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Regional Case Study

Forecasting Methane Emission Reduction through 3R Waste Treatment Facility: The Case of Janti-Sidoarjo

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Abstract

Municipal solid waste (MSW) generation contributes to methane emission, formed during anaerobic decomposition of organic. The MSW reduction can be forced into an integrated solid waste management site through 3R paradigm built in each municipal level area. This is because methane has a relatively short atmospheric lifetime of about 12 years compared to CO_2. This means that reducing methane can quickly impact slowing global warming in the short term. This study aimed to achieve maximum results in reduction methane emission generated from an urban area through 3R waste treatment facility with measurable evaluation in 3 scenarios. The method used to gather the data analysis is Minitab 22 software, which forecasts an approach through trend method analysis, moving average, single exponential smoothing, and double exponential smoothing model to obtain the best-fit model for scenario analysis. The result showed that trend analysis has a high accuracy category with the smallest error (<10%: strong accuracy) in BaU, scenario 1, scenario 2, and scenario 3 with the MAPE value 0.002071 (0.2%), MAD value 0.00, and MSD value 0.00. Meanwhile, scenario 3 could decrease the amount of waste sent to landfills 188.03 tons/year in 2024 and 203.53 tons/year in 2033. Whilst, it could reduce methane up to 0.829126 tons-CO_2-eq /year in 2024 and 0.897479 tons-CO_2-eq /year in 2033 from total waste in Janti or 8-10% from the total methane emissions in Jabon landfill (65683,8 tons-CO_2-eq /year). It concluded that optimizing the activities of 3R waste management facility units in each area, particularly in Sidoarjo, can significantly reduce the effect of methane emissions that arise in landfills.

Keywords: Methane emission; municipal solid waste; forecasting; 3R waste treatment facility

1. Introduction

Waste is an integral part of our daily activities and have an impact on increasing environmental waste generation (Nagong, 2021). This condition is worsened by several factors such as the rate of urbanization, population growth, increasing in income, and environmentally unfriendly behavior. This has resulted in an increasing amount of waste (Goh et al., 2022; Kittipongvises & Vassanadumrongdee, 2018; Xu et al., 2017). According to World Bank report, global waste generation is expected to increase by 70% in 2050 and generate 3.40 billion tons of waste per year, up from 2.01 billion tons today. The East Asia and Pacific region is responsible for nearly a quarter (23%) of all waste generated (Kaza et al., 2018). Hence, it is necessary to manage sustainable municipal solid waste for a healthy and inclusive environment. Inappropriate waste disposal can harm human health, cause various kinds of environmental pollution, and impact climate change (Fadzoli et al., 2023; Meidiana et al., 2021). It needs to be managed optimally in order to minimize the impact of waste generation.

TPS-3R can be said to be a material recovery facility, which is useful in reducing urban solid waste generation on a small scale (Budihardjo et al., 2021). Waste management at TPS-3R includes transportation, sorting by type, shredding organic waste, composting, and disposal (residue) to landfill (Zubair & Haeruddin., 2011). In Indonesia, about 60% to 70% of waste is transported to landfills, with the remaining 30%-40% ending up in rivers, burned, or managed independently by households (Kristanto & Koven, 2019). Sidoarjo is an urban and industrial area located on the border of Surabaya city and it has the highest population growth rate in that region reaching 1.53% in 2017 (BPS, 2023). Based on data from the Environmental Agency and Cleanliness (DLHK) Sidoarjo can process only 17% of the total routine waste generated. The remaining 83%, or equivalent to 1032 tons of waste per day, is disposed of in Jabon Landfill, Sidoarjo Regency (Prakoso & Gunarta., 2021). In general, 70% of developing countries consist of degradable (organic) materials (Ramachandra et al., 2018). This can increase the potential for global warming with climate pollutants such as black carbon, and release methane (Koderi et al., 2018; Lee et al., 2017; Premakumara et al., 2018). Methane contributes 15% to Global Warming Potential (GWP) and theoretically, each kilogram of organic waste produces 0.5 m^3 of methane. Besides, it is formed from anaerobic decomposition waste in Material Recovery Facility (MRF) or the final disposal site, organic waste is formed in the combustion of organic materials (Artiningrum, 2017). Methane which is not managed properly in the final disposal site, potentially causes problems such as explosions, odors, and fires. It has the limits of flammability of 5 %-15 % by volume in air (Armi & Mandasari, 2017; Ratih et al., 2015).

Several researchers have invetigated an appropriate strategy to reduce methane and Greenhouse Gases (GHG) in waste management. Hermawati et al. (2015) investigated the strategies of GHG reduction that can be achieved in two ways: through reduction from its sources of biodegradable organic waste (composting) and management of emissions from landfills. Demir et al. (2019) also supported the strategy for municipal waste management and emission reduction to prevent or minimize waste from its sources. Thus, waste management strategies are based on the total solid waste generation and disposal, the economic level, and the operation and management of each municipality (Bian et al., 2020). Meanwhile, Budihardjo et al. (2022) and Tsai et al. (2020) suggested the development of a small-scale, community-driven material recovery facility to achieve the objectives of reduction, reuse, recycling with the lowest environmental impact. Moreover, the strategies mostly focus on the assessment of the environmental impacts and management approaches, i.e., landfilling (Sauve & Van Acker, 2020), incineration (Yao et al., 2019), and bio-chemical processing (Lu et al., 2020), with the integrated municipal solid waste management (Nevrlý et al., 2019).

