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Investigation on the Impact of Recycling on the Correlation between Waste Disposal Rate and Gross Domestic Product for the Assessment of Feedstock Sustainability of Waste to Energy Plant

Iqbal Hakim Tahir, Wai Shin Ho*, Haslenda Hashim

Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.
hwshin@utm.my

Waste to Energy (WtE) plant has been acknowledged as one of the important approaches to solve solid waste management issues. The knowledge of the current and future trends of solid waste disposal rate are important to assess the feedstock sustainability of WtE plant. Future trend study requires the understanding of the factors influencing the disposal rate. Gross Domestic Product (GDP) has been acknowledged to be positively correlated with the waste disposal rate and could be used as dependent variable in waste disposal forecasting model. The implementation of compulsory recycling program might decouple the waste disposal rate and the economic indicator. This study aims to investigate the effect of recycling program on the correlation between waste disposal rate and GDP by analysing the correlation coefficient between both variables before and after separation at source program. Results of the study showed that the annual average daily disposal rate was reduced by 105 t/d or 5.5 % after the implementation of the SAS program. Decoupling effect between the waste disposal rate and gross domestic product was observed with a change in the Pearson correlation coefficient from 0.92 to -0.46 after the program implementation. The estimated maximum diversion rate from the program was 11 %. Taking the program's impact into account, waste disposal rates in Kuala Lumpur were projected to increase from 1,649 t/d or 0.93 kg/capita/d in 2021 to 2,706 t/d or 1.3 kg/capita/d in 2050, which indicated the sustainability of the waste supply even after the program implementation. The study also found a significant reduction in solid waste disposal rate during the period of movement control order. This was not considered in the forecasting model due to its' temporary effect.

1. Introduction

Kuala Lumpur faced a significant waste generation problem, with limited available space for waste disposal. The waste is currently transported to Bukit Tagar Sanitary Landfill in Selangor via Taman Beringin Transfer Station, the sole waste management facility in the city. To solve this issue, the government proposed to construct a Waste to Energy (WtE) plant. Determining the appropriate capacity for the plant required an understanding of the local waste disposal trend to ensure sustainable feedstock for the plant (Benjamin et al., 2017). The WtE furnace needed to be designed to achieve a temperature of at least 850 °C for 2 s, enabling effective destruction of pollutants (Wienchol et al., 2020). The furnace volume was based on the desired temperature and expected heat input from the combustion process, which relied on the amount and calorific value of the waste. Insufficient waste feeding rates could result in inadequate temperatures and require additional auxiliary fuel, making WtE operation less economical (Meissner, 1961). The availability of waste should be always higher than the minimum feeding rate required, depending on the turndown ratio of the plant.

This research aims to forecast the solid waste disposal rate in Kuala Lumpur by understanding the factors influencing disposal rates. Gross Domestic Product (GDP) typically found to be positively correlated with waste disposal rates as demonstrated by Diacon and Maha (2015) with data from 79 countries and Khajuria et al. (2010) with data from five Asian developing nations. Thus, it can be utilized as a dependent variable in waste disposal forecasting models. However, many of the previous correlation studies did not consider the impact of

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compulsory segregation program. The implementation of the compulsory Separation at Source (SAS) program in Kuala Lumpur may decouple waste disposal rates from the economic indicator. This program, implemented in September 2015, mandated waste separation into recyclable and non-recyclable materials to achieve national landfill diversion and recycling targets (Prime Minister's Department of Malaysia, 2015). The separated recyclables were sent to recycling facilities.

The research aims to analyze the impact of the SAS program on the correlation between waste generation rates and GDP. A prediction model for solid waste disposal rates in relation to GDP was developed using linear regression method, considering the program's effects. This model was used to forecast future solid waste disposal rates in Kuala Lumpur and assess the feedstock sustainability for the proposed WtE project.

2. Materials and Methods

2.1 Overall Methodology

This study started with the data collection and validation of the Kuala Lumpur waste disposal rate, population, gross domestic product and recyclable material collection rate from SAS program. Then, the collected data were analysed with the aim to determine the impact of the program on the correlation between per capita waste disposal rate and per capita gross domestic product.

