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Original Research

Waste Management Strategy as an Effort to Reduce Emissions Due to Open Waste Burning: Demak Regency Case Study

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Abstract

Waste management services in the Demak Regency only reached 35% in 2021, resulting in those without waste management services using outdated waste disposal methods such as littering, river dumping, hoarding, and open waste burning. Open waste burning activities are dangerous to the environment because they produce greenhouse gas (GHG) emissions, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), causing extreme climate change that affects land productivity. This study aims to develop a waste management plan to reduce emissions from open waste burning in the Demak Regency. A transect walk survey determined the waste burning point and the burned waste composition. IPCC 2006 is the basis for calculating emissions and determining emission-reduction strategies using the analytical hierarchy process (AHP). As a result, the projection of open burning of waste in the Demak Regency increases the amount of waste in open burning every year. In 2022, the projected emissions from open burning activities amounted to 48.69 Gg/year, and in 2031 to 55.08 Gg/year. After waste management, the emission rate due to open burning activities in 2022 will be 27.87 Gg/year, and in 2031 will be 31.53 Gg/year. There is a considerable decrease of 42.76%. Therefore, there is excellent potential for emissions reduction through improved waste management.

Keywords: waste management, open waste burning, GHG emissions, Demak Regency, transect walk

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Introduction

Environmental problems are among the key issues in Indonesia. Air pollution is a major environmental problem. Based on Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management, air pollution is defined as the entry or inclusion of substances, energy, and other components into the ambient air by human activities, such that it exceeds the established ambient air quality standards. One air pollution source is open waste burning. Open waste burning is material combustion that produces a product emitted directly into the ambient environment or surrounding air without passing through layers, channels, or chimneys [1]. Open waste burning activities occur because of an inadequate waste management system [2].

The Demak Regency's waste management is mainly conducted at temporary dumpsites, reduce, reuse, and recycle (3Rs) waste management sites, and integrated waste management sites. However, some areas in the Demak Regency still require waste services [3]. The waste service level in Demak Regency in 2021 only reached 35% of the population, due to the non-functioning of nine integrated waste management sites and four 3Rs waste management sites [4]. Consequently, some residents manage their waste by open burning in fields or yards, burial, or indiscriminate disposal [5]. Open waste burning produces carbon monoxide (CO), carbon dioxide (CO2), hydrocarbon (HC), and nitrous oxide (NOx) emissions. CO2, methane (CH4), ozone (O3), nitrous oxide (N2O), methyl chloride, and water vapor are greenhouse gasses (GHGs) [6, 7]. GHGs are atmospheric gasses that absorb and release infrared radiation. GHG accumulation side effects can cause extreme climate change, which affects land productivity [8, 9]. Thus, open waste burning contributes significantly to air pollution [10]. Besides that, based on Law Number 18 of 2008 concerning Waste Management, in Chapter x regarding prohibitions, Article 29, point F, states that individuals are prohibited from burning waste that does not meet waste management technical requirements [11], showing that burning waste that is not based on waste management technical requirements violates laws and regulations.

Given its significant negative impact, the low percentage of waste service level must be addressed immediately. In addition, there needs to be more research on repairing and improving the waste management system in the Demak district. Therefore, this research aims to provide a solution to waste management, planning to reduce emissions from the open burning of waste in the Demak District. Integrated waste management planning by improving operational and technical aspects, ranging from segregation, transportation, and processing to estimating the amount of waste entering the landfill, regulation, institutional, financial, investment, and community participation is tested to determine its feasibility in reducing GHG emissions. The transect walk is used as a method to determine the waste burning point, amount of waste burned, and combustion tests using an incinerator to determine waste combustion emissions. This method allows researchers to collect information across a specific spatial gradient or along a representative path, helping to understand patterns, relationships, and variations in the area under study [12]. The IPCC 2006 is the basis for calculating emissions and determining emission reduction strategies using an analytical hierarchy process (AHP) [13]. Waste management is a complex problem with various criteria and alternatives, making it suitable for AHP analysis.