However, appropriate and acceptable comprehensive models are required to account for the impact of waste management approaches. As accordance with the national action plan for the waste sector sets to reduce GHG emissions by 26% to 41% by 2030 (Darajati, 2012; Dewi, 2011). The accounting for emission reductions in waste management provides more accurate view of the environmental impacts of managing the waste sector that generates emissions (Ooi et al., 2021). Novelty discussion in the journal, to achieve maximum results in reducing the impact of methane emissions, measurable evaluation is carried out by controlling from its source and managing the impacts caused through forecasting scenarios (Candradevi & Puspitasari, 2016). The forecasting method predicts variable values based on known values of existing and related variables (Mariani & Rosyida, 2023).

It is important to forecast the potentials of methane concentrations in the air over time as a basis for setting baselines to ensure reductions occur. Therefore, an accurate methane prediction model is needed to project how methane emissions emerge to provide an informative and rapid analysis, which allows the regulators and communities to take action. This study uses forecasting approach by integrating several strategies from research for scenario-based analysis to evaluate the effectiveness of emission impact reduction strategies by using the concentration of time series prediction. The forecasting approaches use different time series like trend, moving average, single and exponential to get the best-fit models with the smallest error of MAPE, MAD, MSD (Luo et al., 2024; Malik et al., 2020; Tudor & Sova, 2021). Likewise, the forecasting errors are compare to obtain the best-fit models. As an appropriate tool for scenario analysis, can assist policy-makers in making decision of waste management strategies (Salmeron et al., 2012).

Additionally, the government of Sidoarjo has municipal waste solid management by providing waste management facilities. Waru district, as an urban and industrial area, has the largest population in Sidoarjo Regency, exceeding 192613 (BPS Sidoarjo, 2023) and is located on the border with Surabaya City. Based on report from DLHK (2018) in Waru district has 4 TPST-3R. The only 3R waste treatment facility still running well is TPST-3R Janti, followed by composting organic waste management (Cahyani et al., 2020). The limitation of this study is to analyze methane reduction estimates by forecasting the scenario contribution through community-sorted involvement, implementation of TPST-3R Janti and waste restriction regulations of its sources (reducing). The results of this study are expected to guide the improvement of other TPST-3R in Sidoarjo.

2. Methods

The data collection methods used in the study are primary data and secondary data (Sugiyono, 2017). The primary data on the existing conditions of the amount of waste at TPST-3R Janti, management and sorting systems. The amount of household waste generation data was carried out by direct survey, questionnaires in observing the activity of sorting waste from its source. The secondary data includes documents on TPST-3R, documents on RT/RW, BPS data, and DLHK Sidoarjo Regency. Forecasting consists of qualitative and quantitative methods. Qualitative methods discuss mathematical and statistical approaches, while quantitative methods are distinguished in two ways: the causal method and the time series method. The forecasting is used to determine MAD, MSD and MAPE so that the lowest error value can be obtained with the help of Minitab.22 software.

2.1. Case Study Location and Period

This study took place in a settlement area with 2042 households. It has an area of 82.67Ha ((BPS Sidoarjo Regency, 2022). As illustrated in **Figure 1**, Janti village, as an urban and industrial area, is located in Sidoarjo Regency. The study area was determined based on the presence of 3R waste treatment facility Janti, which still exist in composting and recycling process, and potentially provides services households along the area. Currently, 72% of households are registered and participate actively as an area served. Meanwhile, the others 3R waste treatment facility in Waru sub-district like Tambak Rejo and Ngigas have not run the process yet (Cahyani et al., 2020).

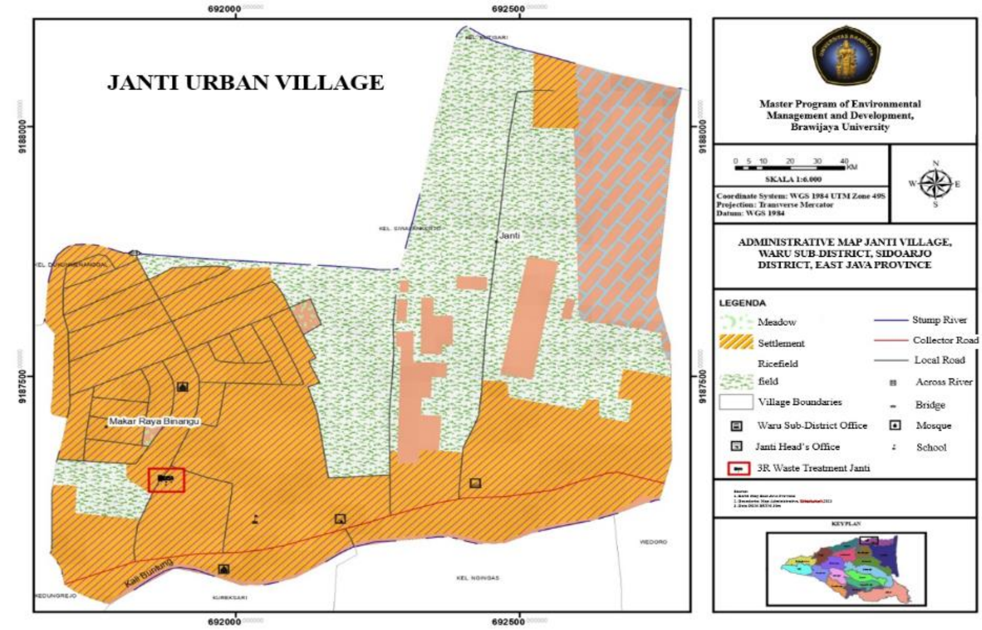

Figure 1. The research site of Janti urban village

2.2. Scope and Boundary

This study aims to measure the environmental impact of biological treatment in three scenarios to select the best scenario with minimum emissions for future waste management in Janti, Sidoarjo Regency. The scope of this study includes unmanaged waste, waste management by composting using the open windrow composting, recycling and reducing from its source as an alternative approach.