2.2 Data Collection

Datasets were collected between 2009 and 2021, except for the recyclable material collection rate from the SAS program, which was available from September 1, 2015. The waste disposal data for Kuala Lumpur was based on waste received at the Taman Beringin Transfer Station (excluding bulky materials) that was measured using weighbridge. The data was obtained from various sources including the National Solid Waste Management Department, Solid Waste Corporation, and Alam Flora Sdn Bhd, the facility operator. The accuracy and representativeness of the collected waste data were verified through interviews, crosschecking, and map analysis. Similar waste generation data from Penang and Melaka were also collected for comparison. Recyclable material collection rate data from the SAS program in Kuala Lumpur and other states were obtained from SWCorp and Alam Flora and verified through interviews and site visits. Population data and per capita GDP for Kuala Lumpur were obtained from the Department of Statistics Malaysia (DOSM). The population data for subsequent years were updated using birth, death, and net-migration data. GDP data was reported in constant 2010 prices to eliminate the impact of price changes (Statistical Office of the European Union, 2020).

2.3 Data Analysis

Pearson correlation test was used to quantify the correlations strength between waste disposal rate and per capita GDP. The critical point of Pearson correlation coefficient was based on table provided by Fisher and Yales (1971) where the values varied for different levels of significance and degrees of freedom. For instance, the correlation coefficient of two tailed test must exceed 0.669 to be significant for the case of 5 degrees of freedom and 0.05 significance level. The Pearson correlation test results were also validated using the R-programming software, which is currently a widely employed tool for statistical analysis.

2.4 Data Modelling

This study employed regression analysis to model the relationship between solid waste disposal rate and per capita GDP. By plotting the data of waste disposal rate (dependent variable) against per capita GDP (independent variable) and fitting a regression line, the relationship between the two variables was summarized by the equation of the regression line.

2.5 Data Forecasting

The forecasting of waste generation trend was conducted based on the developed model and the future projections of population and per capita GDP. The two projections were conducted using Exponential Smoothing Algorithm. Assessment on WtE feedstock sustainability was assessed based the forecasted data.

3. Results and Discussions

3.1 Current Trends of Population and Gross Domestic Product in Kuala Lumpur

Figure 1 represent the trends of population and per capita gross domestic product in Kuala Lumpur from 2009 to 2021. Kuala Lumpur population showed an increasing trend with an average annual growth rate of 0.9 %/year. Significant annual growth rate (2.5 %/y) was observed from 2013 to 2014. From 2015 to 2017, the growth rate reduced from 0.5 %/y to 0.2 %/y that might be contributed by the 6 % decrease of annual live births and 12 % increase of annual deaths number (Department of Statistics Malaysia, 2019). The Kuala Lumpur population had

decreased by 2 % from 1.79 million in 2017 to 1.77 million in 2021. This might be contributed by interstate migration from Kuala Lumpur to Selangor. Kuala Lumpur is enclaved within Selangor state, and has a very high population density of about 6,890 per square km. Migrants are moving out of Kuala Lumpur into the surrounding Klang Valley due to high costs of living in Kuala Lumpur and numerous new residential areas that are available outside Kuala Lumpur (Abdul Rashid et al., 2014),

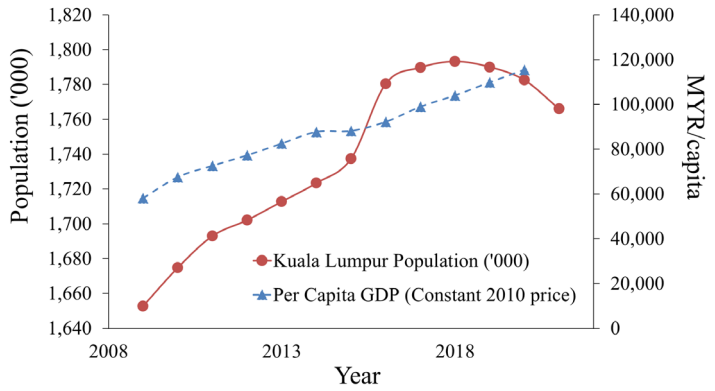

Figure 1: Trends of Population and Per Capita Gross Domestic Product in Kuala Lumpur from 2009 until 2021

