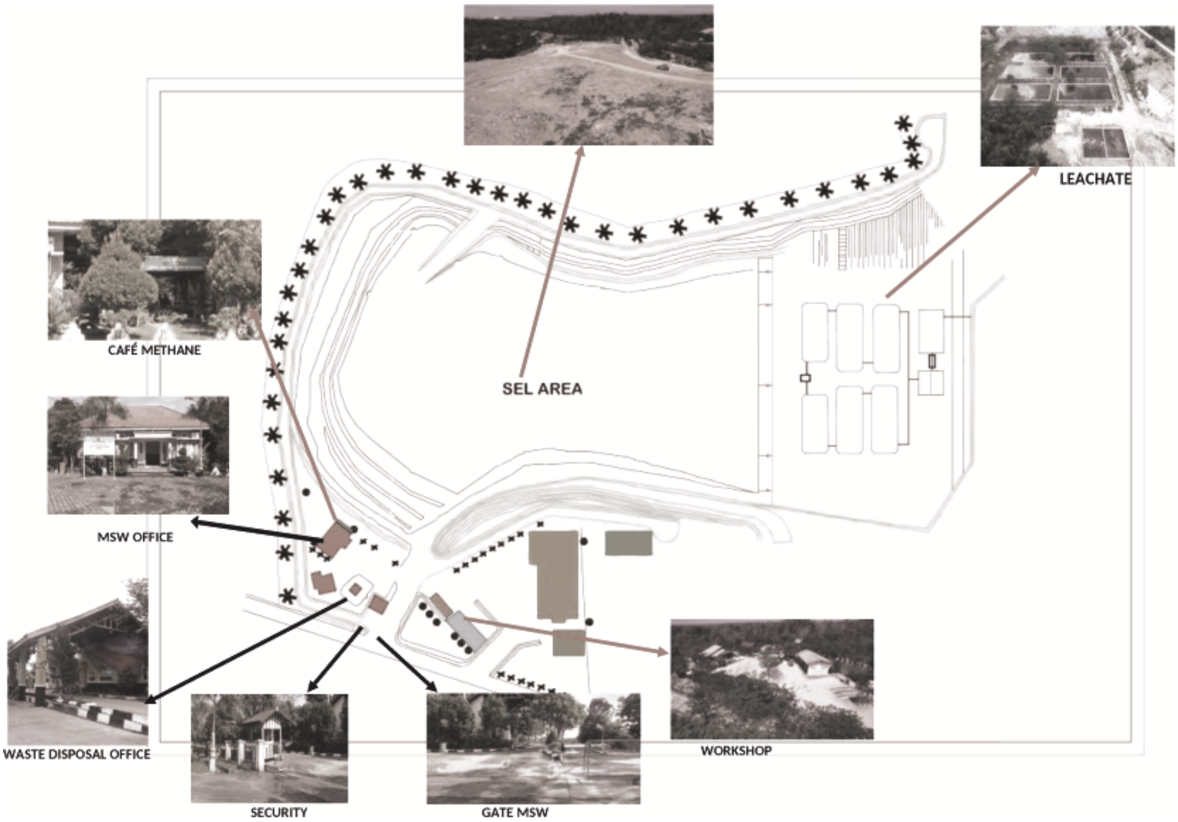


FIGURE 1. Layout of waste landfills utilization in Bontang City

4. Results and Discussion.

4.1. Estimation of landfills gas emission of Bontang City. The average population growth of Bontang City from 2005 to 2020 is relatively high with 1.62% per year. The population is spread in three sub-districts, which are North Bontang, South Bontang and West Bontang sub-districts. The projection of population is calculated by the least square method in Equation (1) with the correlation coefficient approaching 1.0. The calculation result indicates that the population in Bontang City as shown in Table 1 is predicted to be 200,339 people in 2020.

TABLE 1. Projection of population of Bontang City

Total Population (People)									
Year	2003	2004	2005	2006	2007	2008	2009	2010	2011
People	117,082	118,548	122,043	128,614	133,737	138,861	143,984	149,107	154,230
Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
People	159,353	164,477	169,600	174,723	179,846	184,969	190,092	195,216	200,339

Such a large number of people surely contribute to the municipal waste volume. In this case, the waste composition is the component of each solid waste stated in the weight percentage of waste [14]. The waste composition components consist of two groups, i.e., the organic and inorganic waste compositions. The organic wastes are for instance the food remnant, carbon, rubber, wood, paper, leather, and fabric. Meanwhile, the inorganic wastes are glass, aluminum, ash, metal, plastic. Data utilization is stated as recovery factor. This factor is related to the percentage of every waste composition groups which can be reused or recycled from the total waste [15]. Figure 2 shows the percentage of recovery factor of waste in Bontang City. The compositions of organic landfills wastes are 44% of remaining organic food, 13% of paper, 9% of wood and leaves. On the other

