CARBON REDUCTION OPTIMIZATION IN WASTE TREATMENT USING DECENTRALIZED SYSTEM WITH THE APPLICATION OF A JOINT CREDIT MECHANISM

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Abstract: The volume of waste generated in Bandung is increasing along with the increase of population and its activities. Through the process of natural degradation, garbage produces carbon emissions as what happened in waste treatment process. Responding to the waste problem in Bandung related to carbon emissions, it is necessary to make an optimization model to determine the best waste processing techniques for each area in Bandung which are devided by a decentralized system. Reduction in waste treatment costs are obtained from insentive which refers to the joint credit mechanism pattern, while the optimization model using linear programming will be solved using simplex method. Simulation of optimization model is run with a condition where service scope for waste is 70% with middle income people of 40% and low income people of 60%. According to mass balance concept, for 30% emission reduction target, Bandung Utara, Bandung Barat, and Bandung Selatan mostly use composting as their waste treatment with the input allocation of 90%, 99%, and 90% from the total amount of waste in each region, respectively, while Bandung Timur use sanitary landfill the 100% input of waste. When the same condition is applied but the constraint is changed into combined emission reduction for whole Bandung, the operational cost is reduced as much as 998.1 millions rupiah from initial cost. From this study, linear programming can be used for determining waste treatment plant with emissions constraints for making government's policy.
Keywords: organic waste, joint credit mechanism (JCM), optimization, linear programming

INTRODUCTION

Through the natural degradation process, organic waste emitted carbon emission, as the same with waste treatment process. Every treatment process will emit a different amount of carbon due to its technology. The more advance the technology used, the less carbon emitted, but the operational cost spent can be more expensive. In Joint Credit Mechanism (JCM) initiated by Japan there is carbon trading system where the amount of carbon reducted by Indonesia will be paid by incentive. This incentive from carbon trading can be used to reduce the operational cost for waste treatment process in Bandung City. Management of solid waste system in Bandung City are a decentralized system which mean there are several waste treatment process which are placed according to residential area division. In this research optimization will be conducted to obtain the cheapest waste treatment technology which emitt the smallest amount of carbon emission in each area of decentralized system.

The volume of solid waste generated in Bandung City raised as the population and its activity raises which become a big problem related to the lack of solid waste treatment facilities. The management of solid waste is only done by collecting and shipping the waste from TPS to the final disposal station (TPA) continuously, meanwhile the capaCity left for solid waste can only be used for 6 years ahead (Sriwuryandari dan Sembiring, 2009). In the final report of Bandung City BPLH in 2013, it is mentioned that the pilot project of solid waste management is one of the government effort to reduce the generation of solid waste which will give a long term advantage. It is also explained that the pilot project will be conducted in modular system, where certain area is determined together to applied a new management system that can reduce the investment and operational cost, increase the final disposal's lifetime, and also give working opportunity (BPLH, 2013). The average volume of wate generated in Bandung City is 3 Liter/person/day (BPLH, 2013) with the composition of kitchen waste as much as 58% (Sondari, et al., 2012). With the amount of population of 2.5 millions, so the total waste generated is 7500 m^3/day. When the amount of waste generated exceeds the final disposal capaCity, new problem will be arised that gives negative effect to the environment such as the green house gas (GHG) emission. Various solid waste treatments have been done, such as recycling organic waste to compost. Composting have a small reduction number of carbon which is 8 kg CO_2 equivalent/ton of waste, meanwhile the recycling of organic waste generated can reduce the volume of waste thrown to the final disposal which can indirectly reduce the GHG emission (Sunarto, et al., 2013). Landfill is the most expensive waste treatment after incineration with the efficiency of bolume reduction less than 50%, while the efficiency of volume reduction of incineration is greater which is higher than 50% (Minoglou, et al., 2013).

Landfill also contributes GHG emission of 3-4% from the global emission (Eggleston, et al., 2006). Green house gases emitted from solid waste sector are various, but the dominant gases that must be noticed in National GHGs Inventory are CO_2, CH_4, and N_2O. These gases included as GHG's have big potential related to global warming. Purwanto (2009) explained that the potential of global warming or global warming potential (GWP) is the radioactive effect unit of GHG which is compared to CO_2, in other words GWP is an indication of how many ton of CO_2 emitted is equal to other one ton of each GHG.

