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Optimizing Waste Management Systems to Reduce Greenhouse Gas Emissions on the Small Island of Kodingareng Lompo, Indonesia

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ABSTRACT

The absence of an effective waste management systems in small island areas significantly contributes to greenhouse gas (GHG) emissions, particularly from uncontrolled open burning. This study analyzes the potential of an integrated waste management system to reduce GHG emissions in Pulau Kodingareng Lompo by comparing existing practices with an alternative scenario aligned with Presidential Regulation of the Republic of Indonesia No. 97 of 2017, which targets 30% waste reduction and 70% waste handling. Emission estimates were calculated using the IPCC methodology and Global Warming Potential (GWP) approach. Under existing conditions, waste reduction is minimal (1.37%), while 98.63% of waste is handled through environmentally unsound practices, primarily open burning, marine disposal, and landfilling. The alternative scenario introduces a resource-oriented paradigm, achieving 31.88% waste reduction and 68.12% controlled waste handling. As a result, total GWP decreases substantially from 171,708.79 kg CO_2e/year to 61,123.91 kg CO_2e/year, representing a 64.40% reduction. This decline is driven by significant decreases in CO_2, CH_4, and N_2O emissions following the elimination of open burning and the optimization of biological and controlled treatment processes. These findings demonstrate that the proposed integrated waste management scheme significantly reduces GHG emissions and provides a feasible and replicable model for small island contexts facing similar infrastructural and governance constraints. Its implementation requires coordinated engagement among local authorities, communities, and waste management operators, contributing to climate change mitigation and supporting sustainable coastal ecosystem management.

1. INTRODUCTION

The increasing volume of waste driven by population growth and consumption patterns has intensified pressures on both the environment and governmental systems. This condition is further exacerbated by inadequate disposal practices, limited resources, rapid urbanization and industrialization, socioeconomic disparities, weak policy enforcement, governance deficiencies, and low levels of public participation. Consequently, countries are compelled to formulate waste management strategies and regulatory frameworks to mitigate environmental impacts (Awino and Apitz, 2024). Waste management has also become a critical issue in Southeast Asia, where despite the introduction of various strategies implementation outcomes have been mixed and many initiatives have failed to meet their intended targets. The limited capacity of government institutions and the absence of sustainable waste management approaches have contributed to the continued degradation of environmental quality and public health (Aziz and Ariffin, 2023). The efficiency of waste collection in developing countries remains approximately 40%, less than half of that in developed countries, which achieve rates as high as 90%. Compared to the emphasis placed by developed countries on sustainable resource use, energy recovery, and safe waste disposal, developing nations are often able to meet only the minimum standards for safe disposal (Zhang et al. 2024).

Indonesia, through Presidential Regulation of the Republic of Indonesia No. 97 of 2017, establishes a strategic framework for the management of domestic waste and waste similar to domestic waste, aimed at developing an effective, integrated, and sustainable waste management system. The regulation outlines two key national targets to be achieved by 2025: a 30% reduction in waste generation and a 70% improvement in waste handling. The 30% reduction target focuses on upstream interventions, particularly limiting waste generation at the source, optimizing reuse activities, enhancing recycling efforts, and promoting the development of a circular economy. Meanwhile, the 70% waste handling target emphasizes strengthening downstream management capacities, including waste sorting, collection, transportation, processing, and environmentally sound final disposal. Achieving these targets requires enhanced coordination among government bodies, private-sector actors, and community participation, as well as revitalization of institutional structures, financing mechanisms, technological adoption, and planning instruments. Thus, this regulation serves as both a normative and operational foundation that reinforces Indonesia’s commitment to significantly reducing waste burdens and improving waste management quality, thereby contributing more measurably to environmental sustainability and public health.

According to the Ministry of Environment and Forestry of the Republic of Indonesia, the total waste generation across Indonesia had reached 67.8 million tons at the beginning of 2020. The household sector was identified as the largest contributor, accounting for approximately 48% of total waste, followed by traditional markets 24% and street waste 7%. Over the years, waste-related issues have shown an increasingly complex trend. According to data from the Environmental Office of Makassar City, daily waste generation reaches 905 tons, consisting of 54.46% organic waste, 27.48% inorganic waste, and 18.06% other waste types. Waste reduction efforts have achieved an annual rate of 2.09%, while waste handling measures have reached 74.74% per year.

Kodingareng Lompo Island is administratively part of Kodingareng Village, located within the Sangkarrang Island District, Makassar City, South Sulawesi Province, Indonesia. Geographically, the island lies in the Makassar Strait at coordinates 119°5'53.40"E and 5°8'53.06"S. Based on distance measurements using Google Earth, Kodingareng Lompo Island is situated approximately 14 kilometers from the mainland of Sulawesi. The area of Kodingareng Lompo covers 0.48 square kilometers with a total population of 4,977 inhabitants. The island is part of Makassar City, which serves as the capital of South Sulawesi Province and is classified as a metropolitan city with a population of 1,474,393 people (Makassar City Statistics Agency, 2024). Makassar City faces significant waste management challenges, particularly at the Tamangapa Final Disposal Site (Tamangapa landfill), where the waste volume has exceeded its maximum capacity since 2019 (Rusni, 2024). However, the unique condition of Kodingareng Lompo Island is that the waste generated there is not transported to the Tamangapa landfill. The island has a relatively high population density, which directly influences the amount of waste produced. The community lacks an effective waste management system, and waste is often disposed of directly into the sea (Gani and Iksan, 2020). In addition, residents also handle waste by burning and burying it (Adriani et al. 2023). The increasing volume of waste poses substantial environmental risks and contributes to climate change. In the absence of reliable waste management systems, open dumping and open burning have become default alternatives for reducing waste accumulation (Gómez-Sanabria et al. 2022). These conditions illustrate the environmental and management challenges faced by small island communities with limited land availability. Therefore, Kodingareng Lompo Island serves as a representative case study for analyzing waste management practices and potential greenhouse gas emissions in small island environments.

Greenhouse gas (GHG) emission can be prevented through effective waste management practice, in which the amount of properly managed waste exceeds the amount of waste generated. Such emissions may arise directly from landfills, open burning, recycling activities, and waste collection and transportation (Bakas et al. 2011). Therefore, emission reduction strategies such as waste reduction, recycling, and composting are required to move toward a more sustainable and low carbon future (Hoy et al. 2024). However, waste management on small island does not have straightforward solutions. Various challenges exist, including limited area, restricted opportunities for recycling and resale, and increasing environmental impacts, particularly when the island is small and densely populated (Camilleri-Fenech et al. 2018).

This study aims to analyze the quantity and composition of waste on Kodingareng Lompo Island and to compare waste management practices and the potential greenhouse gas (GHG) emissions and Global Warming Potential (GWP) generated under current (existing) conditions with alternative waste management strategies based on waste reduction and handling approaches in accordance with prevailing regulations. The novelty of this research lies in the application of an integrated waste management system in a small island context, which has been relatively underexplored from a greenhouse gas emission perspective. This study not only compares existing conditions with alternative waste management scenarios on the island and estimates potential GHG emissions and GWP using the Intergovernmental Panel on Climate Change (IPCC), but also emphasizes the importance of community participation and locally based management in supporting climate change mitigation through the waste sector. The findings provide a scientific basis for the implementation of sustainable waste management policies on small coastal islands in Indonesia.

2. MATERIALS AND METHODS

This study focuses on analyzing waste generation rates and composition from residential areas representing waste originating within the island, as well as waste data collected from coastal areas representing waste originating from outside the island. Subsequently, the waste generation and composition data evaluated based on current waste reduction and management practices (Scenario 1) and compared with an alternative waste management scenario that could be implemented on Kodingareng Lompo Island (Scenario 2). Furthermore, both scenarios are assessed in accordance with IPCC Guidelines to estimate greenhouse gas (GHG) emission potential and Global Warming Potential (GWP). The research employs a quantitative approach, as it relies on numerical data and statistical methods for data collection and analysis. The map of the study location is presented in the figure below.