Materials and Methods

Data Collection

Location Determination

This study used data obtained from field sampling. The required samples were related to open waste burning activities conducted by communities in the Demak Regency. The sample locations were determined before sampling. The Demak Regency, which consists of 14 subdistricts and 249 villages, was grouped using cluster analysis. Cluster analysis is a technique for grouping several objects (in this case, urban villages) into groups based on their characteristics [14]. The subdistricts in the Demak Regency were classified into four clusters according to their similarities: rural, outer peri-urban, inner peri-urban, and urban. Data from the Demak Regency Central Bureau of Statistics and other sources were used in the classification process. The data variables included topography, land use, population density, public facilities, accessibility, activity intensity, and economic structure.

Transect Walk

Once the sampling location was determined, a survey was conducted using the transect walk method. A transect walk is a survey method performed along a predetermined road route [12]. Effective and efficient implementation of the transect walk method begins by determining the route at each location. The route was created randomly by forming a loop or straight line along 10 km in each village. This route was made through the main roads and residential areas at the location. The route will not pass through the same road repeatedly, or even if the road is passed more than once, it will still be counted only once. The route was created using the Google Earth application, with the map as a guide. Every time a garbage pile was found along the route, the garbage pile location geographical coordinates were recorded. In addition, a digital photograph of the waste pile, along with its dimensions, were recorded.

The survey was conducted in two stages. The first stage of the survey was conducted in the morning and afternoon, indicating that there are frequent open waste burning activities during this period. The map marker application marks open burning points along the transect walking route. The first step was to estimate the open waste burning point distance from the road and conduct a brief interview with the residents who were burning waste. Brief interviews were conducted to obtain information related to the reasons and objectives of residents who practiced waste burning, and to determine the waste burning intensity. In addition, the conditions at each open waste burning point were recorded: whether the garbage pile had completely burned, was burning, half-burned, or not. A few days later, during the survey second phase, the transect walk was repeated along the identical route [15]. This was conducted to check whether there was any recent activity at the previously found open waste burning points, or whether new open waste burning points would be found. One of the open waste burning points found in the villages was taken as a sample to determine the waste composition in the Demak Regency.

Data Processing and Analysis Technique

Data in this study were obtained from surveys and direct interviews in the field, which were then processed, descriptively evaluated and analyzed. Secondary data were obtained from the local agencies; the Demak Regency Central Bureau of Statistics for location maps, population data, demographic and monographic area conditions, and an overview of the general conditions; and the Environmental Agency for data on existing waste management conditions, air pollution regulations, and waste generation and composition.

Clustering determination involves data processing and analysis using SPSS, because the data come from various units. K-means clustering must meet two criteria, the first being regression analysis [16]. Regression analysis in statistics is a method used to determine the causal relationship between one variable and another, where the regression VIF value must be < 10 [17]. The second is to conduct KMO and Bartlett's tests, where the KMO value must range between 0.5–1 while the Bartlett's test significance value must be 0 [18]. Standardized data can be entered into a cluster if they meet the requirements. Using SPSS, the results were obtained in the form of cluster members, distances between clusters, and distances between cluster members and the cluster center. The smaller the distance between cluster members, the closer and more valid the cluster [19].

Based on primary and secondary data collection related to waste generation and open waste burning activities, a waste management process flow/chain was obtained or created for the Demak Regency informal sector. The waste management process flow was developed using the material flow analysis (MFA) method, assisted by substance flow analysis (STAN) software. STAN is software developed to apply the MFA method using the ONORM S 2096 standard with applications in waste management [20]. [21] noted that emissions generated from open waste burning activities can be analyzed using the IPCC. The IPCC was used to enter waste management related data obtained from a transect walk survey [22, 23]. Specific data related to open waste burning activities occurring in the field through transect walks were then processed and analyzed with Microsoft Excel using a predetermined emission calculation formula to obtain emission calculations generated from open waste burning activities.

The analytical hierarchy process (AHP) ranks decision alternatives and chooses the best one based on several criteria [24]. [13] noted that the AHP method develops a numerical value to rank each decision alternative based on the extent to which each alternative meets the decision-making criteria. The AHP method was applied using an Expert Choice application. The Expert Choice application facilitates analysis using the AHP method [25] to form a hierarchy for determining emission reduction policies. The values were entered into the application by clicking on the pairwise numerical comparison toolbar according to the respondents' completed questionnaires. After respondents' answers were entered, the determination value of potential emission reduction policies was obtained [13, 26].

