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# OPTIMIZATION OF WASTE MANAGEMENT IN SUMBAWA DISTRICT USING A DYNAMIC SYSTEM MODEL

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*ABSTRACT*

*The main problem that occurs in society today apart from basic needs is the problem of waste. This waste problem certainly needs a solution in good, effective, sustainable and long-term management. The waste issue not only occur in big cities but also in developing areas. Sumbawa Regency as one of the regions that continues to develop and grow requires optimum and long-term planning of solid waste management and systems. In 2021, the waste handled in Sumbawa Regency will only be around 17.5% of the total waste. This shows that the waste management system in Sumbawa Regency is not optimal. Optimal waste management can be achieved by taking an academic approach through model development. One such model is the dynamic system model. This can describe the causal relationship between variables that affect solid waste problems and to provide an overview of the waste management system through simulations based on the factors that influence the processing model. Therefore, it is necessary to develop an optimization model for waste management specifically in Sumbawa Regency using a dynamic systems approach. The purpose of this study is to describe waste management in the form of an optimization model for waste management in Sumbawa Regency with a dynamic system. Optimization results show that the optimistic model yields a total of 127.01 tons/day, the moderate model yields a total of 98.23 tons/day and the pessimistic model produces 62.5 tons/day*



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## 1. INTRODUCTION

The waste problem is a complex problem in every region. Indonesia is included in the top 10 largest waste producing countries in the world. Based on data from the Ministry of Environment and Forestry (KLHK), in 2021 Indonesia's national waste production reached 175,000 tons with a total of 69% of waste only being landfilled in landfills (TPA) and will continue to increase in the next 10 years. This problem certainly needs good and sustainable management so that it does not become a source of problems with long-term effects. Sumbawa Regency as one of the regencies in West Nusa Tenggara produces 187.04 tons of waste per day. Of the total amount, only around 17.5% of waste can be handled, while the rest cannot be handled due to the lack of facilities and infrastructure [1]. This total waste will certainly continue to increase every year in line with the increasing population growth.

Sumbawa Regency is one of the districts in West Nusa Tenggara where waste management is inadequate. Waste management still uses conventional systems, namely, collecting, transporting and landfilling. A management system like this is certainly not a good system for future sustainability. Considering that Sumbawa Regency will continue to develop in the future, of course it must have a good and more modern waste management model system, no longer using a conventional system. If waste management still uses a landfill system, it will cause new problems, for example environmental pollution, which will have an effect on health and other problems.

A sustainable and long-term waste management system is certainly needed by the Sumbawa Regency government. If not handled properly it will cause pollution to the environment and health problems for individuals. One thing that needs to be done is to create a long-term waste management optimization model. There are many methods that can be used to optimize this waste management problem, one of which is using a dynamic system. One model that is commonly used in waste management policy analysis is modeling with a dynamic system approach [2]. The dynamic system (DS) method is used to describe, model, simulate, and analyze complex problems and/or systems dynamically including processes, information, organizational boundaries and strategies [3]. Simulation of different scenarios with DS method allows users to accelerate collective learning about the likely behavior and impacts of complex systems; model and test policies and program design options; analyze and improve business processes; design and test new strategies that can be implemented for better results. Dynamic system modeling has been widely used to find alternative scenarios that are effective in reducing waste [4]–[6], reduce waste management costs [7]–[9], improve environmental quality [10], extending the useful life of embankment land [11], and increasing service coverage [12], as well as obtaining operational management that is stable and sustainable economically and environmentally [13].

The waste management infrastructure modeling process is complex and dynamic in nature. Dynamic means that there are factors causing waste accumulation that is constantly changing over time, namely the population that tends to change over time. It is complex because there are many aspects that influence it, such as government policy, finance, public awareness in household-based waste management and other factors. Therefore, one of the general models used to determine a policy is a dynamic system model. This dynamic system model is also able to predict future performance based on existing systems. The formula used can be adjusted to the conditions of each region so that the model developed tends to be able to be used in many regions, only changes are made to the variable formula that causes waste accumulation.

Therefore, to create an optimization model for waste management infrastructure in Sumbawa Regency that can be used long term with changes in each variable that are quite dynamic and complex, the appropriate model is the Dynamic System model.

