Overview of Municipal Solid Waste Generation and Energy Utilization Potential in Major Cities of Indonesia

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Abstract. Problems in municipal solid waste sector remains a challenge to solve for the government of Indonesia. Processing waste into fuel, or known as refuse derived fuel (RDF), are some of the technological alternatives considered to tackle the waste problem. This paper aims to describe recent information on municipal solid waste generation in major cities of Indonesia, including DKI Jakarta, Tangerang, Bekasi, Bandung, Semarang, Surakarta, Surabaya, Makassar, Denpasar, and Palembang, and to overview its potential for energy utilization as refuse derived fuel (RDF). Municipal solid waste generation in Indonesia was assessed based on sources, generation rate, and composition data by year of 2018. Data was obtained from the State Ministry of Environment and Forestry’s (SMEF) national inventory of waste generation website, the National Waste Information System (SIPSN). To assess refuse derived fuel (RDF) potential, waste characteristics such as calorific value, water content, volatile content, ash content is evaluated for each composition. In those cities, municipal solid waste generation rate was 0.69 kg/capita-day, with 1780 tonnes/day generated on an average per city. Household sector was significantly the largest source of municipal solid waste generation in all cities in Indonesia, which contributed 44-75% to total waste generated. The composition of municipal waste consists of 43.78% of food waste, 16.05% of paper, and 14.08% of plastics. The result of calculations showed that, mixed municipal solid waste from those cities has high water content with average of 49.94%, high volatile content with average of 53.34%, and low ash content with average of 6.12%. Calculated heating value of the mixed municipal solid waste is 9.5 MJ/kg which is lower than standard for refuse derived fuel of 12.56 MJ/kg. Therefore, sorting and pre-treatment mixed municipal solid waste in Indonesia is necessary to meet the criteria of refuse derived fuel material.

1. Introduction
Indonesia, which ranks fourth largest country by population in the world, still faces many challenges in municipal solid waste treatment and disposal. Population growth are contributing to ever increasing amount of waste generated in Indonesia. Based on the last population census in 2010, total population of Indonesia was 237,641,326 people with 1.36% growth rate and was estimated to reach 271,066,400 people by 2020 [1]. Meanwhile, more than 38.5 million tonnes municipal solid waste was estimated to be generated yearly with 2-3% increase every year [2]. With its increasing amount, municipal solid waste sector has a big challenge to tackle waste problems because there will be an increase in demand of resources, facilities, budget,
and risks. Appropriate management of municipal solid waste is critical, due to unsustainable handling of waste might result in bigger problem. On the other hand, around 70% of MSW worldwide still ends up in landfills or uncontrolled dumpsites, which often cause surface water, soil or groundwater contamination and release greenhouse gases [3]. The United Nations on Sustainable Development Goals (SDG) and the New Urban Agenda of UN Habitat also mentions the importance on proper treatment of MSW, highlighting call for changes to waste management activities as a basic service to people.

By the year of 2013, solid waste sector data in Indonesia was limited and may be inadequate. Management of the solid waste sector in Indonesia is coordinated by two main stakeholders, consist of the Ministry of Public Works and Public Housing (MPWPH) for the infrastructure, and the State Ministry of Environment and Forestry (SMEF) for control and monitoring [4]. Waste generation data provided by cities to the national stakeholders may be obtained by field survey and sampling or by estimation. Estimation usually was conducted by using average generation rate 2.5–3.0 l/capita/day based on National Standard of Indonesia (SNI) SNI S 04-1993-03 regarding National Standard of Municipal Solid Waste Management in Indonesia [5]. As the main stakeholder for waste management in national level, State Ministry of Environment and Forestry (SMEF) had just established the National Waste Information System (SIPSN) in 2016. Using the newly established data, we can better understand real data on municipal solid waste generation, by cities in a national level. The purpose of this paper is to describe updated and recent information on generation rate, percent composition, and characteristics of municipal solid waste, especially in major cities of Indonesia, consist of DKI Jakarta, Tangerang, Bekasi, Bandung, Semarang, Surakarta, Surabaya, Makassar, Denpasar, and Palembang, and to overview the potential of using municipal solid waste as a source of renewable energy utilization.