Many countries, including Indonesia has given attention toglobalwarming effect. Internationally global warming mitigation included in Kyoto Protocol which governs the obligation to reduce GHG emission related to climate change issue, Japan released a new mechanism to reduce carbon concentration worldwide which is known as Joint Credit Mechanism (Oghihara, 2013). Furthermore it is explained that in bilateral cooperation, Japan gives incentive to its partner who is able to reduce the amount of carbon in its country through project agreed by both parties. Oghihara (2013) also explained that Indonesia is legally cooperates with Japan since 2013. Emission trading process have important role in Post-Kyoto which aim to reduce GHG emission worldwide (Jaehn, et al., 2010).

To response waste issue in Bandung City, optimization model is needed to determine waste treatment method which has greatest carbon reduction with cheapest operational cost for every residential area based on decentralized system. Waste treatment method addressed for only organic waste considering this kind of waste has the greatest percentage of waste in Bandung City (BPLH, 2013). By using Intermediate Treatment Facility (ITF) in every residential area, it is hoped that the economic value, environmental quality and regional income can be raised.

RESEARCH METHOD

Decentralization of Bandung City

In this research, Bandung City is devided into 4 regions that are North Bandung, West Bandung, East Bandung, and South Bandung. Decentralization is based on administrative division where assumed that every region has 1 ITF.

Waste Generation in Each Region

Waste generation data is secondary data from 2013 in Laporan Ringkasan Eksekutif tahun 2013 (BPLH Kota Bandung, 2013). In this research assumed that the ratio of population consist of 40% intermediate income residence (IIR) and 60% low income residence (LIR) with waste generation coefficients for IIR and LIR are 0,12 kg/person/day dan 0,18 kg/person/day respectively.

Waste generation assumed 70% consider the waste management service can not reach 100% of waste because blind spot. Blind spot is area that can not be reached by waste transportation such as area without good access, area with few people which not efficient because the cost is too large compared with the waste handling. Waste generation followed **Equation 1.**

$$\boldsymbol{Waste\ Genration = Waste\ Generation\ coefficient\ x\ population} \qquad \textbf{Equation (1)}$$

Open Dumping Emission

Open dumping emission calculated in term of carbon according to **Equation 2** based on EPA.

$$\boldsymbol{Carbon\ emission = Waste\ generation\ x\ biogenic\ carbon} \qquad \textbf{Equation (2)}$$

where: $Carbon\ Emission =$ *open dumping emission;* $Waste\ genreation$=waste generation in tones/year*;* $biogenic\ carbon$ = organic compound carbon (kg C / ton of wet waste)

Waste Treatment Technology

Waste treatment technology which used in this research is composting, anaerobic digestion, incineration, and sanitary landfill. All technologies must be accredited by JCM or other institution which handle climate change such as UNFCCC, already applied in Japan, have known efficiency value, specialize to treat food waste (FW), and suitable for Bandung City by considering the economic, field availability, accessibility, and the efficiency aspects.

Emission of Waste Treatment Alternatives

Every waste treatment technology emitted different amount of emission. All of the emission, either carbondioxide, carbon,or methane emission will be converted to equivalent carbon emission (C-eq). Carbon emission for composting, anaerobic digestion refer to Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), while carbon emission for incineration and sanitary landfill refer to Emission Inverntory Guidebook (EEA, 2013) and EPA's Waste Reduction Model (WARM, 2015), respectively.

