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Cost Optimization of Aerobic-based Compost Production by System Dynamics Study in PT Eastern Sumatra Indonesia (PT ESI)

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Abstract

The process of compost production with anaerobic system produces methane gas (CH4). Currently,there are palm oil processing requirements in Palm Oil Mills (POM) to reduce greenhouse gases as much as possible. An alternative solution is to use the aerobic system to treat POME without producing CH4 gas. The purpose of this study was to optimize the cost of using the aerobic system in PT ESI by developing system dynamics with STELLA Ver 9.02. The results of the system dynamics provided the cost equation for anaerobic $y = 146758x^2 + 24848x + 1x10^6$ and aerobic $y = 14277x^2 - 96412x + 235539$, where x is the time in years and y is the total cost per ton of compost produced. Cost balance occurred in the second year when the anaerobic system incurred GHG (greenhouse gas) tax of IDR 75,000/ton equiv CO2 for the CH4 gas produced, while the aerobic system did not produce CH4 gas. The cost balance between aerobic and anaerobic systems was IDR 145,400.44/Ton POME (Palm oil mill effluent). This proved that compost with GHG tax scenario in the anaerobic process required higher cost than aerobic process without CH4 gas. However, the initial development process for the aerobic system was expensive, such as at IDR 235,471.41/ton POME.

Keywords: Organic fertilizer, Empty Fruit Bunch, Emission Tax, Palm Oil Mill Effluent

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1. Introduction

The process of palm oil processing produces a lot of solid and liquid waste. Solid waste includes empty fruit bunches, palm shells, and fibers. Whereas liquid waste is processed before it is released into the environment (rivers). The waste released by palm oil factories has a big contribution in producing methane gas emission that triggers global warming. The United Nations launched The United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janeiro in 1992 to stabilize greenhouse gas concentration in the atmosphere by preventing human behaviors that are harmful to the climate. At the same, there was a commitment to reduce emissions by 29% to 41% by the year 2030 with international cooperation as outlined in Nationally Determined Contributions (NDC) subjects to Paris Agreement. One of the efforts by the government to contribute to reducing greenhouse gas emissions is by implementing a carbon tax like other countries that have implemented it [1]. The government is imposing a carbon tax, expected in January 2022, that is planned to be set at a minimum of IDR 75 per kg carbon dioxide equiv (CO2eq) [2]. Palm shell and fiber waste are usually used by palm oil mills as fuels for power plants. Oil palm empty fruit bunches (OPEFB) are the main waste from the palm oil processing industry. On the basis of processing, 1-ton fresh fruit bunches (FFB) will produce 0.21 ton (21%) crude palm oil (CPO), 0.05 ton (5%) palm kernel oil (PKO), and the rest is waste, such as OPEFB, palm fibers, palm shells, and seeds amounted to 20%, 12% and 6% of FFB respectively [3]. Liquid waste from Palm Oil Mills (POM) hurts the environment as it has very high BOD and COD (Chemical Oxygen Demand) content so they must be reduced before being flowed into the plantation [4].According to [5], composting is one of the doable ways to increase the nutrient value and reduce the volume of unused OPEFB. The utilization of OPEFB as materials for compost will be able to solve the problems caused by the accumulation of empty fruit bunches in the oil palm industry. Moreover, this approach can bring additional revenue from the selling of composts, as well as reduce the cost from the use of inorganic fertilizers. compost production from OPEFB also reduces GHG produced by palm oil plantations [6]. Composting with aerobic process means using airflow in the process. For microorganisms, airflow may be more important than food. Generally, in the heaps of composts, airflow runs out faster than food. If there was not enough airflow, anaerobic decomposition would take place and that would be bad for two reasons. First, the process would go slower than aerobic composting, and second, some of the products, such as ammonia and hydrogen sulfide, give off a foul odor [7]. This paper aims to produce compost in a palm oil mill in order to utilize OPEFB. Both solid and liquid waste ideally have the potential used as compost. According to [8], composting is the process of decomposing a biologically complex organic matter into a simple and relatively stable humus-like substance under controlled aerobic conditions. Composting or converting agricultural waste into compost is one of the most preferred, inexpensive, and simple methods for handling and stabilizing such waste and producing organic fertilizers [9]. According to [10], composting is one way to increase the nutrient value and reduce the number of empty fruit bunches of unused oil palm. Using empty fruit bunches as compost materials can not only solve the problem of factory accumulation but also provide additional income from compost sales and reduce the cost of using inorganic fertilizers. As a sequence, environmental management should pay great attention to how to minimize waste and do recycling. Composting offers a feasible opportunity method for managing natural waste [11].

