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# Towards a low carbon solid waste management in West Papua

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**Abstract.** Solid waste is one of the main contributors to greenhouse gas (GHG) emissions. With an increasing population and Gross Domestic Regional Product (GDRP) of West Papua at 2.65% and 5.2% per annum, solid waste production will also be increased and GHG emissions. However, a specific amount of GHG emission in West Papua was yet to be determined due to the unavailability of solid waste generation across all districts within West Papua. This paper aims to assess solid waste generation by using a dynamic model system that involved total population and GDRP across West Papua as the main variables to measure the data above. This paper shows that 2 (two) scenarios to simulate the business as usual (BAU) process of existing waste management and proposed scenarios to reduce GHG emissions at a convenient level. Based on the BAU model, West Papua will produce 3.7 million tons of waste and 1.1 million tons CO<sub>2</sub>e in 2030. The proposed scenario suggests that West Papua should manage their waste of up to 118.297 tons/year to meet the NDC 29% emission reduction target. These models could be replicated to solve the same issues in different areas.

#### **1. Introduction**

Waste is a compulsory by-product of human activities and natural processes, consisting of household waste and specific waste. Indonesian act no 18/2018 stipulates that daily activities are the household waste sources that exclude feces and specific waste (Act No. 18/2008 of Home Affairs Ministry of Republic Indonesia) [1]. When accumulates, waste will lead to environmental degradation and various health-related problems [2]

Waste characteristics can vary widely, depending on waste components. What can be considered solid waste from human and animal activities is ordinarily solid and regarded as useless by the waste producers [3]? The uniqueness of solid waste from various places or regions and its different types allows different characteristics [4]. The solid waste generally produces greenhouse gas emissions in the form of CH<sub>4</sub> and CO<sub>2</sub>. The solid waste burning activity produces CO<sub>2</sub> gas, while open dumping in the landfill causes the organic waste accumulation under anaerobic decomposition and produces CH<sub>4</sub> gas [5]. These gases, which are included in greenhouse gases (GHGs) has great potential for global warming. Waste management activities contribute around 4% of greenhouse gases [6]. The existing solid waste disposal site contributes 3-4% of GHG emissions globally [7]. However, appropriate waste management reduces atmospheric pollutants, odors, and greenhouse gases emission [8]. Conserve

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local and global environment, proper waste management is deemed pivotal and should be an integral part of public and environmental health.

West Papua province is located in eastern Indonesia, with a total area of 567 km<sup>2</sup>. In 2010, the total population in West Papua was 765,258 people 2010 but increased to 959,617 in 2019 with a population growth rate of 2.65% per year [9]. The increasing population will create unavoidable consequences for increasing the volume of waste, which could seriously impact the environment if it is not appropriately managing. Thus, waste management should be prioritized to reduce the GHG impact on the atmosphere. This follows Minghua [10], which stated that solid waste generation at the municipal level grows faster as population growth, increasing influx of urbanization, economic growth, and improved living standard [10].

Based on the waste composition data in West Papua, 70% of solid waste mainly originated from food scraps or leftovers, while the remaining 20% and 10% originated from woods and paper, respectively. Most of solid waste produced in West Papua has not been appropriately managed. Households, industrial and commercial sectors usually dispose of their solid waste in the waste bins provided by the Environmental Service of local government in each area without any separations. Consequently, the wastes are taken by the local government service into an open dump or landfills for final disposal and yet to be treated.

By looking at the facts above, the awareness of waste management in West Papua is considerably low. Inadequate knowledge and lack of skills in waste management are the main concerns in empowering local people. Although the local government has already provided waste bins in certain areas, the separation of specific bins for organic and inorganic waste is yet to be established. Therefore, proper solid waste management is needed because any waste impacts GHG (greenhouse gas) emissions and pollutants. The alternative 3R methods (reduce, reuse, recycle) can be applied to reduce the volume of solid waste and implementing strong laws in handling/regulating solid waste to improve the quality of environmental sustainability and reduce carbon gas emissions into the atmosphere.

One of the problems in building a proper waste management system is data collection. Most waste is just dumped and due to huge waste production per day from every household (not to mention other sectors), exact weight and volume measurement would be complicated to account-for. Hence, some approaches are required to estimate the total waste produced. In this paper, total waste is estimated by involving total population and gross domestic product (GDRP) that is easier to obtain as the main variables. A further calculation will be exercised using a dynamic system model. System dynamics provides construction to rationally analyze the structure and its interactions in environmental systems [11].