Carbon Reduction Emission

Carbon reduction emission is the amount of carbon that can be reduced using alternative waste treatment compared to the amount of carbon emitted by open dumping. The calculation of carbon emission reduction follows **Equation 3**.

$$\%eff = \frac{Carbon\ emission(open\ dumping) - Carbon\ emission(alternative)}{Carbon\ emission(open\ dumping)} x100 \qquad \textbf{Equation(3)}$$

Alternative Treatment Cost

Waste treatment alternatives cost is secondary data from Peraturan Menteri Pekerjaan Umum which can be seen in **Table 1.**

Table 1 Waste Treatment Alternatives Cost

Facilities	Investment Cost (Rp)	Operational Cost (Rp/ton of waste)
Insenerator (IF)	225 million - 3.3 billion/ ton of waste	400 - 600 thousand
Composting (CM)	500 million - 2.4 billion/ ton of waste / day	80 - 200 thousand
Anaerobic Digestion (AD)	660 million - 2.64 billion / ton of waste/ day	125 - 250 thousand

Source: Lampiran IV Peraturan Menteri Pekerjaan Umum No.3 Tahun 2013

Policy Related to Carbon Emission

Carbon emission reduction target according to Peraturan Presiden RI Nomor 61 Tahun 2001 about National Action Mitigation of Green House Gases is 26% on 2020 from Bussiness As Usual (BAU) scenario. If it is related with JCM, carbon emission reduction targeted by Japan for developing country is only 3%. (DNPI, 2013).

Model Development

Waste management system used in this research can be seen on **Figure 1.** It is assumed that every ITF consists of composting facility, anerobic digester, incineration facility, and sanitary landfill. Based on waste management system on **Figure 1**, it can be formulated from decision, objective function, and constraint variables.

Mathematic model begin by determine variable, constraints, and objective of system model. The n measured relation $(r_1, r_2, \dots, r_n)$ will be stated by decision variable where each value is determined. Decision variable can be expressed in the ammount of carbon emitted by each source. In this research, amount of carbon reduced by each waste treatment defined in form of carbon emitted by related treatment. There are 16 decision variables (x_{ij}) on this optimization model. Those values are multiplication product of 4 decentralized areas and 4 kinds of waste treatment technologies.

Critical step in building mathematical model is when making the objective function. Quantitative measurement development is needed from relative relation showed by every formulated object. Because of that it is not needed to put every unnecessary detail or factor that predicted to give same response to all considered alternative treatment. The optimized variable in this model is total cost for waste management system and emitted carbon in each system. Objective function in optimization model is to minimize total cost of waste management system.

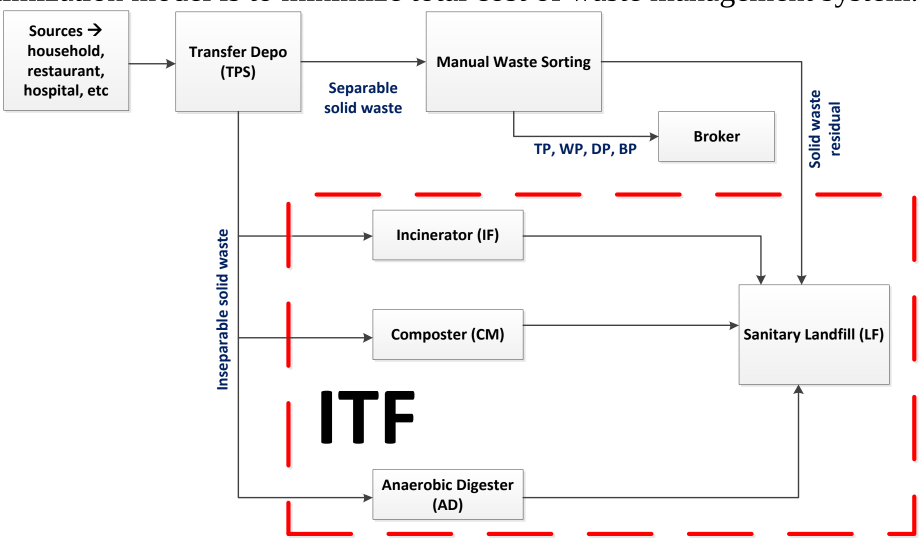

Figure 1 Sistem Pengelolaan Sampah di ITF

The main constraint in this optimization model is elaborated in **Equation 4**.

$$\sum_{j=1}^{4} X_{i,j} = 1 \text{, with } i = 1 \text{ to } 4 \qquad \textbf{Equation(4)}$$

That mass balance equation shows that waste can be allocated in various waste treatments, but the sum of each waste fraction inputted in the treatment plant must be equal to the total mass of each component.

