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Model of municipal solid waste treatment using mixture design

Christia Meidiana, Febrina Ambar, and Wawargita Permata Wijayanti

Department of Reginal ad Urban Planning, Faculty of Engineering, Universitas Brawijaya, Malang 65147, Indonesia

Abstract

The study aims to propose a model enabling to determine the optimum combination of three waste management constituents, i.e, reuse, incineration and recycle which produces the lowest GHG emission. Simplex mixture design was used to determine the model. Change of the greenhouse gas (GHG) emission as a regressand is analyzed over the various waste amount. The best model is is generated from the combinantions for its lowest P-value and the highest adjusted R-squared which is less than 0.0001 and 0,9999 respectively. The model describes that lowest GHGs emission can be achieved by optimizing plastic recycle (into flakes), limiting incineration and increasing paper, glass and metal reuse. Incineration, reuse and recycle is proportional to the GHGs emission individually. Combination of 42.56% recycle, 0.57% incineration, and 56.88% reuse will generate the lowest GHGs which is 0.00025 Gg CO_{2eq}/yr.

Keywords: Mixture design, municipal solid waste, waste treatment

1. Introduction

Municipal solid waste management (MSWM) comprises many perspective requiring integrated solution. It is distinctive because it has complexity covering many different discrete issues, i.e. waste characteristic, waste actors, waste economy, and waste impact on environment. The complexity may lead to uncertainties since it involves data derivation which is also a sort of estimation [1, 2]. Waste related data such as population growth, waste generation rates and flow, waste reduction rate, local labor and waste economic are often derived from secondary data do not represent the local conditions. Furthermore, decision analysis for MSWM is multi-objective because MSWM requires integrated solution [3]. Decision maker need to pay attention that one decision in certain level of MSWM may affect other levels and produce different conclusion to different problems influencing by factors, technical or non-technical. Subjectivity is common problem in MSWM including environmental valuation depending on the methodology used involving personal view of the analyst and consequently his own weighted utility function [4]. Though this subjectivity, tools in waste related analysis are necessary to seek the optimum conditions for a multivariable system. Mixture design is a tool claimed as an efficient procedure to determine a strategic planning through experiments execution so that the data obtained can be analyzed to yield valid and objective conclusions. Originally, mixture design was used to create the possible compositions of selected solid feedstock [5]. Three standard mixture designs are simplex-lattice, simplex-centroid, and extreme vertices designs. All methods consist of upper and lower bound constraints for each constituent.

Using the simplex centroid mixture design, the study determines the model optimum for the local conditions in term of GHGs emission. Measurement of waste flow and potential waste reduction through incineration, reuse and recycle were investigated first. The combination of each constituent was evaluated afterwards. Finally, the composition of the mixed waste treatment was optimized using response surface methodology.

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Corresponding author. Tel.: +62-341-587711; *E-mail address*: c_meideiana@ub.ac.id.

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2. Method

2.1. Waste reduction

Measurement of waste reduction is conducted for 7 days and analyzed from 7 am until 11 am and from 3 pm till 4 pm using Load-count Analysis. [6] proposed the method by counting the total number of dump trucks entering the landfill per day as described in Equation 1.

$$V_{tot}=V_t \times n \tag{1}$$

where V_{tot}, V_t and n is total waste volume, waste volume per truck and number of trucks respectively. Volume of each waste type is calculated based on the typically local waste composition [7] and the amount of material potential for treatment is determined using Eq.2 based on its recovery factor in site and the maximum capacity of incinerator and reuse as well as recycle center.

$$V_r=V_i \times Rf_i \tag{2}$$

where V_r, V_i and Rf_i is waste reduction (m^3), waste volume (m^3) and recovery factor of each waste type respectively. Recovery factor is a constant describing the waste percentage potential for waste treatment and Table 2 shows the typical recovery factor in study area.

2.2. Greenhouse gas emission

GHGs are emitted during the waste treatment coming from waste degradation and fuel combustion. Emission is calculated referring the Tier 2 method. Tier 2 method provides some default values not available locally due to field measurement absence and local data shortcomings [8].