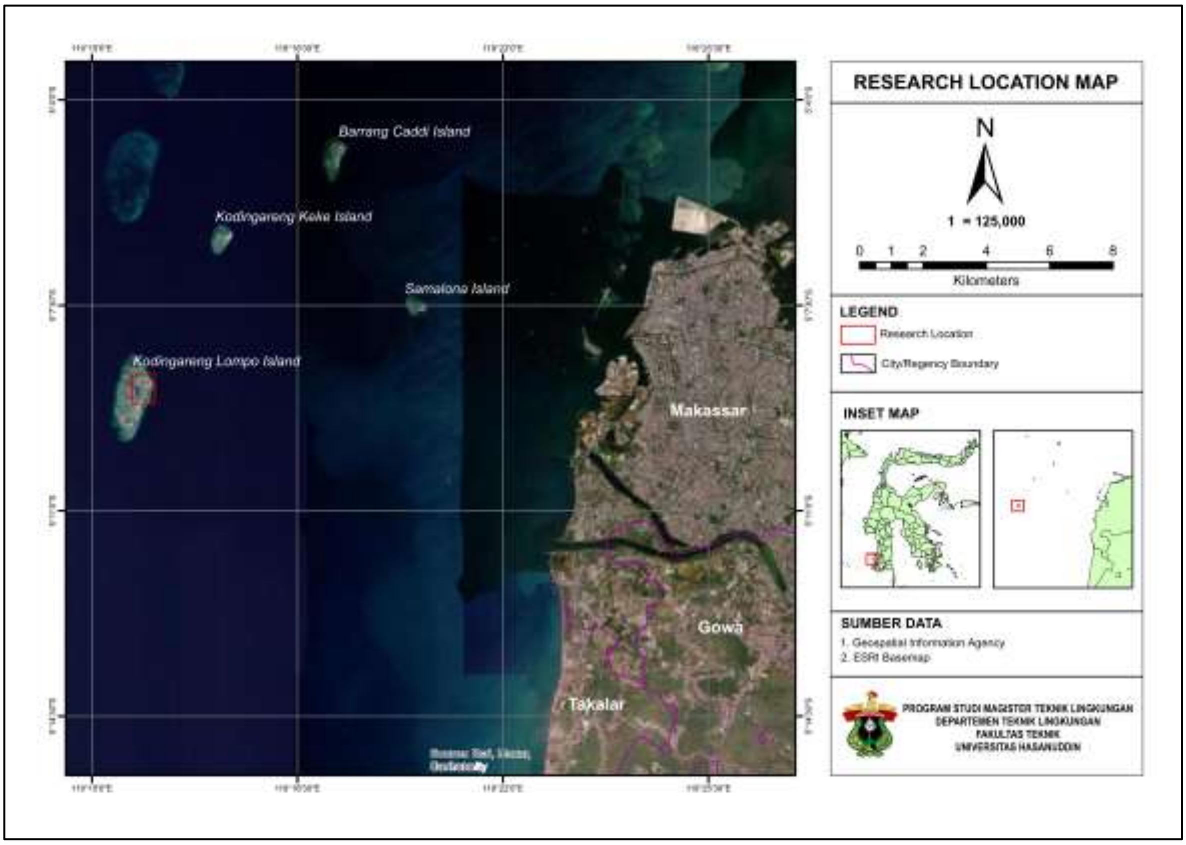


Fig 1: Research map area Kodingareng Lompo Island

2.1. Waste Generation and Composition in Residential Area

SNI 3964:2025 is a standard method for sampling and measuring household waste generation and composition, as well as waste similar to household waste, developed and established by the National Standardization Agency of Indonesia (BSN). According to this standard, waste generation refers to the quantity of waste generated by the community, expressed in units of volume or weight per capita per day, per building area, per unit of time, or per length of road. Given that the study area is an island setting, this research focuses exclusively on waste generated from households. The implementation of waste generation sampling in this study was conducted using a stratified random sampling approach, with the sample size determined as follows:

$$Ps = Cd\sqrt{Pt} \qquad \ldots (1)$$

Where Ps denotes the total number of individual samples (persons), Cd represents the population coefficient, and Pt refers to the total population (persons). Subsequently, the proportion of the number of sampled households (Heads of Household/HH) is calculated using the following equation:

$$K = Ps\,x\,N^{-1} \qquad \ldots (2)$$

Where K denotes the number of sampled households, Ps represents the total number of individual samples (persons), and N refers to the average number of persons per household, assumed to be 5 in accordance with the example provided in SNI 3964:2025). Subsequently, the calculation of the number of houses to be sampled is determined as follows:

$$Nr = Sn\,x\,K \qquad \ldots (3)$$

Where Nr denotes the number of houses selected for waste sampling (housing units), Sn represents the proportion of the socioeconomic level of a given area based on secondary data or field observations (%), and K refers to the total number of sampled households (HH), under the assumption that one house corresponds to one household.

Waste sampling was conducted over eight consecutive days at the same households in order to obtain the average waste generation from the residential area. The average waste generation was calculated using the following equation:

$$qr(i) = qi(i)\,x\,n^{-1} \ldots (4)$$

Where qr denotes the average waste generation rate (kg/day), qi represents the amount of waste generated (kg), n refers to the number of sampling days (days), and i indicates the housing category (permanent, semi-permanent, and non-permanent). Subsequently, the per capita waste generation on Kodingareng Lompo Island was calculated using the following equation:

$$Qsrt(i) = qr(i)\ x\ Psrt(i)^{-1} \qquad \ldots (5)$$

Where Qsrt represents the waste generation rate (kg/person/day), qr is the average daily waste generation (kg/day), Psrt is the number of individuals included in the sample (persons), and i refers to the housing category. Subsequently, the total waste generation was estimated using the following equation:

$$\sum srt = Qsrt(i)\ x\ Sn(i)\ x\ Pt \qquad \ldots (6)$$

Where ∑srt denotes the total waste generation (kg/day), Qsrt is the waste generation rate (Kg/person/day), Sn is to the persentage of each housing category (%), Pt indicated the total population (persons), and i refers to the housing category.

According to the Guidelines for National Greenhouse Gas Inventories, waste composition is one the primary factors influencing emissions from solid waste management, as different waste types contain varying amounts of degradable organic carbon and fossil carbon. Understanding the composition of solid waste therefore highly valuable and essential for those responsible for proper solid waste management (Nell et al. 2022). Studies related to the characterization of household solid waste can be defined as the process of sampling, collecting, sorting, and analyzing household solid waste to identify and determine both the overall composition and the composition of individual components such as glass, metal, paper, or plastic within a given area (Nell and Waal, 2020). The detailed composition of waste is calculated using the following equation.

$$Kjs = Bjs(j)\ x\ BBs^{-1}\ x\ 100\% \qquad \ldots (7)$$

Where Kjs denotes the composition by waste type (%), Bjs represents the weight of waste by type (kg), BBs is the total weight of all waste, and j indicates the waste category. The specific and general types of waste referred to in equation (5) are presented in table 1 below.

Table 1: Detailed and general composition of waste types

No.	Detailed Waste Type	General Waste Category
1	Food waste	Organic
2	Garden waste	
3	Wood	
4	Paper/cardboard	Inorganic
5	Plastic-film	
6	Plastic-rigid	
7	Metal	
8	Fabric and textile products	
9	Rubber and leather	
10	Glass	
11	Hazardous waste	Hazardous waste
12	Nappies	Other/residual waste
13	Other waste	

2.2. Waste Generation and Composition in Coastal Area

The methodology for assessing marine debris along the shoreline employed an area-transect approach, following the Marine Debris Monitoring Guidelines issued by the Ministry of Environment and Forestry of the Republic of Indonesia. This method was selected because it provides a representative depiction of the distribution, types, and quantities of debris accumulated in coastal zones. During the assessment, the beach area was divided into several systematically designated transects to ensure comprehensive spatial coverage. All debris found within each transect was subsequently identified, classified, and quantified according to predefined categories. The monitoring focused on debris larger than 2.5 cm, categorized as macro debris, which generally includes plastics, glass, metals, textiles, and other sizable materials. This approach enables researchers to obtain accurate data on the volume and characteristics of coastal debris, thereby supporting the development of more effective marine litter management strategies.

2.3. Waste Sampling Procedure

Waste generation and composition data were obtained from field surveys conducted in both the residential area and the coastal area. The procedure for measuring waste generation and composition data in the residential area of Kodingareng Lompo Island is as follows:

- Distribute labeled plastic bags (R1 to R7) to each sampling location one day prior to collection.
- Record the total number of sampling units.
- On the following day, collect the plastic bags containing the waste.
- Transport all collected waste bags to the measurement site.
- Prepare a box to be used for waste weighing.
- Prepare a weighing scale
- Sequentially empty each sample into the measuring box and record the weight of each individual waste sample.
- Combine all waste samples in the measuring box and record the total weight of the waste.
- Sort the waste according to its composition categories.
- Weigh and record the mass of each waste composition category.

The procedures for measuring waste generation and composition data in the coastal area are as follows:

- Establish a transect area measuring 100 meters in length and 13 meters in width.
- Divide the transect area into five sections, each with a length of 20 meters.
- Subdivide each transect section into sub-transect quadrats measuring 5 square meters and label them TR1 to TR5, which serve as the sampling areas.
- Sieve the collected material using a mesh screen with a 2.5 cm^2 opening size to separate meso and macro waste fractions.
- Collect samples from each sub-transect and remove any sand adhering to the waste.

- Sort and identify the waste, then weigh it according to its composition categories.

