Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN : 2550-0023

Vol 18, No 1, 2021, 161-170
Article available at homepage presipitasi

Research article

The Effect of Household Waste Reduction on the Lifespan of Parit Enam Landfill in Pangkalpinang City: Using Dynamic System Modeling

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Abstract

Currently, there are still problems occurring in waste management activities in Pangkalpinang City. Solid waste that is scattered in the City of Pangkalpinang is caused by waste that has not been transported and handled. TPA Parit Enam's capacity, which serves solid waste in Pangkalpinang City, will decrease every year due to an overload of incoming waste generation. Currently, the City of Pangkalpinang aggressively implements a waste management policy at the source or the 3R program, including waste bank activities and waste processing at reduce, reuse and recycle (3R) landfills. The purpose of this study was to determine the effect of household waste reduction activities on the current use of the Parit Enam landfill in Pangkalpinang City in each of the scenarios that were compiled. The compilation model uses Powersim Studio 2005. The dynamic analysis shows that the activities that follow the waste at the source and respect what happens in TPS 3R Pangkalpinang City can affect TPA Parit Enam's useful life and produce a suitable scenario to be applied in the waste management activities of Pangkalpinang City. Scenario C (Optimistic), the valuable life of Parit Enam Landfillreaches 2023, and scenario C (Optimistic) can reduce the amount of waste transported by 29.65% compared to scenario A (Business as Usual). Besides, the proportion of household waste reduction reached 48% at the end of the simulation year.

Keywords: dynamic system model, household waste, Pangkalpinang City, wste management, waste reduction

1. Introduction

Indonesia, in 2010, 49.8% of Indonesia's population lived in cities, and this number will continue to increase to reach 60% in 2025 (BPS, 2010). Cities are areas with a higher population concentration and density among the surrounding areas. This causes the city to become an activity of human life, where this activity will then produce waste. Data (UNEP-DTIE, 2013) shows that in 2013 more than half of the world's population living in urban areas consumed around 75% of the earth's resources. The high consumption of resources will cause a significant waste generation. According to Chen (2018), I explained that the presence of waste generation that has not been appropriately handled would harm the quality of the environment and the quality of life for residents who live in these urban areas. Whereas in research (Ezeah & Roberts, 2012), the result of increasing population, urbanization, and massive economic development can increase waste production, so the challenges in managing solid waste will be even more significant.

Pangkalpinang City is one of the cities currently developing, as the capital of the Bangka Belitung Islands Province, which has an area of ± 118.4 km2 and a population of 212,727 people (BPS Kota Pangkalpinang 2019). Based on DLH Pangkalpinang City data in 2019, the waste generation generated in Pangkalpinang City reached ± 168 tons/day with 63% of the households' waste. The generated waste has not been fully managed at the source or TPS 3R and is directly transported to the TPA without any waste processing; the waste goes to Parit Enam Landfillwhich still uses an open dumping system which causes the capacity of Parit Enam Landfillto to be increasingly limited. Meanwhile, according to (Ali *et al*., 2014), it is clear that waste management based on an open dumping system will cause environmental pollution, including water, soil, and air pollution, and make the pile of waste a source of disease. The Pangkalpinang City Government, which related agencies carry out, implements programs to overcome waste problems through the waste generation reduction approach. Waste reduction activities are carried out through the Waste Bank activities and 3R landfills. An alternative solution to the waste problem by processing waste from the source of waste can reduce the burden on local governments in terms of transportation activities and waste disposal facilities (Elza *et al*., 2020).

Solid waste management, especially in urban areas, is a complex and dynamic problem. Complex means that the waste problem is caused by the influence of various aspects related to waste management. Meanwhile, it is dynamic because the amount of waste generated by Pangkalpinang City residents will continue to increase over time. The dynamic system is an alternative that can solve waste problems, especially in cities, because the dynamic systems approach can simplify the structure of a complex or complex system (Achachlouei & Hilty, 2015). In the urban solid waste problem itself, a dynamic system model can be used to assess the conditions that occur and produce simulations that show the techniques used to study the causal interactions of the variables used in the closed-loop chain (Ilgin & Gupta, 2010). The dynamic system feature allows the modeler to model the causal loop, time delay, and the interaction of linear and non-linear variables in all integrated waste management processes in the conditions that occur. In recent decades, using a dynamic systems approach has been widely used in research covering various disciplines, such as urban waste management systems in India and Thailand (Ahmad, 2012; Sukholthaman & Sharp, 2016).