Waste transportation and treatment generates GHG emission sources from fuel combustion in shredder and trucks. Total emission is calculated using Equation 3 and Equation 4 from these activities.

$$E_{tot} = \sum_a \left(En_{Fi} \times EF_i\right) \tag{3}$$

$$V_{Fi}=CF \times t \tag{4}$$

where E_{tot}, En_{Fi} and E_{Fi} is total emission ($GgCO_{2e}$), fuel energy (TJ) and emission factor of each waste type (kg/TJ) respectively. Fuel energy for gasoline and diesel gas is 44.8 TJ/10^3ton and 43.3 TJ/10^3ton. Meanwhile, V_{Fi}, CF and t stands for fuel consumption (L), fuel consumption factor (3 liter/hour) and operational time (hour). Waste volume and shredder capacity are the factors for operational time as showed in Eq. 5

$$t = \frac{V_i}{C} \tag{5}$$

where t, Vi and C is operational time (h), waste volume (m^3) and shredder capacity (300 kg/hour) respectively.

2.3. Determining the best alternative for waste treatment

The experiment mixture design (MD) was used to achieve the optimum composition of the waste treatment for minimum GHGs emission. In this case, a model is constructed to describe the best alternative for waste treatment based on the lowest GHGs emission. Three constituents are set, i.e. composting, reuse and recycling and extreme lattice design has been employed in which each constituent is studied in different volumes based on its lower and upper limit.

The regression model equations were fitted to a quadratic expression as follows:

$$Y_i = \Sigma b_j x_j + \Sigma b_{jk} X_j X_k \tag{6}$$

where Y is the response, b is the constants and X is the independent parameters. Statistical analysis of the model was performed to evaluate the analysis of variance (ANOVA). The output are alternatives of models which are tested statistically such as normality test and ANOVA test. The results are models with all possible combinations of three constituents. Model with the lowest GHGs emission is the best models.

3. Result and Discussion

The result shows that the average waste production in transfer point is 93.5 m^3/d which equals to 22.472 t/d. As the waste reduction target is 10 %, 9.3 m^3 is set to be the maximum waste reduction volume. This amount requires certain mixed waste volume which is defined as potential waste. Totally, the potential waste reduction is 61.19 % that equals to 52.7 m^3 (Table 1).

Potential organic waste can be reduced through composting is 49.2 m^3 comprising of 11.9 m^3 food waste and 37.3 m^3 leaves remaining residue of 8.6 m^3/d transported to landfill. Potential inorganic waste can be treated through reuse and recycle is 8.0 m^3/d comprising of 6.5 m^3 plastic waste, 1.1 m^3 paper, 0.4 m^3 glass, and 0.36 m^3 metal. The lower and upper limit is determined based on those values afterwards (Table 2)

Table 1. Waste reduction potential in Sidoarjo city 2017.

Waste type	Total Volume mixed waste (m^3/d)	Waste reduction potentials (m^3/d)	Percentage (%)
Plastics	93.5	6.5	6.95
Paper	93.5	1.1	1.17
Glass	93.5	0.4	0.42
Metal	93.5	0.03	0.03
Organic	93.5	49.2	52.62
Total		**52.7**	**61.19**

Table 2. Lower and upper limit for mixture design.

Waste type	Treatment	Lower limit (%)	Upper limit (%)
Organic	Composting	0	100
Inorganic	Reuse	0	100
Inorganic (plastic)	Recycle	0	100

The values are fed into software of Design Expert to produce sample points describing the percentage of each waste management constituent based on the GHGs emission in Gg CO_{2e}/yr. Table 3 shows 16 combination of three constituents amounting the potential waste volume for treatment and fuel consumption.

Table 3. Matrix of the extreme lattice mixture design for GHGs emission.

Run	Waste Volume ($m^{3/}$d)			Fuel Consumption (liter/yr)	
	Composting (C)	*Reuse (Re)*	*Recycling (Rc)*	*Diesel*	*Gasoline*
1	3.98	2.78	2.54	3.352,0	390.87
2	1.3	4.66	3.34	4.542,9	390.87
3	2.88	5.51	0.90	6.512,5	390.87
4	7.63	0	1.66	3.974,7	390.87
5	5.95	1.73	1.62	9.574,7	390.87
6	5.98	0	3.31	6.963,7	390.87
7	5.94	0	3.36	6.963,7	390.87
8	3.04	1.63	4.63	6.512,5	390.87
9	9.3	0	0	9.574,7	390.87
10	5.25	4.053	0	3.352,0	390.87
11	7.58	1.713	0	9.574,7	390.87
12	5.25	4.05	0	3.352,0	390.87
13	2.8	0	6.5	1.821,6	390.87
14	1.3	4.66	3.34	4.542,9	390.87
15	1.3	1.5	6.5	1.821,6	390.87
16	1.3	8	0	1.822,8	390.87

Classic statistical test is conducted to review the data validity and to find out the coefficient of the variables in the models afterwards.