Based on the waste composition in Janti, most of the waste consists of organic waste that can be treated biologically. This study is based on government policy, where 70% of the waste generated will be treated before the remaining is generated in the landfill. The system limitation in this study is limited to composting, recycling, and reducing from its source as an alternative scenario proposed to minimize the amount of waste transported to the landfill to reduce methane emission. Furthermore, this scenario limitation will be included as a basis for forecasting the smallest error as a step to determine future policies. The following proposed scenario is seen in **Figure 2** below.

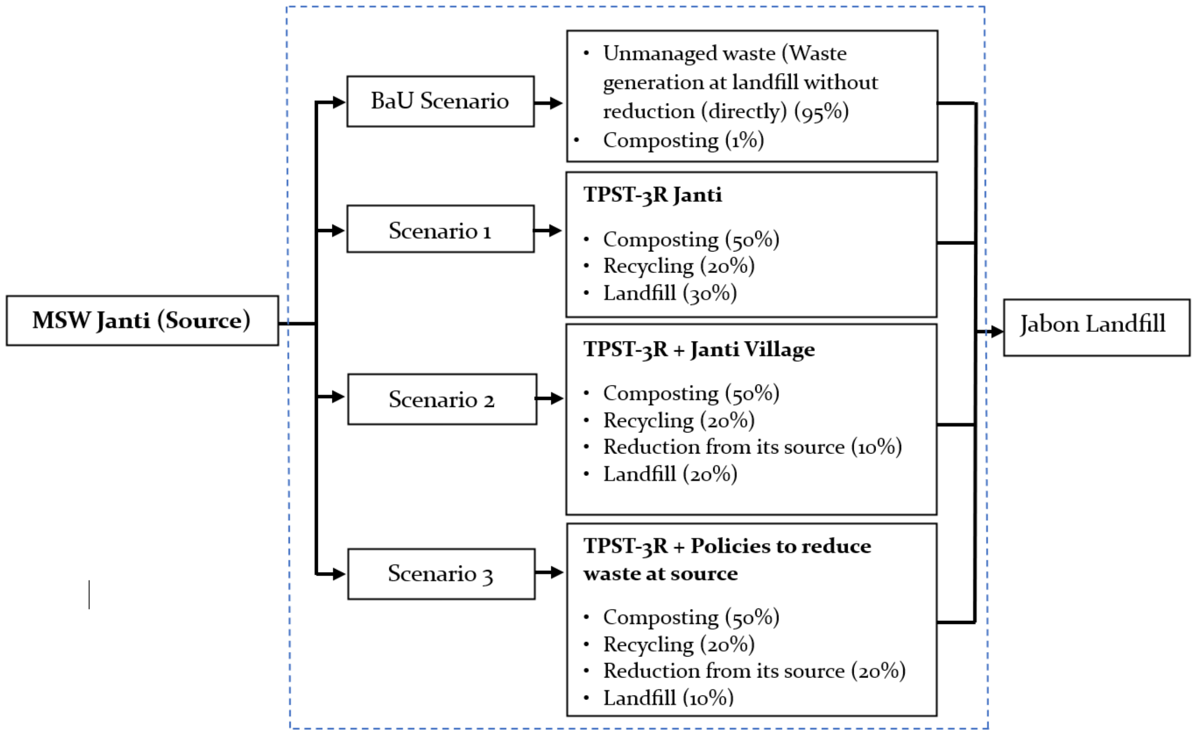

Figure 2. System boundary of the study

2.3. Population Projections

The secondary data was obtained from BPS Sidoarjo and confirmed by the local government of Janti village. The number and rate of population growth which used for next 10 years estimation. The population projection data obtained, then was calculated to estimate MSW generation. Therefore, population projection in this study uses the geometric method (1).

$$P_t = P_o (1 + r)^t \quad (1)$$

Where *Pt* is the population after time, *Po* is starting population, *t* is time period, and *r* is the population growth rate. If the value $r > 0$, it means population growth is positive (increase) from previous year. If the value $r < 0$, it means negative (decrease) from previous year.

2.4. Forecasting and Validation Test

The forecasting methane impacts from population and waste generation data were calculated using Minitab 22 to determine the best forecast with the smallest amount of error. The most suitable time series model was decided based on the accuracy of the historical data parameters. The errors of the different approaches forecast each scenario are compared (Kristanti, 2015). Forecasting accuracy refers to the smallest forecasting deviation between the actual and the forecasted value, which also means the smallest forecasting error. According to Makridakis et al. (1978) the forecasting time series is a special form of ordinary regression where time is an explanatory variable. It is used to observe data trends over a long period, predict the condition of data in the future, and predict data at a certain time.