Ahmad's research (2012), it was using a dynamic system to describe a model of waste management system in Delhi City, India, which aims to predict the waste generated, collected, destroyed, and estimate the amount of electricity generated from waste management activities and the need for waste management costs. Meanwhile, the research conducted by Sukholthaman & Sharp (2016) evaluated the effect of sorting waste at the source on waste collection and transportation. This study's dynamic system explains the relationship between source sorting and the effectiveness of waste management in Bangkok, Thailand. In contrast to other studies through dynamic systems approach studying the effect of urbanization on municipal waste management and concluding that an increase in population size can lead to an exponential increase in the amount of waste generation in India (Pai *et al*., 2014). The purpose of this study was to determine the effect of household waste reduction activities on the current use of the Parit Six Final Disposal Site in Pangkalpinang City in each of the scenarios that were compiled. In this study, the intervention model that was compiled emphasized the 3R-based program activities. The research was conducted by developing a comprehensive model that considers the dynamic relationship between waste reduction and landfill life based on a dynamic systems modeling approach.

2. Method

This research was conducted in the administrative area of Pangkalpinang City in 2020. Modeling in this study used the help of Powersim Studio 2005 software. Meanwhile, policy analysis was used in determining the selected scenarios that had been compiled. In terms of the intervention model prepared, this study emphasizes the activities of the 3R program in Pangkalpinang City. Several previous studies conducted by Dace *et al*., (2014); Xiao *et al.* (2020) explain that there is a process in carrying out dynamic system modeling related to the topic of urban solid waste, including (1) reviewing literature related to the basic theory of waste management and looking at the existing conditions of waste management in Pangkalpinang City to identify problems and fundamental theories in developing model; (2) collecting secondary data in Pangkalpinang City, especially those related to waste management; (3) compiling a dynamic system model using Powersim Studio 2005 software; (4) simulating and validating the model; (5) determine related policy alternatives and conduct evaluation.

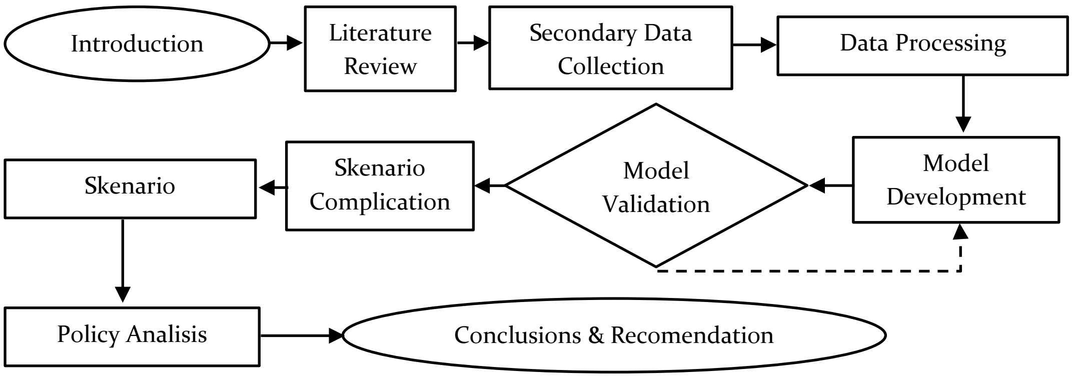

Figure 1. Schematic of dynamic system modeling stages

3. Result and Discussion

3.1 Submodel Diagrams and Causal Loop Diagrams

What is depicted in the model is a simplified Pangkalpinang City waste management system according to the research objectives and the availability of related secondary data. In the model to be built, waste at the source will be simplified to be processed at the source with environmental scale composting activities, waste bank activities, and not handled, which explains that waste taken by scavengers is an existing condition and will be considered untreated waste (Tan *et al*. ., 2018). In terms of simplifying the model adjusted to the availability of secondary data, it is assumed in the model that the waste from the source will be transported directly to the TPS and the waste from the TPS will be transported to the TPA. The below is the handling of Pangkalpinang City waste in the model.