Research Area

Study area in this research is Bandung City which consists of 4 administrative regions.

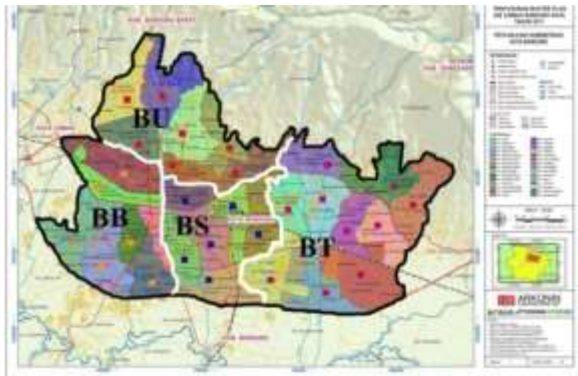

Figure 2 Regions Division (Laporan Ringkasan Eksekutif BPLH Kota Bandung, 2013)

The division of administrative region can be seen in **Figure 2** which consists of 4 region and 30 districts of Bandung City. Waste generation prediction in 2015 for every region of Bandung City is shown in **Table 2.** The predicted waste generation will be used for calculating the baseline emissions for the next 5 predicted years.

Table 2 Predicted Waste Generation in 2015

Area of Bandung	Predicted Waste Generation (FW) in 2015 (ton/year)
Bandung Utara (BU)	38727.34 ≈ 38700
Bandung Barat (BB)	45220.09 ≈ 45200
Bandung Timur (BT)	47273.73 ≈ 47300
Bandung Selatan (BS)	33008.63 ≈ 33000

RESULTS AND DISCUSSIONS

Condition of Each Area

From **Table 3**, it can be seen that incineration emitted lowest carbon of other waste treatment technologies. Considering that, incineration has a good potential as Bandung waste treatment technology, but the cost needed is relatively more expensive than others (see **Table 4**).

Table 3 Emission Carbon from Location (i) Using (j) Technology

Carbon Emission ($EM_{i,j}$) (ton C-eq/year)	**Location (i)**			
Treatment Technology (j)	BU (1)	BB (2)	BT (3)	BS (4)
Composting (1)	1858.912	2170.564	2269.139	1584.414
AnaeDig (2)	464.728	542.6411	567.2848	396.1036
Incineration (3)	1.74273	2.034904	2.127318	1.485388
Sanitary LF (4)	774.5467	904.4018	945.4747	660.1727

Moreover not every area has good economic value for using incinerator which should be built in densely populated area. For relatively low populated area, usage of incineration technologies needed more cost than sanitary landfill, about 51.42 times more expensive.

Table 4 Operational Cost for Each Source (i) Using (j) Technology

	Operational Cost ($C_{i,j}$) (millions Rp/ton FW)		
Treatment (j)	**2015**	**2020**	**2025**
Composting (1)	0.483	3.495	7.743
AnaeDig (2)	0.646	4.681	10.363
Incineration (3)	1.725	5.850	19.843
Sanitary LF (4)	0.115	0.384	0.521

All of the calculation conducted in the model use open dumping as the baseline. Suggest the government apllied policy for carbon emission reduction of 20%, so the maximum emission permitted from all waste treatment is 80% from total carbon emission (see **Table 5**).