Some previous studies have been conducted to estimate waste production using dynamic models. Oriola (2014) demonstrated system dynamics to study the increment of waste generation and its waste collection effectiveness [11]. Muhsin et al. (2018) developed system thinking to understand the abundance of litter generation on urban lake in developing countries [12]. This paper emphasizes dynamic system models to estimate waste generation and GHG emissions following NDC targets of emission from waste. In order to address the above problems, this study aims: (1) to assess GHG emissions from solid waste generated in West Papua from 2010-2030, (2) to propose the minimum portion of waste to be managed in order to maintain GHG emissions at convenient level with the available capacity in West Papua.

#### 2. Method

This research was conducted in West Papua, Indonesia, located at  $0^{\circ} - 4^{\circ}$  S latitude and 128°50' – 135°20' E longitude. The gathered data to support this research are the total population in West Papua, Gross Regional Domestic Product (GDRP) of West Papua, annual income per capita, and solid waste components that are considered independent variables to obtain solid waste emissions. All data is formulated using a system dynamics model to simulate GHG emissions and its intervention for

mitigation action. Variables relations of the solid waste emission in this study are simulated using Powersim Studio Academic 2010.

#### 2.1. Variables determination and data collection

In this paper, the total waste generation is affected by the total population but also the growth of GDRP that represents income per capita. Hence, the variables and numbers that are included in the system dynamics model are depicted as follows.

			5
No	Variable Name	Unit	Source/Estimation Method
1	GRDP West Papua	billion	BPS Report West Papua 2010-2018
2	Total Population	number	[9]
3	Solid Waste	ton	National Environmental Quality
4	Landfill Capacity	ton	Index Report 2010-2018 [13]

**Table 1.** General variables for solid waste dynamic model simulation.

Table 2. GRD	P. populatio	n number, a	nd solid was	ste generated i	n West Pa	pua from	2010 to 2018.
		,		0			

Variable/ Year of	GRDP (in Billion)	Population Number	Solid Waste (Ton) *	Landfill Capacity
collected data				(Ton) **
2010	41,361.7	760,422	62,623.0	2,000,000
2011	42,867.2	785,979	64,186.9	2,060,000
2012	44,423.3	806,995	79,284.7	2,121,800
2013	47,694.2	828,293	87,223.9	2,185,454
2014	50,259.9	849,809	89,535.3	2,251,017
2015	52,346.5	871,510	91,908.6	2,318,548
2016	54,711.3	893,362	94,343.5	2,388,104
2017	56,906.8	915,361	96,843.7	2,459,747
2018	60,453.6	937,458	99,410.0	2,533,540

\*: Due to limitations on solid waste sources of data, the 2014-2018 solid waste numbers are generated using the average dividing factor of historical population number and solid waste from 2010-2018.

\*\*: Total landfill capacity is assumed at 2.000.000 tons with a 3% extension per annum.

# 2.2.Dynamic system modelling

In order to obtain the best scenario of low carbon emission from solid waste, this paper provides 2 (two) system models to depict the existing/business as usual (BAU) waste generation and a proposed model to reduce the GHG emission from waste.

1) Business As Usual (BAU) Model

The model will provide interlink connection between total population, GDRP, waste and landfill capacity for BAU. These factors are crucial to represent the growth of the waste rate every year. This BAU model becomes the groundwork for designing the proposed scenario to reach low carbon emission from waste targets.

#### 2) Proposed Model

This proposed model will include some interventions as part of the scenario to reduce low carbon emission. The interventions will be elaborated as waste processing and treatment on landfill to reduce the amount of waste rate and reduce GHG emissions.

# 2.3. Model validation

Model validation is required to verify and identify potential errors in exercising the simulation. This validation will also ensure the behavior of the model has similarities to actual records on the field. In

this paper, the validation process is using AME (Absolute Mean Error) method with the equation as follows:

$$AME = (Si - Ai) / Ai \times 100\% (1)$$

where A is the actual value, and S is the value of simulation.

#### 3. Results and discussion

#### 3.1. Existing/BAU Scenario (2010-2018)

The existing/BAU of waste and emission factor is depicted on the model as follows.



Figure 1. Existing/BAU Simulation Model.

As mentioned above, the rate of solid waste generation aligns with the population and GDRP growth rate. Figure 1 depicts a model based on historical data from 2010 until 2018; solid waste increased as the population and GDRP increased. This model also involved landfill (TPA) capacity as a constraint and issue managing waste on the area. In this paper, landfill capacity is assumed at 2 MT (million tons) with a 3% landfill extension every year. Another concern is landfill capacity and GHG emission that unavoidably kept increasing as the waste generation rate was unstoppable. The GHG emission rate is depicted in Figure 2 below. Since the waste is not specified (mixed dump), the emission factor used in this calculation is 786 kgCO<sub>2</sub>e/ton or 0.786 tonCO<sub>2</sub>e [14].

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Figure 2. Emission Rate BAU.