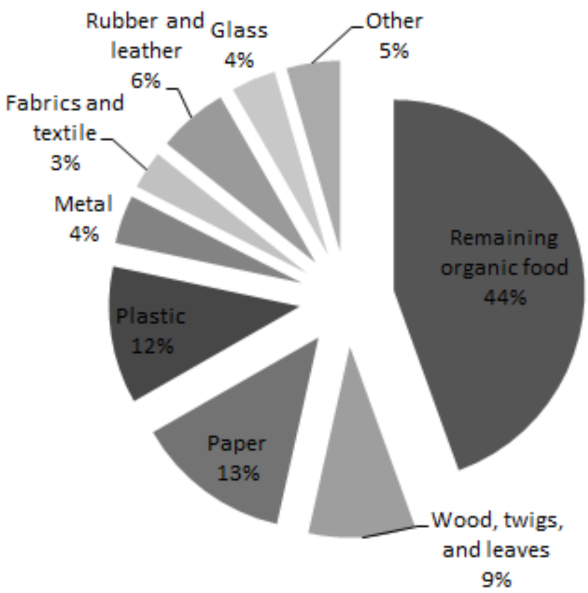
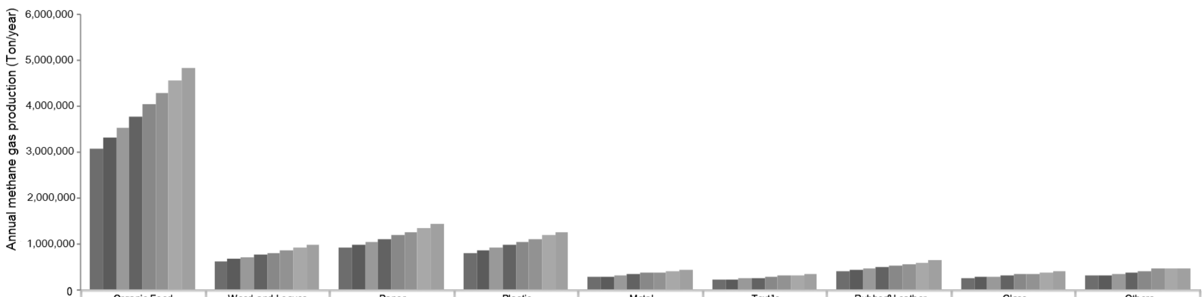


FIGURE 2. Composition of waste in Bontang City



	Organic Food	Wood and Leaves	Paper	Plastic	Metal	Textile	Rubber&Leather	Glass	Others
2009	3,084,523	626,338	917,658	806,678	286,464	224,732	412,703	262,881	314,209
2010	3,307,934	671,703	984,123	865,106	307,213	241,009	442,595	281,922	336,967
2011	3,539,156	718,654	1,052,912	925,576	328,687	257,856	473,532	301,628	360,521
2012	3,778,187	767,192	1,124,025	988,089	350,886	275,271	505,514	321,999	384,870
2013	4,025,030	817,315	1,197,462	1,052,644	373,810	293,256	538,541	343,037	410,015
2014	4,279,682	869,024	1,273,222	1,119,242	397,460	311,809	572,613	364,740	462,692
2015	4,542,145	922,320	1,351,306	1,187,882	421,836	330,932	607,730	387,108	462,692
2016	4,812,418	977,201	1,431,713	1,258,566	446,937	350,623	643,892	410,143	490,223

Waste of Composition 2009-2016

FIGURE 3. Annual expectation of methane gas production

hand, the compositions of inorganic landfills waste are 12%, 6%, 4% and 8% of plastic, rubber & leather, glass & metal and other materials, respectively.

The waste group in Figure 2 influences the result of calculation of methane gas emission to be converted into electrical energy as shown in Figure 3. The waste composition of organic food remnants in 2009-2016 produced the average maximum of methane gas emission of about 3.92 Mton/year. The wastes of paper and other organic materials contribute to the average methane gas emission of 2.26 Mton/year and 1.54 Mton/year, respectively. Meanwhile, the inorganic plastic waste produced methane gas emission of 1.99 Mton/year. The overall waste composition in Bontang City between 2009 and 2016 was averagely about 17.1 Mton/year of methane gas emission. These methane gas emissions might be converted into electrical energy. There is gradually increase in potential harvesting of electrical energy from 6.9 GWhin 2009 to 10.8 GWh in 2016 as shown in Figure 4.