Using regression analysis, this study can model and forecast the trend of a time series data by including element $t = 1,2, \ldots, T$ as predictor variables (Hyndman & Athanasopoulos, 2013). Linear regression analysis can be used to analyze trend variations in time series data, which can be expressed as a linear function where there is a linear trend in the regression equation with the following equation (2):

$$yt = \beta 0 + \beta 1t + \varepsilon t \qquad (2)$$

where,

$\beta 0$ = Constant

$\beta 1$ = Regression coefficient

tt = Time unit value

εt = Error value

The coefficient $\beta 1$ is the slope of the linear function, i.e., the linear trend. The regression coefficients $\beta 0$ and $\beta 1$ can be calculated by the least square method, ε is the residual (Zhou et al., 2019).

The error test determines which forecasting method is suitable and which has the smallest error value. The measures of accuracy that are often used to determine of a forecasting method in modeling time series. To analyze the data value of forecasting MAPE, MAD, and MSD, with Minitab 22 process aplication (Jain et al., 2018; Jiang et al., 2020).

The method used in this study are :

Mean Absolute Deviation (MAD) measures the accuracy of the forecast by measuring how much the average difference between each value in the data is with the average value where each forecast has an absolute value for each error. The equation (3) of MAD is:

$$MAD = \frac{1}{n}\sum_{\{i=1\}}^{\{n\}} |\mathrm{yi} - \hat{y}\mathrm{i}| \qquad (3)$$

Mean Squared Deviation (MSD) is a method of measuring the accuracy of forecasting that has a greater effect than MAD. This method provides more detailed information about the distribution and level of data deviation because this method squares the difference between each value and its average. The equation (4) of MSD is :

$$MSD = \frac{\sum_{\{i=1\}}^{\{n\}} |\mathrm{yi} - \hat{y}\mathrm{i})|^2}{n} \qquad (4)$$

Mean Absolute Percentage Error (MAPE) is calculated by finding the absolute error of each period, then dividing by the actual data value in that period, then averaging the absolute percentage error. The following equation (5) of MAPE is:

$$MAPE = \frac{1}{n}\sum_{\{i=1\}}^{\{n\}} \left|\frac{y_i - \hat{y}_i}{y_i} X \quad 100\right| \qquad (5)$$

where :

Yi = Actual value of the period i

Ŷi = Forecast value in the period i

Based on (Azman, 2019; Lewis, 1982), the MAPE value can be divided into four categories as follows:

1. <10% = Excellent
2. 10-20% = Good
3. 20-50% = Eligible
4. >50% = Poor

2.5. Scenario Methane Emission Calculations

Methane emission calculation was implemented using 3 scenarios approach. The statistical test aims to picture the correlation between two or more nominal scale variables. The indications of those variables' occur because of "cause and effect" (Darmawan, 2018). The waste management scenarios consist of the BaU scenario, which represents current waste management practices involving landfill and composting. Proposed scenario in the journal and its basis, scenario 1 assumes 50% of waste goes to composting, 20% recycling and 30% to landfill. Scenario 2 assumes 50% of the waste goes to composting, 20% to recycling, with 10% reducing from its source and 20% to landfill. Scenario 3 assumes 50% of waste to composting, 20% to recycling, with 20% reducing from its source and 10% to landfill (**Table 1**). The design of this scenario considers several regulations in Indonesia, such as Presidential Regulation No. 83/2018 on the prevention of marine debris, Ministerial Regulation No. 75/2019 on the roadmap of waste management by producers and Presidential Regulation No. 97/2017 on the National Policy and Strategy (Jaktranas) (Budihardjo et al., 2023; Mustafa et al., 2022), which encourages the role of composting, recycling and reducing from its source.

Table 1. The estimation of methane emissions at TPS-3R in Janti village

Scenario	Composting	Recycling	Reduction from its source	Landfill
BaU	1 %	0 %	0 %	95 %
1	50 %	20 %	0 %	30 %
2	50 %	20 %	10 %	20 %
3	50 %	20 %	20 %	10 %

An estimate the total of methane emissions from MSW disposed to landfill without any reduction or recycling can be determined using the Equation 6 as mentioned in the IPCC (Eggleston et al., 2006).

$$\text{Methane emission} = (MSW_t \times MSW_f \times MCF \times DOC \times DOC_F \times F \times 16/12 - R) \times (1 - OX) \quad (6)$$

In which MSW_t is the generation of waste (Gg/year), MSW_f is the proportion of waste being treated at the landfill, *MCF* is the methane correction factors, *DOC* is the amount of degradable organics carbons, DOC_f is the proportion of degradable organics carbons that can be degraded, F is the proportion of CH_4 in the landfill, *R* is the methane recovered (Gg/year), and *OX* is an oxidization factor (EPA, 2020). MSW reduction activities in 3R waste treatment facility Janti (existing condition). 3R waste treatment facilities in Janti mostly use biological treatment, mainly composting. The emission inventory for biological treatment included methane, as mentioned in the IPCC (Budihardjo et al., 2021; IPCC, 2006).