The approach above requires a systems approach that deals with the problems by not only paying attention to the problem details but also the position of the problems in a broader perspective. In order to understand and apply the systems approach well to solve the problems, it is important to understand or know the weakness and strengths of the systems approach. Meanwhile, the next step is to develop model, which is a simplified abstraction of the real world with only its important parameters and variables. A model can reflect or create an abstraction from an object, a process, a situation, or a system. In a broad manner, a model can reveal and explain the relationships in various components, actions and reactions, and causal relationships. Simulation modeling is the design model used. It is the process of changing the real system concept into a system compiled in computer languages by using simulation software. At this stage, causal loop diagram (CLD), sub-system, stock, and flow diagrams equipped with the mathematical formulation are drawn. CLD is drawn to observe the relationships between variables that affect the system. A stock and flow diagram is drawn to determine the relationship between variables over time. After the conceptual model is structured, the next process is to formulate the mathematical model so that the simulation of the existing system condition can be run. System dynamics research has been widely used to solve complex problems. [12] used a system dynamics model to assist decision-making in production design capacity based on the needs and planning of the installed capacity. If the increase in installed capacity was not balanced with the increase in domestic demands, production would be an excess that would be detrimental to the company. Moreover, [13] prepared a production capacity plan for instant noodle products with a system dynamics approach that enables them to fulfill diverse demands in large quantities accordingly to the production schedule. The above concept is to be used to predict or optimize the cost of waste treatment, either by aerobic or anaerobic cycle.

This research aims to calculate the optimum cost of palm oil mill waste by aerobic and anaerobic methods to determine the cost-efficiency point in PT Eastern Sumatra Indonesia (PT ESI) in Simalungun regency, North Sumatra. While the merit of this research is served as the initial information in measuring the economic value of the treatment of palm oil mill waste.

2. Materials and methods

Data collected in this research was secondary data obtained from PT Eastern Sumatra Indonesia (PT ESI) by documentation. Data required was the cost of organic fertilizer usage composted from EFB and POME through aerobic and anaerobic system and palm oil productivity data.

There were two stages in this method, such as compiling causal loop diagram (CLD) as the material to dynamically analyze the model, followed by the use of appropriate system dynamics based on collected CLD. CLD model is widely used in problem-solving, together with a systems approach that considers the dynamic complexity or supports a system dynamics approach.

The CLD model approach has a few advantages, as follow:

i. Encourage problems to be seen as a whole, in both scope and time aspects, to prevent narrow thinking.
ii. Describe the causal relationship chain more explicitly and create better rationale.
iii. Enable effective communication to take place and build better teamwork.
iv. Assist the exploration of alternative policies and decisions to anticipate consequences early.
v. Allow good positions for the decision-making process.

[14] provided essential clues in understanding the CLD of a problem, such as know the problem limitation and scope. Start from one exciting variable. Through CLD, we were able to find out the factors and variables involved or related to the problem we were facing, including the causal relationship between concerned variables in the context of the problem. Based on that knowledge, we were able to choose and determine actions required to overcome the problem and where to start, as well as the emerging consequences with the taken measures. The more complete, relevant, and measurable those variables put forward by CLD, the more suitable the choice of steps we could take. The stages of research in the system dynamics were as follow:

i. Variable identification made to acknowledge the involved variables in the modeling of the system. The variables were compiled based on literature studies and in-depth interviews with the stakeholders in the companies. Next, simulation modal was designed referring to identified variables.
ii. Model designing converted an actual system into computer languages by using simulation software. In this research, Stella software designed the system model to determine the model composition. In this stage, we drew a causal loop diagram (CLD), sub-system, and stock and flow map equipped with mathematical formulation.
iii. Model verification assessed the suitability or accuracy of the model’s logic and ensure there were no errors in the model. There was a processing of units or variable units assessment here. Whereas model validation compared the behavior between the simulation model and the actual model. If there was a significant behavior difference during the assessment, then the system variables could be reviewed or necessarily modified. On the other hand, if successfully obtained behavioral conformity, the model could be accepted as a valid representation of the actual system.
iv. Policy scenario design observed the impacts of each scenario, should it be applied in the model. The policy-

making changed the values of the respective variables that affect the system, making or adding new models to the existing models, or changing the system's structure to determine the optimum cost composition scenario between aerobic and anaerobic waste treatment in PT ESI.