Based on the BAU model (Figure 1) above, the GRDP growth rate in West Papua was 5.2% per year, while the population growth rate was 2.65% per year during 2010-2018. Simultaneously, the solid waste rate was 93,877 tons per year, while the amount of waste produced per capita was 1.5 tons/billion or 15 kg/million. For validation, total GDRP and total population will be used as the parameters. The validation of this BAU model is depicted as follows.

Total GDRP (Billion)		RP (Billion)	Total Population (People	
Year	Data		Data	
	Collection	Simulation	Collection	Simulation
2010	41,362	41,362	760,422	760,422
2011	42,867	43,512	785,979	780,573
2012	44,423	45,775	806,995	801,258
2013	47,694	48,155	828,293	822,492
2014	50,260	50,660	849,809	844,288
2015	52,346	53,294	871,510	866,661
2016	54,711	56,065	893,362	889,628
2017	56,907	58,980	915,361	913,203
2018	60,454	62,047	937,458	937,403
Average	50,114	51,095	849,910	846,214
AMĔ	1.9	6%	0.4	13%

**Table 3.** Validation of the BAU model.

Based on the validation above, the BAU model represents the field's actual condition with low AME of 1.96% and 0.43% of total GDRP and population of West Papua, respectively. By exercising this model, the BAU activities of solid waste generation produced a tremendous amount of emissions at 682,073 tonCO2e in 2018 and will keep increasing to 1,135,577 tonCO<sub>2</sub>e in 2030. Hence, this paper proposes a new scenario to intervene in the waste generated to be aligned with the NDC target of emission from waste and propose a particular area of landfill extension as depicted in Section 3.2 below.

#### *3.2.Proposed scenario (2021-2030)*

Mitigation strategy will improve solid waste management and hence reducing GHG emissions from the stable waste sector. Incineration can be proposed for one of the methods of reducing the effect of solid waste. As food waste comprises most solid waste in West Papua, incinerated waste reduces the energy and increases combustion efficiency [15, 16]. However, apart from incineration, more reliable recycling technologies such as anaerobic digestion for food waste [15, 17]. Anaerobic digestion can turn food waste into useful products that seem to be one of the most effective technologies [15, 17, 18]. The application of 3R (Reduce, Reuse, and Recycle) of solid waste can be an option in a sustainable development strategy and has a profound socioeconomic impact on climate change

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mitigation [19]. Therefore, mitigation of solid waste through the strategy 3R for paper and wood waste is a suitable option for reducing GHG emissions.

For the government's waste management efforts, a management system that involves private and community participation is needed. The government monitors and evaluates waste management by involving the community's active participation to ensure waste management. The research results in a residential community revealed that the community was able to solve the problem of waste in their environment as a form of high awareness in responding to the problem of waste based on common interests. The proposed scenario involving the effort to reduce solid waste generation is depicted as follows.



Figure 3. Proposed scenario with waste treatment intervention.

As depicted in Figure 3 above, intervention to mitigate the increasing waste rate is added by having waste processing and treatment. The intervention amount is aligned with 29% NDC target reduction from waste emission as depicted in Table 4 below.

Sector	2030 GHG Emission Rate (MtonCO <sub>2</sub> e)		GHG Emission Reduction	
	BAU	CM1	(MtonCO <sub>2</sub> e)	% of BAU
Waste	296	285	11	0.38%

Fable 4.	Emission	reduction	target.
	Linnssion	reaction	tur get.

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By exercising the proposed model, total waste generated will be reduced to 2,991,409 tons compared with the existing/BAU model that will produce 3,785,257 tons in 2030. Total emission from waste will also be reduced to 897,422 tonCO2e or equivalent with 27% emission reduction close to the NDC target of 29% emission reduction. Not only waste intervention, but this model also proposes an extension of landfill capacity at 3% per annum to cater to the rapid increment of solid waste generation. The following graph (Figure 4) shows that the 3% per annum capacity extension would cater to the need for waste landfills up to 2030 if the waste treatment were implemented.



Figure 4. Waste BAU vs. waste treatment intervention vs. landfill capacity.

### 4. Conclusion

The aforementioned proposed models can estimate total solid waste produced and its GHG emission in West Papua. By 2030, West Papua will produce an abundance of solid waste of about 3.785.257 million tons and unavoidably produce GHG emissions up to 1.135.577 tonCO2e if the BAU (business as usual) waste management remains. As part of the NDC target to reduce GHG emissions, a new scenario is proposed by applying the BAU model with proper solid waste treatment. By exercising the proposed scenario, West Papua is obliged to process its waste up to 118.297 tons/year to maintain the GHG emission at 897.422 tons CO2e in 2030 and meet the NDC 29% emission reduction target. Also, at least 3% per annum should be increased in landfill capacity to cater to the upcoming solid waste capacity as the population and GDRP keep increasing. These models could be replicated to solve the same issues in different areas, and any further improvements are welcome.

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