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The Regional Assessment on the Solid Waste-to-Energy Potential in the Island of Luzon, Republic of the Philippines

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The biomass from solid waste contains significant amount of carbohydrates and other combustible chemical compounds that has potential as an alternative energy source. In this paper, the synthesis of energy potential assessment from the biomass energy resources of solid waste and the development of a mathematical model equation are presented, in order to utilize as assessment tools for the local government units (LGUs) in the Philippines, most especially for the established sanitary landfills and the waste-to-energy technologies and facilities that are soon to be installed. The data for the development of the regional solid waste-to-energy potential assessment model equation is obtained from various Philippine government agencies, such as Philippine Statistics Authority (PSA), Department of Energy (DOE), Environmental Management Bureau–Department of Environment and Natural Resources (EMB–DENR), Metropolitan Manila Development Authority (MMDA), and others. In order to accumulate those obtained data in the said model equation development, numerous mathematical tools and concepts are applied in this study, such as the application of the dimensional analysis, parameterization approach, and others. A decadal trend study is subjected for analysis, in order to predict the forecast of the solid waste-to-energy potential in the Island of Luzon, Republic of the Philippines, particularly in these 3 regions, namely National Capital Region or NCR, CALABARZON Region, and MIMAROPA Region. Based from the decadal forecast results, the 2028 solid waste-to-energy potential assessment for the three (3) above-mentioned regions found in the Island of Luzon are said to be estimated as 2.70×10^9 MWh/y for NCR, 9.00×10^6 MWh/y for CALABARZON Region, and 5.40×10^5 MWh/y for MIMAROPA Region. This parameterized equation can be further utilized in the solid waste-to-energy potential assessment for the rest of the regions in the Philippines as well.

1. Introduction

Municipal solid waste (MSW) is a growing problem in fast-growing countries, such as the Philippines and the rest of the world. Over the span of years, the generation of MSW in large countries grew very rapidly from almost one and half times. Much of this increase was due to population growth, but the rate of solid waste generation per person. Landfill sites are rapidly being filled and the availability of new sites is limited, especially near cities. In addition to the problem of site availability, there are problems of groundwater contamination, odor, disease, toxic chemicals, and escaping methane (Ristinen et al., 2016). The average heat content of MSW is about 10,000 kJ/kg that is around a third that of good coal. While disposing of the waste is the primary goal, sufficient heat can be released by burning waste to make a worthwhile contribution to steam-generated electric power. The waste incinerators must be designed to dry the waste as well to burn it. This is accomplished by injecting enough air into the firebox for complete burnout. The hot exhaust gases must be cleaned by electrostatic precipitators or bag houses to remove particulates, combined with wet or dry scrubbers to remove acid gases. The incinerators are designed differently depending on whether they are intended for mass burning of the normal mix of municipal wastes, or for incinerating wastes that are separated prior to burning (Premakumara et al., 2018).