Table 5 Open Dumping (As Baseline)

Location (i)	**FW (ton/year)**	**Carbon Emission (ton C-eq/year)**
NB	38727.34 ≈ 38700	4260.01 ≈ 4260
WB	45220.09 ≈ 45200	4974.21 ≈ 4970
EB	47273.73 ≈ 47300	5200.11 ≈ 5200
SB	33008.63 ≈ 33000	3630.95 ≈ 3630
TOTAL	≈ 164200	≈ 18060

Mathematical Formulation

Waste management allocated to several kind of technology according to the needs. Based on that it is needed to find the best proportion of each allocation of treatment. By using cost efficient $C_{i,j}$ from **Table 3** and decision variable $X_{i,j}$, an objective function of total cost can be formulated (**Equation 5**).

$$Z_{cost} = \sum_i^m \sum_j^n (C_{i,j}) x (X_{i,j})$$

Equation(5)

where: m= the amount of emission sources; n=the amount of technology; i=index for emission sources; j=index of technology; Z=cost for

To obtain the objective function of Z in **Equation 5**, variable decision $X_{i,j}$ need to be solved using linear system with constraints as follow (**Equation 6** and **Equation 7**):

$$\sum_j^n (X_{i,j}) = 1 \; for\; each\; region\; with\; i = 1\; to\; 4$$ **Equation(6)**

$$\sum_i^m \sum_j^n \left[(EM_{i,j}) x (X_{i,j}) \right] \leq (1 - \%Red) x Total\; C\; Emission$$

Equation(7)

Where: m=the amount of emission sources; n=the amount of technology; i=index for emission sources; j=index of technology; %Red is the percentage of emission reduction according to the policy applied; Total C emission=total carbon emission from open dumping

Determining Suitable Technologies for Each Region

Every waste treatment technologies have their own needs. As an example, not every region can be used for landfill site. When it is raining, runoff spreadings from a higher area will gives bigger spreading effect then those in flat areas. Other consideration is about the land availability. Area with smaller residential dense is more feasible for sanitary landfill site with the hope that negative impact in that area can be minimalized. Based on spatial pattern plan map of Bandung for 2011- 2031 (Bappeda, 2012) in **Figure 3**, it can be seen that North Bandung and East Bandung is the most feasible areas for sanitary landfill site, but due to its topograph, the elevation in North Bandung is relatively high so it is not suitable as sanitary landfill site. Because of that, it is determined that East Bandung is choosen as the location for sanitary landfill site.

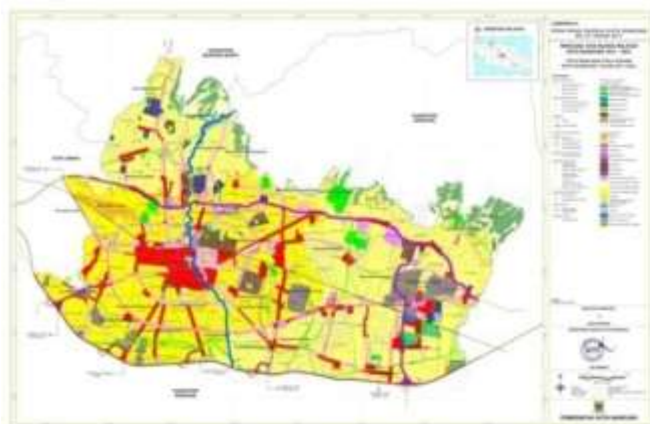

Figure 3 Spatial Pattern Plan Map of Bandung for 2011 – 2031 (BAPPEDA, 2011)

One of the considerations for choosing incineration site is the cost efficiency problem. If the incinerator used is a mass burn incinerator in modular combuster type with a capacity of 130 ton of waste/day, so it is better if the amount of waste generated has the same amount of the incinerator capacity because if the amount of waste generated is much more smaller than the treatment capacity, operational cost needed will be higher. According to that problem, only West Bandung and East Bandung area which can give higher economic efficiency with the amount of waste generation of 123.84 ton/day and 129.59 ton/day, respectively. Other consideration is population density. Areas with higher population representate a condition where land availability is not much. According to that, incineration will be used in West and East Bandung. Biological waste treatment can be done in aerobic condition with composting or anerobic condition using biodigestion. The problem here is the final product of its treatment which depends on waste composition. To obtain good quality of liquid fertilizer, biological treatment process must be mixed with animal feces. It is related to the anaerobic bacteria needed to activate substrate from

FW. According to this consideration, better to locate biodigester and composter site near farms so animal feceses can be transferred to composting or biodigestion plant without spending much money. If it is assumed that liuid fertilizer and compost produced will be used for city garden, so from **Figure 3**, green open space and gardens can be founded in every area in Bandung City. According to all of the considerations before, it is determined to use biodigester and composter in every area of Bandung City.