3. Result and Discussion

3.1. Waste Generation and Population Estimation Projection

The data used in this research consisted of waste generation obtained from calculating the daily waste ritase for 8 consecutive days at TPST-3R. While, the time used starts from November 2023 to January 2024. Meanwhile, data on the amount of waste in Jabon landfill, Sidoarjo Regency, was obtained as much as 1206.65 m^3/day or 329198.9 kg/day and 120249.1 tons/year based on the calculation of Jabon landfill waste generation by Gaol & Warmedewanthi (2017). The primary survey method was used to obtain the main data in this study.

The estimated population and the total amount of waste generation at TPST-3R are obtained by calculating the incoming daily waste for 8 consecutive days. Where the transportation volume loading unit is 2.1357 m^3. The total MSW entering 3R Waste Treatment Facility Janti is 3.693,375 kg/day. The following observation of MSW started from January, 22 2024 until January, 29 2024 (**Table 2**). According to population estimates, the estimate of MSW in 3R waste treatment facility Janti is done until 2033. The calculation of MSW is explained as follows: the average MSW generation can be calculated from the total of MSW entering 3R waste treatment facility Janti divided by the number of people served in 2023, which is 0,83 kg/person/day. As mentioned in SNI-3242-2008, the total of MSW generation "big cities to medium cities" is 0,8 kg/person/day. According to Goh *et al.* (2022) the increase of MSW generation is owed to many factors such urbanization, population growth, higher disposal income, and unsustainable consumer behaviors.

Table 2. MSW in 3R waste treatment facility Janti

FORM SAMPLING TOTAL MUNICIPAL SOLID WASTE (MSW)								
Loading units	**Days-1 MSW(kg)**	**Days-2 MSW(kg)**	**Days-3 MSW(kg)**	**Days-4 MSW(kg)**	**Days-5 MSW(kg)**	**Days-6 MSW(kg)**	**Days-7 MSW(kg)**	**Days-8 MSW(kg)**
Units- 1	354	431	376	571	432	386	351	389
Units- 2	406	437	398	379	364	427	348	409
Units- 3	383	394	421	433	453	459	417	375
Units- 4	429	445	397	418	403	451	379	433
Units- 5	452	381	413	447	439	393	451	423
Units- 6	371	411	451	386	387	415	383	384
Units- 7	437	418	377	367	409	421		411
Units- 8	391	403	407	453	423	403		439
Units- 9		373	427	429		373		493
Units- 10		367	392			369		
Units- 11			367			427		
Total	3223	4060	4462	3883	3310	4524	2329	3756
Averages loading/day	8	10	11	9	8	11	6	9
Average total MSW	(Volume total/8) = 29.547 kg/8 days= **3.693,375 Kg**							

Source: Primary data analysis results, 2024

The total population served in 2023-early 2024 by 3R waste treatment facility Janti is 6247 people and the total of service is 4482 people. Based on the result of population estimation, the total population in the final estimate (2033) is 6762 and total of service is 5477 people with regression value (r) is 0,62290 using the geometric method (**Table 3**).

In the calculation of the total of waste generation in Janti village, it has increased along with the increase in population. Meanwhile, the number of service percentages has also increased. The waste management in the Janti TPST-3R unit also needs to be improved so that waste reduction is more optimal and the impact of the environmental problems can be reduced. This is in accordance with the mandate of the Jakstrada Sidoarjo target.

Table 3. The MSW generation estimate in 3R waste treatment facility Janti

Year	**Population estimates (person)**	**Total MSW (kg/day)**	**Total MSW (Ton/day)**
2024	6247	3693	1349
2025	6302	3791	1385
2026	6358	3877	1416
2027	6414	3964	1448
2028	6471	4052	1480
2029	6528	4142	1513
2030	6586	4233	1546
2031	6644	4325	1580
2032	6703	4419	1614
2033	6762	4514	1649

Source: Primary data analysis results, 2024

3.2. Waste Composition

The types of waste composition of MSW generation at 3R waste treatment facility Janti is dominated by organic waste (1945 kg/ 53%). Meanwhile, the smallest waste composition is diapers or masks (33,9 kg/ 1%). The recyclable waste such as papers, plastics, metals, and glasses have been already picked up by the informal sector (off taker) for sale. Whereas, organic waste is composted using windrow composting method. **Figure 3** shows the MSW composition at 3R waste treatment facility Janti. Furthermore, the MSW composition in 3R waste treatment facility Janti is explained in percentage (%) as explained.

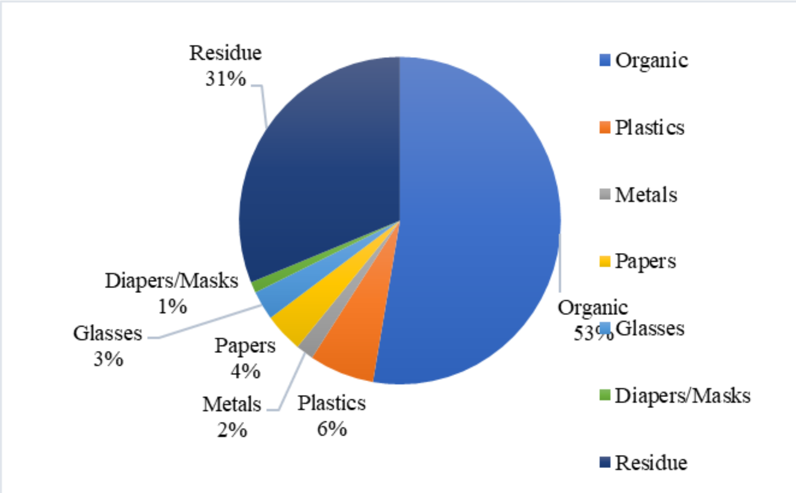

Figure 3. MSW composition in 3R waste treatment facility Janti
Source: Primary data analysis results, 2024