Waste sampling and measurement were conducted using a digital weighing scale with a maximum capacity of 40 kg and an accuracy level of 1 gram. Prior to data collection, the scale's accuracy was verified using a reference weight to ensure measurement consistency throughout the sampling period. Waste segregation was performed directly by the research team based on predetermined composition categories in accordance with the study protocol. All sorting and weighing procedures were conducted under direct supervision of the researchers to ensure consistency in classification and measurement. Each measurement result was recorded systematically using structured observation sheets. To ensure data quality and minimize measurement error, all recorded weights were cross-checked immediately after each weighing session. Any discrepancies were re-verified before final data entry. This quality control procedure was applied consistently during the entire sampling period.

2.4. Greenhouse gas (GHG) and Global Warming Potential (GWP)

Municipal solid waste (MSW) is an anthropogenic contributor to GHG emissions generated from landfilling and open burning (Li, 2024). Solid waste management is a cross sectoral issue that significantly affects multiple environmental and socio-economic aspects. The waste sector represents a major anthropogenic source of GHG emissions (Oo et al. 2024). According to the IPCC, an organization established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), its primary objective is to provide scientific information to governments at all levels to support the development of climate policies. The IPCC Guidelines for National Greenhouse gas Inventories offer standardized methodologies for estimating and reporting GHG inventories. This study employs the Tier 1 approach, which utilized default values provided in the IPCC Guidelines, as the required activity data are not yet available.

2.5. Research Conceptual Framework

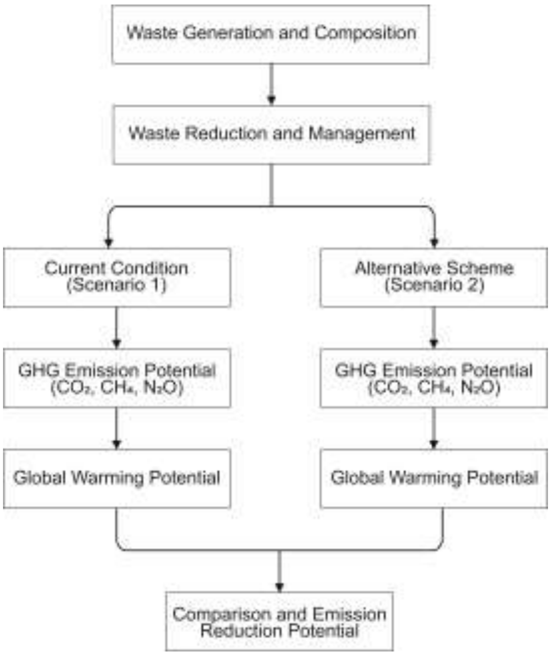


Fig 2: Research conceptual framework

The conceptual framework of this study begins with the identification of waste generation and composition as the basis for determining waste management practices, which are then analyzed under two scenarios: the existing conditions (Scenario 1) and an alternative scheme (Scenario 2). For each scenario, greenhouse gas (GHG) emission potentials (CO_2, CH_4, and N_2O) are calculated and subsequently converted into Global Warming Potential (GWP) values to represent their overall climate impact. The results from both scenarios are then compared to assess the magnitude and potential for emission reduction achieved through the implementation of the alternative waste management system, thereby illustrating the causal relationship between waste management practices and climate change impacts.

3. RESULTS AND DISCUSSION

3.1. Waste Generation and Composition in Residential Areas

SNI 3964:2025 provides options for classifying sample locations based on welfare level, income, electricity connection capacity, and housing type. However, such secondary data were not available from the local government or regional statistical agencies. Therefore, this study utilized secondary data derived from the research conducted by Idrus et al. (2023), which reported that the housing typology on Kodingareng Lompo Island consists of 148 permanent houses (16%), 525 semi-permanent houses (58%), and 232 non-permanent houses (26%). Accordingly, based on Equation (1), combined with population data and housing typology data as secondary sources, the calculation is as follows:

$$\begin{aligned} Ps &= 0.5\sqrt{4977} \\ &= 0.5 \ x \ 70.55 \\ &= 35.23 \text{ (rounded to 35 persons)} \end{aligned}$$

Thus, the total number of individual samples (persons) selected for waste generation measurement is 35 persons. The following table presents the coefficient (Cd) values based on total population size.

Table 2: Cd Coefficient (SNI 3964:2025)

Total Population (persons)	Coefficient Value
≥ 5,000,000	1.5
1,000,000 - < 5,000,000	1
500,000 - < 1,000,000	1
100,000 - < 500,000	0.5
< 100,000	0.5

Subsequently, the number of sampled households (Heads of Household/HH) selected for waste generation measurement was determined in accordance with Equation (2), as follows:

$$\begin{aligned} K &= 35 \ x \ 5^{-1} \\ &= 7 \end{aligned}$$

Thus, the total number of sampled households (HH) selected for waste generation measurement is 7 households. Subsequently, the calculation of the number of houses to be sampled was conducted in accordance with Equation (3), under the assumption that one house corresponds to one household (HH), and integrated with the secondary data on housing typology presented in the following table 3 below.

Table 3: Number of houses as samples

Housing Category	Level Category (Secondary Data)	Number of Sampled Households (HH)	Number of Sampled Houses
Permanent	16%	7	1.14 (rounded to 1)
Semi-permanent	58%	7	4.06 (rounded to 4)
Non-permanent	26%	7	1.79 (rounded to 2)


(a) (b) (c)

Fig 3: Categories of sampled households: (a) permanent, (b) semi-permanent, (c) non-permanent

Fig 4: Sampling points

Table 4: Sampling Coordinate Points

Area	Point	Category	Coordinate Point	
			Latitude	*Longitude*
Residential Area	R1	Semi-permanent	5° 8'55.51"S	119°15'56.96"E
	R2	Semi-permanent	5° 8'44.57"S	119°15'54.55"E
	R3	Permanent	5° 8'49.89"S	119°15'54.11"E
	R4	Semi-permanent	5° 8'57.52"S	119°15'55.17"E
	R5	Semi-permanent	5° 9'0.24"S	119°15'53.35"E
	R6	Non-permanent	5° 8'43.33"S	119°15'51.48"E
	R7	Non-permanent	5° 8'48.30"S	119°15'54.49"E
Coastal Area	P	Beach	5° 9'6.69"S	119°15'50.09"E

The results of waste generation measurements in the residential area of Kodingareng Lompo Island conducted over eight consecutive days, along with the calculated average daily waste generation in accordance with Equation (4), are presented in Table 5. Meanwhile, the per capita waste generation rate (kg/person/day), calculated based on Equation (5), is presented in Table 6.

Table 5: Measurement results and average waste generation in the residential area

Household category	Measurement results (kg)								Total (kg)	Average waste generation (kg/day)
	1	2	3	4	5	6	7	8		
Permanent	3.18	1.99	1.66	1.67	2.90	2.21	1.64	2.25	17.48	2.19
Semi-permanent	3.19	2.36	6.18	3.92	4.12	3.40	5.38	4.21	32.76	4.09
Non-permanent	0.59	0.65	0.89	0.59	0.74	0.81	0.60	0.87	5.72	0.72

Table 6: Waste generation unit

Household category	Total (kg)	Average waste generation (kg/day)	Sample size (persons)	Waste generation rate (kg/person/day)
Permanent	17.48	2.19	5	0.44
Semi-permanent	32.76	4.09	20	0.20
Non-permanent	5.72	0.72	10	0.07

Tables 5 and 6 indicate that waste generation from permanent houses amounted to 17.48 kg (0.44 kg/person/day), semi-permanent houses generated 32.76 kg (0.20 kg/person/day), and non-permanent houses produced 5.72 kg (0.07 kg/person/day). The data further demonstrate that the highest waste generation originated from permanent houses, followed by semi-permanent houses, and the lowest from non-permanent houses. In general, waste generation volume shows a positive correlation with household income levels and the degree of urbanization in a given area (Kaza et al. 2018). Similar findings were reported by Popli et al. (2021), who stated that increasing per capita income is associated with higher waste generation rates. Other studies have also revealed that living standards and waste generation are closely related, whereby higher-income groups tend to generate greater amounts of waste, while lower-income groups produce relatively less waste (Zia et al. 2017). The total waste generation produced in the residential area of Kodingareng Lompo Island, calculated in accordance with Equation (6), is presented in the table below.