Simulation Results For 2020

After the condition of waste for 2015 is known already, prediction of optimization for waste allocation in 2020 is conducted in two different conditions. Simulation result gives graph shown in **Figure 4.**

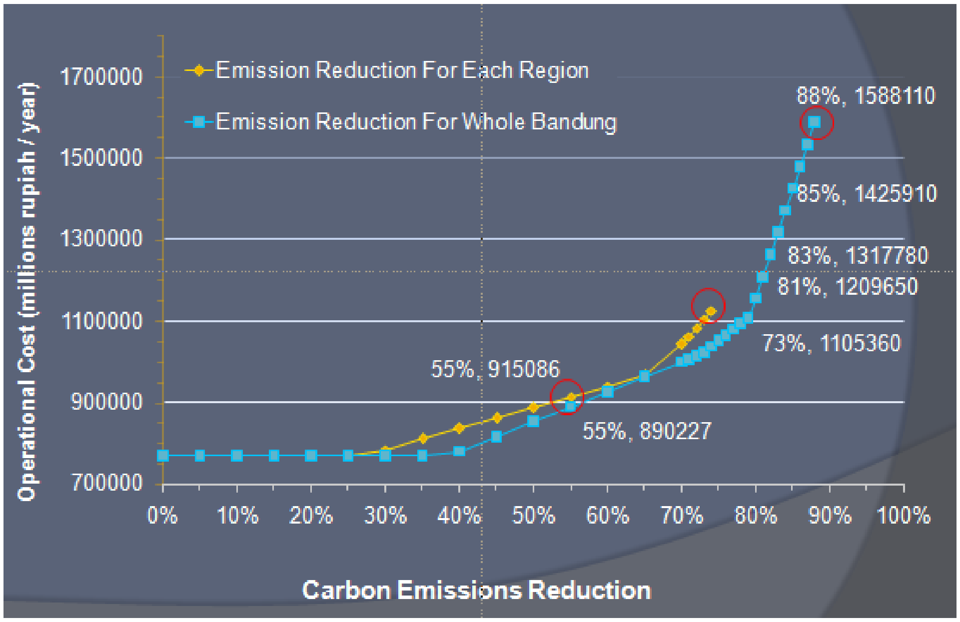

Figure 4 Comparison of Operational Cost in Both Situations

The first situation is conditioned that every region have its own emission reduction target, while the second situation is conditioned that Bandung City has a certain emission reduction and reduction target in each regions are neglected. It can be seen in **Figure 4** that by the presence of carbon trading (see the red line), operational cost of waste treatment in Bandung City became cheaper than before (see the blue line). **Figure 4** also shows the maximum reduction that can be achieved from each condition where the maximum target reduction for combined emission constraint is higher than the other one which is 88%.

Allocation of Waste to Be Treated

Figure 5 shows the allocation of waste (ton of FW/year) in Bandung Utara to be treated using each kind of treatments. The allocation of waste to be treated in Bandung Utara for target reduction of 30% using emission constraints for each region is as follows: X_{11}=64784.88, X_{12}=6415.09, X_{21}=78191.16, X_{22}=8.861468, X_{23} until X_{33} is zero, X_{34}=93100, X_{41}=55052.15, X_{42}=5747.831