The data of GDP/capita showed an upward linear trend with an average annual growth rate of 7 %/y. It had increased by 79 % from MYR 58,171/capita in 2009 to MYR 115,438/capita in 2019. The increase of GDP/capita might be attributed to the increase of population and urbanization in Kuala Lumpur. Becker et al. (1999) suggested that the rise of population in urbanized area might increase the income growth as a result of increasing return from greater specialization. Specialization was when a business focused on producing a specific type of goods or services that would enhance the productivity of workers (Powell, 2000). Bucci (2015) also agreed upon this positive impact of specialization on productivity. The GDP/capita was then decreased by 8 % to 106,118 GDP/capita in 2020. This might be attributed to the implementation Movement Control Order (MCO) commencing on 18th March 2020 that restricted the economic activities.

3.2 Current Trends of Waste Disposal Rate in Kuala Lumpur

Figure 2 represents the yearly average of daily solid waste generation rate in Kuala Lumpur from 2009 to 2018, in total and on per capita bases. From 2009 to 2014, the solid waste generation rate had increased by 13 % from an average of 1,685 t/d in 2009 to an average of 1,897 t/d in 2014. This was correlated with the population rise in Kuala Lumpur. Fluctuation trend was observed afterwards. The generation rate declined by 5.7 % to 1,790 t/d in 2017 before it increased by 4 % to 1,870 t/d in 2019. It dropped by 12 % to 1,650 t/d in 2021. This fluctuation trend are discussed in more details later in this section.

Similar trend was observed for per capita basis. The per capita generation rate increased by 8 % from 1.02 kg/capita/d in 2009 to 1.10 kg/capita/d in 2014. This was expected due to the increase of per capita gross domestic product (GDP) in Kuala Lumpur. This was explained by the fact that higher GDP indicates the increases of consumer activities and business expansion that increases waste generation (Mazars, 2003). The 0.4 % reduction during 2010 to 2011 period was due to the higher growth of population (1.1 %) as compared to 0.7 % increment of the average daily waste tonnage. From 2014, the per capita generation then dropped by 9.2 % to 1.00 kg/capita/d in 2017. It was then rose by 4 % to 1.04 kg/capita/d in 2019 and then fell by 11 % to 0.93 kg/capita/d in 2021.

The downtrend observed in the period of 2014 to 2018 might be due to the implementation of SAS program, which was started in 1st September 2015. Further analysis showed that this peculiar trend was due to the fluctuated trend of waste tonnage collected by Alam Flora, which were mostly composed of residential waste. This strengthened the theory of the impact of SAS program as the program was only implemented in residential areas.

Penang, a state with a development level similar to Kuala Lumpur, experienced a similar situation. Between 2012 and 2015, the solid waste disposal rate in Penang decreased significantly, primarily attributed to increased recycling efforts. In 2016, despite a rise in total waste generation, the continuous improvement in recycling practices resulted in a further decrease in the disposal rate. The percentage increase in recycling rate outpaced that of waste generation rate during this period. Melaka, the state that also implemented SAS program also showed reduction trend of solid waste disposal after 2015.

The downtrend observed during 2019-2021 period might be due to the implementation of MCO that restricted the economic activities. The restriction might reduce the product consumption rate and reduce the waste

generation rate. Fear of food supply insecurity during the MCO also caused the residents to preserve their food, which also contribute to the reduction of waste generation rate.