Table 7: Total waste generation

Household Category	Waste generation rate (kg/person/day)	Percentage of housing Categories (%)	Population (persons)	Daily waste generation (kg/day)	Annual waste generation (kg/year)
Permanent	0.44	16	4977	347.99	127,017.02
Semi-permanent	0.20	58		590.95	215,698.00
Non-permanent	0.07	26		92.52	33,770.69
Total				**1,031.47**	**376,485.71**

Based on Table 7 above, the total waste generation from the residential area amounts to 1,031.47 kg/day, equivalent to 376,485.71 kg/year. This total comprises 347.99 kg/day (127,017.02 kg/year) from permanent houses, 590.95 kg/day (215,698.00 kg/year) from semi-permanent houses, and 92.52 kg/day (33,770.69 kg/year) from non-permanent houses. The projected waste generation originating from the residential area is presented as follows:

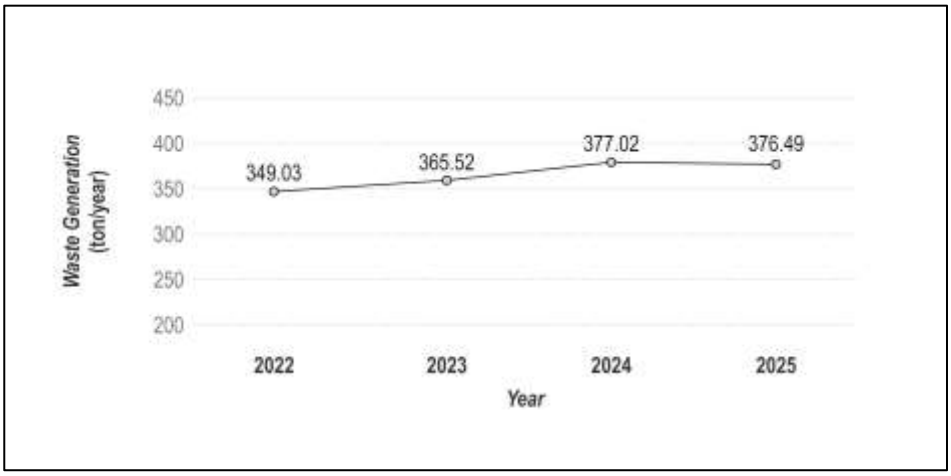


Fig 5: The projected waste generation originating from residential areas on Kodingareng Lompo Island

The figure above illustrates the projected annual waste generation originating from residential areas on Kodingareng Lompo Island for the period 2022–2025. The data reveal a gradual upward trend, beginning at 349.03 tons per year in 2022 and increasing to 365.52 tons per year in 2023. Waste generation continues to rise in 2024, reaching 377.02 tons per year, which represents the highest value within the projection period. In 2025, the projection indicates a slight decline to 376.49 tons per year; however, the overall trend still reflects an increase relative to the baseline year. These fluctuations indicate a steady growth in household waste production.

Waste composition refers to the classification of waste based on its constituent materials or components. This measurement is essential for determining an effective waste management system that aligns with the types or composition of waste and its recycling potential. Detailed data on waste composition, calculated based on Equation (7) is presented in the following table 8 below.

Table 8: Waste composition

No.	Type of waste	Percentage (%)	General waste category
1	Food waste	8.03	Organic 49.60%
2	Garden waste	39.28	
3	Wood	2.29	
4	Paper/cardboard	13.30	Inorganic 31.88%
5	Plastic-film	13.71	
6	Plastic-rigid	4.38	
7	Metal	0.40	
8	Fabric/textile	0.07	
9	Rubber/leather	0.03	
10	Glass	0	
11	Hazardous waste	0	Hazardous waste 0%
12	Nappies	0.39	Other/residual waste 18.51%
13	Other waste	18.12	

The table 8 above shows that garden waste constitutes the largest proportion of waste generated on Kodingareng Lompo Island, accounting for 39.28%. This is followed by other waste at 18.12%, plastic-film at 13.71% and paper/cardboard at 13.30%. Wood waste accounts for 2.29%, while metal waste contributes 0.40%. Fabric/textile and rubber/leather waste represent 0.07% and 0.03%, respectively. No glass or hazardous waste was identified during the study period. In general, organic waste constitutes 49.60% of the total waste generated, followed by inorganic waste at 31.88%, other/residual waste at 18.51%, and hazardous waste at 0%.

Fig 6: Measurement of waste generation in the residential area

3.2. Waste Generation and Composition in Coastal Area

The measurement of waste generation in this study was also conducted in the coastal area. This measurement aimed to identify the quantity and types of waste stranded along the coastline of Kodingareng Lompo Island as a result of marine dynamics, such as currents and wave action. Data on stranded waste in the coastal area were obtained through direct field observation and recording, and subsequently classified according to material type. The results of the measurement and classification of stranded waste along the coast of Kodingareng Lompo Island are presented in detail in Table 5 below.

Table 9: Waste generation in the coastal area

No.	Type of waste	Waste generation (kg)		Average waste Generation (kg/day)	Total waste (kg/year)	Percentage (%)
		Month 1	Month 2			
1	Wood	0.476	0.955	0.024	8.71	7.88
2	Plastic-film	1.881	2.698	0.076	27.86	25.23
3	Plastic-rigid	0.867	0.660	0.025	9.29	8.41
4	Metal	0.015	0.027	0.001	0.26	0.23
5	Fabric/textile	4.041	3.985	0.134	48.82	44.22
6	Glass	0.595	0.680	0.021	7.76	7.02
7	Nappies	0.462	0.560	0.017	6.22	5.63
8	Other waste	0.213	0.037	0.004	1.52	1.38
	Total	**8.55**	**9.602**	**0.303**	**110.42**	**100.00**

Table 9 presents the magnitude of waste generation in the coastal area of Kodingareng Lompo Island based on waste types and observation periods. The total waste generation increased from 8.55 kg in the first month to 9.602 kg in the second month, with an average generation rate of 0.303 kg/day and a total annual accumulation of 110.42 kg/year. In terms of composition, fabric/textile waste constitutes the largest contributor to coastal waste generation, accounting for 44.22% of the total. The next dominant waste type is plastic film, contributing 25.23%, indicating that plastic waste particularly plastic-film, remains a major issue in the coastal area. Other waste types, such as plastic-rigid, wood, glass, and nappies, exhibit relatively smaller quantities but are consistently observed across both monitoring periods. Meanwhile, metal waste shows the lowest contribution, with an average share of only 0.23%, suggesting that this waste type is relatively infrequent at the study site. Overall, these findings indicate that coastal waste generation on Kodingareng Lompo Island is predominantly composed of textile and plastic materials, which may pose significant negative impacts on coastal ecosystems if not properly managed in small island coastal environments. Furthermore, the projected total waste generation from the inland (residential) and coastal areas for the year 2025 is presented as follows.

Table 10: Total waste generation from residential area and coastal area

No.	Type of Waste	Residential area (kg/year)	Coastal area (kg/year)	Total Waste (kg/year)	Percentage (%)
1	Food waste	30,244.00	0	30,244.00	8.03
2	Garden waste	147,889.48	0	147,889.48	39.27
3	Wood	8,612.31	8.71	8,621.01	2.29
4	Paper/cardboard	50,059.04	0	50,059.04	13.29
5	Plastic-film	51,606.57	27.86	51,634.42	13.71
6	Plastic-rigid	16,484.50	9.29	16,493.79	4.38
7	Metal	1,513.88	0.26	1,514.14	0.40
8	Fabric/textile	269.13	48.82	317.96	0.08
9	Rubber/leather	100.93	0	100.93	0.03
10	Glass	0	7.76	7.76	0.002
11	Hazardous waste	0	0	0	0
12	Nappies	1,480.24	6.22	1,486.46	0.39
13	Other waste	68,225.63	1.52	68,227.15	18.12
	Total	**376,485.71**	**110.42**	**376,596.13**	**100.00**

Based on the composition of waste generation on Kodingareng Lompo Island, the total waste generated from residential and coastal areas reaches 376,596.13 kg/year, with the dominant contribution originating from residential areas at 376,485.71 kg/year, while coastal areas contribute 110.42 kg/year. This indicates that waste generation from residential areas remains highly dominant; therefore, waste management strategies should be primarily focused on the reduction and handling of waste generated from residential sources on Kodingareng Lompo Island.