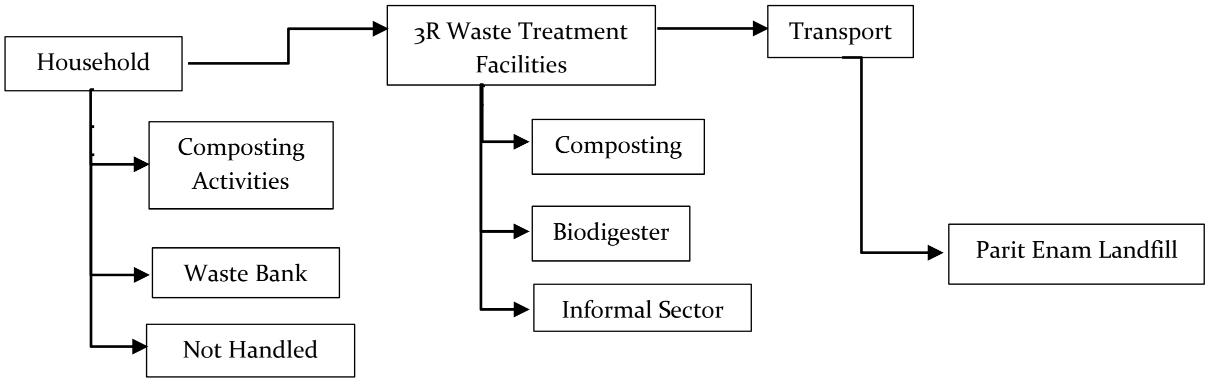

Figure 2. Pangkalpinang city waste management in model

A critical part of dynamic modeling is making a causal loop diagram. A causal loop diagram is the first step in compiling a system. The causal loop diagram can be in the form of assumptions, strategies, or a perspective with deep roots in the various actions taken on the model to be built (Pai *et al.*, 2014). The research of Popli *et al.* (2017) explains the causal relationship to a city's waste problem, starting with population growth that occurs in cities. Meanwhile, this research shows a causal process related to urban waste problems in Pangkalpinang City until municipal waste ends up at the Parit Six waste final processing site in Pangkalpinang City. The increase in population has implications for an increase in the amount of waste generated in Pangkalpinang City. Based on the conclusion, the amount of waste generation depends on the number of people who produce waste. Below is a causal loop diagram that represents waste management in Pangkalpinang City.