Beside the problem waste may create, it can also be seen that Indonesia has large untapped potential as renewable energy sources. Waste to Energy (WtE), which transforms waste into renewable energy in the form of electricity and heat, is one of the promising approaches to counter waste problem. Worldwide, there are multiple WtE options, such as anaerobic digestion, incineration, gasification, co-processing of refuse derived fuel (RDF), and landfill gas capture [5, 6]. Several waste-to-energy systems are currently operating in some Indonesian landfills, such as the Bantargebang landfill using landfill gas recovery methods [7], which assessed to have the potential of electricity generation up to 4.5 GWh, emission reduction potential to 4325.88 tCO2/year, and economic benefit from electricity price to 3.7 billion rupiah [8]. One challenging in WtE implementation in Indonesia is majority landfill still using an open dumping method. Most municipal solid waste generated in Indonesia ends in open dumping landfill by 85.4%, controlled landfill 10%, and sanitary landfill 4.6% [9, 10]. This paper would also give overview of using current municipal solid waste generated in Indonesia, for use in a waste-to-energy scheme, as an RDF sources. RDF production is intended to redirect combustible fractions from municipal solid waste (MSW) to fuel production and then to be used as a replacement or supplementary energy [11].

2. Material and Method

2.1. Municipal Solid Waste Generation

Municipal solid waste generation in Indonesia is assessed based on sources, generation rate, and composition data. Data used in this research is secondary data, which obtained from the State Ministry of Environment and Forestry’s (SMEF) national inventory of waste generation data, which published on the National Waste Information System (SIPSN) website, http://sipsn.menlhk.go.id. Municipal Solid Waste generation data were collected by cities from the latest year available, which is year of 2018. Cities included in this research were cities prioritized for development of waste-to-energy treatment plants (PLTLSa) based on Presidential Regulation No 35 Year of 2018 regarding the Acceleration of the Construction
of Waste-to-Energy Treatment Plants based on Environmentally-Friendly Technology. Based on the regulation, 10 cities covered in this study are DKI Jakarta, Tangerang, Bekasi, Bandung, Semarang, Surakarta, Surabaya, Makassar, Denpasar, and Palembang. Manado City and South Tangerang City were also regulated but were excluded from analysis due to lack of data available on the SIPSN website.

2.2. Water Content and Heating Value
The potential of solid waste into energy can be predicted based on parameters such as calorific value, water content, ash content, and several other parameters. The potential of using municipal solid waste as renewable energy source is related to its high calorific value [12]. In this study, the parameters were focused on calorific value and water content for calculation. The determination of waste characteristics from municipal solid waste in Indonesian city was carried out by [13] by using proximate analysis, as shown in Table 1. Whereas, the heating value is calculated based on several studies in various regions, namely Indonesia [14], Korea [15], Algeria, America [16], California, America [17], as well as based on Stuttgart, Europe [18], in Table 2. As for food waste composition, the heating value is considered zero due to its high percentage of water content.

Waste to energy concept will be applied to determine the RDF potential which is depend on its heating value of each waste types. The heating value for mixed municipal solid waste is calculated based on each water content and heating value of waste composition data. Heating value of mixed municipal solid waste then compared to the standard heating value for RDF. It is based on the application of RDF for co-processing in cement kilns by PT. Indocement is 12.56 MJ/kg [19], and typical refuse derived fuel standard by [20] is 12 MJ/kg.

### Table 1. Municipal solid waste characteristics in Indonesian cities [13]

| Parameters            | Food waste | Paper waste | Yard waste | Leather and rubber waste | Textile waste |
|-----------------------|------------|-------------|------------|--------------------------|---------------|
| Water content (%)     | 76.46      | 42.74       | 71.59      | 57.17                    | 64.38         |
| Volatile content (%)  | 91.07      | 86.91       | 74.93      | 80.92                    | 77.92         |
| Ash content (%)       | 8.92       | 13.09       | 25.06      | 19.08                    | 22.07         |

### Table 2. Higher Heating Value by composition on various literatures (MJ/kg)

| Composition          | Heating Value (MJ/kg) |
|----------------------|-----------------------|
|                      | Indonesia¹ | South Korea² | Algeria, US³ | California⁴ |
| Plastic              | 40.0       | 33.49       | 33.5        | 32.56       |
| Rubber and Leather   | 21.8       | 30.14       | 23.5        | 23.26       |
| Paper                | 15.2       | 15.02       | 17.7        | 16.75       |
| Yard                 | 40.7       | 18.42       | 20.0        | 17.45       |
| Textile              | 18.9       | 21.77       | 32.5        | 17.45       |