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In some studies, Shin et al. (2019) mentioned about proposing some criteria or indices in converting MSW to energy in term of safety and health parameters. The potentiality of converting MSW to energy has a great opportunity based on its chemical components as shown in the study of Ho et al. (2019).
According to the study conducted by Sapuay (2016), the waste-to-energy facilities are very capital-intensive and many municipalities find it difficult to make the necessary investment. There has been a trend toward private rather than public ownership. Most of the existing facilities generate electricity alone, and the rest generate steam or combined steam and electricity. While the energy derived from MSW is far from negligible, the contribution of the recycling program to a reduction of the solid waste going into landfills is probably more significant. As reported by various media with regards the Payatas tragedy (Sison and Felipe, accessed May 2019), a mountain-full of garbage was collapsed at the Payatas dumpsite in Quezon City. As a result, numerous shanties and communities living near were trapped and buried alive.
Another report by Rañada (accessed May 2019), the Quezon City government was hastening to find a new place to dump the more than 397,346,916 kg of garbage from the city that generated every year which was equivalent to 146,000 dump trucks.
Several shown Philippine documentary television programs, like Reporter's Notebook (2018), tackled San Juan River in Mandaluyong City, Philippines as one of the polluted bodies of water around Metro Manila. Numerous garbage bags were floating across the river that is eventually crossed in the Pasig River. Similarly, another documentary program like I-Witness (2018), upon exploring the Freedom Island, an oasis of lush mangroves on the shores of Manila Bay and the famous last wild space in concrete jungle of a metropolis, by the research team, they have encountered a sea of garbage that pushed against the mangroves' edge, that composes most are plastics. The team then began their investigation into how such a material of convenience has become a scourge of the earth and a threat to life.
Based on the Energy Data Statistics of the Department of Energy (2019), there are no further studies conducted and assessed with regards to the feasibility of the MSW as fuel source. In addition, there is the potential of recovering waste heat released by the incinerator or pyrolyzer and utilizing its thermal energy to compensate for energy requirements upon using certain garbage as fuel source, particularly on combustible materials (e.g. supplying electricity, or for lighting and transport purposes in the communities living nearby open dumpsites and sanitary landfills). In the study conducted by Othman et al. (2018), a method of pinch analysis is used in order to estimate the amount and identify the minimum capacity of total non-biodegradable waste accepted and diverted in the landfill. As a result, this study is conducted to have an initial feasibility application of the resource assessment on municipal solid waste turning energy in Philippine setting. This is where the researcher has conducted further studies with this type of potential energy source. Similarly, in the study conducted by Co (2015), the Boiler 1 from the Coal-Fired Boiler House of a local Philippine food snack manufacturing company, was recommended by the Engineering and Maintenance Manager to the researcher as pre-ORC (Organic Rankine Cycle) source equipment. There was still some potential for recovering waste heat released by the boiler and utilizing its thermal energy to compensate for energy requirements in other parts of the plant, (e.g. supplying electricity to the pumps inside the beverage manufacturing department, or for lighting and transport purposes in wastewater treatment facility, and others).
In the present study, parameterization technique is used in the development and formulation of the municipal solid waste-to-energy model equation. Parameterization is the specification of a curve, surface, etc., by means of one or more variables which are allowed to take on values in a given specified range. It is widely used in mapping of curves in two- (2D) and three-dimensional (3D) plotting, e.g. conducting study is discrete exponential models in statistics, as mentioned by Améndola et al. (2018) with the use of iso-geometric analysis on domains that contain singularities (Qarariyah et al., 2018) and, using parameterization in studying time-frequency analysis (Yang et al., 2018).
Here in the Philippines, most of the typical solid wastes are currently generated by most residences of every local government units, based on their daily consumptions. Those waste generated are delivered, recovered in material recovery facilities (MRF) and recycled in for further use. These materials, most especially the recyclable and residual wastes, are comprised of material-to-energy potentials, as referred to combustible materials. These combustible materials are great potential in terms of secondary fuel and energy sources. Waste-to energy technologies are very rare in the country, due to its very costly implications and strict implementations from the government. Also, there are no current study with regards to the existing feasibility tools and techniques in the country, in terms of estimating and evaluation the possible waste-to-energy potentials coming from those combustible wastes, as lump-sum wastes dumped from various dumpsites and landfills.
This study is mainly aimed to assess the solid waste-to-energy potential along the three (3) regions found in the Island of Luzon, Republic of the Philippines, namely National Capital Region or NCR, CALABARZON Region, and MIMAROPA Region. It aims specifically to as follows, (a) formulate an annual-based model equation with the use of the parameterization technique that are based on such parameters, like social factors,

waste compositions, and net calorific value; (b) assess the regional solid waste-to-energy potential with the use of the proposed model equation; and (c) to provide a decadal forecast energy trend with the use of the proposed mathematical model equation.