## 2. RESEARCH METHODS

The research method used is a quantitative method with a dynamic system modeling approach. The data used is secondary data sourced from the Central Statistics Agency of Sumbawa Regency, the Environment and Forestry Service of Sumbawa Regency as well as other regulations related to waste. The dynamic system model is used as an optimization process in waste processing. The forecast data up to 2050 is the reference and basis for this research. The steps taken in this research are as follows:

1. **Creating an optimization model with a dynamic system**. At this stage, the design of the optimization model with a dynamic system is carried out. There are several basic things that are done at this modeling stage, namely the formation of a Causal Loop Diagram (CLD) to produce cause and effect relationships between system elements and model behavior. Then a stock flow diagram (SFD) is made for each submodel. In this research, simulations with Powersim software.
2. **Performing Validation and Verification of The Model**. Model verification aims to ensure that the computer program and implementation of the conceptual model are valid. The verification process is carried out by checking the computer program and its implementation. So, in the Vensim program, the verification process is carried out when the model can be run or running. Model validation aims to ascertain whether the behavioral output from the model is accurate, realistic and acceptable [14]
3. **Scenario Modeling**. After the management model is declared valid, a waste management scenario is formed which consists of 3 categories, namely optimistic, moderate and pessimistic models.

## 3. RESULTS AND DISCUSSION

There is some data obtained to be used as an initial basis for forming an optimization model, including data on the population of Sumbawa Regency from 2011 to 2019 as presented in Table 1 below:

**Table 1. Population Data for Sumbawa Regency**

| No | Year | Number of Population (people) |
|---|---|---|
| 1 | 2011 | 422 192 |
| 2 | 2012 | 427 119 |
| 3 | 2013 | 431 924 |
| 4 | 2014 | 436 599 |
| 5 | 2015 | 441 102 |
| 6 | 2016 | 445 503 |
| 7 | 2017 | 449 680 |
| 8 | 2018 | 453 797 |
| 9 | 2019 | 457 671 |

***Data Source**: BPS Sumbawa, 2021*

Based on the data obtained, forecasting is then carried out using four methods, namely linear, quadratic, exponential and logarithmic. Obtained the equation of the equation as well as the value of $R^2$ as in Table 2 below:

**Table 2. Sumbawa Regency Population Forecasting Model**

| No | Model | Equation Model | $R^2$ |
|---|---|---|---|
| 1 | Linear | $y = 3995.5x + 425748$ | 0.9997 |
| 2 | Quadratic | $y = -121.5x^2 + 5696.5x + 419875$ | 1 |
| 3 | Exponential | $y = 426578e^{0.0088x}$ | 0.9996 |
| 4 | Logaritmic | $y = 27750\ln(x) + 399908$ | 0.9994 |

Based on forecasting results in 2050 using a quadratic model, the total population of Sumbawa Regency is 826,840 people. According to the National Urban Development Study (NUDS) Sumbawa Regency will be categorized as a big city in 2050. Proper waste management is based on Law of the Republic of Indonesia Number 18 of 2008 concerning Waste Management [15] then the system that is considered the best is the 3R system (Reuse, Reduce, Recycle). For now, the system pattern for the Final Disposal Site (TPA) for Sumbawa Regency waste uses an open dumping system, that is, waste is only stockpiled and disposed of in an open area without covering it with soil [16]. This waste management system is not recommended because it has quite a lot of negative impacts. There are 2 landfills in Sumbawa Regency, namely landfill (TPA) Raberas with an area of 6 Ha and landfill (TPA) Lekong with an area of 9 Ha.

Before the model is run, several assumptions about the elements that form the variables and sub-variables include:

1. Population growth rate 0.03%

2. The gross death rate of the population 0.02%
3. Initial waste generation 187.04 ton/day
4. Percentage of waste transported 56%
5. Percentage of waste processed 10%
6. Initial population 457671 people
7. Waste volume per person 0.68 kg/day
8. PDRB growth 2.48%

## 3.1 Dynamic System Optimization Models

### Causal Loop Diagram

Modeling waste with a dynamic system in Sumbawa Regency consists of a sub-model of the waste pile at the source. Stock Flow Diagrams are made for this sub-model before later optimistic, moderate and pessimistic management scenarios will be made. The relationship between constituent variables is described in the form of a Causal Loop Diagram (CLD). The CLD developed in this research describes a conceptual model that is targeted to accommodate many waste management variables. Waste generation is influenced by two main factors, namely population growth and waste processing needs. Communities are expected to sort waste at the source before it is collected and transported to a waste processing facility. Waste that exists before it ends up becoming a waste dump would be better if 3R processing was carried out so that when it reaches disposal there is still residual waste which of course will be the duty of policy holders to process it further. The relationship between variables is marked with an arrow symbol, where a positive symbol means that a change in the value of one variable has a directly proportional effect on other variables. While the negative symbol has a proportional effect on other variables. As for CLD waste management as in **Figure 1.**