vi. equation in each plan.

vii. The analysis and interpretation of the results of running simulation were carried out to determine the system behavior compared to the actual system. The results of the running simulation can describe the effects of the variables on each determined cost composition in the treatment of palm oil mill waste.

viii. The analysis and interpretation of the results of applying the scenario determined the behaviors of variables after the simulation in different plans. The scenario design used in different conditions from the actual would affect

v. Policies were decided and selected from 3 scenarios. Scenario 1 was the simulation of the existing conditions. Scenario 2 was the simulation of 100% anaerobic waste treatment. Scenario 3 was the simulation of 100% aerobic waste treatment. From all these scenarios, we obtained balanced value from the
other variables. Therefore, we could determine the main variables to be prioritized in decision-making policy.

2.1 Research Location

PT Eastern Sumatra Indonesia (PT ESI) is an oil palm plantation company in Pematang Syahkuda, Gunung Malela district, Simalungun regency, North Sumatra.

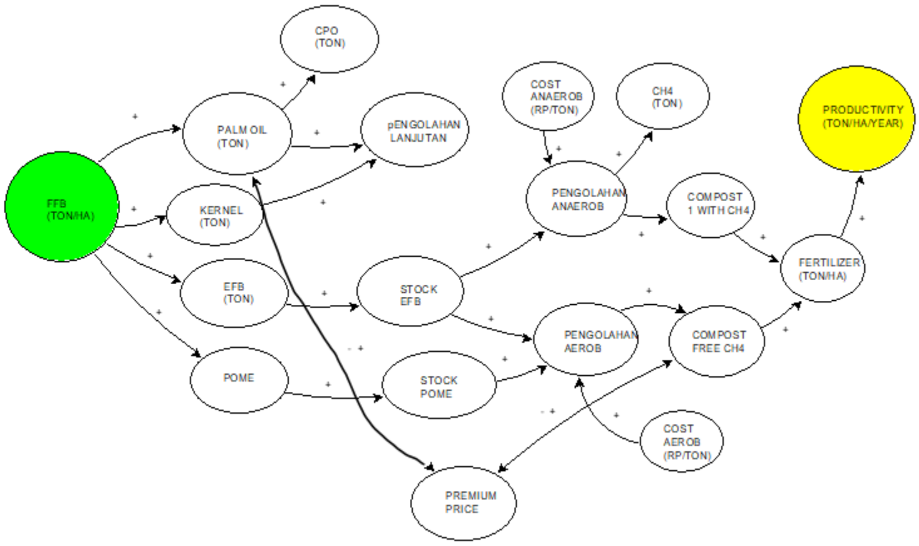

Figure 1. Causal Loop Diagram (CLD) of waste treatment in the palm oil mill

3. Results and discussion

3.1. Causal Loop Diagram (CLD)

The systems thinking method has various tools to comprehensively observe interconnected situations. One of the tools is the causal loop diagram (CLD), which is a model used in problem solving and prevention by considering every factor that is interconnected with other factors. Causal loop diagram (CLD) consists of variables that are connected by arrows that show the causal influence between the variables, which is called the causal link. Each causal link was assigned a positive (+) or negative (-) polarity to indicate how the dependent variables changed when the independent variables changed too. Important loops are marked with signs that show whether the loops had positive or negative feedback. Note that these loop signs are made of circular arrows in the direction of the loops. The discussion of problems in the system approach that uses SMF input-output model is more focused on the static relationship in the system. The input-output model can indeed support the implementation of a system approach in designing and improving various organizational and management systems that are relatively stable. However, SMF's static approach is not sufficient for broad and complex social problems that are dynamic in nature. Because as we know in general, most living systems are not in static nor linear causal relationships. Our world is in a state of constant motion and change or in a dynamic state. Moreover, the world seems to be in a state of disorganization.

