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Regional Study Case

Greenhouse Gas Emission Reduction Strategies in the Transportation, Waste, and Domestic Sectors

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Abstract

Population growth in Pekalongan City leads to increased community activities, which in turn increases Greenhouse Gas (GHG) emissions in the transportation, waste, and domestic sectors. This study aimed to inventory and project GHG emissions, develop reduction strategies, and design regulations to mitigate these emissions. The method used to inventory GHG emissions from the transportation sector is based on Tier 1 and 2 approaches, while the waste and domestic sectors use the 2006 Intergovernmental Panel on Climate Change method with Tier 1 accuracy. The inventory and projection results show that GHG emissions in the transportation sector will reach 455.084 Gg CO2eq by 2032. Strategies to reduce these emissions include optimizing green open spaces (RTH), rejuvenating public transportation, and developing a Bus Rapid Transit (BRT) system, which are expected to reduce emissions by 1.23%. In the waste sector, the projected emissions amount to 27.88 Gg CO2eq. Planned strategies, such as increasing waste service coverage of the Degayu Landfill, optimizing waste facilities, and utilizing biogas, can reduce emissions by 15.85%. In the domestic sector, projected emissions are 27.97 Gg CO2eq, with the strategy of developing community-based livestock biogas expected to reduce emissions by 0.22%

Keywords: greenhouse gas emission inventory; transportation sector; waste sector; domestic sector

1. Introduction

Global warming is the process of increasing the average temperature of Earth's atmosphere, seas, and land. Over the past hundred years, the global average temperature on Earth's surface has increased by 0.74 to 0.18°C (Utina, 2009). The Intergovernmental Panel on Climate Change (IPCC) concluded that much of the increase in global average temperatures since the mid-20th century was most likely due to rising concentrations of greenhouse gases. According to Presidential Regulation Number 98 of 2021 concerning the Implementation of the Economic Value of Carbon for the Achievement of Nationally Determined Contribution Targets and Control of Greenhouse Gas Emissions in National Development, Greenhouse Gases (GHG) are gases contained in the atmosphere, both natural and anthropogenic, which absorb and re-emit infrared radiation.

The area of Pekalongan City is relatively small compared with the surrounding region, covering 42.52 km². However, the population of Pekalongan City in 2021 has reached 308,310 people, with a population density of 6,788 people per km² and a population growth rate of 0.38% (BPS Kota Pekalongan, 2022). The population density of Pekalongan City continues to increase with rising population growth rate.

Changes in population significantly affect the amount and composition of energy use, either directly or through their impact on economic development (Dewan Energi Nasional, 2014). Households

are one of the sectors that consume a substantial amount of energy in various activities. According to the 2019 Indonesia Energy Outlook Report, the household or domestic sector is the third-largest energy consumer after the industrial and transportation sectors.

One common use of energy in the domestic sector is as fuel for cooking, such as kerosene, LPG, natural gas (in some large cities), and firewood (in some rural or suburban areas) (Made Wiratama et al., 2016). Household fuel use will continue to increase with population growth (number of households), purchasing power (GDP per capita), and urbanization rate. Pekalongan City has also experienced an increase in LPG gas usage, with consumption increasing from 15,075 MTon in 2020 to 15,598 MTon in 2021 (BPS Provinsi Jawa Tengah, 2022). However, the use of household fuel also contributes to the increase in GHG emissions. Household fuel combustion can produce CO_2, CH_4, and N_2O gas emissions.

Data from the Central Bureau of Statistics of Pekalongan City indicate an increase in the number of motorized vehicles, including private, public, and government vehicles. The average increase in the number of motorized vehicles throughout 2020 was 2.36%. The rapid growth of motor vehicles has led to an increase in fuel use in the transportation sector, which in turn has contributed to higher greenhouse gas emissions. According to Indonesia's Energy Outlook Report 2019, the transportation sector is the second-largest energy consumer in the industrial sector.