¹Damanhuri, 2010
²Dong & Byeong-Kyu, 2009
³Cheremisinoff, 2003
⁴Tchobanoglous, Theisen, & Vigil, 1993 (typical value)
Table 3. Contribution of different sectors to total waste generation (SIPSN, 2018)

| Province/City    | Household | Office | Traditional Market | Commercial Facilities | Public Facilities | Estate | Other |
|------------------|-----------|--------|--------------------|-----------------------|-------------------|--------|-------|
| DKI Jakarta      | 51.00%    | 9.00%  | 5.00%              | 8.50%                 | 9.50%             | 8.00%  | 9.00% |
| Tangerang        | 76.80%    | 0.30%  | 14.10%             | 5.80%                 | 2.80%             | 0.10%  | 0.10% |
| Bekasi           | 65.03%    | 3.02%  | 11.03%             | 8.99%                 | 4.00%             | 5.96%  | 1.96% |
| Bandung          | 66.00%    | 3.00%  | 19.00%             | 6.00%                 | 5.00%             | 1.00%  | 0.00% |
| Semarang         | 70.00%    | 2.00%  | 5.00%              | 5.00%                 | 3.00%             | 10.00% | 5.00% |
| Surakarta        | 62.68%    | 1.42%  | 16.24%             | 5.98%                 | 4.56%             | 3.13%  | 5.98% |
| Surabaya         | 43.45%    | 4.97%  | 4.53%              | 12.60%                | 13.30%            | 5.98%  | 15.16%|
| Makassar         | 62.99%    | 8.49%  | 2.98%              | 13.37%                | 1.13%             | 0.90%  | 10.14%|
| Denpasar         | 70.00%    | 2.00%  | 5.00%              | 3.00%                 | 10.00%            | 10.00% | 0.00% |
| Palembang        | 74.68%    | 0.31%  | 15.47%             | 1.74%                 | 2.93%             | 0.02%  | 4.86% |
| Average          | 64.26%    | 3.45%  | 9.84%              | 7.10%                 | 5.62%             | 4.51%  | 5.22% |

3. Result and Discussion

3.1. Source of Municipal Solid Waste

Source of waste is one of the important factors to determine waste characteristics. Based on Table 3, among other sectors, households significantly were the most dominant source by percentage to the total municipal waste generation in all cities. This generally represents dominant source of municipal solid waste in Indonesia. According to [7], the principal source of municipal solid waste in Indonesia is household sector, which generated 50–60% (wet-weight) of the total generation per day. Moreover [21] mentioned that residential localities, small-scale industries, commercial areas, markets, and public facilities are the major source of municipal solid waste in Indonesia. In general, DKI Jakarta and Surabaya have a relatively lower contribution from household sector, by 51% and 43.45% respectively. This might relate to characteristics of human activities done in those two metropolitan cities with various facilities.

3.2. Municipal Solid Waste Generation

Jakarta as the capital of Indonesia and the highest population city in Indonesia produces the highest municipal solid waste generation and is followed by Surabaya City. Based on the National Urban Development Strategy (NUDS) in 2006 the potential of municipal solid waste in Jakarta was 4892 tonnes/d, Surabaya of 1457 tonnes/d, and Bandung of 1301 tonnes/d. This greatly increases from the current data that can be seen in Table 4. Community-based solid waste management (CBSWM) in Jakarta plays a role on municipal solid waste reduction by composting and recycling inorganic waste with local community helps [22]. Based on data obtained by Juhaidah (2019), waste generation in Makassar City reaches around 600-700 tonnes/d, which are very different from the SIPSN data. By average, 0.69 kg of municipal solid waste is generated per capita per day from major cities of Indonesia.

In Figure 1, the trend of total municipal solid waste generation (tonnes/d) was compared to the rate of municipal solid waste generation per capita (kg/cap/d) by cities. Total municipal solid waste generation in a city was not always linearly related to its per capita rate of generation. For instance, in cities with relatively large generation of municipal solid waste, such as DKI Jakarta and Surabaya. In Surabaya, rate of generation per capita was the highest than all cities. Meanwhile, for DKI Jakarta which total generation is the largest, its per capita rate of generation is relatively low, nearly the same as Surakarta, which total generation is the smallest. The production of municipal solid waste is directly linked to its contributing population [23].
While rate of municipal solid waste generation is related to the human consumption behaviour.

3.3. Municipal Solid Waste Composition

The composition of waste used based on SIPSN data can be seen in Table 5 and Figure 2. According to Tchobanoglous (1993), the simpler lifestyle of the community will contribute to more components of organic waste (leftovers, etc.). The greater and more diverse activities of a city will give smaller proportion of waste from household activities which are generally dominated by organic waste. Table 5 shows that the weight of food waste is the biggest compared to others composition. This food waste is very suitable for use in biological processing processes such as biodigester [24, 25]. Figure 3 highlights the variation of municipal solid waste composition by cities, all cities is dominated by food waste composition, except for Denpasar.