Emissions from Open Waste Burning

Refuse open waste burning releases CO_2, CH_4, and N_2O [27]. The amount of waste burned in the open space was measured before calculating emissions from the process. The data used to calculate the percentage of waste burned using the 2006 IPCC Guideline default number of 0.6 included the annual number of residents, waste management distribution by burning, waste production, and percentage of waste burned. Equations can be used to determine the carbon emissions produced by open waste burning [28-30]. The amount of open waste burned was calculated by multiplying the total population of Demak City by the fraction of the population that carried out open burning and the fraction of waste burned by the amount of waste processed [28].

Meanwhile, the CO_2 emissions were multiplied by the total weight of the burned waste or the result of multiplying waste burned with waste composition (%) (Gg/y) and the dry matter content, with the dry matter carbon fraction, the fossil carbon fraction in total carbon, the oxidation factor (fraction), 44/12 (the C to CO_2 conversion factor), and the waste type [29]. Total CH_4 emissions were calculated from the burned waste weight multiplied by the CH_4 correction factor, and N_2O emissions were multiplied by the correction factor [30, 31]. The correction factors for CH_4 and N_2O were 6,500 kg CH_4/Gg waste and 150 kg N_2O/Gg waste, respectively [32].

Result and Discussion

Current MSWM Status

Waste generation is the amount of waste generated by the community in units of volume and weight per capita daily, building area, or road length [33]. Waste generation data contain the amount of waste generated by the community from the source (home) in units annually. Waste generation data must be understood to understand waste management flow in the Demak Regency. Information on garbage production in the Demak Regency is provided by Fig. 1.

To calculate GHG emissions, emissions from open waste burning activities were calculated based on the type of waste managed. Based on data from the Demak Regency Environmental Agency, the amount of waste transported to the landfill was 175,210,295 tons/y, and the amount of unmanaged waste was 88,456,071 tons/y. The waste management percentage distribution in the Demak Regency in 2021 is shown in Fig. 2.

During the transect walk, visual observations were made to determine burned waste composition. After all waste samples were sorted and grouped according to type, the waste composition and pile density of

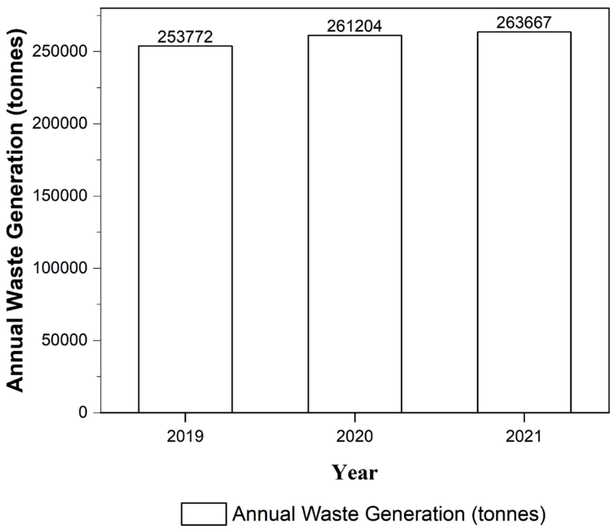

Fig. 1. Total waste generation in Demak Regency.

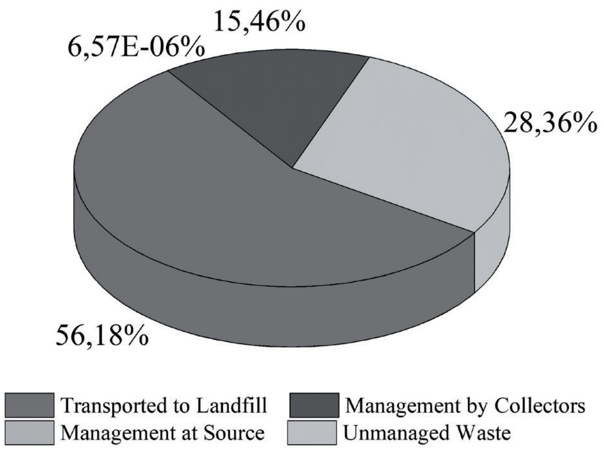

Fig. 2. Demak Regency waste management distribution.

each neighborhood in each cluster was obtained. Leaf composition dominated open waste burning samples in each urban village. Leaves dominated Cluster 1 by 52.3%, Cluster 2 by 50.6%, and Cluster 3 by 66.3%. In Cluster 4, 30.2% of the leaves were burned, followed by branches and twigs at 36.1%. The least burned waste types in each cluster were metal, rubber, and glass. The total sample of waste burned in the Demak Regency obtained from the transect walk survey amounted to 25,246.25 g, where leaves were the main waste burned and accounted for 49.29%. Branch and twig waste were the second-largest contributors (29.62 %), as shown in Table 1.

