proceedings

Proceedings

Regression Linear Model of Air Pollution Emission on the Example of a Waste Incineration Plant †

Monika Załuska * and Katarzyna Gładyszewska-Fiedoruk

Department of HVAC Engineering, Faculty of Civil Engineering and Environmental Sciences, Białystok University of Technology, 15-351 Białystok, Poland; k.gladyszewska@pb.edu.pl

* Correspondence: m.wysocka@doktoranci.pb.edu.pl; Tel.: +48 500-682-207

† Presented at the 9th Innovations-Sustainability-Modernity-Openness Conference (ISMO'20), Bialystok, Poland, 20–21 May 2020.

Published: 10 October 2020

Abstract: The level of environmental quality is the result of many factors, and the most important of these is human activity. A responsible approach to the environment is looking for methods to eliminate pollution from the environment. Waste incineration is a way to rationally manage and process waste, minimize emissions of air pollutants and ecologically produce heat and electricity. The purpose of this article is to build and analyze a regression model describing the relationship of pollutant emissions to air from waste incineration plants depending on various factors.

Keywords: energy production; air quality; air pollutants; incineration plant; regression model

1. Introduction

The environment in which we operate is exposed to the costs of our activities. These costs are produced waste, municipal sewage and industrial products and the pollutants emitted into the air. The essence of caring for the environment is rational management, striving to minimize the production of various types of pollution and maximize reuse of seemingly unnecessary waste [1].

An example of good practice in waste management are incineration plants, i.e., installations for the thermal transformation of waste [2]. Waste incineration on a massive scale is currently one of the most important technologies used in municipal waste management in the most industrialized countries of the world [3–6]. There are currently eight modern municipal waste incineration plants in Poland. Their total waste treatment efficiency is a maximum of approximately 1,114,000 Mg/year, which is 9.3% of the amount of municipal waste generated in Poland. Thermal transformation of waste consists in its transformation into electricity and heat. The process also produces air pollution, mainly PM10 and PM2.5 dust, nitrogen oxides and CO, but most of them are retained by various types of filters (Figure 1).

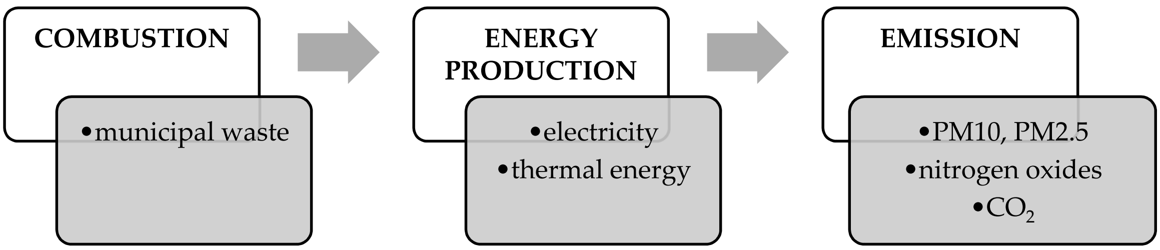

Figure 1. Chronology of processes occurring during the thermal transformation of waste.

An important issue in the fight for a clean environment is mainly sustainable development that can be achieved through the optimization of production processes [7]. The thermal transformation of waste allows for minimizing the contact of the environment with waste and generating energy; however, attention should be paid to the emission of pollutants into the air resulting from the waste incineration process. The use of filters and a thorough understanding of the relationship between the various factors involved in the combustion process allows minimizing emissions to air. The purpose of this article is to build and analyze a regression model describing the relationship of pollutant emissions to air from waste incineration plants depending on various factors.

2. Materials and Methods

The analysis used the results of measurements for 2019 from the Municipal Waste Treatment Plant in Bialystok in the Podlaskie Voivodship. Mixed municipal waste from Białystok and neighboring municipalities goes to the incineration plant. Residues from the waste-sorting process whose calorific value is above 6 MJ/kg are also neutralized here and, according to the ordinance of the Minister of Economy, they cannot be stored.

The incineration plant is able to process up to 15 tons of municipal waste per hour, i.e., up to 120,000 Mg per year. Thanks to the technology used, it is possible to generate about 43,000 MWh of electricity and 360,000 GJ of heat energy annually, which goes to the municipal heating network. As a result of waste incineration, air pollution is formed, and the quantity is influenced by factors such as:

- Amount of waste accepted for incineration;
- Fuel oil consumption (in spare burners);
- Consumption of activated carbon for waste gas treatment;
- Electricity generated;
- Heat generated.

The following table (Table 1) summarizes the amounts of individual factors affecting the amount of pollutant emissions.

Table 1. Quantities characterizing thermal waste treatment—data for 2019.