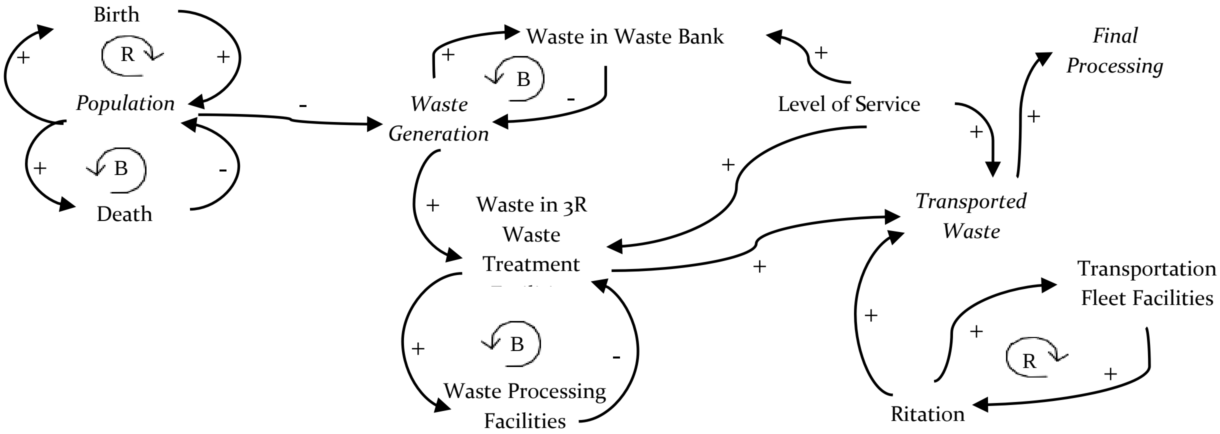

Figure 3. Causal loop diagram

3.2. Model Description and Formulation

At the stage of developing the causal loop model, the next step is to translate the causal loop relationship into a model that can be run on software that is used as a tool to perform dynamic systems. Using these assumptions can make it easier to develop scenarios that will be applied to the model that has been developed. Submodel in this research, namely population submodel, waste generation, and infrastructure needs related to solid waste, can be seen in Figure 4 of the overall model.