2. Methodology

2.1 The data gathering process

The data gathering process for this study is presented in Figure 1. Data are gathered from various references, most of them are from various Philippine government agencies and experimental results from bomb calorimeter (PARR Series 6000) found in a laboratory at the Department of Chemical Engineering Building. For the waste types, recyclable and residual wastes are taken only to be considered. Shown in Eq(1) is the solid waste-to-energy potential terms based from the recyclable wastes is dependent or function of certain parameters, such as the waste collection rate, population, area ratio, waste composition ratio and net calorific value (based from recyclable waste). Likewise, as presented in Eq(2), the solid waste-to-energy potential term is a function of the waste collection rate, population, area ratio, waste composition ratio and net calorific value (based from residual waste).

$$E_{\mathrm{RC}} = f(G, p(t), a, w, NCV)_{\mathrm{RC}} \tag{1}$$

$$E_{\mathrm{RS}} = f(G, p(t), a, w, NCV)_{\mathrm{RS}} \tag{2}$$

where E is the solid waste-to-energy terms for each local government unit or LGU (kJ/y), G is the waste collection rate [kg/(capita-y)], p(t) is the population for each LGU at any time t (capita), a is the land consumption ratio (km^2/km^2), w is the average waste composition ratio (kg/kg). NCV is the average net calorific value for each solid waste type (kJ/kg), and subscripts, RC and RS, represent the recyclable and residual wastes.

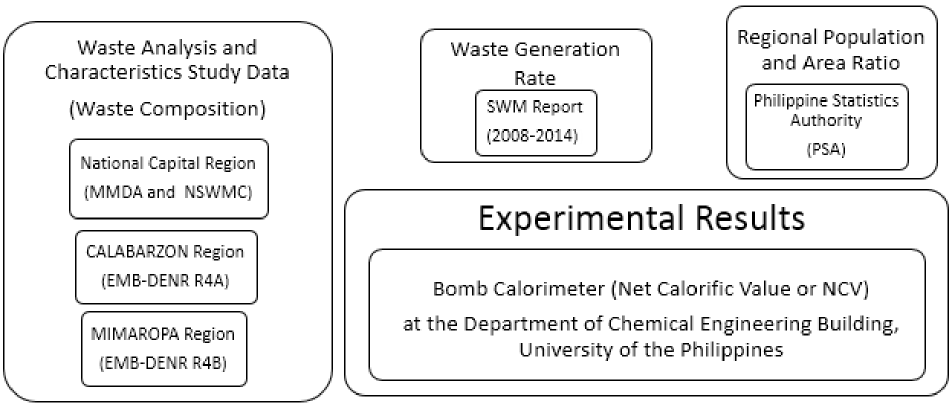

Figure 1: The Data Gathering Process

The population parameter or p(t) is further extracted in terms of equation, in order to estimate the number of people living in the region as a function of time, t, as shown in Eq(3) for NCR, Eq(4) for CALABARZON Region, and Eq(5) for MIMAROPA Region (PSA 2015). Table 1 represents the waste generation rate (G) values used in this study (EcoGov Project, 2011). Table 2 represents the values for the land consumption ratio (PSA, 2015). Table 3 shows the values for the waste composition ratio of different waste with its corresponding experimental net calorific values (NCV) from different wastes.

$$p(t) = 216{,}076\, t - 42{,}251{,}587 \tag{3}$$

$$p(t) = 2.72961 \times 10^{-6}\, t - 723{,}786{,}521 \tag{4}$$

$$p(t) = 2.16046 \times 10^{-5}\, t - 90{,}303{,}736 \tag{5}$$

where p(t) is the population at any time t (capita) and t is the time (y).
This study is limited to as follows, (a) the types of collected residential waste, also known as simulated combustible waste, namely recyclable and residual waste; (b) the covered site regions from the Luzon, namely National Capital Region (NCR), CALABARZON Region, and MIMAROPA Region; (c) the local government

units covered per region are starting from provinces until its covered towns or municipality and cityhood levels only; (d) the specific regulation of population per LGU (gender and age); (e) the basis of the waste generation rate are obtained from the Solid Waste Management Report (2008-2014); (f) the start of the decadal forecast period is from the year 2018 until 2028, due to the data gathered from the Waste Analysis and Characterization Study (WACS) and the experimental results gathered from the bomb calorimeter found in the Department of Chemical Engineering Building, University of the Philippines; and (g) such exclusions like (1) other types of waste (biodegradable and special wastes); and (2) other regions from the rest of Philippines.