But actually, beneath the surface of the disorganized conditions, there are orders. In this context, orders or regularity do not mean calm, static, or good, but they mean the ability to adapt to the pattern, shape, and structure of the world. The pattern and shape are created through the active interactions or relationships between the elements or components in the respective system. The above CLD system approach started from the harvesting of fresh fruit bunches (FFB) that would turn to palm oil, kernel, empty fruit bunches (EFB), and palm oil mill effluent (POME). The following process was to process FFB into crude palm oil (CPO) and other following procedures. The waste obtained from the processing of FFB, such as EFB and POME, were processed into composts through two types of routes, such as the anaerobic route that is carried out often in the palm oil mill and the aerobic route. The anaerobic route would produce methane gas, and with greenhouse gas (GHG) calculation using emission factor from ISCC standard, the GHG effect it made became a limitation [15]. Whereas, the aerobic process route did not produce methane gas. Therefore, the route was highly recommended as an alternative to composting without producing GHG. This route was closely related to the lucrative CPO price incentive (premium price) provided by the international community for zero CH_4 waste handling [16]. However, the aerobic process faced a more complicated processing route that involved pretty complex technology and high initial investment. The anaerobic process route, on the other hand, did not require a complex technology with a cheap and straightforward process route. However, it was no longer strategic because there was no CPO price incentive, and a relatively high GHG tariff imposed on industries that still emit GHG.

3.2. Dynamic Model

The model in Stella ver 9.02 was compiled from EFB and POME, both solid and liquid, waste treatment flowchart based on the prepared CLD.