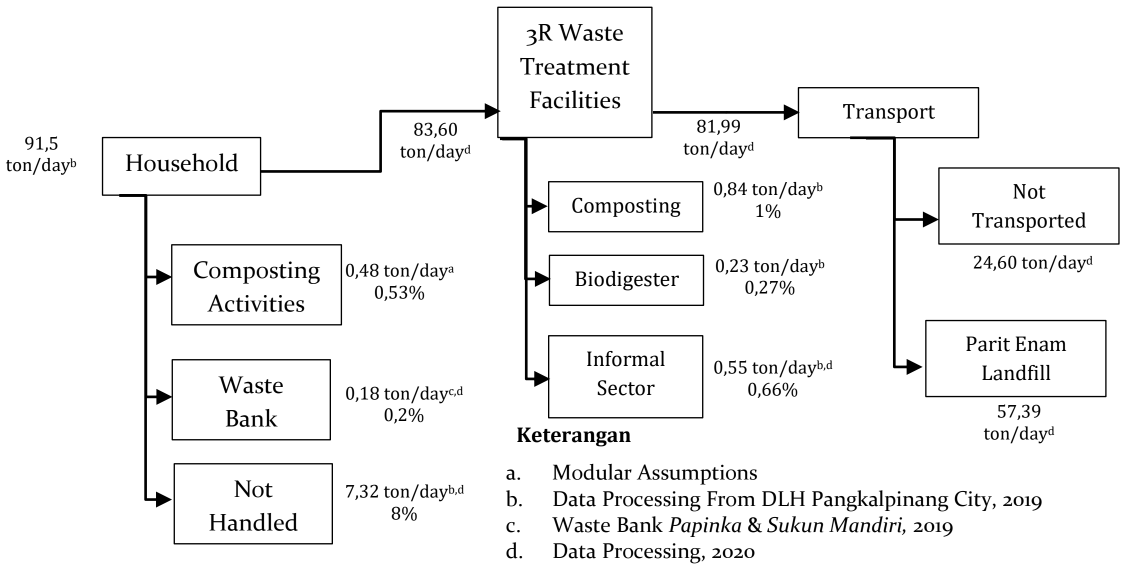

Figure 4. Pangkalpinang city waste management assumptions in the model

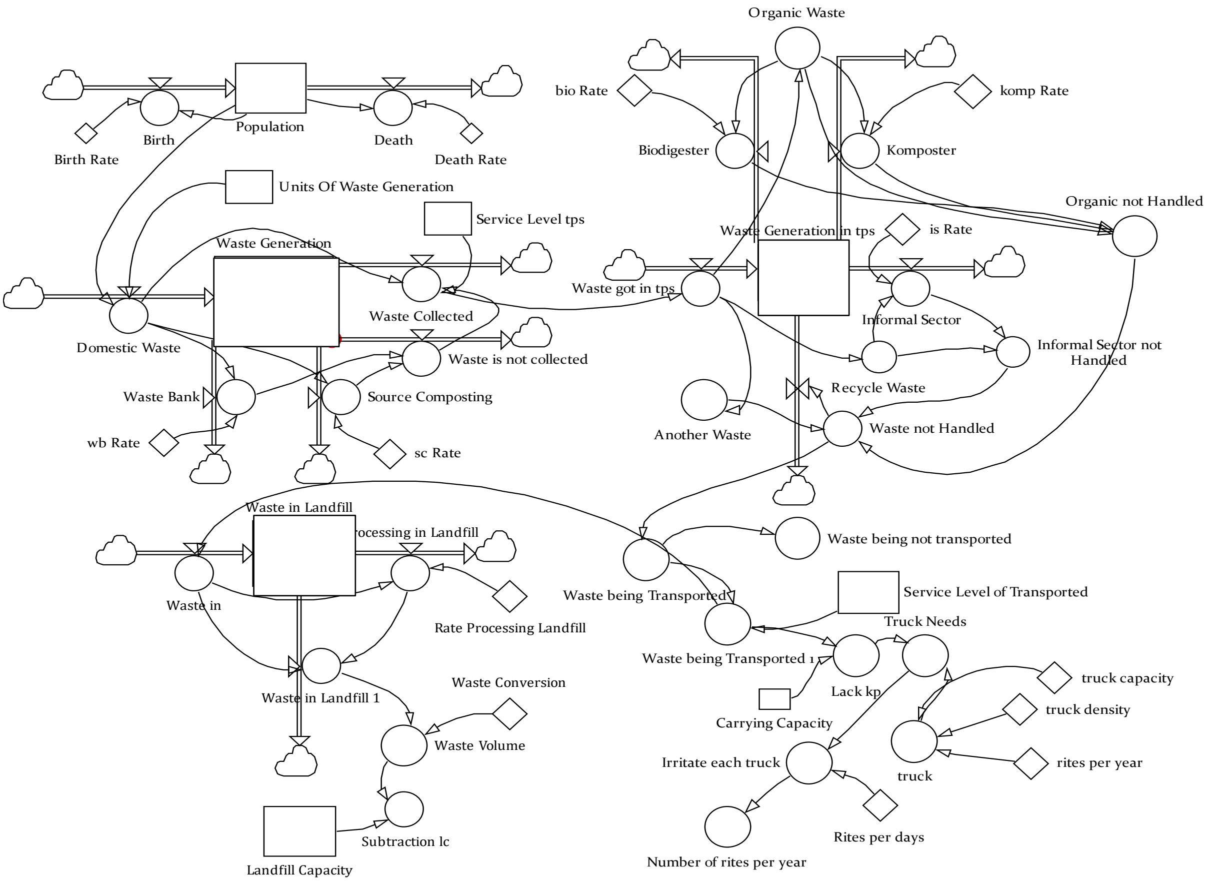

Figure 5. Solid waste management model in Pangkalpinang City

3.3 Model Validation

Model validation explains the extent to which a model constructed can mimic a fact. This can be shown by the extent to which simulation data can mimic the actual existing data. The process of seeing this is called performance validation or output validation. In this study, the model created produced several outputs, including the number of population, especially Pangkalpinang City, based on the simulation results.

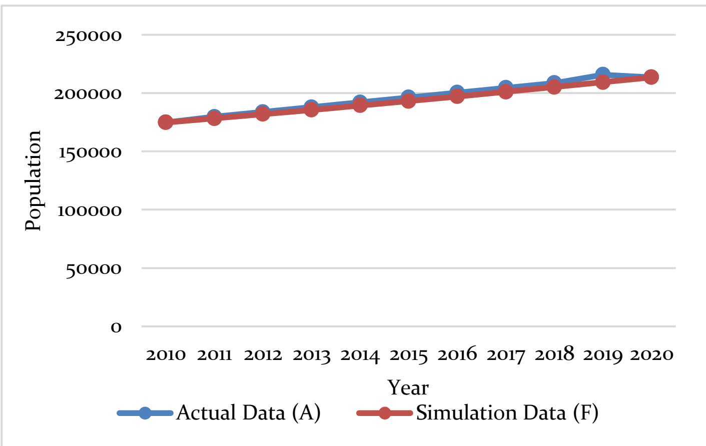

Figure 7. Comparison of actual data and population simulation results

The application of the MAPE (Mean Absolute Percentage Error) method aims to quantify the magnitude or nature of the model's error. The data used in the validation of the population model is data for 11 years, in which the population data is from 2010 to 2020. Based on the validation results using the MAPE method, the MAPE value in the population model is 1.276%. This shows that the developed model's MAPE value has good accuracy (<5%).