Fig 7: Measurement of waste generation in the coastal area

3.3. Waste Reduction and Management on Kodingareng Lompo Island

3.3.1. Current Conditions (Existing)

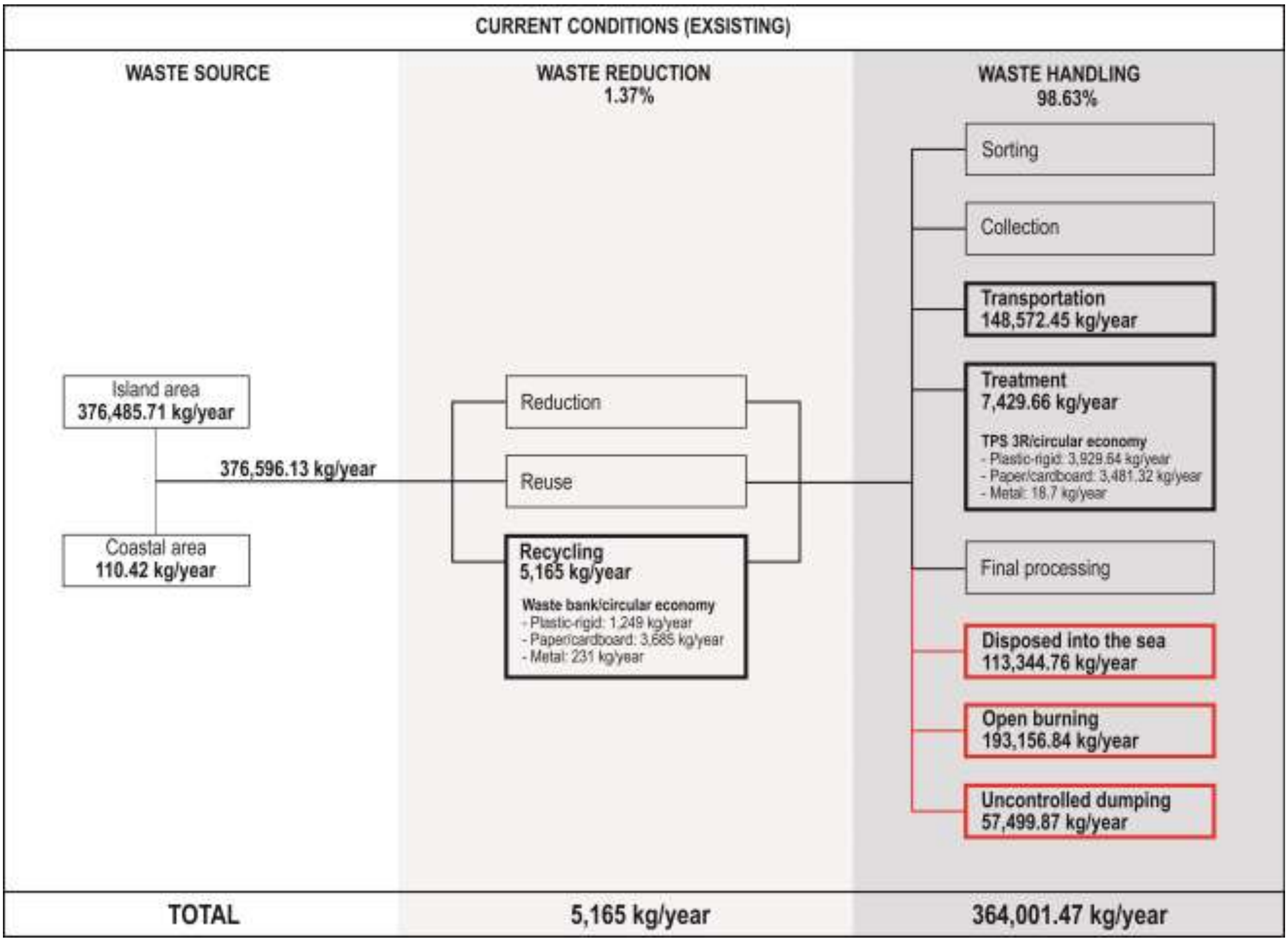


Fig 8: Waste reduction and waste handling under the current conditions

Based on Fig. 8, waste management on Kodingareng Lompo Island remains dominated by end-of-pipe handling rather than source reduction. Of the total annual waste generation of 376,596.13 kg, only 1.37% (5,156 kg/year) is reduced through recycling activities conducted by a single community-managed Waste Bank Unit (BSU) in collaboration with the Central Waste Bank of Makassar City. The remaining 98.63% enters the municipal waste handling system, although community participation is largely limited to informal household-level segregation. Waste segregation infrastructure and temporary storage facilities are absent, and collection services cover only about 40% of total waste using a single three-wheeled collection vehicle. The TPS 3R facility contributes an additional 2% reduction (7,429.66 kg/year), but its operation remains suboptimal due to limited management and funding. As a result, approximately 96.66% (364,001.47 kg/year) of total waste is managed through environmentally unsound practices, including open burning (53.06%), marine disposal (31.14%), and land burial (15.80%), with no organic waste treatment currently implemented on the island.

Table 11: Waste composition resulting from environmentally unsustainable waste management practices

No.	Type of Waste	Open burning (kg/year)	Disposed into the sea (kg/year)	Uncontrolled dumping (kg/year)
1	Food waste	18,146.40	7,561.00	4,536.60
2	Garden waste	88,733.69	36,972/37	22,183.42
3	Wood	5,172.61	2,155.25	1,293.15
4	Paper/cardboard	25,735.63	10,723.18	6,433.91
5	Plastic-film	30,980.65	12,908.61	7,745.16
6	Plastic-rigid	6,789.09	2,828.79	1,697.27
7	Metal	758.66	316.11	189.67
8	Fabric/textile	190.78	79.49	47.69
9	Rubber/leather	60.56	25.23	15.14
10	Glass	4.65	1.94	1.16
11	Hazardous waste	-	-	-
12	Nappies	891.87	371.61	222.97
13	Other waste	15,692.24	39,401.18	13,133.73
	Total	**193,156.84**	**113,344.76**	**57,499.87**