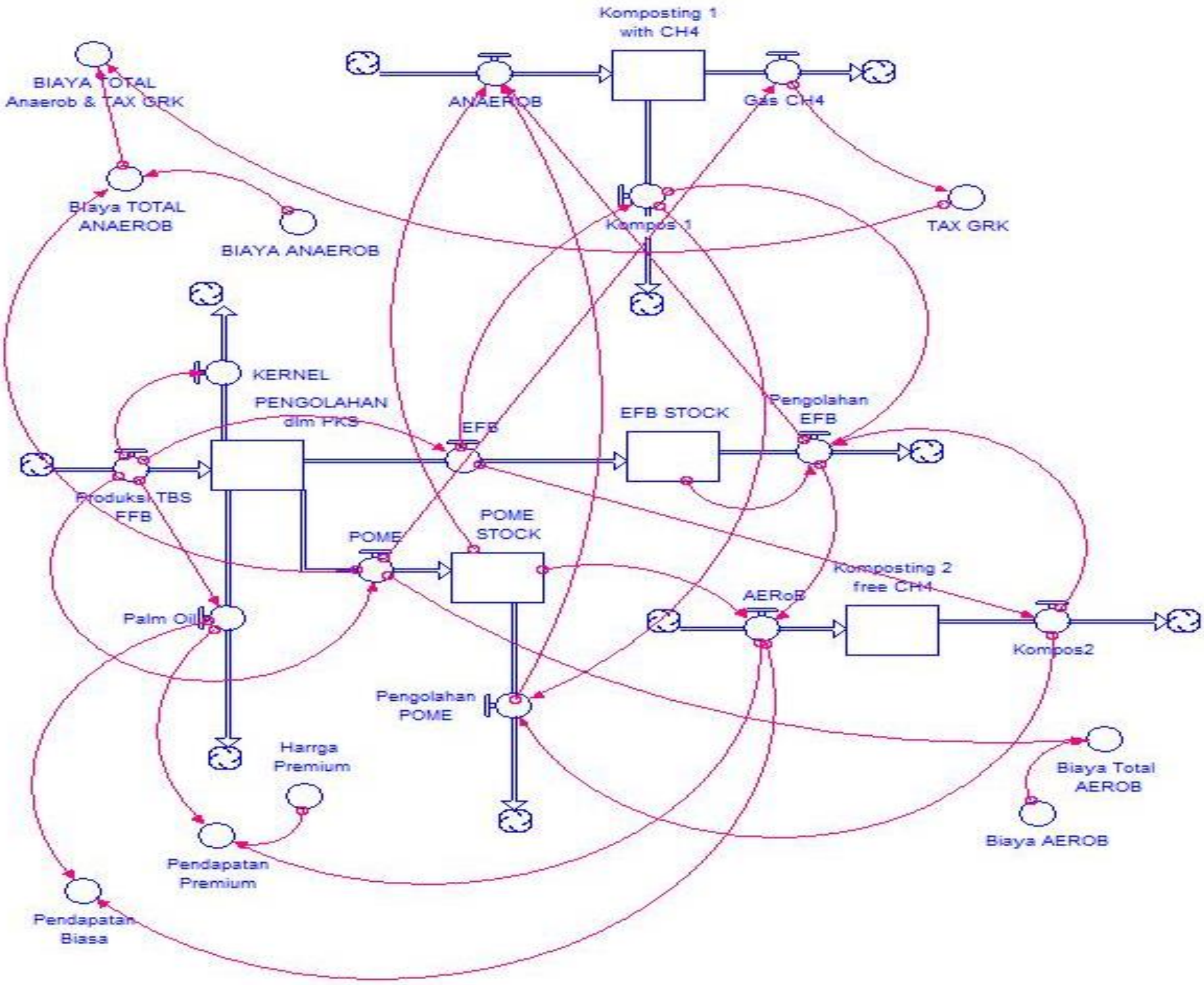

Figure 2. Flowchart of system dynamics of waste treatment in palm oil mill

The model in Stella ver 9.02 was prepared by using processing cost model in the first and second routes – first route as an anaerobic process, and second route as an aerobic process. The total cost of each cycle was closely related to the production of fresh fruit bunches (FFB) that produced EFB and POME in ton/ha/year. This data provided EFB and POME stock in a series of years for processing in different places by different processes. Composting zone was also differentiated between an anaerobic composting with CH_4 output and an aerobic composting with zero CH_4. Each composting, by trend, would produce compost with different estimated total costs and plot together in a graph to estimate the balance cost for determining the efficient cost to process POME waste by the aerobic process.

The equation compiled for the cost optimization model of waste treatment in the palm oil mill is presented as follows. The cost optimization equation was obtained as $y = 146758x^2 + 24848x + 1x10^{\wedge}6$ for the anaerobic process, and $y = 14277x^2 - 96412x + 235539$ for the aerobic process, with x is time in year and y is the total cost per ton of compost produced. The equations were compiled using quadratic equations, where the two equations had a coefficient of determination or R^2 at 0.9997 (almost close to one). Both equations also began with a simple equation that involved y=ax+b, where the two results showed a relatively bad R^2 value, which was < 0.8999. Therefore, the quadratic equation was the right choice, as shown in Figure 3.

Cost balance occurred in the second year when an anaerobic system incurring greenhouse gas (GHG) tax of IDR 75,000/ton CO_2 equivalent to CH_4 gas produced. Meanwhile, the aerobic system did not produce CH_4 gas. Moreover, there was a CPO premium price scenario in the international trade for the zero CH_4 waste disposal.

Table 1. Equations compiled for Stella 9.02.

No	Equation
1	EFB_STOCK(t) = EFB_STOCK(t - dt) + (EFB - Treatment_EFB) * dtINIT EFB_STOCK = 0 INFLOWS: EFB = Production_FFB*0.22 OUTFLOWS: Treatment_EFB = Compost2+Compost_1+EFB_STOCK
2	EFB_STOCK(t) = EFB_STOCK(t - dt) + (EFB - Treatment_EFB) * dtINIT EFB_STOCK = 0 INFLOWS: EFB = Production_FFB*0.22 OUTFLOWS: Treatment_EFB = Compost2+Compost_1+EFB_STOCK
3	Composting_1_with_CH4(t) = Composting_1_with_CH_4(t - dt) + (ANAEROBIC - Gas_CH_4 - Compost_1) * dtINIT Composting_1_with_CH4 = 0 INFLOWS: ANAEROBIC = POME__STOCK+ Treatment_EFB+ Treatment__POME OUTFLOWS: Gas_CH4 = POME*0.16*1000
4	Compost_1 = EFB*0.90 Composting_2_free_CH_4(t) = Composting_2_free_CH_4(t - dt) + (AEROBIC - Compost2) * dtINIT Composting_2_free_CH_4 = 0 INFLOWS: AEROBIC = POME__STOCK+ Treatment_EFB OUTFLOWS: Compost2 = EFB*0.90
5	TREATMENT__dlm_POM(t) = TREATMENT__dlm_POM(t - dt) + (Produksi_FFB - EFB - Palm_Oil - KERNEL - POME) * dtINIT TREATMENT__dlm_POM = 0 INFLOWS: Production_FFB = 20.8 OUTFLOWS: EFB = Production_FFB*0.22 Palm_Oil = Production_FFB*0.22 KERNEL = Production_FFB*0.06 POME = Production_FFB*0.67
6	POME__STOCK(t) = POME__STOCK(t - dt) + (POME - Treatment__POME) * dtINIT POME__STOCK = 0 INFLOWS: POME = Production_FFB*0.67 OUTFLOWS: Treatment__POME = Compost2+Compost_1
7	Cost_AEROBIC = (14277*TIME^2)-(96412*TIME)+235539 COST_ANAEROBIC = 11135*(TIME^2)-37812*TIME+66402 COST_TOTAL_ANAEROBIC_&_TAX_GHG = Cost_TOTAL__ANAEROBIC+TAX_GHG Cost_Total__AEROBIC = Cost_AEROBIC*POME Cost_TOTAL__ANAEROBIC = COST_ANAEROBIC*POME Price__Premium = 30*14.000 Revenue__Normal= IF AEROBIC=0 THEN Palm_Oil ELSE 0 Revenue__Premium = IF AEROBIC=1 then Price__Premium*Palm_Oil else 0 TAX_GHG = 75000*Gas_CH_4