3.4 Preparation of Policy Scenarios

Public policies related to waste management in Pangkalpinang City are the basis for consideration in preparing this scenario. The standard to be achieved in the developed scenario is to find a minimum accumulation of waste generation that must be disposed of in the TPA; this can affect the useful life of the TPA. This research will develop a model scenario which is divided into 3 (three) scenarios, including scenario A or the Business as Usual (BaU) scenario, scenario B or moderate scenario, and the last one is scenario C or the Optimistic scenario. Below is an explanation of each scenario:

1) Scenario A (Business as Usual): this scenario describes the continuity of the existing waste management conditions without any significant changes from waste reduction activities and the level of waste management services. This is due to the high load generation of waste without waste management at a huge source.
2) Scenario B (moderate): this scenario explains that there are efforts that are considered / quite significant in managing waste in the waste bank, biodigester, and composting activities at TPS, which are considered as 3R-based programs in Pangkalpinang City. Waste processing facilities can be used more effectively, and improvements are occurring continuously. The service level of TPS and waste transportation increases every year.
3) Scenario C (optimistic): this scenario describes an optimistic scenario in municipal waste management activities, especially Pangkalpinang City waste, where composting and biodigester waste processing at TPS and waste bank activities are efficient, which are considered as 3R-based programs in Pangkalpinang City. The activity of reducing waste at the source increases. The level of TPS and waste transportation services increases every year.

In observing a model's behavior that shows the interactions between system components, several basic assumptions are made to apply to each scenario shown in the table below.

Table 2. Basic assumptions in each scenario

Scenario	Activity	Asumtion
BaU	Conventional	Continuity of existing conditions of waste management (generated waste entering the TPA)
Moderate*	(Centralization)	The waste bank processes 10% of inorganic waste*
Optimistic**	Garbage Bank	Waste banks process 20% of inorganic waste**
		25% of organic waste is processed by composting *
	Composting	35% of organic waste is processed by composting**
		10% of organic waste is processed by a biodigester*
	Biodigester	15% of organic waste is processed by biodigester**
		The informal sector processes 10% of inorganic waste*
		20% of inorganic waste is processed by the informal sector**

Based on each scenario's basic assumptions, it can be seen in Table 2 that in the moderate scenario, the target of 35% organic waste at the source can be processed, and 20% inorganic waste can be reduced. Meanwhile, the optimistic scenario targets that half or 50% of organic waste can be processed and 40% of inorganic waste must be processed.

3.5 Application of Policy Scenarios & Analysis of Modeling Simulation Results

3.5.1 Total population

Population growth in Pangkalpinang City that occurred within ten years of planning was simulated for the entire scenario preparation because no specific population variables were set. Based on the population simulation results above, it is shown that the population of Pangkalpinang City in 2020 is 213,572 people, while at the end of the planning year in 2030, it will reach 236,033 people. The following is the result of the population projection of Pangkalpinang City with a model simulation using the help of the Powersim Studio 2005 software below

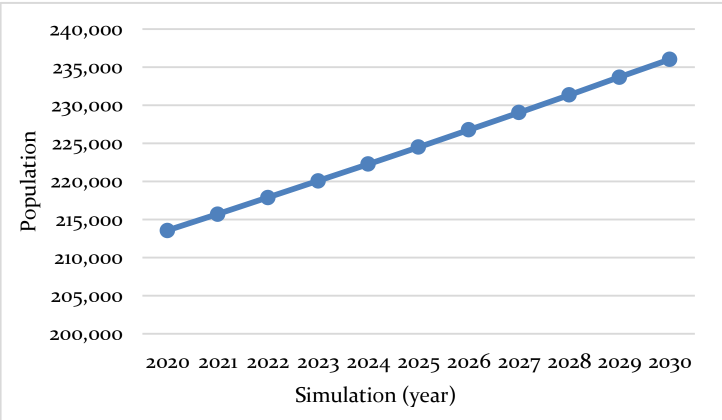

Figure 8. Population simulation graph in pangkalpinang city

3.5.2 Waste Generation

The amount of waste generated from the source used in each scenario is the same. This is because all the given model behaviors in predicting the amount of waste generation at the source are also the same. The difference in each scenario lies in the waste generation at the TPS and the amount of waste that will be transported to the TPA. Below is a comparison of each scenario's behavior can be seen in Figure 9 and Figure 10.