Pile densities generated from the transect walk survey in each village showed average pile densities in clusters 1-4 of 0.52, 0.25, 0.11 and 0.15 tons/km^2, respectively. Although all clusters were in the same area, significant differences in geographical boundaries, economic activities, and lifestyles resulted in differences in waste density and composition.

Open Waste Burning GHG Emission Project

Total GHG Emissions

GHG emission calculation using IPCC 2006 Chapter 5: Incineration and waste open burning guidelines use the tier 2 accuracy method which is based on specific waste generation, composition, and management practice data. Based on the calculations that were carried out, the GHG emission inventory results from open burning activities in the Demak Regency were obtained. In 2021, it accumulated to 16.81 Gg CO_2-eq/y. The high open burning activity in the Demak Regency is proportional to the high GHG emissions produced. GHG emission calculation generated from open waste burning activities in the Demak Regency is shown in Table 2.

Air Pollution Modelling

Based on open waste burning points and emissions obtained from the transect walk, air pollution modeling was conducted in each village to determine emission distribution generated from open waste burning activities. ArcGIS was used to determine emission numbers in areas not transected during the walk survey [34]. Modeling of N_2O air pollution shows the N_2O emissions in Bintoro Village. Most areas in this village are green, which means that the air quality is still healthy and safe when people perform outdoor activities. However, continued open waste burning can harm the environment and human health. CH_4 air pollution modeling revealed the amount of CH_4 emissions in the Bintoro Village area. CH_4 air pollution conditions remain safe and healthy, however, if open waste burning activities continue, they will potentially affect human health and the environment [35].

Emission Reduction Strategy Planning

The AHP method was used to determine open waste burning emission reduction strategies in the Demak Regency. Emission reduction efforts are based on existing waste management and processing conditions [36]. Inadequate facilities and infrastructure, an incorrect mindset in managing waste, and minimal public awareness of environmental cleanliness and health have increased the percentage of people who burn waste.

Based on these considerations, efforts should be made to reduce emissions through educational approaches. This countermeasure can be implemented by providing various kinds of knowledge about the environment to improve understanding and change behaviors [37]. Some approaches can be implemented by providing socialization regarding waste and the environmental impact of burning waste, as well as education regarding

Table 1. Waste composition of Demak Regency.

Composition	Demak Regency	
	Weight (gram)	%
Food Waste	140.33	0.53
Branch and Twig	7,273.15	29.63
Paper and cardboard	934.27	3.67
Plastic	3,460.5	13.95
Metal	57	0.25
Textiles	455	1.99
Rubber	11	0.05
Glass	151	0.54
Leaves	12,741.29	49.29
Hazardous waste	22.67	0.09
Others	0	0
Total	25,246.25	100

applying the 3Rs in everyday life within the community [38, 39]. This approach can be implemented by various parties such as the government, environmental activists, researchers, or institutions engaged in the environment. Law No.18 of 2008 concerning waste management Chapter X, Article 29, paragraph 1, point (g), states that everyone is prohibited from burning waste that does not meet the technical requirements of solids. This implies that a binding regulation or legal basis exists wherein people should not burn waste openly. However, this regulation needs to be properly implemented. Thus, it is necessary to impose strict sanctions on the community so that incorrect forms of waste management activities can be minimized or even eliminated.

Providing waste facilities in an area is necessary to support this change. The main facility was a container or temporary dumpsite. The field observation results showed that several areas still require temporary dumpsites; therefore, there is a need for additional container facilities to accommodate waste. In addition, providing retribution services with a consistent transportation schedule is necessary to ensure that waste is transported properly. Related agencies such as the Demak Regency Environmental Agency can provide this waste service. Implementation of a community involvement 3Rs/simple recycling culture, an important factor in emission reduction from open waste burning, reduces or emphasizes the amount of waste generated from the source [40]. To personally avoid reusing and reducing efforts, other processing strategies can be implemented, such as creating a Waste Bank in each village.