Month	Waste Accepted for Incineration	Consumption of Heating Oil (Auxiliary Burners)	Consumption of Activated Carbon	Electricity Generated	Heat Generated
	(Mg)	(kg)	(kg)	(MWh)	(GJ)
January	10,236.64	0.00	2861.04	4613.52	48,026.39
February	10,189.14	60.00	2055.93	4222.54	42,635.98
March	10,096.52	840.00	2245.03	4824.17	42,653.52
April	9916.24	565.00	1394.23	4771.58	38,146.46
May	8036.38	14,335.00	1114.72	4064.62	20,441.55
June	10,097.48	144.00	884.5	5625.69	13,535.42
July	11,163.62	427.00	2751.88	5819.11	13,967.86
August	10,744.08	6.00	3781.81	5772.26	14,482.11
September	3011.6	14771.00	4892.1	22074.1	54,976.3
October	12,056.3	530.00	38,511.3	5151,05	342,759.6
November	10,093.02	136.00	19,281.1	45,199.8	44,240.26
December	9533.1	0.00	25,647.8	49,487.2	378,565.1
Total	115,174.12	31814.00	25,922.37	56,540.65	355,759.65

The data (Table 1) were used to build a linear regression model. Linear regression is the simplest variant in statistics. It assumes that the relationship between the explained and explanatory variables is a linear relationship. In a linear regression, it is assumed that the increase of one variable (predictor, predictors) is accompanied by an increase or decrease in the other variable. The purpose of linear regression analysis is to calculate such regression coefficients (coefficients in a linear model) so that the model predicts the value of the dependent variable in the best possible way and the estimation error is as low as possible.

Below is the equation (1) which takes into account factors influencing the emission of pollutants into the air and which will be used to build the regression model:

$$\begin{gathered}\text{Pollution emission}\ (\mathrm{Y}) = \text{Heat generated} * a_1 + \text{Electricity generated} * a_2 + \text{Waste accepted for incineration} * a_3 + \\ + \text{Consumption of heating oil (auxiliary burners)} * a_4 + \text{Consumption of activated carbon} * a_5 + a_0\end{gathered} \tag{1}$$

where:

Y —independent variable;

$a_{1\ldots n}$—dependent variable factors;

a_0—absolute term in an expression.

3. Results

A linear regression model was developed assuming the following explanatory and explained variables:

Y —dust emission, independent variable (kg/m^3);

X_1—waste accepted for incineration (Mg);

X_2—consumption of heating oil (auxiliary burners) (kg);

X_3—consumption of activated carbon (kg);

X_4—electricity generated (MWh);

X_5—heat generated (GJ).

The first step in creating the model was to study the variation variables X. Due to the fact that the variability of explanatory variables for each variable was more than 10%, all variables were analyzed further. Then, the Helwig method was used to identify the most favorable combination of variables. The number of combinations for five variables was $2^5 - 1 = 31$. A correlation matrix was obtained, and then individual and integral information capacities of a given combination of variables were calculated. The combination C15 = {X4, X5} was selected because the value of information capacity was H = 0.554376.

Analysis of variance was performed, which allowed to estimate the coefficients a_4 and a_5 of the model. The obtained regression model before substantive verification took the following form (2):

$$\hat{Y} = -5.72644966 - 0.01504279 \times X_4 + 0.00063801 \times X_5 \tag{2}$$

Two explanatory variables qualified for the model: the amount of electricity generated and the amount of heat produced, which means that these two factors have the greatest impact on the amount of dust emissions to air.

4. Conclusions

A linear regression model is a great tool for prediction and optimization, which can be successfully used in environmental protection.

Author Contributions: M.Z. conceived and designed the experiment, analyzed the data and wrote the paper. K.G.F and M.Z. proved the results in terms of content.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ramos, A.; Teixeira, C.A.; Rouboa, A. Environmental Analysis of Waste-to-Energy—A Portuguese Case Study. *Energies* **2018**, *11*, 548, doi:10.3390/en11030548.

2. Pires, A.; Pires, A.; Chang, N.-B. Solid waste management in European countries: A review of systems analysis techniques. *J. Environ. Manag.* **2011**, *92*, 1033–1050, doi:10.1016/j.jenvman.2010.11.024.
3. Zhang, D.; Huang, G.; Xu, Y.; Gong, Q. Waste-to-Energy in China: Key Challenges and Opportunities. *Energies* **2015**, *8*, 14182–14196, doi:10.3390/en81212422.
4. Ryu, C.; Shin, D. Combined Heat and Power from Municipal Solid Waste: Current Status and Issues in South Korea. *Energies* **2012**, *6*, 45–57, doi:10.3390/en6010045.
5. Inoue, K.; Yasuda, K.; Kawamoto, K. Report: Atmospheric pollutants discharged from municipal solid waste incineration and gasification-melting facilities in Japan. *Waste Manag. Res.* **2009**, *27*, 617–622, doi:10.1177/0734242X08096530.
6. Margallo, M.; Aldaco, R.; Irabien, A.; Carrillo, V.; Fischer, M.; Bala, A.; Fullana-I-Palmer, P. Life cycle assessment modelling of waste-to-energy incineration in Spain and Portugal. *Waste Manag. Res.* **2014**, *32*, 492–499, doi:10.1177/0734242X14536459.
7. Cucchiella, F.; D'Adamo, I.; Gastaldi, M. Sustainable management of waste-to-energy facilities. *Renew. Sustain. Energy Rev.* **2014**, *33*, 719–728, doi:10.1016/j.rser.2014.02.015.