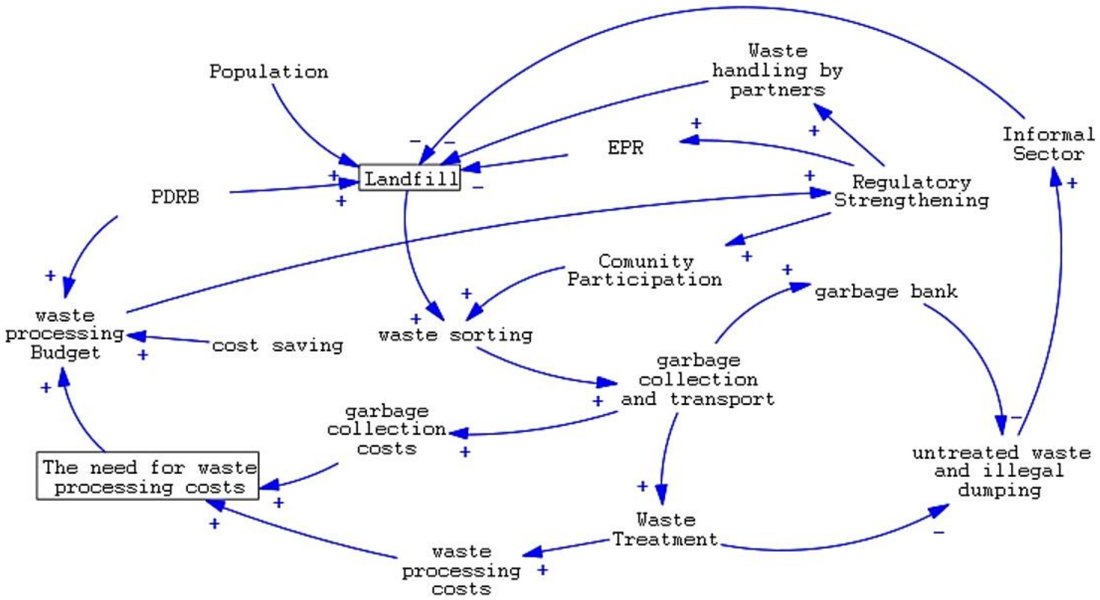


**Figure 1. Causal Loop Diagram of Waste Management**

Two types of feedback loop, namely reinforcing loops ($R$) and balancing loops ($B$). Reinforcing loop is used to describe growth in a positive direction, namely continuous growth in a system. Meanwhile, balancing loop ($B$) is the opposite of a modeled system.

### Stock Flow Diagram

**Figure 2** shows the landfill submodel at source. This submodel is able to predict the waste pile each year. The amount of waste continues to increase as the population increases. Waste accumulation can only be reduced if reduce, reuse, recycle (3R) processing is carried out first. This submodel is used to describe predictions of total waste generation each year. Simulations continue to improve along with increases in population and economic changes which of course affect the amount of waste per capita. In addition, other simulation results obtained are the dynamics of segregated and non-sorted waste