3.3.2. Alternative Scheme

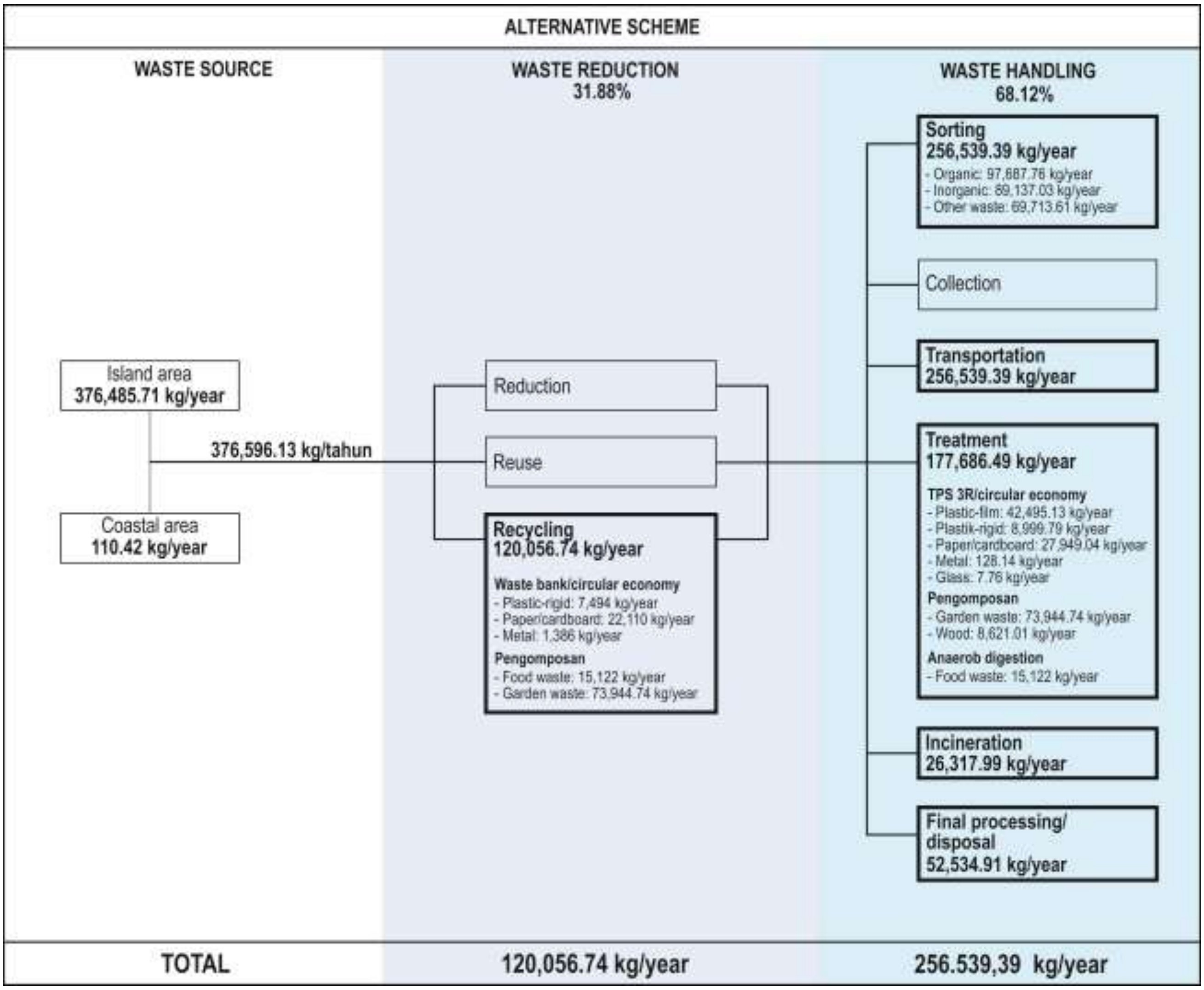


Fig 9: Waste reduction and handling under the alternative scenario

Fig. 9 presents the proposed alternative scenario, which shifts waste management toward a more sustainable and circular approach in line with Law No. 18/2008, emphasizing waste as a resource with economic value. This scenario strengthens source-based management through the expansion of Waste Bank Units (BSU) in each Community Unit (RW), collaboration with the Central Waste Bank of Makassar City, and household-scale composting. Waste reduction is projected to reach 31.88% (120,056.74 kg/year), including 30,990 kg/year from optimized BSU operations and 89,066.74 kg/year from composting, assuming 50% of organic waste is managed at the household level. Environmentally sound waste handling increases to 68.12% (256,539.39 kg/year), significantly reducing open burning, marine disposal, and land burial practices. The system requires mandatory household waste segregation, expansion of collection services from one to three three-wheeled vehicles to ensure full coverage, and centralized processing at the TPS 3R facility with a total capacity of 177,686.49 kg/year. Processing consists of recycling (44.79%), composting (46.47%), anaerobic digestion (8.51%), and controlled incineration for non-recyclable combustible waste (26,317.99 kg/year), while inert residues totaling 52,534.91 kg/year are directed to final disposal.

Overall, the comparison between current conditions and the alternative scenario indicates that the implementation of a waste management system based on source reduction, combined with systematic waste handling from segregation to final processing, has strong potential to reduce environmental burdens caused by unmanaged waste. This alternative scenario is consistent with the targets set out in Presidential Regulation of the Republic of Indonesia No. 97 of 2017. Therefore, the implementation of the alternative scenario not only supports the achievement of national targets but also represents a relevant strategy for small islands, which face land limitations and high vulnerability to environmental, coastal, and marine pollution resulting from unmanaged waste.

(a) (b)

Fig 10: (a) Waste processing at the TPS 3R facility and (b) waste transportation from the island to the Central Waste Bank in Makassar City

3.4. GHG and GWP Potential

3.4.1. Current Conditions (Existing)

3.4.1.1. Carbon dioxide (CO_2) emissions potential from the waste transportation process

Table 12: CO_2 emission potential from waste transportation (existing)

Fuel type	Fuel consumption (TJ)	Emission factor (kg/TJ)	CO_2 Emission (kg)
Gasoline	0.018	69,300	1,243.81

Fuel consumption for waste transportation activities using a three-wheeled motorized vehicle on Kodingareng Lompo Island is recorded at 547.5 liters/year using one vehicle, with an average daily consumption of 1.5 liters/day. The calculation of fuel consumption in energy units (terajoules, TJ) is conducted by multiplying the fuel volume (liters) by the fuel density (0.74) and the Net Calorific Value (NCV) of 44.3 TJ/Gg. Table 8 presents the estimated potential CO_2 emissions generated from the waste transportation process on Kodingareng Lompo Island, which uses gasoline fuel with a total energy consumption of 0.018 TJ. Based on the standard gasoline emission factor of 69,300 kg/TJ, the total CO_2 emissions are estimated at 1,243.81 kg/year. CH_4 and N_2O emissions from transportation are considered negligible and therefore excluded.

3.4.1.2. CO_2 emissions potential from open burning

Open burning of waste can be defined as the combustion of unwanted waste materials of various composition types, conducted in open environments or at open dumping sites, where smoke and other emissions are released directly into the atmosphere without passing through a chimney or exhaust system (IPCC, 2006). The calculation is based on the estimated amount of waste (wet weight) burned, considering the dry matter content (dm), total fossil carbon content (FCF), total carbon fraction (CF), oxidation factor (OF), and the carbon to CO_2 conversion factor (44/12). The resulting CO_2 emission potential is presented in the following table below.

Table 13: CO_2 emission potential from open burning

Type of waste	Total waste-wet weight (kg)	dm (fraction)	CF (fraction)	FCF (fraction)	OF (fraction)	Conversion factor (44/12)	CO_2 Potential (kg)
Paper/cardboard	25,735.63	0.90	0.46	0.01	0.71	3.67	277.40
Plastic-film	30,980.65	1.00	0.75	1.00	0.71	3.67	60,495.22
Plastic-rigid	6,789.09	1.00	0.75	1.00	0.71	3.67	13,256.90
Fabric/textile	190.78	0.80	0.50	0.20	0.71	3.67	39.74
Rubber/leather	60.56	0.84	0.67	0.20	0.71	3.67	17.75
Nappies	891.87	0.40	0.70	0.10	0.71	3.67	65.02
Other waste	15,692.24	0.90	0.03	1.00	0.71	3.67	1,103.11
TOTAL							**75,255.13**

Table 13 presents the estimated CO_2 emissions from open burning on Kodingareng Lompo Island. Plastic waste, particularly plastic-film, contributes the highest emissions at 60,495.22 kg/year due to its large volume, high fossil carbon fraction, and efficient combustion. Plastic-rigid follows with 13,256.90 kg/year, while other waste types contribute 2,877.67 kg/year. Plastics generally produce higher CO_2 emissions during open burning because of their high carbon content and combustion efficiency (Wang et al. 2023). In contrast, paper/cardboard and organic materials such as textiles, rubber, leather, and nappies generate relatively low emissions due to their low fossil carbon content and incomplete combustion. Overall, total potential CO_2 emissions from open burning reach 75,255.13 kg/year, with plastics as the dominant source. Food waste, garden waste, wood, metals, and glass do not contribute to fossil-based CO_2 emissions, as they contain no fossil carbon fraction (FCF), in accordance with IPCC Guidelines.

3.4.1.3. Methane (CH_4) and nitrous oxide (N_2O) emission potential from open burning

CH_4 and N_2O emissions result from incomplete combustion during incineration and open burning processes, in which a significant portion of the carbon contained in the waste is not fully oxidized. These conditions may vary because waste is a heterogeneous and low-quality fuel with diverse calorific values (IPCC, 2006). The potential CH_4 emissions were estimated by multiplying the total mass of waste burned by the open burning emission factors. The potential CH_4 and N_2O emissions are presented as follows.

Table 14: CH_4 and N_2O emission potential from open burning

Type of waste	Emission type	Total waste weight (kg)	Emission Factor (g/t)	Conversion (g/t to kg/kg)	Total emission (kg)
Solid waste	CH_4	192,393.52	6,500	10^{-6}	1,250.56
	N_2O	192,393.52	150	10^{-6}	28.86

The total waste amount was based on the projected quantity subjected to open burning on Kodingareng Lompo Island, excluding metal and glass since these materials contain no carbon fossil and do not produce CH_4 or N_2O emissions. Estimated CH_4 emissions from open burning reach 1,250.56 kg/year, while N_2O emissions amount to 28.86 kg/year. Although N_2O emissions are relatively low compared to CO_2 and CH_4, N_2O has a much higher Global Warming Potential (GWP), 273 times greater than CO_2 (IPCC, 2023).

3.4.1.4. CH_4 emission potential from landfilled waste

One of the primary inputs in this calculation is the amount of decomposable degradable organic carbon (DDOCm) contained in the quantity and composition of disposed waste, such as food waste, paper, wood, textiles, and similar materials. The value of DDOCm is obtained by multiplying the waste generation, the fraction of degradable organic carbon in the waste (DOC), the fraction of degradable organic carbon that decomposes under anaerobic conditions (DOCf), and the portion of waste that decomposes under aerobic conditions, represented by methane correction factor (MCF). The calculated values of DDOCm and the corresponding methane emission potential are presented as follows.

Table 15: The DDOCm values

Type of waste	Waste generation (kg)	DOC (Fraction)	DOCf (Fraction)	MCF (Fraction)	DDOCm (kg)
Food waste	4,536.60	0.15	0.7	0.6	285.81
Garden waste	22,183.42	0.20	0.7	0.6	1,863.41
Wood	1,293.15	0.43	0.1	0.6	33.36
Paper/cardboard	6,433.91	0.40	0.5	0.6	772.07
Fabric/textile	47.69	0.24	0.5	0.6	3.43
Rubber/leather	15.14	0.39	0.5	0.6	1.77
Nappies	222.97	0.24	0.5	0.6	16.05
Total					**2,975.90**

Table 16: CH_4 emission potential from landfilled waste

Type of waste	DDOCm (kg)	F (Fraction)	CH_4/C Ratio (16/12)	CH_4 Potential (kg)
Solid waste	2,975.90	0.5	1.33	1,983.94

The table above shows that the total decomposable degradable organic matter (DDOCm) generated from waste on Kodingareng Lompo Island amounts to 2,975.90 kg, with the largest fraction originating from garden waste. The potential CH_4 formation is calculated by multiplying the DDOCm value by the CH_4 fraction in landfill gas (F) and the molecular weight ratio of CH_4 to C (16/12). The resulting potential CH_4 emissions from the waste disposal process are estimated at 1,983.94 kg/year.