3.1. Test of normality

Test of normality was conducted to determine if the data of waste volume is well-modelled by a normal distribution and to compute how likely it is for a random variable underlying the data set to be normally distributed and described using line plots represent the experimental and predicted values. The residual is the difference between the observed and the predicted value from the regression. If the points of the plot are seen closer to the straight line, then the data is normally distributed [12]. Fig. 1 shows the normal plot of residuals and it is clearly that the experimental points were reasonably aligned suggesting the normal distribution. The residuals were found dispersed randomly about zero indicating that the errors have a constant variance.

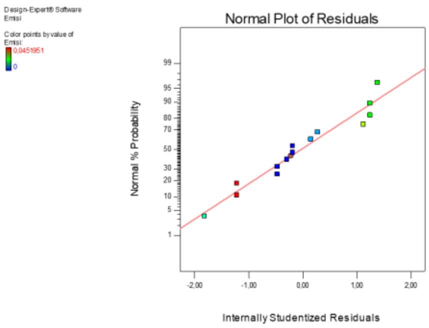

Fig. 1. Normal probability plots of the residuals for GHGs emission.

3.2. Model fitting and regression analysis

All of the independent and response variables were tested to fit in to a linear, quadratic or special cubic model. The coefficient of determination (R2), and the F-test (analysis of variance-ANOVA) were used to verify the quality of the models. The analysis of variance (ANOVA) results indicated that the models are significant, and the system can be described using these models. The predicted values were in agreement with the experimental data indicating that the simplex centroid lattice mixture design (SLMD) is a reliable method for determining the optimum composition of the quadratic model was identified as the best suited model for GHGs emission. Based on 16 iterations, a predicted regression equation representing the model with the significant factors for GHGs emission is generated as followed:

$$E\ (Gg\ CO_{2\ Eq}) = 2.026\ A + 4.519\ B + 2.432\ C \tag{9}$$

where E, A, B, and C is emission (Gg CO_{2eq}), recycle (m^3), incinerator (m^3), and recycle (m^3). The variation of the GHG s emission using different waste treatment methods is shown in two-dimensional ternary contour plot area graphs (Fig. 2). Each constituent is represented in one corner of an equilateral triangle. Each point within this triangle refers to a different volume of constituent s in the mixture [9].

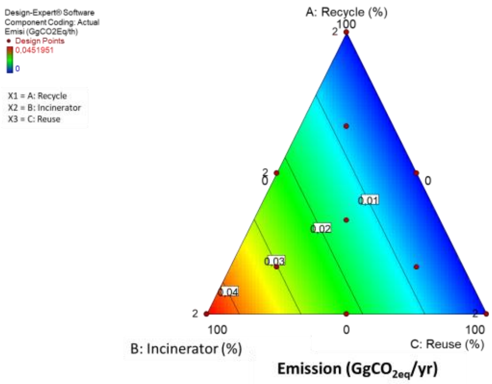

Fig. 2. Mixture surface plots for the GHGs emission.

4. Summary

Design of Experiment (DoE) is used in the study to determine the best alternative for solid waste management based on its three constituents i.e. composting, reuse and recycling. The analysis comes to the result that the total waste generation in site is 93 m^3/day collected and transported to 13 transfer points. Waste volume potentials for waste treatment is 57.33 m^3/day (61.3 % of total waste) consisting of 49.3 m^3/day organic waste and 8 m3/day inorganic waste. There are 16 iterations to find out the best model resulting to 42.56% recycle, 0.57% incineration, and 56.88% reuse as the best combination and generates the lowest GHGs which is 0.00025 Gg CO_{2eq}/yr.

Conflict of Interest

I/We declare no conflict of interest and have mentioned the relevant references within my/our knowledge

Author Contributions

Christia Meidiana accomplished all calculations in the work and reviewed the references and elaborating it to be part of the introduction for the paper. Meanwhile, Febrina Ambar conducted data collection (primary and secondary) and related references and Wawargita P. Wijayanti analyzed the characteristic of the waste and simulated the calculation to gain the model. All the authors had approved the final version.

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