Waste management is another source of greenhouse gas (GHG) emission. Waste management includes sorting, collection, transportation, processing, and final disposal. Activities that produce greenhouse gases include waste disposal in landfills, biological waste processing, incineration, and open burning. According to the IPCC report (2006), landfills contribute approximately 3-4% of global greenhouse gas emissions in the waste sector each year. Based on data from the Waste Management Study conducted by the Environmental Office of Pekalongan City (2021), the amount of waste generation in Pekalongan City in 2021 was 0.44 kg/person/day or 49,514.59 tons/year. Of this waste, 88% is transported to landfills and managed at TPS3R and waste banks. Pekalongan City has a landfill called the Degayu Landfill, located 5 km from the city center, which uses a controlled landfill method, although its implementation could be improved. In underserved areas, open burning is a commonly used method to increase greenhouse gas emissions.

Given these conditions, efforts are needed to reduce greenhouse gas emissions in Pekalongan City to support the government in meeting the national target set by Presidential Regulation 98 in 2021. The regulation outlines the Nationally Determined Contribution (NDC), targeting a 29% reduction in emissions by 2030, equivalent to 834 million tons of CO_2 for all sectors. This study aims to fill the research gap regarding GHG emission reduction strategies in the transportation, waste, and domestic sectors of Pekalongan City.

2. Method

2.1 Location and Time

The location of this planning initiative is Pekalongan City, which is divided into four districts: North Pekalongan District, West Pekalongan District, East Pekalongan District, and South Pekalongan District. Each district has unique characteristics and challenges that are considered during the planning process. North Pekalongan District is known for its coastal areas and fisheries industry, contributing significantly to the local economy. West Pekalongan District, on the other hand, is characterized by its bustling markets and trade activities, playing a crucial role in the commerce of Pekalongan City. East Pekalongan District is recognized for its cultural heritage and traditional batik production, attracting both tourists and scholars interested in Javanese culture. Lastly, South Pekalongan District features a mix of residential areas and emerging industries, showcasing a blend of urban and suburban lifestyles. The planning timeline spans August 2022 to June 2023, a period of approximately 11 months. This duration allowed for thorough research, community engagement, and strategic development to ensure that the plan addressed the needs and aspirations of Pekalongan City residents. The initial phase, from August to October 2022, focuses on data collection and stakeholder consultation. This is followed by the

analysis and draft planning phase from November 2022 to January 2023. The subsequent months, from February to April 2023, are dedicated to refining the plan based on feedback and additional data. Finally, the implementation and monitoring phase will occur from May to June 2023, ensuring that the proposed initiatives are effectively executed and any necessary adjustments are made.

2.2 Field Data Collection

The data used in this planning includes primary data and secondary data. Primary data collection techniques employed in this planning include field observations, questionnaire distribution, and interviews. Field observations involved odometer recordings to determine vehicle mileage data. Additionally, questionnaires were distributed to the residents of Pekalongan City to gather household LPG consumption data. These questionnaires were also used to determine strategic priorities through SWOT and QSPM analyses. A total of 100 respondents were selected based on Slovin's formula. When determining the sample, it is essential to consider the characteristics and distribution of the target population. Therefore, for the household LPG consumption questionnaires, the sample was proportionally distributed based on districts. For the SWOT and QSPM questionnaires, a total of fifteen respondents were selected from related stakeholders and decision-makers. Meanwhile, other data and information were collected through interviews with relevant agencies (Bappeda, DLH, Dishub, Dinperpa), as well as from secondary data and literature studies.

2.3 Transportation Sector

The calculation of emissions in the transportation sector is conducted based on Book II of the guidelines for implementing a greenhouse gas inventory. In this plan, the accuracy used is Tier-1 and Tier-2. Emission calculations in the transportation sector involve multiplying activity data by emission factors. The activity data required for calculating the emission load in the transportation sector includes fuel consumption data for each type of vehicle. This data is obtained using the average vehicle trip length approach (vehicle kilometers traveled – VKT). The VKT data considers the optimum fuel consumption of the vehicle, derived from traffic counting sampling and odometer sampling. The odometer data is measured by recording the mileage shown on each type of vehicle and averaging it based on the vehicle's age as recorded in the sample.