3.3. Projections of Methane Emission from MSW

In this study implemented methane emission calculation using 3 scenarios as mentioned above. Firstly, by knowing the total MSW generation in Jabon landfill (MSW_t), Sidoarjo is 1206,65 m^3 /day or 329198,9 kg/day or 120249,1 tons/year (Gaol & Warmadewanthi, 2017). DOC (Degradable Organic Carbon) calculation value obtained 0,182 Gg C/gram MSW. Then the total waste generated from Janti will be reduced to calculate the impact of waste reduction. As a shown on the **Table 4**.

Table 4. The methane emission (ton/year)

Type of Waste	(MSWt) (Ton/Year)		MSWf	DOCi	DOCf	MCF	F	Lo CH4
	Ton/Year	Percentage	(ton/Year)					(Ton/year)
Organic	990.63	53%	0.82%	0.20	0.50	0.40	0.50	0.195862703
Plastic	122.55	7%	0.10%	0.00	0.50	0.40	0.50	0
Paper	73.00	4%	0.06%	0.40	0.50	0.40	0.50	0.002127435
Metal	33.60	2%	0.03%	0.00	0.50	0.40	0.50	0
Glass	54.28	3%	0.05%	0.00	0.50	0.40	0.50	0
Nappies/Diapers	20.23	1%	0.02%	0.24	0.50	0.40	0.50	9.80118E-05
other (Textile, leather, Sludge)	585.71	31%	0.49%	0.39	0.50	0.40	0.50	0.133513046
Total	**1880.00**							**0.331601**

Source: Primary data analysis results, 2024

Based on the analytical calculation, methane emission of Jabon landfill is 6568380 -ton $CO_{2\text{-eq}}$ /year according the generated waste (L. Gaol & Warmadewanthi, 2017). This is due to the large population and estimated methane emissions calculated without any reduction efforts from several TPST in Sidoarjo, such as from the Janti TPST-3R unit. Secondly, It is necessary to optimize the waste management facility unit's activities in each area to reduce the effects on the final disposal site.

The estimation of methane emissions of MSW disposed to Jabon landfill without reduction of Janti 3R waste treatment facility in 2024 amounted to 0.331601 Ton/Year or 82900 -ton $CO_{2\text{-eq}}$ /year. This projections will be included in the proposed scenarios to see which scenario is the most fit in reducing the impact of methane generated in Janti until the following years, as in **Table 5** below:

Table 5. Projection methane emission scenarios (ton/year)

Year	Solid Waste Generation (Ton/Year)	Waste Generation (MSWt) (ton/year)				Lo CH_4 (Ton/Year)			
		BaU	Scenario 1	Scenario 2	Scenario 3	BaU	Scenario 1	Scenario 2	Scdenario 3
2024	1880	1786.26	564.08	376.06	188.03	0.315	0.099	0.066	0.033
2025	1897	1801.99	569.05	379.37	189.68	0.318	0.100	0.067	0.033
2026	1914	1818.00	574.11	382.74	191.37	0.321	0.101	0.068	0.034
2027	1931	1834.02	579.16	386.11	193.05	0.323	0.102	0.068	0.034
2028	1948	1850.32	584.31	389.54	194.77	0.326	0.103	0.069	0.034
2029	1965	1866.61	589.46	392.97	196.49	0.329	0.104	0.069	0.035
2030	1982	1883.20	594.69	396.46	198.23	0.332	0.105	0.070	0.035
2031	2000	1899.78	599.93	399.95	199.98	0.335	0.106	0.071	0.035
2032	2018	1916.65	605.26	403.51	201.75	0.338	0.107	0.071	0.036
2033	2035	1933.52	610.59	407.06	203.53	0.341	0.108	0.072	0.036

Furthermore, the accuracy measurements of MAPE, MAD, and MSD are calculated, with the trend analysis, moving average, single exponential, and double exponential approaches having the smallest error values. The output results can be seen in **Table 6** below.

Table 6. The results of MAPE, MAD, and MSD

Forecasting Measurements		BaU	Scenario 1	Scenario 2	Scenario 3
TREND	MAPE	**0.002071**	**0.002071**	**0.002071**	**0.002071**
ANALYSIS	MAD	**0.0000067**	**0.0000021**	**0.0000014**	**0.0000007**
	MSD	**0**	**0**	**0**	**0**
MOVING	MAPE	0.87633	0.87633	0.87633	0.87633
AVERAGE	MAD	0.000911	0.000911	0.000608	0.000304
	MSD	0.000001	0.000001	0	0
SINGLE	MAPE	2.04313	2.04313	2.04313	2.04313
EXPONENTIAL	MAD	0.00677	0.00214	0.00142	0.00071
	MSD	0.00006	0.00001	0	0
DOUBLE	MAPE	0.0274618	0.0274618	0.0274618	0.0274618
EXPONENTIAL	MAD	0.0000902	0.0000285	0.000019	0.0000095
	MSD	0	0	0	0

The comparing result of the four outputs shows MAPE, MAD and MSD have the smallest error rate. Based on existing survey data from the above forecasting calculations, the trend analysis method has the smallest error value among others with a level of α = 0.2, using Minitab 22 software. Taking into account the value of the MAPE indicator in each scenario, namely BaU, Scenario 1, Scenario 2, and Scenario 3 with a value of 0.2% (in the <10% category) has a high accuracy category in the trend analysis method in forecast. The actual data from the trend analysis forecasting results are shown in **Figure 4** (a,b,c,d).