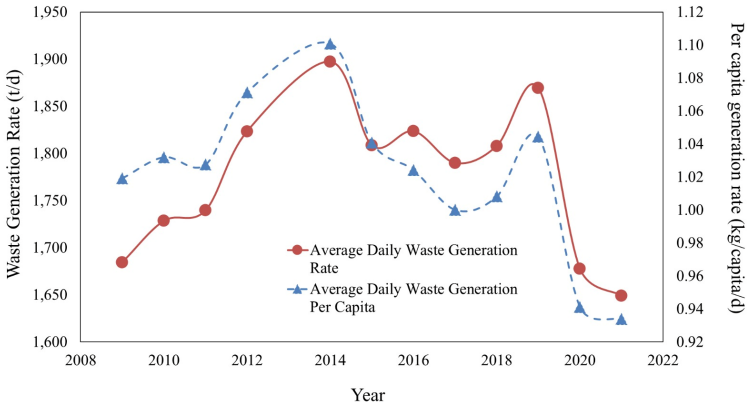

Figure 2: Solid Waste Disposal Rate Trend in Kuala Lumpur from 2009 until 2021

3.3 Recyclable Material Collection Rate from SAS Program

The collection rate of recyclable materials from the SAS program in Kuala Lumpur was unexpectedly low, despite previous discussions on waste reduction. From September 2015 to December 2018, the monthly average of daily tonnage ranged from 0.3-2.0 t/d. Factors contributing to this low recycling rate, according to discussions with authorities, include illegal collection by scavengers and street collectors, poor enforcement, and residents selling recyclable materials directly to vendors. Similar low collection rates were observed in other states implementing the SAS program. In 2016, based on yearly tonnage data, Putrajaya had the highest collection rate (1.10 kg/capita/y), while Perlis had the lowest (0.03 kg/capita/y). Kuala Lumpur (0.25 kg/capita/y) and Pahang (0.24 kg/capita/y) showed similar collection rates. This supports claims of illegal collection and direct selling of recyclable materials in Kuala Lumpur. Considering that Pahang had a lower per capita GDP (MYR 30,754/capita) compared to Kuala Lumpur (MYR 97,060/capita), a lower collection rate was expected, in line with the study by Hoornweg and Bhada-Tata (2012) showing a positive correlation between income level and recycling rate. The similar recycling rate between the two states may be attributed to a higher number of recycling centers in Kuala Lumpur, potentially increasing illegal collection and direct selling, reducing the authority's collection rate.

3.4 Correlation Tests

This section presents the correlation test between per capita waste disposal rate, and per capita GDP. The correlation tests were conducted for the datasets before and after SAS program implementation. The correlation data obtained from R-programming software also showed a similar result. It should be noted that the correlation test did not include the waste disposal data from 2020 to 2021 to eliminate the potential influence of the movement control order (MCO) imposed during the COVID-19 pandemic. The movement control order restricted the movement of people and goods, which could have affected the waste disposal patterns during this period. Excluding data from this period could eliminate any potential confounding variables and provide a clearer picture of the impact of SAS program alone. This effect of MCO was only temporary and not suitable to be taken into account for future forecasting. Table 1 shows the changes in correlations coefficient after the program implementation.

Table 1: Pearson Correlation between waste disposal rate and per capita GDP

	Before SAS Program Implementation (2009-2014)	After SAS Program Implementation (2014-2019)
Correlation Coefficient	0.92	-0.46
P-Value	0.03	0.44

High correlation between the economic variable and per capita waste generation rate was observed in 2009-2014 period with r and p values of 0.92 and 0.03 respectively. The P-value indicates that the probability of null hypothesis to be true was 3 %. As the probability was less 5 %, the hypothesis was rejected and the correlation was considered significant. This was a typical correlation between the two variables as reported by Diacon and Maha (2015), whom conducted the study using the data from 79 countries and Khajuria et al (2010), whom

analyzed the data from 5 Asian developing coutrires. As the impact of SAS program was included (2014-2019 period), a negative correlation between the variables was observed with r and p values of -0.46 and 0.44 respectively. This was tallied with Alajmi (2016) whom suggested that policy measures could inverse the positive relationship between waste generation rate and economic growth. Gu et al (2015) also agreed on the significant impact of policy measures that related with instrumental motivators such as fees, charges, and subsidies on waste reduction performance.

3.5 Regression Model Development

This research developed a per capita waste disposal rate prediction model in the function of per capita GDP through regression analysis. Figure 3 shows the scatterplot of per capita waste generation rate versus per capita GDP. For 2009-2014 period, the correlation behaviour could be described as linear regression model. The coefficient of determination (R^2) value of the model was 0.84, which indicates that 84 % of the variation in waste generation data was explained by the regression line equation. For 2014-2019 period, the waste generation rate showed the initial sharp decline that might indicate the significant recycling activities in Kuala Lumpur during the first year of the program implementation. As the recycling rate was limited due to the fact that not all waste materials could be recycled, subsequent slower decline or flattened pattern was observed. This correlation behaviour could be described by polynomial regression model. The coefficient of determination (R^2) value of the model was 0.76.