3.4.1.5. Global Warming Potential (GWP) of current conditions (existing)

GWP is a metric used to assess the extent to which a greenhouse gas (GHG) contributes to global warming compared to carbon dioxide (CO_2) as the reference gas, taking into account its radiative efficiency and atmospheric lifetime (IPCC, 2023). The GWP value is obtained by multiplying the potential emissions produced by the GWP factor, which is provided as a default value in the IPCC Sixth Assessment Report (AR6). The GWP results for Scenario 1 are presented in the table below.

Table 17: Result of GWP from current conditions (existing)

Component	Gas	Emission (kg/year)	GWPh	CO_2e Emission (kg/year)
Waste transportation	CO_2	1,243.81	1	1,243.81
Open burning	CO_2	75,255.13	1	75,255.13
Open burning	CH_4	1,250.56	27	33,765.06
Open burning	N_2O	28.86	273	7,878.51
Waste disposal (landfilling)	CH_4	1,983.94	27	53,566.28
Total				**171,708.79**

Based on Table 17, the total Global Warming Potential (GWP) under current waste management practices on Kodingareng Lompo Island is 171,708.79 kg CO_2e/year. Open burning is the main contributor, generating 75,255.13 kg CO_2e/year from CO_2, 33,765.06 kg CO_2e/year from CH_4, and 7,878.51 kg CO_2e/year from N_2O due to its widespread use by residents. Additionally, CH_4 emissions from landfilling contribute 53,566.28 kg CO_2e/year. Overall, open burning is the dominant source of GWP on the island.

3.4.2. Alternative Scheme

3.4.2.1. CO_2 emissions potential from the waste transportation

Table 18: CO_2 emission potential from waste transportation (alternative)

Fuel type	Fuel consumption (TJ)	Emission factor (kg/TJ)	CO_2 Emission (kg)
Gasoline	0.054	69,300	3,731.42

Fuel consumption for waste transportation activities using three-wheeled motorized vehicles on Kodingareng Lompo Island is estimated at 1,642.5 liters/year, utilizing three vehicle units to accommodate waste collection based on the calculated waste generation results. This corresponds to an energy consumption of 0.054 TJ. Accordingly, the estimated CO_2 emission potential amounts to 3,731.42 kg/year.

3.4.2.2. CH_4 and N_2O emission potential from biological treatment

Biological treatment through composting and anaerobic digestion of organic waste is a common practice implemented in various countries. The benefits of these treatment methods include waste volume reduction and the production of biogas as a renewable energy source. In addition, the final products can be recycled as compost fertilizer or disposed of at landfill sites (IPCC, 2006). The emission values of CH_4 and N_2O are obtained by multiplying the amount of organic waste composted (kg) by the respective emission factors (g/kg). The resulting emission potentials are presented in the following table.

Table 19: CH_4 and N_2O emissions from biological waste treatment

Biological treatment	Emission type	Treated Organic Waste (kg)	Emission factor (g/kg)	Conversion (g to kg)	Total Emission (kg)
Composting	CH_4	171,632.50	4	0.001	686.53
	N_2O	171,632.50	0.24	0.001	41.19
Anaerobic digestion	CH_4	15,122.00	0.8	0.001	12.10

Table 19 shows the estimated CH_4 and N_2O emissions from biological waste treatment on Kodingareng Lompo Island, including composting and anaerobic digestion. Composting treats 171,632.50 kg/year of organic waste (food, garden waste, and wood waste), producing 686.53 kg/year of CH_4 and 41.19 kg/year of N_2O. Anaerobic digestion processes 15,122.00 kg/year of food waste, generating 12.10 kg/year of CH_4, while N_2O emissions are considered negligible and excluded from the calculation.

3.4.2.3. CO_2 emission potential from controlled incineration

The estimation of CO_2 emission potential from waste incineration follows a similar principle to that of open burning. The main distinction between these two processes lies in the oxidation factor (OF). According to the IPCC guidelines, when waste is combusted either in an incinerator or through open burning, most of the carbon contained in the combustion products is oxidized to CO_2. However, in the case of waste incineration, the combustion efficiency is assumed to be nearly 100 percent, whereas open burning typically exhibits substantially lower efficiency. The calculated potential CO_2 emissions from waste incineration are presented in the following table.

Table 20: CO_2 emission potential from controlled incineration

Type of waste	Total waste-wet weight (kg)	dm (fraction)	CF (fraction)	FCF (fraction)	OF (fraction)	Conversion factor (44/12)	CO_2 Potential (kg)
Plastic-film	9,139.29	1.00	0.75	1.00	1	3.67	25,133.05
Nappies	1,486.46	0.40	0.70	0.10	1	3.67	152.61
Other waste	15,692.24	0.90	0.03	1.00	1	3.67	1,553.53
TOTAL							**26,839.20**

Based on the calculation results, the total potential CO_2 emissions from the incineration process amount to 26,839.20 kg/year. Controlled incineration is applied to specific waste types, particularly plastic films that are difficult to recycle, nappies (diapers), and other combustible waste such as foam or styrofoam materials. Plastic films contribute the highest emissions, reaching 25,133.05 kg/year, even though other waste fractions are incinerated in larger quantities. This is attributable to their high dry matter content (dm), carbon content (CF), and fossil carbon fraction, which significantly influence CO_2 emission levels.

3.4.2.4. CH_4 and N_2O emission potential from controlled incineration

Table 21: CH_4 and N_2O emission potential from controlled incineration

Type of waste	Emission type	Total waste weight (kg)	Emission factor (g/t)	Conversion (g/t to kg/kg)	Total emission (kg)
Solid waste	CH_4	26,317.99	60	10^{-6}	1.58
	N_2O	26,317.99	56	10^{-6}	1.47

CH_4 emissions from solid waste incineration are estimated at 1.58 kg/year, while N_2O emissions reach 1.47 kg/year, both significantly lower than CO_2 emissions from the same process. This is due to the high combustion efficiency and operating temperatures of the incinerator, which promote near-complete carbon oxidation to CO_2. As a result, CH_4 and N_2O formation is minimal and negligible compared to total greenhouse gas emissions (IPCC, 2019).

3.4.2.5. Global Warming Potential (GWP) of alternative scheme

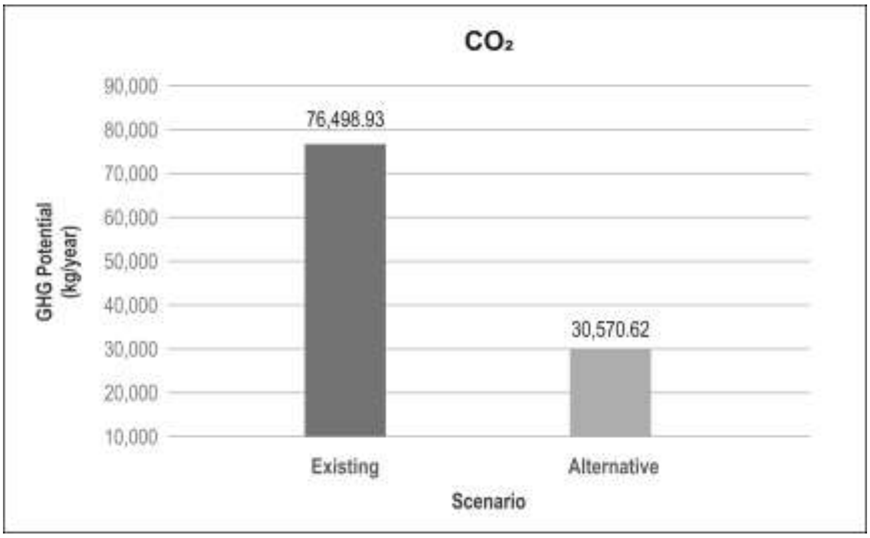
Table 22: GWP of the alternative waste management scenario

Component	Gas	Emission	GWPh	CO_2e Emission

		(kg/year)		**(kg/year)**
Waste transportation	CO_2	3,731.42	1	3,731.42
Composting	CH_4	686.53	27	18,536.31
Composting	N_2O	41.19	273	11,245.36
Anaerobic digestion	CH_4	12.10	27	326.64
Controlled incineration	CO_2	26,839.20	1	26,839.20
Controlled incineration	CH_4	1.58	27	42.64
Controlled incineration	N_2O	1.47	273	402.35
	Total			**61,123.91**

Table 22 shows that total GWP under the alternative waste management scheme reaches 61,123.91 kg CO_2e/year. The largest contribution comes from controlled incineration, particularly CO_2 emissions (26,839.20 kg CO_2e/year), followed by composting, which generates significant CH_4 (18,340.33 kg CO_2e/year) and N_2O emissions (11,126.47 kg CO_2e/year) due to their high GWP values. Waste transportation contributes 3,731.42 kg CO_2e/year, while anaerobic digestion accounts for a relatively small share at 365.64 kg CO_2e/year.