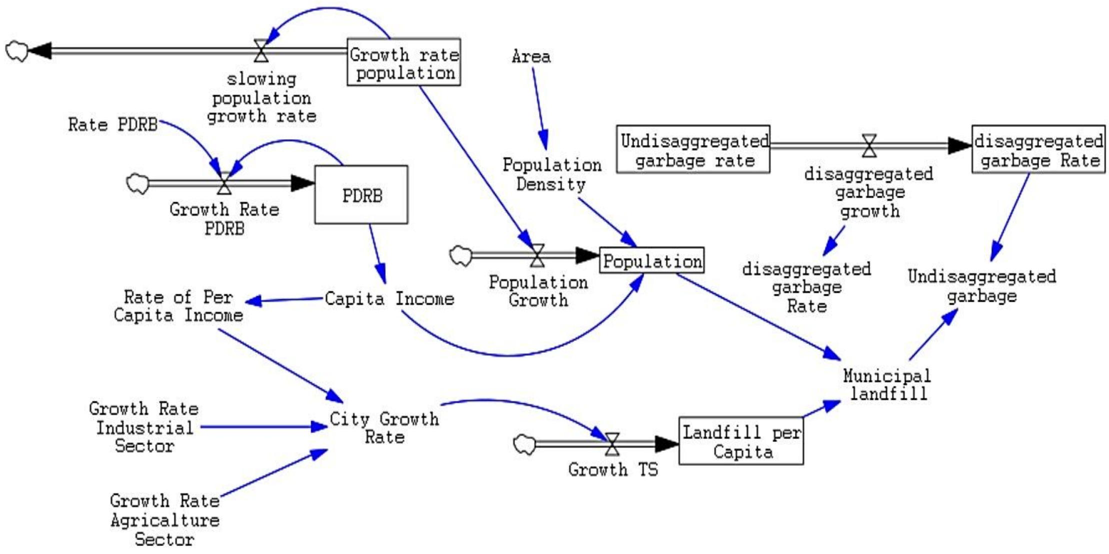


**Figure 2. Stock Flow Diagram Garbage Generation at Source**

### 3.2 Validation dan Verification of The Model

Model validation and verification are carried out to ensure the simulation results are in accordance with real conditions and are valid. Validation was carried out on historical waste data for Sumbawa Regency from 2013 to 2021. The numerical data and assumptions entered during model validation were data during business-as-usual conditions. Only some of the simulation data can be validated due to the limitations of historical data. **Table 3** shows the results of several variables that were validated and obtained mean comparison values < 5% and error variance < 30%.

**Table 3 Total Waste Generation**

| Variable | Mean Comparison (%) | Error Variance | Description |
|---|---|---|---|
| PDRB | 0,0034521 | 0,6666321 | Valid |
| The amount of waste transported | 0,001567 | 0,1329552 | Valid |
| Population | 0,0245135 | 0,255379 | Valid |
| Income per capita | 0,284444 | 4,217985 | Valid |

### 3.3 Scenario Modeling

Model simulations were carried out from 2020 to 2050. In preparing alternative scenarios It is assumed that by 2035 service coverage will reach 100%. The scenarios being simulated are, firstly, the Business as Usual (BAU) Scenario, which aims to see changes in conditions in the future if current trends follow trends. Second, an optimistic scenario was prepared with a focus on seeing the effect of optimizing existing waste processing facilities when the waste service level reaches 100%. In this optimistic scenario there will be no additional waste processing facilities. Third, the moderate scenario, which was prepared with a focus on seeing how significant the reduction in waste to landfill would be if referring to applicable regional regulations. In this moderate scenario, it is assumed that there will be a reduction in waste through EPR. Fourth, the pessimistic scenario aims to see how significant the reduction in waste to landfill will be if the government's target of 30% reduction and 70% handling is achieved and its value continues to be maintained in the following years. In this pessimistic scenario, it is assumed that there will be a reduction in waste through EPR, involvement of the private sector in handling its own waste. The parameters that are the basis for creating model scenarios are as follows **Table 4**.

**Table 4. Scenario Model Parameters**

| Parameter | Unit | Base (2021) | Scenario | | |
|---|---|---|---|---|---|
| | | | Optimistic | Moderate | Pessimistic |
| EPR | % | 0 | 0 | 10 | 10 |
| The government handles the waste | % | 65 | 100 | 85 | 70 |
| Garbage is handled by private sector | % | 0 | 0 | 0 | 10 |
| Waste not handled | % | 35 | 0 | 0 | 0 |
| Increase in EPR percentage | %/year | 0 | 0 | 0 | 0 |
| Increased percentage handled by the government | %/year | 2 | 10 | 8 | 5 |
| Increased percentage handled by private sector | %/year | 0 | 0 | 0 | 5 |
| Total waste generation | Ton/day | 187,04 | 127,01 | 98,23 | 62.5 |

Based on the data presented in Table 4, waste generation values are obtained in each scenario. The scenario with the lowest total waste generation, namely the pessimistic model with a total of 62.5 tons/day, is significantly reduced compared to the basic model (BAU). This scenario is quite good in reducing the amount of waste generation, but it is still not enough to reduce the total waste generation. With a total daily waste generation of 62.5 tons, of course this situation still does not meet the best waste generation standards based on the rules of the ministry of public works and public housing, namely the total waste that goes to landfills, which is as much as 30% of the total waste. This condition will certainly make landfills in Sumbawa Regency full and no longer able to accommodate waste production which continues to increase along with population growth. The Raberas and Lekong landfills covering an area of 6 Ha and 9 Ha, based on forecasting results, can only accommodate the total waste generated until 2037.

## 4. CONCLUSIONS

The results of forecasting the population of Sumbawa Regency have increased, but the growth rate has tended to decrease as seen from the increase in population which is not too significant. This increase in population has resulted in an increase in total waste considering that the pattern of increase is due to an increase in the consumption pattern of the community. Using the dynamic system model, 3 optimization models were obtained to reduce waste accumulation. The optimistic model reduces 187.04 to 127.01 tons/day. The second model is the moderate model which generates 127.01 tons/day of waste generation and the pessimistic model produces 62.5 tons/day of total waste generation. These three models will be able to work optimally if all the variables in CLD and SFD work optimally and need to add other variables, for example community participation in household waste processing so that the waste that goes to landfills is a type of inorganic waste that requires modern processes for its processing.

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