Waste Management Treatment

Centralized Open Waste Burning Design

The community conducts waste management by burning to quickly eliminate waste generated. Open burning activities conducted by the community and the resulting emissions can endanger human health [41]. Centralized open waste burning in the Demak Regency was designed as an effort by the community to reduce open waste burning activities. The regulation on the ban on burning waste in households has been launched by the government in Law Number 18 of 2008 concerning Waste Management, in Chapter X regarding prohibitions, Article 29 point F, which states that every person is prohibited from burning waste that does not meet the technical requirements of waste management [11]. However, in practice, the enforcement of this

Table 2. Total GHG emission calculation for open waste burning.

Year	MSWb	CO_2 emissions	CH_4 emissions		N_2O emissions		Black Carbon
		Gg CO_2	Gg CH_4	Gg CO_2-eq	Gg N_2O	Gg CO_2-eq	Gg CO_2-eq
2021	29.97	11.33	0.19	4.09	0.004	1.39	31.17
2022	30.42	11.49	0.20	4.15	0.005	1.41	31.64
2023	30.86	12.08	0.20	4.21	0.005	1.44	32.10
2024	31.30	11.83	0.20	4.27	0.005	1.46	32.56
2025	31.75	12.00	0.21	4.33	0.005	1.48	33.02
2026	32.19	12.16	0.21	4.39	0.005	1.50	33.48
2027	32.63	12.33	0.21	4.45	0.005	1.52	33.94
2028	33.08	12.50	0.22	4.52	0.005	1.54	34.40
2029	33.52	12.66	0.22	4.58	0.005	1.56	34.86
2030	33.96	12.83	0.22	4.64	0.005	1.58	35.32
2031	34.41	13.00	0.22	4.70	0.005	1.60	35.78

prohibition has yet to be thoroughly carried out, given the lack of adequate infrastructure in Demak Regency to manage waste, such as an efficient waste collection and processing system. As a result, some people may feel that they have no other option but to burn their waste. The community still needs to be better educated regarding the importance of enforcing this ban. Therefore, there is a need for increased law enforcement, campaigns that educate the public on the negative impacts of burning waste, and improvements to waste management infrastructure through more environmentally friendly alternatives, such as centralized burning.

Centralized burning is implemented using a waste burner designed according to waste management needs. The waste burner was designed to overcome the limited waste management services coverage in the Demak Regency, which is only 35%. With centralized open waste burning, communities are no longer exposed to emissions from direct waste combustion. The waste burner is designed with emission control devices such that the emissions generated from burning waste with the device are not harmful [42]. This tool must be able to burn waste completely and exhaust the waste that enters the waste incinerator. Complete combustion is related to the amount of oxygen entering the chamber and determines the first combustion [43].

The design of a waste combustion device begins by determining the design parameters. Required parameters are: combustion chamber volume, amount of air required for combustion, type and amount of waste to be burned [44]. Installing the designed waste combustion device is an urban waste management system, especially in settlements in the Demak Regency. Domestic waste includes paper, dry leaves, twigs, wood, and plastic solid waste. The expected combustion processes are complete combustion and combustion. The designed waste burner refers to a design constructed by PT Sankyo, which has a combustion chamber with combustion capacity, namely, if the waste mixture comprises 50% wet and 50% dry, that is, 80-160 kg/h, the maximum waste burned is 3,840 kg/24 h at a temperature of 600-900ºC, while a waste mixture (25% wet and 75% dry) is 80-210 kg/h and the waste maximum burning is 5,040 kg/24 h. Waste managed by burning is residual waste that has gone through previous sorting at the integrated waste management site.

Materials used in the design of this waste incinerator included SK-34 refractory bricks [45], fiber ceramics, iron structures of at least 6 mm thickness, iron plates of at least 3 mm thickness, and rubber-resistant iron chimneys.