4.2. **Realistic model of urban waste reduction.** The volume number of waste is highly depending on the population size. The population data is obtained from population

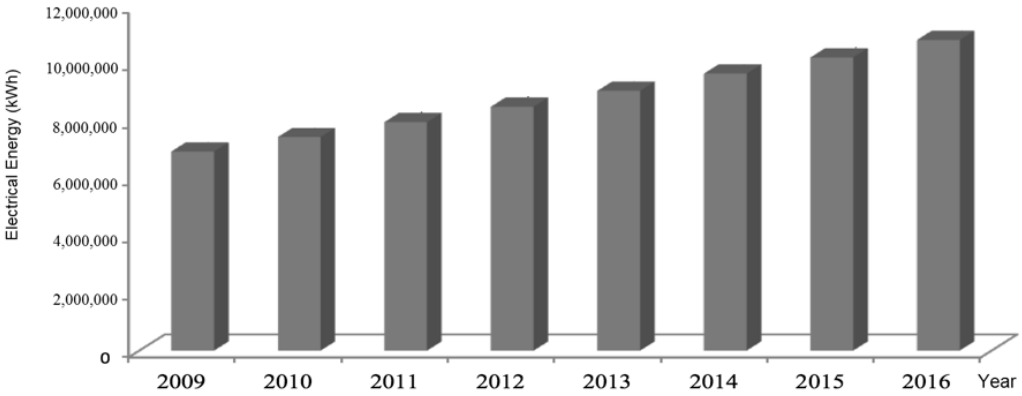


FIGURE 4. Potential electrical energy of waste composition

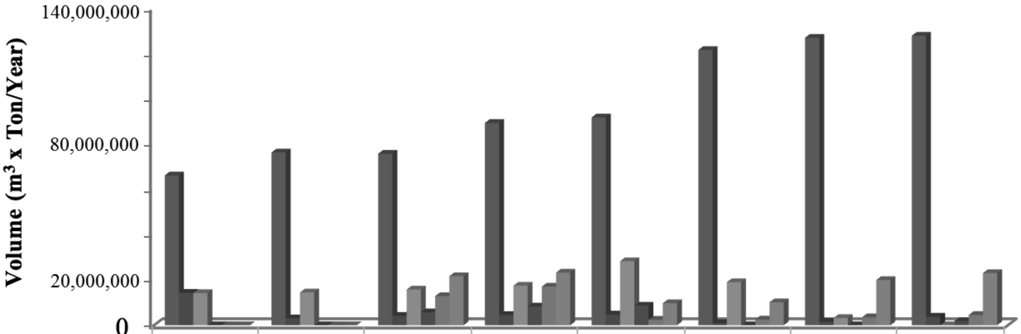
TABLE 2. Waste generation of Bontang City in 2009-2016

Total Population (People)				
Year	2009	2010	2011	2012
People	137,349	143,683	149,230	154,604
Garbage heap (m^3)	92,710,575	80,821,688	83,941,875	86,964,750
Year	2013	2014	2015	2016
People	158,109	161,413	164,258	166,868
Garbage heap (m^3)	88,936,313	90,794,813	92,395,125	93,863,250

census of Bontang City in 2009-2016. The data is considered as the realistic model to determine the garbage heap of Bontang Lestari landfills. In this respect, the table shows that the population growth of Bontang City increases every year which causes the increase in the amount of waste. The waste generation of landfills utilized the data of waste entering the landfills for 12 months in 2009-2016 which was the last recorded in weighbridge as shown in Table 2.

Waste reduction to landfills process follows some mechanisms. The garbage might be processed through integrated landfills, composting in landfills, garbage from banks and schools and waste processed by scavengers. The waste from banks will not produce emission, but the waste volume is reduced. The calculation results of methane gas emission of waste reduction based on Equation (4) are shown in Figure 5. The waste processed in the landfills contributed an average of 60.5 Mton/year of waste processed in 8 years with the potential electrical energy production of 6.6 GWh as shown in Figure 6. The trend of total waste reduction processed in landfills increased every year. Meanwhile, the wastes volume processed in the integrated landfills, in companies and composting in landfills are fluctuated depending on the environmental awareness, budget and priority development.

It is important to compare the potential electrical energy production from the methane gas harvesting according to two approaches, i.e., the non-realistic model by means of the waste composition and realistic model by means of the urban waste reduction. It can be seen in Figure 7 that through the efforts of waste reduction model, the potential yields of electrical energy production are slightly lower than the results by only the waste composition method. The potential waste to energy of methane gas emission is predicted through waste composition based on solid waste varied from 6.9 GWhin 2009 to 10.8 GWh in 2016. In comparison, the realistic model requires realistic parameter with some limitations. For this reason, the methane gas emission from urban waste reduction method may produce electrical energy varied between 4.6 GWh in 2009 and 6.6 GWh in 2016.