Table 4. Rate of MSW generation in various major cities of Indonesia

| Province/City | Population (capita) | Total MSW Generation (tonnes/d) | MSW Generation Rate (kg/cap/d) |
|---------------|---------------------|---------------------------------|-----------------------------|
| DKI Jakarta   | 10 596 244          | 6234                            | 0.59                        |
| Tangerang     | 2 205 800           | 1223                            | 0.55                        |
| Bekasi        | 2 483 283           | 1224                            | 0.49                        |
| Bandung       | 2 574 874           | 1495                            | 0.58                        |
| Semarang      | 1 780 791           | 1270                            | 0.71                        |
| Surakarta     | 524 256             | 309                             | 0.59                        |
| Surabaya      | 2 801 991           | 2791                            | 1.00                        |
| Makassar      | 1 521 769           | 1425                            | 0.94                        |
| Denpasar      | 936 426             | 750                             | 0.80                        |
| Palembang     | 1 670 493           | 1080                            | 0.65                        |
| **Average**   | **-**               | **1780.11**                     | **0.69**                    |

Figure 1. Comparison of MSW generation (tonnes/d) to rate of MSW generation per capita (kg/cap/d) trends in various major cities of Indonesia.
Table 5. Composition of MSW generation in various major cities of Indonesia by % w/w wet-weight [26]

| Province/City     | Food waste | Yard | Paper | Plastic | Metal | Textile | Rubber & Leather | Glass | Others |
|-------------------|------------|------|-------|---------|-------|---------|-----------------|-------|--------|
| DKI Jakarta       | 53.01%     | 5.82%| 10.37%| 12.40%  | 1.81% | 2.90%   | 1.50%           | 2.45% | 7.65%  |
| Tangerang         | 61.38%     | 2.24%| 8.94% | 10.97%  | 1.68% | 2.32%   | 2.09%           | 1.78% | 8.61%  |
| Bekasi            | 63.19%     | 7.06%| 4.23% | 17.08%  | 0.70% | 6.39%   | 0.51%           | 0.50% | 0.34%  |
| Bandung           | 19.80%     | 32.20%| 10.80%| 11.60%  | 4.30% | 3.50%   | 1.90%           | 3.60% | 12.30% |
| Semarang          | 31.60%     | 12.36%| 14.74%| 15.49%  | 20.81%| 1.72%   | 0.50%           | 0.75% | 2.03%  |
| Surakarta         | 56.75%     | 5.20%| 12.26%| 13.39%  | 1.80% | 1.50%   | 0.50%           | 1.72% | 6.83%  |
| Surabaya          | 54.31%     | 1.61%| 14.63%| 19.44%  | 0.48% | 1.47%   | 2.33%           | 1.12% | 4.61%  |
| Makassar          | 38.82%     | 10.65%| 5.69% | 16.29%  | 2.70% | 1.22%   | 2.18%           | 0.98% | 15.43% |
| Denpasar          | 5.58%      | 3.15%| 62.61%| 7.04%   | 9.12% | 5.10%   | 2.02%           | 5.31% | 0.07%  |
| Palembang         | 53.35%     | 7.60%| 16.20%| 17.05%  | 0.55% | 2.00%   | 0.70%           | 1.15% | 1.40%  |
| Average           | 43.78%     | 8.79%| 16.05%| 14.08%  | 4.40% | 2.81%   | 1.42%           | 1.94% | 5.93%  |

Figure 2. Composition of MSW generated daily in various major cities of Indonesia

3.4. Water content, Volatile content, and Ash Content

According to [27], solid waste treatment with heat energy can be performed through incineration, pyrolysis, and gasification. Study of [28] stated that incineration is carried out using energy recovery systems. Waste processed into RDF can be determined based on parameters such as calorific value, water content, volatile content, ash content, chlorine content, and various other parameters. The results of calculations based on Table 6 show the average water content is quite high at 49.94%. Based on its water content, municipal solid waste in Indonesian major cities has not conformed to the standard of water content for RDF which is only maximum 15% allowed [21]. European countries like Italy, used a value of j20 %d ash content as criteria for standard RDF, and j15 %d ash content for high quality RDF.