Further specifications are dimensions of width (1,080 mm) × length (2,100 mm) × height (1,670 mm), chimney height from the floor 8,000 mm, foundation 2 x 2.7 m, controlled air combustion system, and two combustion chambers, total weight 4,000 kg, that can operate for 24 h continuously. These waste combustion devices are placed at an integrated waste management site in areas where there is no waste service. Waste incineration equipment is placed far from residential areas but can still be reached so that waste burners can be centrally managed, and residents are not directly exposed.

This waste incinerator is used for non- B3 household waste and has the advantages of a simple and practical design with a controlled air system [46], and continuous burning at high temperatures, which only uses waste as fuel. It requires only fuel, electricity, gas, or oil when operating, and is designed and manufactured with the correct engineering to control the combustion chamber airflow and heat power to burn waste, smoke, odors, and gasses, without complicated engines or electrical systems.

The operating procedure is simple, namely: dry waste enters the combustion chamber through the sliding door (feeding door), and a gas or wood match is used to ignite the dry waste through the bottom door (cleaning door). Dry waste is added gradually until the room temperature reaches more than 600ºC, measured through the monitoring hole using a Thermogun. The quality of air released from the chimney meets the quality standards following Permen LHK No. P70 of 2016 and the incinerator has been registered as an environmentally friendly technology from the Ministry of Environment and Forestry of the Republic of Indonesia. In addition, the burned waste shrinks to 2-4% ash. For example, a ton of waste becomes 20-40 kg of ash. This ash can be used as an additional material for creating paving blocks [47].

Expert Choice Result Analysis

The AHP method was applied to determine emission reduction strategies using Expert Choice software [48, 49]. Before choosing to use the AHP method, it is necessary to determine the elements related to emission reduction strategies for open waste burning activities, which are divided into several levels [50, 51]. The AHP method consists of four levels: main goal, factors, objectives, and alternative strategies [52]. The four levels to determine emission reduction strategies for open waste burning are as follows. Level 0 (main objective) covers data collection and processing using the AHP method, namely, determining emission reduction strategies for open waste burning activities in the Demak Regency. Level 1 (causal factor) is the factor that causes the problems discussed, in this case, waste burning by the community. Three factors were identified: the Demak Regency's waste collection services that still need to be improved, legal regulations that are not firm or binding, and a lack of public knowledge. Level 2 (objectives) are the goals to be achieved by implementing the selected strategy to reduce emissions from open waste burning activities in the Demak Regency. There are two objectives: improving the Demak Regency waste management system and increasing people's knowledge of the Demak Regency's proper and correct waste management. Level 3 (alternative strategies) are several