Table 1: Waste generation rate, G

Coverage	G, kg $(\text{capita-y})^{-1}$
NCR	222.65
Other cities and town capitals (excluding NCR)	182.5
Municipalities (excluding cities and town capitals)	113.15

Table 2: Land consumption ratio, a

Region	a, km^2/km^2
NCR	0.005634
CALABARZON	0.150741
MIMAROPA	0.269233

Table 3: Waste composition ratio, w, and its experimental NCV, for different materials used in this study

Waste Material	w, kg/kg	NCV (MWh/kg)
Paper/Cardboard	0.64444	15.93276
Plastic	0.31111	27.5479
Textile	0.04444	20.3138
Rubber	0.176471	26.24805
Leather	0.117647	38.58785
Glass	0.352941	0.222556
Metal	0.352941	1.423828

2.2 The development of the parameterized equation

The parameterization process is started with the application of the material and energy balance concepts with the possible candidate of such parameters found in Eq(1), similarly to Eq(2) (Himmelblau and Riggs, 2012). The Buckingham-π Method of Dimensional Analysis is then applied and resulted to Eq(6) and Eq(7) (Felder and Rousseau, 2005). Arc length method is finally applied to Eq(6) and Eq(7), in order to evaluate the total annual magnitude of the solid waste-to-energy potential, as presented in Eq(8). Eq(8) is the parameterized model equation.

$$\frac{dE_{\mathrm{RC}}}{dt} = c\ G\ a\ w_{\mathrm{RC}}\ NCV_{\mathrm{RC}}\ p'(t) \tag{6}$$

$$\frac{dE_{\mathrm{RS}}}{dt} = s\ G\ a\ w_{\mathrm{RS}}\ NCV_{\mathrm{RS}}\ p'(t) \tag{7}$$

$$E = E_{\mathrm{RC}} + E_{\mathrm{RS}} = \int_{t_{\mathrm{i}}}^{t_{\mathrm{f}}} \sqrt{[c\ G\ a\ w_{\mathrm{RC}}\ NCV_{\mathrm{RC}}\ p'(t)]^2 + [s\ G\ a\ w_{\mathrm{RS}}\ NCV_{\mathrm{RS}}\ p'(t)]^2} \cdot dt \tag{8}$$

where E is the evaluated total solid waste-to-energy potential per region (MWh/y), p’(t) is the first derivative of the population parameter with respect to time t, c and s are the parametric constants (dimensionless), and subscripts, i and f, represent initial and final states.

3. Result and discussion

Shown in Figure 2a is the decadal solid waste-to-energy forecast trend in the National Capital Region. From the data gathered from various Philippine government agencies, like the population data from Philippine Statistics Authority (PSA, 2015) and the WACS Data from the Environmental Management Bureau-Department of Environment and Natural Resources (EMB-DENR, 2018) and from Metropolitan Manila Development Authority (MMDA, 2018) and others, these are carefully executed, analyzed, and evaluation to the parameterized model equation, as shown in Eq(6). Based on the result, the total solid waste-to-energy potential as of year 2028 for the National Capital Region is evaluated around 2.70 x 10^9 MWh/y. The solid waste-to-energy potential from the rest of the regions found in the Philippine archipelago may be further evaluated with the use of the parameterized model equation.