Water content will affect to the initial ignition (sooner or later), therefore it is necessary to look at ash content and volatile levels of waste. The value of volatile content is quite high with an average of 53.34%, while the ash content is relatively low with an average of 6.12%. Chiemchaisri et al. (2010) suggested that the higher content of volatile levels, will make easier process of fuel to be burnt and to be ignited, so that the rate of combustion will be faster. [12] stated that high calorific values usually have high volatile content and low ash content.
3.5. Heating Value of Mixed Municipal Solid Waste

Based on study conducted by [18], RDF is known as an alternative fuel generated from the flammable waste fraction which is composed of plastic waste and other materials such as textiles, wood etc. Paper, wood, cloth and rubber/leather waste is included in the type of waste that can be processed into RDF as an alternative energy substitute for fossil fuels to handle the untreated waste [19]. In order to assess utilization potential as RDF sources, heating value of mixed municipal solid waste then compared to standard heating value for RDF. Figure 3 showed that from the average view, heating value of mixed municipal solid waste in Indonesian Major Cities is 9.5 MJ/kg which is lower than standard for RDF of 12.56 MJ/kg [9], and typical RDF standard by [10] of 12 MJ/kg.

The minimum heating value required for waste incineration is 6.28 MJ/kg, while the average heat value of waste in Indonesia is 4.19 MJ/kg [7]. In order to improve the heating value for RDF sources, separation and selected process of waste is necessary. It will give benefit of more uniform in particle size and has a higher heating value of waste. In Indonesia itself, the use of waste as refuse derived fuel has been carried out in cement industries by co-firing process, using selected municipal solid waste such as tire waste, rice grain, sawdust, oil mud, etc [8]. The biggest challenge to answer in using municipal solid waste (MSW) as solid fuel in developing countries like Indonesia are its high water content, irregular size and shape, and difficulty in processing due to the mixture of plastic and organic waste [9]. Mixed MSW in developing countries usually have lower calorific value than in industrialized countries due to high moisture, organic content, and mineral content in waste [20]. This highlights the importance of pre-treatment and sorting of waste in overall solid waste management process to successful application of refuse derived fuel in Indonesia. There are several pre-treatment methods available, such as wet torrefaction which is currently developed. In addition to converting the mixed MSW into high-energy density solid fuel, the wet torrefaction process can also be used to generate separate organic product that can be used as a solid fuel and plastic product that can be processed for other treatments, such as pyrolysis to produce liquid fuel or recycling waste [6].

Based on Waste-to-Energy Options in Municipal Solid Waste Management: A Guide for Decision Makers in Developing and Emerging Countries document published by [13], co-processing is the use of waste-derived materials, including RDF, in industrial processes to substitute natural mineral resources and/or conventional fossil fuels such as coal, fuel oil and natural gas. Co-processing is applied worldwide mainly in the cement industry and in thermal power plants, while in a few cases it is also applied in the steel and lime industry. In thermal plants where only energy recovery takes place this is called co-incineration. Co-processing in cement plants has also become a wide-spread part of waste management systems in several developing and emerging countries. In Indonesia itself, the use of waste as refuse derived fuel has been carried out in cement industries by co-incineration process, using selected municipal solid waste such as tire waste, rice grain, sawdust, oil mud, etc [7]. Nonetheless, relative to common waste sources such as used tires, toxic industrial waste, contaminated soil, wood residues and sludge from wastewater treatment plants, the proportion of MSW used for co-processing is still small. In the long term, only a small number of projects developed in developing and emerging countries have been successful. To date, some positive experiences found in state-of-the-art co-processing of cement kilns and extraction of landfill gas added to sanitary landfills [13].

4. Conclusion

Indonesia has large untapped potential of renewable energy source due to the large amount of municipal solid waste generated. Municipal solid waste generation in Indonesia was assessed based on sources, generation rate, and composition data. Using the National Waste Information System (SIPSN) data, it can be predicted amount of municipal solid waste generated in a national level. The 10 cities covered in this study are DKI Jakarta, Tangerang, Bekasi, Bandung,
Semarang, Surakarta, Surabaya, Makassar, Denpasar, and Palembang. In those major cities, 1780 tonnes/day MSW generated on average per city, with rate 0.69 kg/capita/day. Household sector was significantly contribute to the largest source of municipal solid waste generation in all cities in Indonesia by 43.45 – 74.68% w/w compared to other sectors, with average contribution of 64.26% w/w. By composition, 43.78% w/w municipal waste generated was food waste, followed by paper of 16.05% w/w, then plastics of 14.08% w/w. The result of calculations showed that the average water content is too high at 49.94%. The value of volatile content is high with an average of 53.34%, while the ash content meets the criteria with an average of 6.12%. By average, calculated heating value of mixed municipal solid waste in Indonesian major cities is 9.5 MJ/kg, which lower than standard for RDF. Pre-treatment and sorting of waste are necessary to ensure the successful application of refuse derived fuel for Indonesian municipal solid waste, mainly in meeting the standard characteristics for heating value, water content, and ash content as RDF.

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