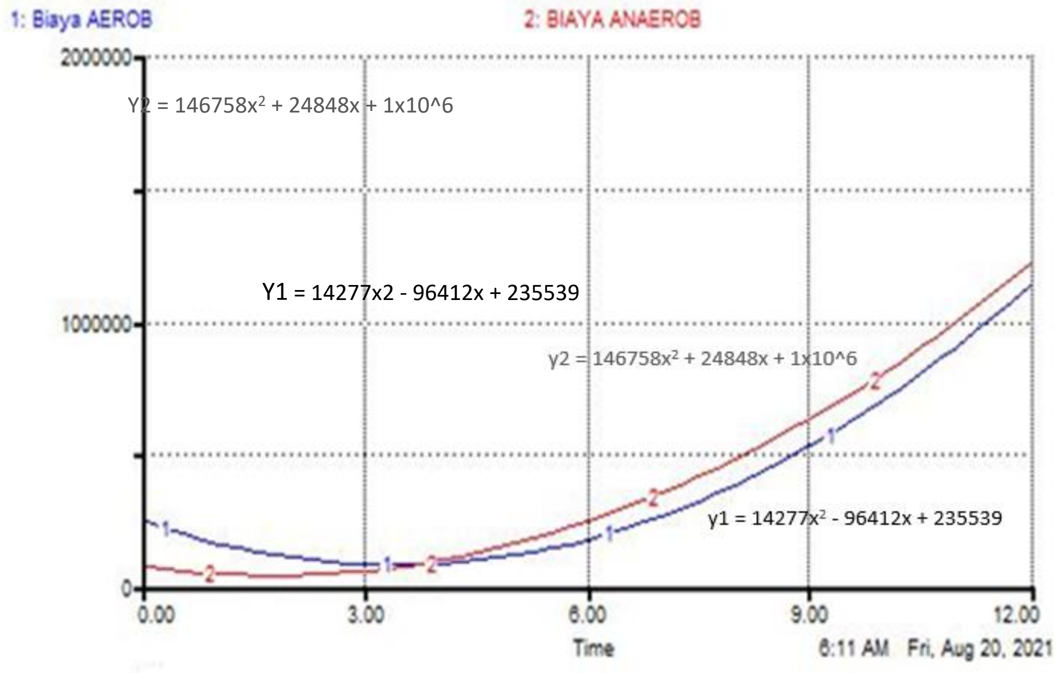

Figure 3. Waste treatment cost optimization result

The two equations resulted in a balanced point between aerobic and anaerobic cost, at IDR 145,400.44/ton POME (Palm oil mill effluent). This balance was the scenario that involved scenario 2 (simulation of 100% anaerobic waste treatment) and scenario 3 (simulation of 100% aerobic waste treatment). Whereas, scenario one, as the existing scenario, had IDR 42,741.57/ton POME and IDR 109.339.80/ton POME cost for anaerobic and aerobic processes.

The scenario that involved composting and GHG tax in an anaerobic process required a higher cost than an aerobic process without CH_4 gas. However, the initial development process for the aerobic system was expensive, such as at IDR 235,471.41/ton POME.

4. Conclusions

The results of the system dynamics provided the equation y = 146758x^2 + 24848x + 1x10^6 for anaerobic system and y = 14277x2 - 96412x + 235539 for aerobic system, where x is time in year and y is the total cost per ton of compost produced. Cost balance took place in the second year when the anaerobic system incurred greenhouse gas (GHG) tax of IDR 75,000/ton CO_2 equivalent to CH_4 gas produced, while the aerobic system did not produce CH_4 gas. The cost balance between aerobic and anaerobic systems was IDR 145,400.44/ton POME (Palm oil mill effluent). Compositing with GHG tax scenario in the anaerobic process required higher cost than aerobic process without CH_4 gas. However, the initial development process for the aerobic systems was expensive, such as at IDR 235,471.41/ton POME.

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