	2009	2010	2011	2012	2013	2014	2015	2016
Waste processed in landfill	66,167,837	76,286,042	75,758,139	89,352,350	91,783,685	121,590,752	126,965,055	127,852,370
Waste processed in landfill temporary	14,348,881	3,052,925	4,161,196	4,536,080	4,744,085	946,626	1,505,445	3,793,838
Temporary dump site	14,210,085	14,465,984	15,767,033	17,446,464	28,282,049	19,017,043	3,185,942	0
Composting in landfill	0	0	5,715,223	8,270,916	8,650,184	0	0	1,860,787
Waste Banks and school	0	0	12,859,253	17,058,765	2,432,864	2,535,605	3,501,035	4,516,474
Waste processed by scavenger	0	0	21,672,898	23,261,953	9,731,457	10,142,423	19,955,902	23,034,021

Figure 5. Volume of methane gas emission of urban waste reduction

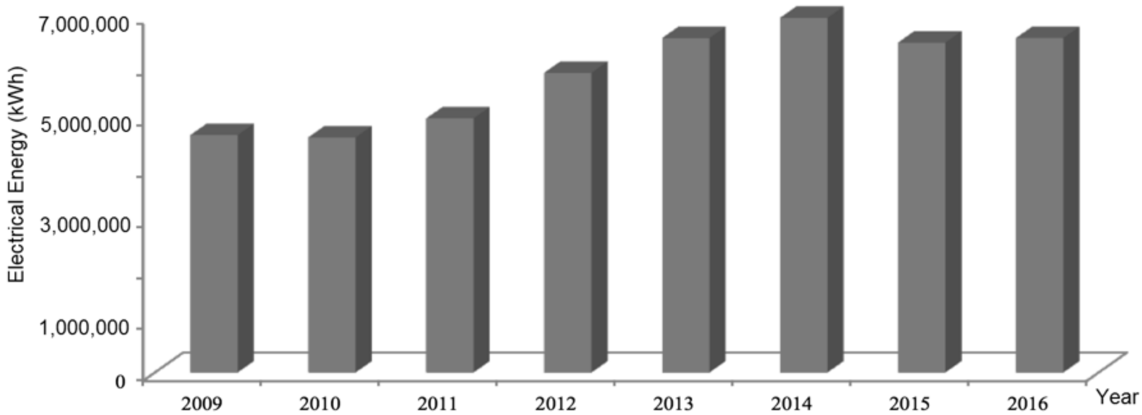


Figure 6. Potential electrical energy production by waste reduction

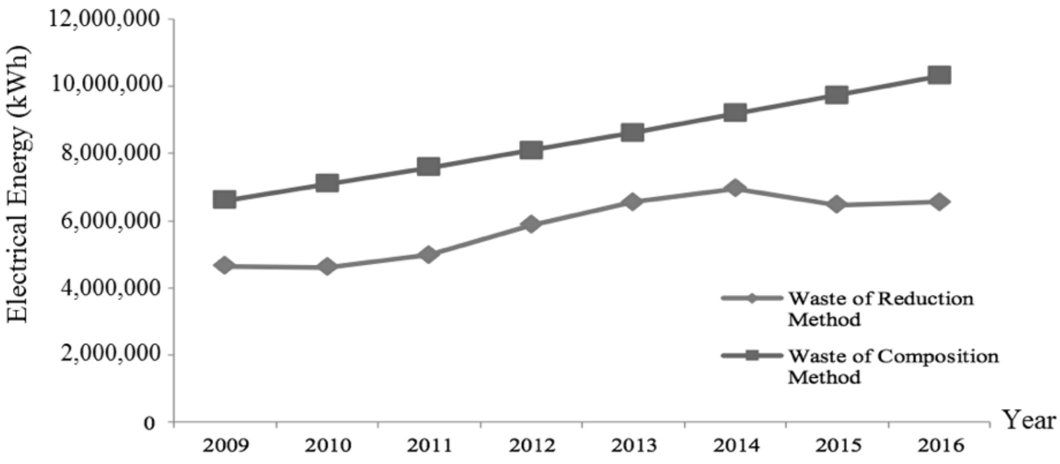


Figure 7. Comparison of estimated energy production

5. **Conclusion.** The population growth is surely increasing the waste generation that may produce the methane gas for electrical energy utilization. The waste composition in Bontang City is dominated by organic food with an average potential of 3.92 GWh. If only the waste volume based on number of population is considered, the potential waste to energy conversion increased from 6.9 GWh in 2009 to 10.8 GWh in 2016. Meanwhile, the realistic model with several constraints regarding the waste management may include the real data of population growth using data of population census of Bontang in 2009-2016. In this respect, the potential waste to energy conversion by urban waste reduction method by means of methane gas emission shows the yield of energy varied between 4.6 GWh in 2009 and 6.6 GWh in 2016. These comparison values are highly important to be determined in order to predict the life operation of landfills waste. In addition, there should be more detailed study to determine the appropriate conditions regarding the landfills waste management, such as the social behaviour of local population to treat the solid waste due to the lack of awareness, limited budget and low priority.

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