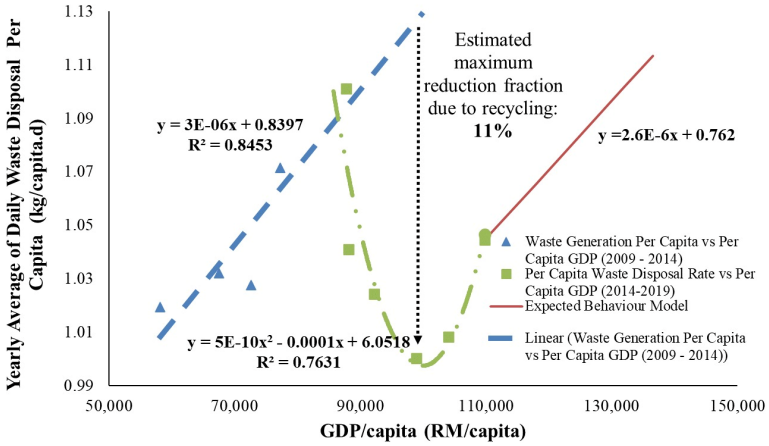

Figure 3: Regression Models of Per Capita Waste Disposal Rate in the function of Per Capita GDP for Different Periods of Time

It was expected that the waste generation rate reached the maximum reduction in 2017, in which per capita GDP was about MYR 98917.79. The maximum recycling rate achieved by the program was estimated to be 11 % with the assumption that the linear increment of as-generated waste tonnage was maintained after the program implementation. It was expected that the per capita waste generation rate after 2019 would continue to have a similar linear correlation with population density as observed during the 2009-2014 period. It is also necessary to take into account the impact of the 11 % recycling rate. It should be noted that, data in 2020-2021 period might not exhibit the expected correlation behavior due to the impact of MCO. It was expected that the MCO effect is temporary. Similar linear regression model as in 2009-2014 period was proposed to describe the correlation behavior after 2021. The manipulated variable coefficient of the model was corrected by considering the 11 % recycling rate.

3.6 Forecasting of Waste Disposal Rate and Feedstock Sustainability Assessment

The population and per capita GDP in Kuala Lumpur were expected to reach around 2.13 M and 235,852 MYR /capita by 2050. Based on developed model; and the projections of per capita GDP and population, the per capita waste disposal rate and annual average waste disposal rate were forecasted. As shown in Figure 4, the waste disposal rate was predicted to be 2,706 t/d or 1.3 kg/capita/d by 2050. Based on the current prediction, it was expected that solid waste supply for WtE project in Kuala Lumpur is sustainable even after the implementation of SAS program.

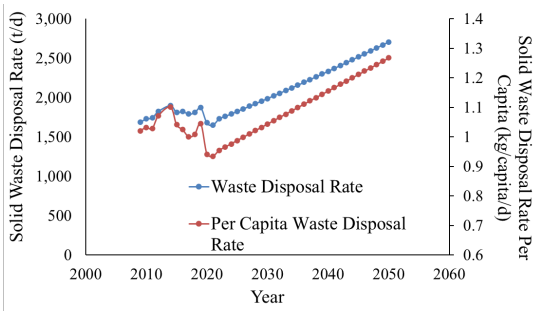

Figure 4: Future Projection of Solid Waste Disposal Rate in Kuala Lumpur

4. Conclusions

Results of the study showed that the annual average daily generation rate decreased by 88.9 t/d or 4.7 % after the implementation of SAS program. The estimated maximum recycling rate contributed by SAS program was 11 %. Decoupling effect between the waste disposal rate and gross domestic product was observed with a change in the Pearson correlation coefficient from 0.92 to -0.46 after the program implementation. Considering this impact, the waste disposal rate was forecasted to be 2,076 t/d or 1.3 kg/capita/d in 2050. The solid waste supply for WtE project in Kuala Lumpur was expected to be sustainable even after the implementation of SAS program. This finding serves as a valuable reference for other locations aiming to integrate Waste to Energy and recycling processes into their waste management systems.

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