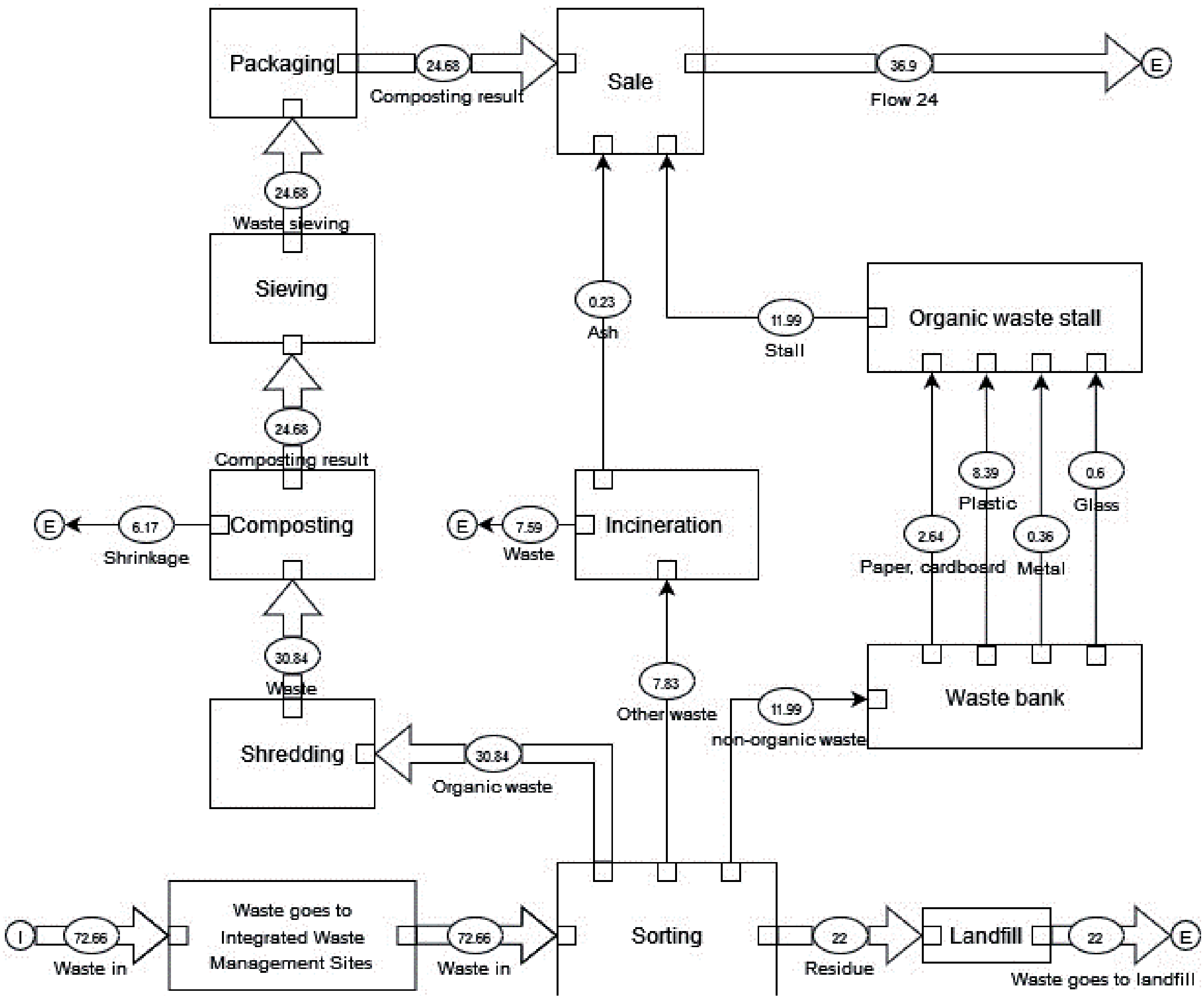

Fig. 3. Waste treatment flow.

strategies that can be chosen to achieve the Level 2 objectives. Alternative strategies include strengthening legal policies related to open waste burning activities that are firmer and more binding; increasing public awareness by providing education, support, and regular supervision to the community to dissuade open waste burning; and fostering a recycling culture in the community from the household level to improve waste management. Improved waste management facilities decrease the need for people to manage waste by burning.

Furthermore, experts in the field prepared a questionnaire form to be completed. The respondents were the Heads of Divisions 1 and 3 of the Demak Regency Environmental Agency. Both respondents were chosen because they understood the existing conditions and problems related to waste management and the Demak Regency community conditions that result in air pollution from open waste burning activities. Respondents completed the questionnaire form provided by assigning a score to each point related to strategy selection to reduce emissions from open waste burning activities. Level 1 compares each causal factor role in open burning activities for managing waste that produces air pollution in the Demak Regency. Level 2 compares the importance or influence of the two objectives, namely improving waste management and increasing public knowledge, of each causal factor at level 1. Level 3 compares the importance or influence of each alternative strategy that can be selected against each objective at Level 2.

Respondents completed the value scale on the questionnaire form following the instructions. The completed questionnaire scale value was then processed using the Expert Choice application to determine the selected strategy. Processed questionnaire data results were obtained using the AHP method using the Expert Choice application [25]. The strategy to reduce emissions from open waste burning activities in the Demak Regency, which was selected with a score of 581, is to increase public awareness by providing education, support, and routine supervision to the community to inhibit open waste burning.

The Demak Regency in Central Java Province consists of 14 subdistricts, 243 villages, and 6 urban villages with a population of 1,212,377 and an average

Table 3. Total GHG emission calculation before and after waste management.