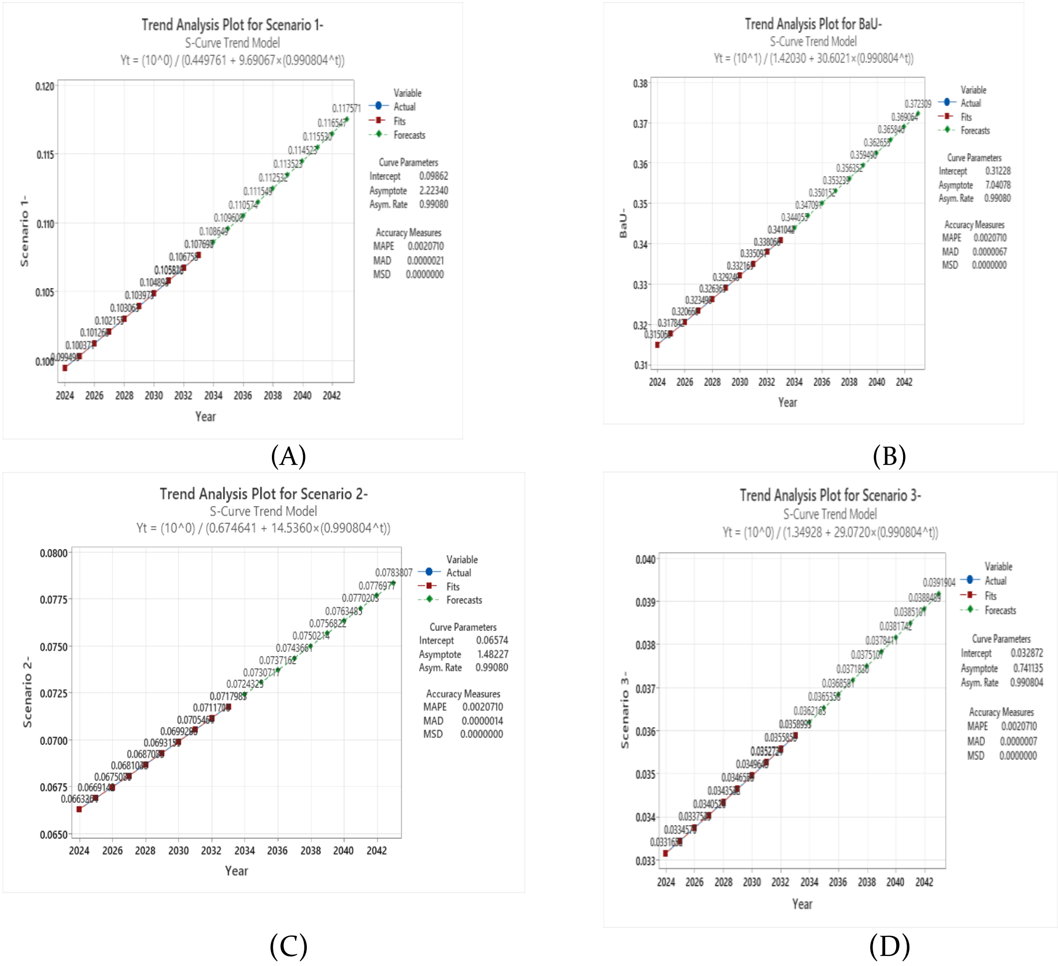

Figure 4 (a) Forcasting result BaU, (b) Forcasting result scenario 1, (c) Forcasting result scenario 2, (d) Forcasting result scenario 3

Lastly, it can be concluded that forecasting using the moving average, single smoothing, and double smoothing approaches has a higher error than trend analysis. Therefore, it is not accurate and cannot be used.

3.4. Interpretation

It can be seen that the MAPE, MAD, and MSD values are the smallest at the α=0.2 level where the smaller the value of MAPE, the better of forecasting value is obtained with the trend analysis approach. However, if the smallest value remains large, forecasting cannot be good because of the greater error rate. Then, among the scenarios considered above, BaU is where most of the waste generated from an area directly delivered to the landfill. Scenario 1, where most of the waste is composted, shows high emissions in all impact evaluation categories, including global warming potential, and recycling of inorganic waste. Scenario 2, where waste management mostly uses the composting and recycling process and with waste reduction at source, has a higher waste reduction impact among the other scenarios. Scenario 3, a combined composting, recycling and implementation of local government policies from its source reduction, showed lower amount of waste delivered to landfill, and higher methane emission reductions, where the emission contribution came from the composting process. Scenario 3 was selected as the optimal waste management approach among the evaluated scenarios as shown in the **Figure 5.**