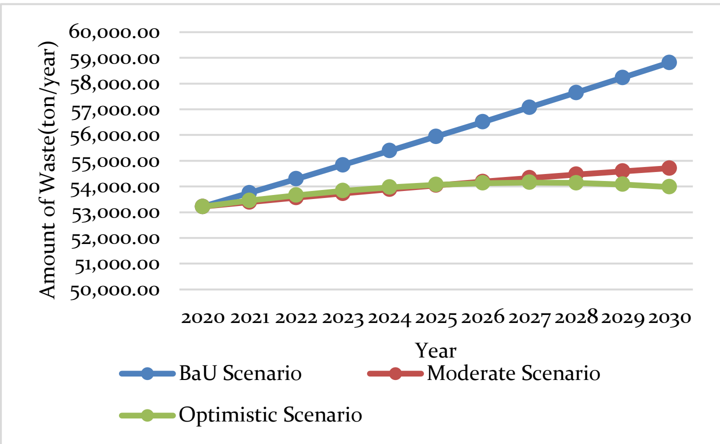

Figure 9. Comparison of waste generation at TPS for each scenario

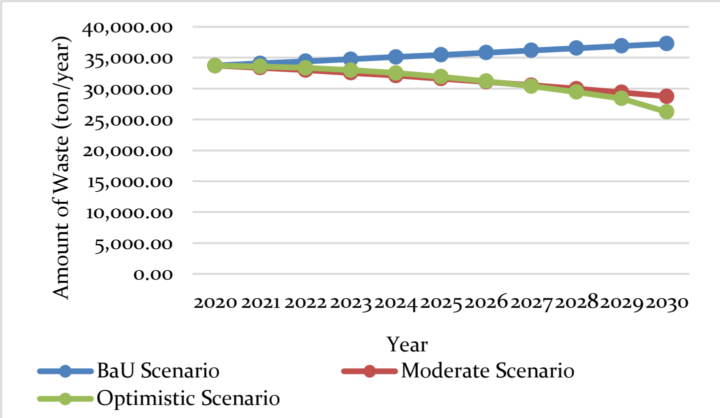

Figure 10. Comparison of waste generation transported to TPA for each scenario

In scenario B (moderate) and scenario C (optimistic), the amount of waste transported to the TPA has decreased. The graph shows that scenario B (moderate) can reduce the amount of waste to be transported by 22.92% compared to scenario A with waste management activities that are kept constant. In scenario C, the amount of waste to be transported to the TPA is the lowest than other scenarios of 26,215 tonnes/year or 72 tonnes/day. The thing to remember is that this amount of waste is the amount of waste originating from households, not including non-household waste. Scenario C (optimistic) shows that it can reduce the amount of waste transported by up to 29.65% compared to scenario A (Business as Usual).

3.5.3 Amount of Trash to TPA and Use Age of TPA

The waste that will enter the landfill of Parit Enam Landfillwas previously carried out by composting processing in Parit Six Landfill. In this modeling, composting processing activities in Parit Enam Landfill are assumed to have a constant or stagnant value each year. This will be applied to each of the scenarios that were compiled. The following below in Figure 11 shows the waste that enters the Parit Six TPA landfill every year in each scenario.