Year	CO_2 emissions (Gg)		CH_4 emissions ($Gg\ CO_2$-eq)		N_2O emissions ($Gg\ CO_2$-eq)		Black carbon ($Gg\ CO_2$-eq)	
	Before	After	Before	After	Before	After	Before	After
2021	11.33	6.48	4.09	2.34	1.39	0.80	31.17	17.84
2022	11.49	6.58	4.15	2.38	1.41	0.81	31.64	18.11
2023	12.08	6.91	4.21	2.41	1.44	0.82	32.10	18.37
2024	11.83	6.77	4.27	2.45	1.46	0.83	32.56	18.64
2025	12.00	6.87	4.33	2.48	1.48	0.84	33.02	18.90
2026	12.16	6.96	4.39	2.52	1.50	0.86	33.48	19.16
2027	12.33	7.06	4.45	2.55	1.52	0.87	33.94	19.43
2028	12.50	7.15	4.52	2.58	1.54	0.88	34.40	19.69
2029	12.66	7.25	4.58	2.62	1.56	0.89	34.86	19.95
2030	12.83	7.35	4.64	2.65	1.58	0.90	35.32	20.22
2031	13.00	7.44	4.70	2.69	1.60	0.92	35.78	20.48

population growth rate of 0.93% in 2021. Currently, the amount of waste generated in the Demak Regency is 1,294,217 tons per day. Meanwhile, the Demak Regency waste service reached only 35%. The unserviced waste generation in the Demak Regency is 841,241 tons daily, of which 571,847 tons of waste is estimated to be managed by the population daily by burning. Open waste burning harms the environment by producing GHG emissions. Therefore, it is necessary to conduct waste management planning in the Demak Regency to reduce open waste burning activities so that GHG emissions can be significantly reduced. Fig. 3 shows the selected waste processing flow.

Based on the Central Java Governor Regulation No. 11 of 2019 concerning Policies and Strategies for Central Java Province in the Management of Household Waste and Waste Similar to Household Waste, the waste reduction target in 2025 is 30%, and the waste handling target is 70%. Therefore, with planned waste management, it is expected that no waste disposal, landfilling, or burning activities will occur because all the waste has been managed. The three subdistricts with the highest open waste burning rates requiring waste management planning were Wedung, Bonang, and Karangawen. Waste management planning includes the five aspects described earlier, and the processing implemented at the integrated waste management sites in each subdistrict. Processing includes composting of organic waste, incineration of other mixed waste, and sale of inorganic waste. However, 30.28% of the waste is still transported to the nearest landfills, namely, the Berahan Kulon and Candisari landfills. The amount of waste burned using incinerators was 10.77% of the total waste entering the integrated waste management site daily. With the same calculation from IPCC 2006 Chapter 5: Incineration and Open Burning of Waste, using tier 2 accuracy, the calculation of GHG emissions can be compared before and after waste management in Table 3.

Projections of open waste burning in the Demak Regency predict an increase from open waste burning annually. Statistical value analysis shows significant differences in the totals, as shown in Table 3. In 2022, emissions from open burning were 48.69 Gg/year and are predicted to increase to 55.08 Gg/year by 2031. After waste management, the emission rate from open burning in 2022 was 27.87 Gg/year and 31.53 Gg/year in 2031. The percentage reduction calculated through the total difference is significant, around 42.76%. This means that waste management is able to reduce emissions.

Conclusions

The STAN waste material flow analysis found that the waste generated in 2021 was 472,389.289 tons/y. Open waste burning accounts for 44.18% of the total waste generated. The outer peri-urban area has the highest open waste burning percentage at 86.22%, with leaf waste being the most commonly burned. GHG emissions from open burning activities in the Demak Regency covering 14 subdistricts by 2031 projected according to IPCC 2006 are as follows: CO_2 emissions generated in 2021 amounted to 20,513 Gg/y and increased to 23,55 Gg/y by 2031, CH_4 emissions generated in 2021 amounted to 7.41 Gg CO_2-eq/y and increased to 8.5 Gg CO_2-eq/y by 2031, N_2O emissions generated in 2021 amounted to 2.52 Gg CO_2-eq/y and increased to 2.89 Gg CO_2-eq/y by 2031, and total GHG emissions generated amounted to 86.91 Gg CO_2-eq/y and increased by 14.78% in 2031 to 99.76 Gg CO_2-eq/y. Waste management planning reduced emission levels due to open waste-burning activities by approximately 42.76%.

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Conflict of Interest

The authors declare no conflict of interest.

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