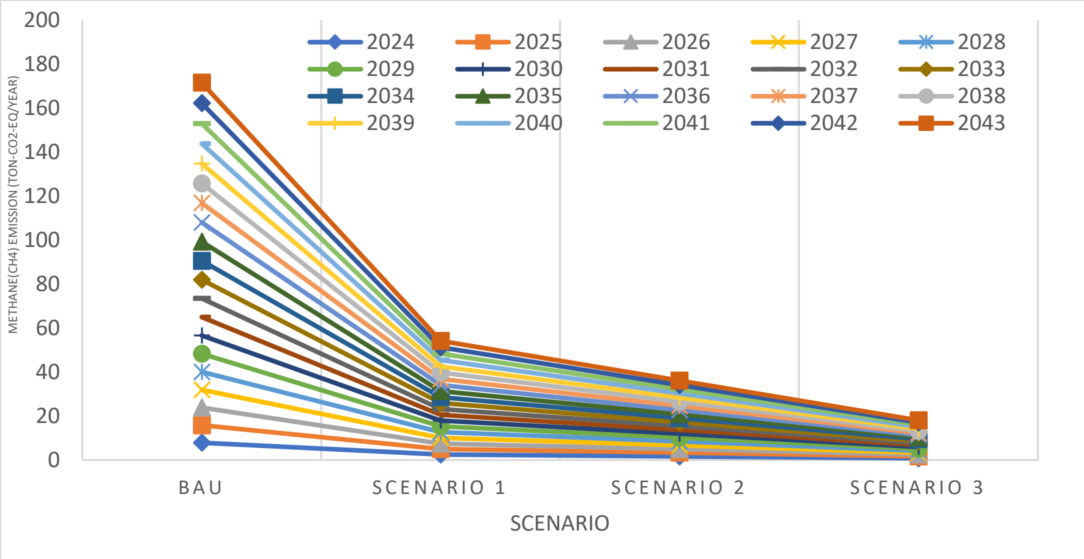

Figure 5. The methane emission for each scenarios

Estimation of waste reduction activities in the scenario above, obtained through the scenario 3 approach is able to maximize the waste reduction from Janti that enters to the landfill. The calculation results in scenario 3 in 2024 reduced waste, amounting to 188.03 tons/year, and 203.53 tons/year in 2033. It is also able to reduce the impact of methane emissions generated up to 0.829126 tons-Co2 Eq/year in 2024, and 0.897479 tons-Co2 Eq/year of total Janti waste or 8-10% of the total methane gas generation in Jabon landfill (6568380 -ton $CO_{2\text{-eq}}$ /year) as also seen on the **Table 7** below.

Table 7. The results of the methane emission for each scenario in Janti

Year	Methane Emission (ton-CO2-Eq/years)			
	BaU	**Scenario 1**	**Scenario 2**	**Scenario 3**
2024	7.876696	2.487378	1.658252	0.829126
2025	7.946044	2.509277	1.672851	0.836426
2026	8.016653	2.531575	1.687716	0.843858
2027	8.087262	2.553872	1.702581	0.851291
2028	8.159132	2.576568	1.717712	0.858856
2029	8.231002	2.599264	1.732843	0.866421
2030	8.304133	2.622358	1.748238	0.874119
2031	8.377264	2.645452	1.763634	0.881817
2032	8.451655	2.668944	1.779296	0.889648
2033	8.526047	2.692436	1.794957	0.897479
2034	8.601375	2.716225	1.810813	0.905408
2035	8.677275	2.74020	1.826793	0.913395
2036	8.75380	2.76435	1.842905	0.921453
2037	8.830975	2.788725	1.859153	0.929575
2038	8.90880	2.81330	1.875535	0.937768
2039	8.987250	2.838075	1.892055	0.946028
2040	9.066375	2.863075	1.908713	0.954355
2041	9.146150	2.88825	1.925508	0.962753
2042	9.22660	2.913675	1.942443	0.971223
2043	9.307725	2.939275	1.959518	0.97976

Based on data, the total of MSW entering Jabon landfill from 3R waste treatment facility Janti, with projection scenarios involving reduction from its source through enforcing regulations from the local government "reducing waste from households in the unit" and recycling is able to reduce the impact of methane generated. From these scenarios, it can be concluded that optimizing the activities of waste management facility units in each region, especially in Sidoarjo, can significantly reduce the impact on landfills.

4. Conclusion

Based on the forecasting scenario calculations to reduce methane emissions through 3R Janti waste treatment facility to the landfill in the projection of 2024-2043 using Minitab 22 software. Furthermore, the measurement of MAPE, MAD, and MSD accuracy was carried out, namely trend analysis, moving average, single exponential, and double exponential approaches which had the smallest error value. The study results show that trend analysis has a high accuracy category (in the <10% category) in BaU, scenario 1, scenario 2, and scenario 3 with a MAPE value of 0.2%, MAD 0 and MSD 0.

The forecasting analysis, it was found that scenario 3 by combined composting, recycling, and implementing of local government policies can reduce waste from its source. The data showed a decrease in the amount of waste sent to landfill, at 188.03 tons/year in 2024 and 203.53 tons/year in 2033 and higher methane reduction, where the reduction reached up to 0.829126 tons-$CO_{2\text{-eq}}$ /year in 2024, and 0.897479 tons-$CO_{2\text{-eq}}$ /year in 2033 from total waste in Janti. Scenario 3, it can maximize methane reduction until 8-10% as 2024-2043 projection in Jabon landfill (65683,8 tons-$CO_{2\text{-eq}}$ /year). This means that optimizing the activities of 3R waste management facility units in each area, particularly in Sidoarjo, can reduce significantly the effect of methane emissions that arise in landfills.

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