Figure 2b presents the decadal solid waste-to-energy potential assessment forecast trend in the CALABARZON Region. Based on the result, the total solid waste-to-energy potential as of year 2028 for the CALABARZON Region is evaluated around 9.00 x 10^6 MWh/y.

The decadal solid waste-to-energy potential assessment forecast trend in the MIMAROPA Region is finally presented in Figure 2c. As a result, the total solid waste-to-energy potential as of 2028 for the MIMAROPA Region is around 5.40 x 10^5 MWh/y.

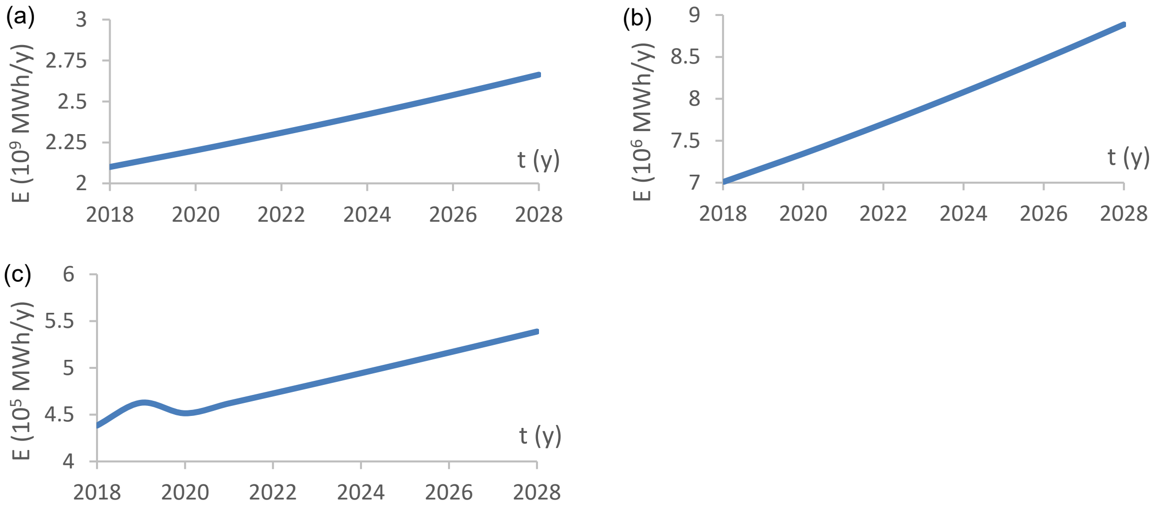

Figure 2: The decadal solid waste-to-energy potential assessment trend for (a) the NCR, (b) the CALABARZON region, and (c) the MIMAROPA region

Based on the results from Figures 2a, 2b, and 2c, high opportunities and great potentials in terms of energy and secondary fuel sources may be harness out from municipal solid waste, particularly on recyclable and residual wastes. Aside from lessen waste generation, creating air pollution, and dumping of waste heat in the atmosphere, utilization of low-waste heat may be served as an alternative source of renewable energy and potential and feasible secondary fuel sources.

4. Conclusions

In this study, the parameterized model equation is being used to assess the solid waste-to-energy potential of three (3) of the main regions found in the Island of Luzon, Republic of the Philippines. Based from the decadal solid waste-to-energy potential assessment trend as evaluated for the three (3) regions, namely (a) NCR in the year 2028, it is resulted to 2.70 x 10^9 MWh/y, (b) the CALABARZON Region, the result is around 9.00 x 10^6 MWh/y. And finally, (c) the MIMAROPA Region has around 5.40 x 10^5 MWh/y. Based on the results, high opportunities and great potentials in terms of energy sources may be harness out from municipal solid waste. This parameterized model equation can be further utilized as part of the feasibility tool in regional solid waste-to-energy potential assessment for the rest of the regions of Luzon and to other regions found in the Philippine archipelago, as well. The results from this study may become further basis for the design of waste-to-energy technologies, such as ORC.

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