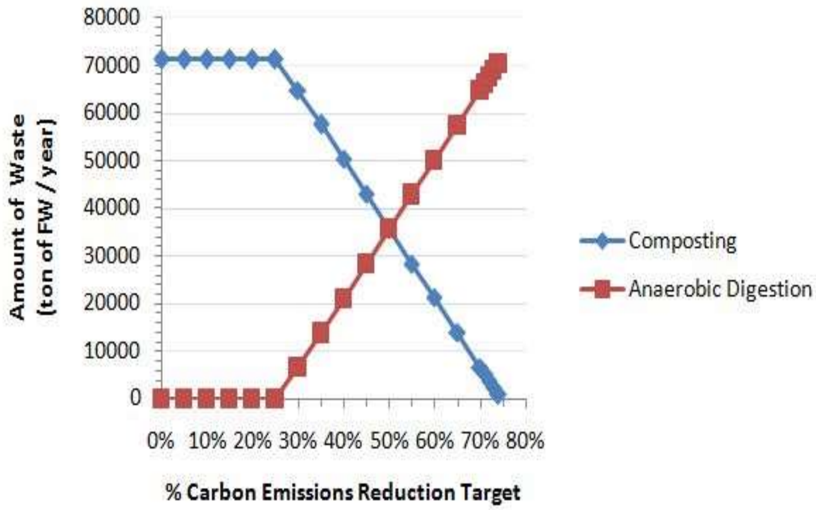

Figure 5 Allocation of Waste to Be Treated in Bandung Utara

Three Phases of Simulation Results

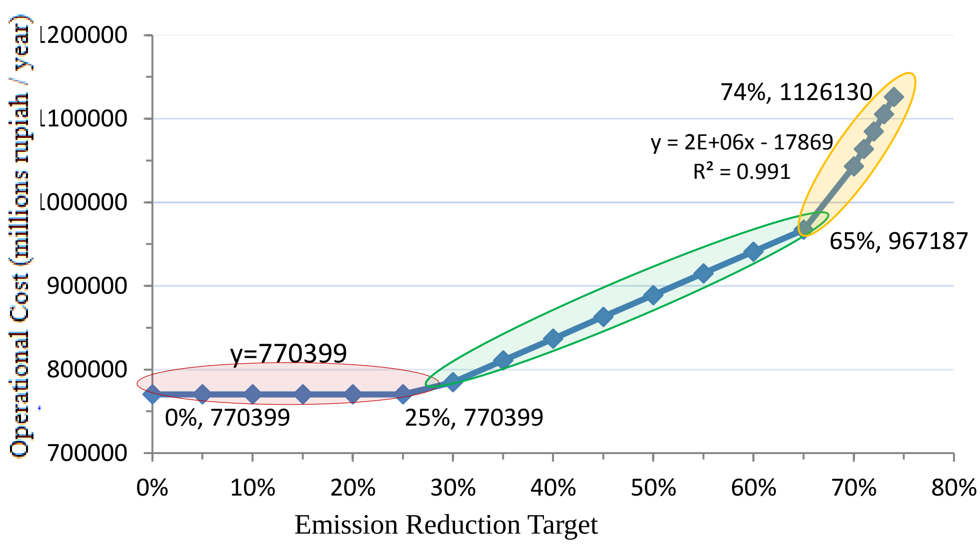

Figure 6 Phases of Simulation in 2020

Figure 6 shows the simulation results in 2020 using separated constraint for emission for each region. There are three phases of simulation results that can be seen in **Figure 6**. First is the constant phase between target reductions of 0% to 25% which consists of the cheapest waste treatment plant in each region. In this phase the realized emission reduction is below target emissions. The second phase occurred when the target for emission reduction is higher than 25% up to 65% where several regions of Bandung City started to use their second cheapest waste treatment plant to meet the reduction target. Bandung Utara and Bandung Selatan started to use Anaerobic Digester. These conditions also occurred for phase three, but it happened in Bandung Timur only which used Inceneration facility to meet the target reduction.

CONCLUSION AND SUGGESTION

Biodigester and composter will be used in every region, sanitary landfill will be used in East Bandung, and incinerator will be used in East Bandung and West Bandung.

Allocation of optimal waste fraction input for each waste treatment in every region for 2020 with emission reduction target of 30% are as follows, x_{11} = 0.9099, x_{12} = 0.0900997, x_{21} = 0.999887, x_{22} = 0.000113318, x_{23} = 0, x_{31} = 0, x_{32} = 0, x_{33} = 0, x_{34} = 1, x_{41} = 0.905463, x_{42} = 0.0945367 with the total operational cost of 784835 millions rupiah.

Carbon trading system application can reduce the operational cost for Bandung City as much as 14436 millions rupiah/year.

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