3.5. Comparison of GHG Emissions Potential and GWP



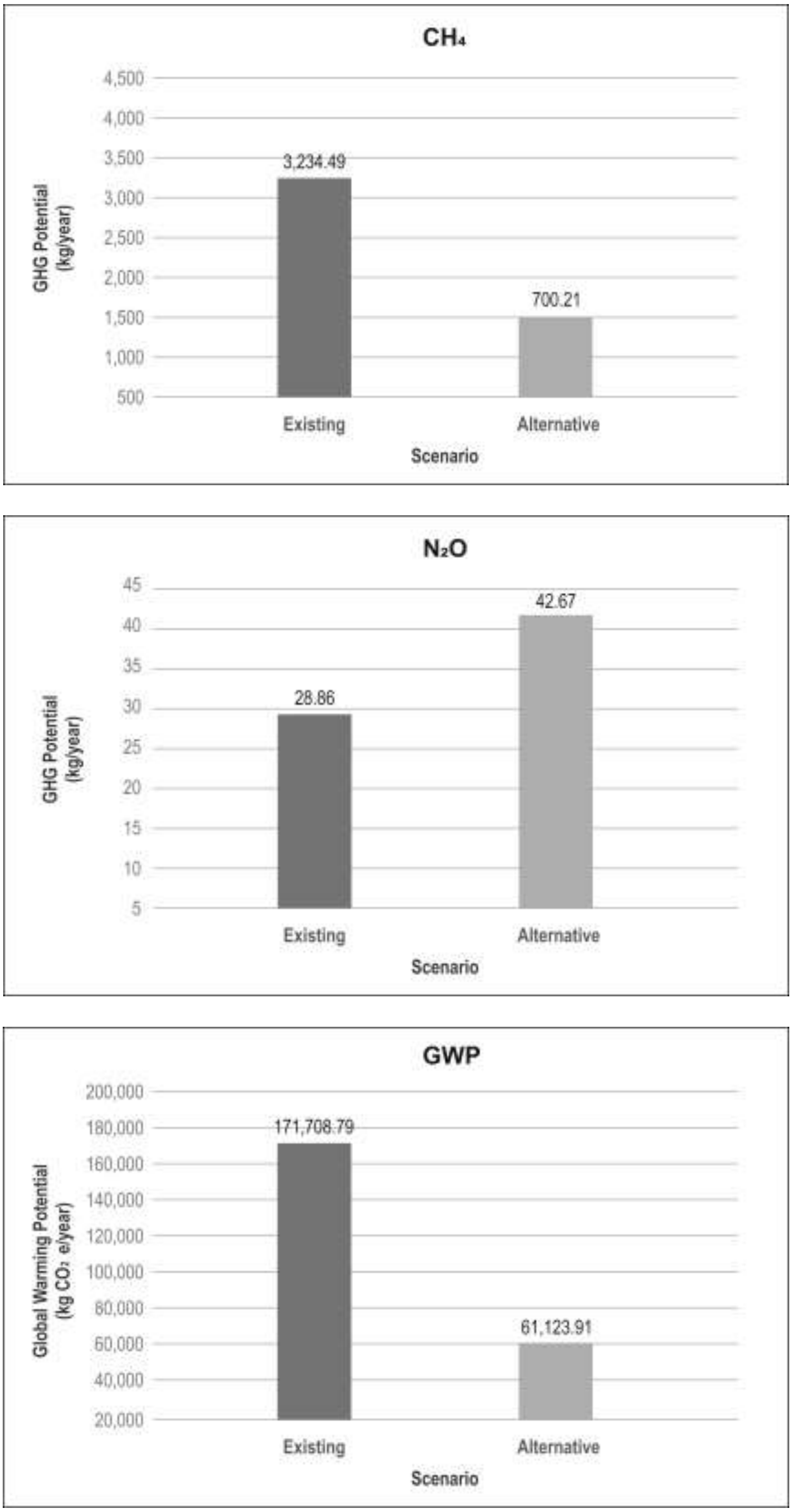


Fig 11: Comparison of GHG emissions potential and GWP under current conditions and the alternative scheme

The comparison between existing and alternative scenarios clearly demonstrates that emission reductions are primarily driven by structural changes in waste management practices rather than marginal technical adjustments. Under current conditions, high CO_2 emissions (76,498.93 kg/year) reflect the systemic reliance on open burning, which remains the dominant disposal method due to limited service coverage and infrastructure constraints. The 60.04% reduction in CO_2 emissions under the alternative scheme confirms that shifting from uncontrolled combustion to regulated treatment significantly lowers carbon emissions, particularly from plastic waste streams.

Methane (CH_4) emissions show an even more substantial decline (78.35%), indicating that reducing landfilling and eliminating open burning are highly effective mitigation strategies. Since CH_4 has a much higher Global Warming Potential than CO_2, this reduction plays a decisive role in lowering overall GWP. Although the alternative scenario introduces biological treatment processes that generate some CH_4 and N_2O emissions, these remain considerably lower than emissions produced under uncontrolled disposal systems. The slight increase in N_2O emissions (47.84%) reflects expanded composting activities; however, this trade-off is offset by the significant decrease in methane emissions, resulting in a net climate benefit.

The overall GWP reduction of 64.40% highlights that the dominant emission sources in small island contexts are closely linked to informal and environmentally unsound practices. Open burning and unmanaged disposal not only generate direct emissions but also reflect institutional and infrastructural gaps. Consistent with previous findings (Zhang et al. 2024; Iqbal et al. 2023), the integration of controlled incineration and biological treatment within a structured waste management system offers a more climate-efficient pathway compared to reliance on open dumping and burning.

These findings imply that emission mitigation in small island environments requires systemic intervention, including mandatory source segregation, expansion of collection services, and institutional strengthening. Without addressing these structural constraints, technological alternatives alone will not achieve substantial emission reductions. Therefore, the proposed alternative scheme represents not merely a technical improvement but a governance and behavioral transformation necessary to transition toward a low-carbon and sustainable waste management system.

4. CONCLUSIONS

The research findings indicate that open burning remains the dominant waste management practice on Kodingareng Lompo Island and constitutes the largest contributor to total Global Warming Potential (GWP). This dominance is closely associated with the limited coverage of waste collection services, inadequate supporting infrastructure, and the absence of a structured household-level waste segregation system. With transportation services covering only a portion of total waste generation and the lack of adequate temporary storage facilities, residents tend to rely on open burning as a practical and rapid disposal method. Similar findings were reported by Gómez-Sanabria et al. (2022), who highlighted that the absence of reliable waste management systems often leads communities to resort to open dumping and burning as alternative solutions. Furthermore, Hajam et al. (2023) emphasized that in many developing countries, waste is commonly landfilled, openly burned, or indiscriminately disposed of without adequate consideration of its environmental and public health impacts.

From a socio-economic perspective, the persistence of open burning practices is influenced by limited operational funding, a shortage of technical personnel, and weak economic incentives for waste segregation. Although Waste Bank Units (BSU) and TPS 3R facilities are available, their limited operational capacity constrains their effectiveness in reducing environmentally unsustainable waste management practices. Community participation in recycling activities is further hindered by suboptimal collection services and the relatively low economic value of recyclable materials. These conditions underscore the need to strengthen institutional capacity, enhance community engagement, and improve infrastructure in order to achieve a more sustainable waste management system on Kodingareng Lompo Island. Factors such as public awareness, education, infrastructure availability, waste composition, and behavioral patterns represent significant barriers to effective waste management. Therefore, future strategies should prioritize waste reduction through recycling, the adoption of circular economy principles, and strengthened community participation, as also suggested by Zhang et al. (2024).

The proposed alternative scenario demonstrates a significant reduction in total GWP compared to existing conditions, indicating that source-based waste management and the implementation of circular economy principles hold substantial potential for emission mitigation. However, successful implementation depends not only on technical feasibility but also on institutional strengthening and sustainable financing mechanisms. Although a comprehensive cost–benefit analysis falls beyond the scope of this study, the expansion of waste bank units, increased revenue from recycling activities, and the reduction of environmental externalities suggest promising long-term economic feasibility.

Overall, the findings affirm that emission mitigation in small island regions requires an integrated approach encompassing infrastructure development, behavioral change, policy reinforcement, and the provision of economic incentives. Without addressing fundamental socio-economic and institutional constraints, environmentally harmful practices such as open burning are likely to persist despite the availability of technically viable alternatives.

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