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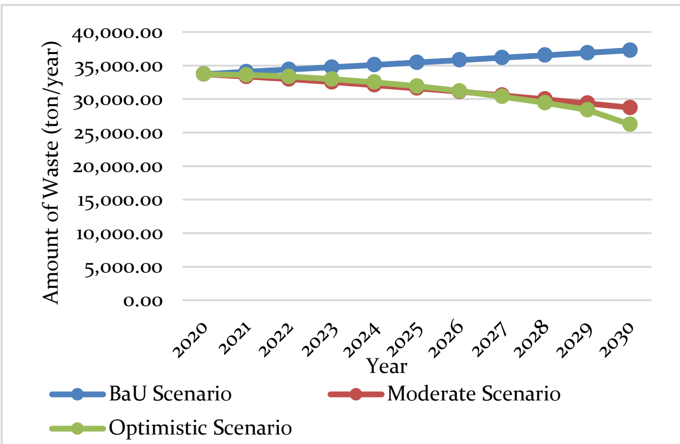

Figure 11. Simulation results of the amount of waste entering the landfill of TPA parit enam

The graph above shows the behavior of the amount of waste that will enter the landfill at Parit Six Landfill. The amount of waste that will enter the landfill in scenario B (moderate) and scenario C (optimistic) shows a decreasing trend until the simulation year. Meanwhile, in scenario A (Business as Usual) there will be an increasing trend every year. Based on the calculation of the current landfill capacity for Parit Six Landfill, the remaining land area is ± 1.2 Ha, which can be used as landfill, and for the maximum height of the landfill is around 8 m (Model Assumption, 2020) it can accommodate landfills of up to 8 meters. 250,606 m3. Figure 12 shows the service life of Parit Enam Landfillbased on the accumulation of waste that will enter Parit Enam Landfillin in each of the scenarios that have been prepared.

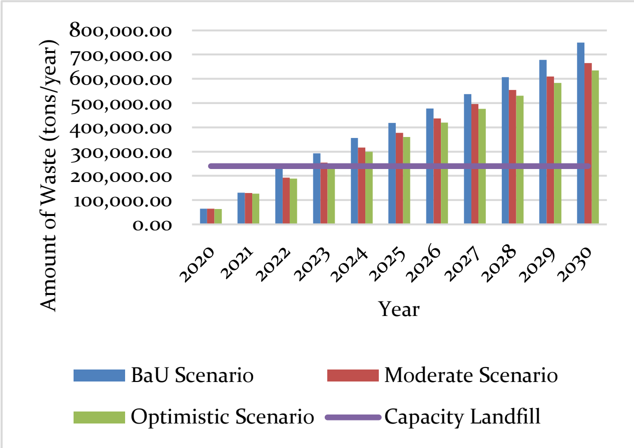

Figure 12. Age of layan trench six landfills every scenario

Figure 12 shows the simulation results of the service life of Parit Enam Landfillfor each scenario prepared. Scenario A (Business as Usual) carries out existing waste management activities in Pangkalpinang City without making significant changes to waste processing activities, resulting in the service life of the TPA ending in 2021. Based on scenario B (moderate), which has a target of reducing organic waste to reach 35% of processing activities in TPS and 20% of inorganic waste, will result in the service life of TPA ending in 2022. As for scenario C (optimistic), which has a target of reducing organic waste to reach 50% and inorganic waste is reaching 40%, the service life of Parit Enam Landfillusing this scenario ends in the year 2023.

4. Conclusion

The scenarios designed to determine the effect of household waste reduction on the useful life of the Sixth Trash Landfill, Pangkalpinang City, are scenario A (Business as Usual), scenario B (moderate), and scenario C (optimistic), each of which describes the conditions waste management. The target is that 35% of organic waste at the source can be processed and 20% of inorganic waste can be reduced in the moderate scenario. Meanwhile, the optimistic scenario targets that half or 50% of organic waste can be processed and 40% of inorganic waste must be processed. The basic assumptions used are based on existing policies and plans based on the 3R program in Pangkalpinang City. The simulation results in the compiled model show that the effort to reduce waste in Pangkalpinang City affects Parit Six Landfill's service life. By carrying out activities to reduce waste, banks and activities to reduce waste at TPS can affect the service life of Parit Enam Landfillto be longer. Scenarios B and C can extend the service life of TPA compared to scenario A. Scenario C (Optimistic) can reduce the amount of waste transported by 29.65% compared to scenario A (Business as Usual). The percentage of household waste reduction based on the 3R program reached 48% at the end of the simulation year.

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