2.4 Waste Sector

It is necessary to group waste based on its management to accurately calculate estimated emissions. The calculation accuracy level for the waste sector was Tier-1 and used several default parameters from the IPCC 2006 guidelines. The sources of GHG emissions to be inventoried include landfill waste, waste from open burning, biologically processed waste (such as composting and anaerobic digestion), and unmanaged waste.

2.5 Domestic Sector

Based on IPCC guidelines (2006), domestic/household activities are classified in the energy sector, specifically in the category of stationary fuel combustion. The calculation of emissions in this sector includes the household-scale LPG fuel use. The amount of emissions produced depends on the quantity and type of the fuel used. In this plan, a Tier-1 level of accuracy was applied, utilizing the IPCC default emission factor (2006). The formula used can be seen in the following equation (1):

$$\text{Emission}_{GRK,\,BB} = BB_{BB}\ \text{Consumption} \times \text{Emission Factor}_{GRK,\,BB} \quad (1)$$

Where:

$\text{Emission}_{GRK,\,BB}$ = Certain types of GHG emissions by fuel type (kg GHG)

BB_{BB} consumption = The amount of fuel burned by fuel type (in TJ)

GHG Emission Factor, $_{BB}$ = Certain types of GHG emission factors by fuel type (kg gas/TJ)

2.6 Strategy Priority Determination

Prioritization of greenhouse gas emission reduction strategies using SWOT and QSPM analysis methods. SWOT analysis was carried out by providing a rating scale for each factor, which was then used to calculate the weight, rating, and score. Influencing factors are divided into four categories, namely strengths, weaknesses, opportunities, and threats, and then will be made into a questionnaire given to five experts from agencies in related sectors. The rating refers to the following conditions.

- Scale 1: Less influential
- Scale 2: Moderately influential
- Scale 3: Very influential

QSPM analysis was conducted to determine strategic priorities. QSPM calculation is done by combining internal factors and external factors with each planned strategy. The size of the score will determine the priority of the strategy. The strategy with the highest score is the best strategy that needs to be prioritized (Qanita, 2020).

3. Result and Discussion

3.1 Inventory of Greenhouse Gas Emissions of the Transportation, Waste, and Domestic Sectors

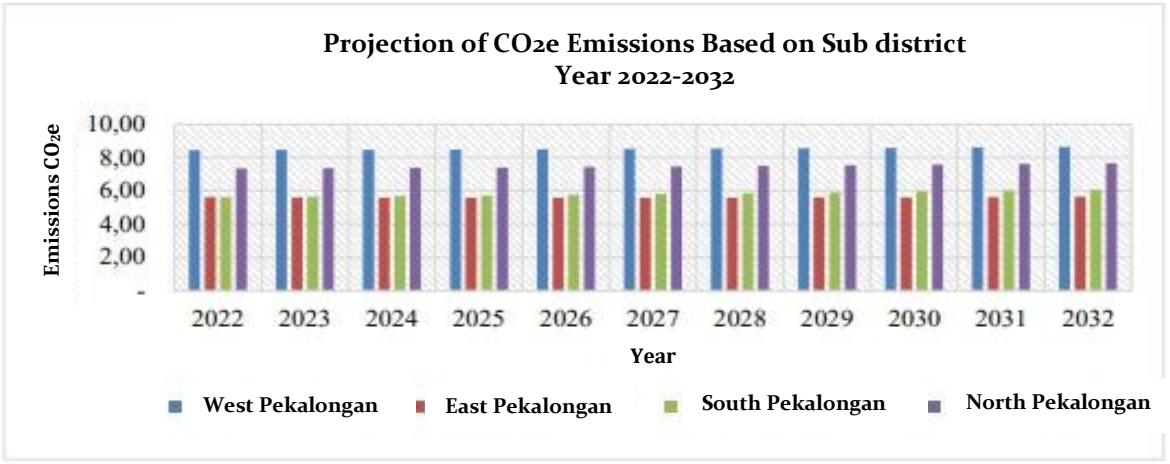
The calculation of GHG emissions in the transportation sector uses Tier 1 and Tier 2 methods, reflecting the existing state of transportation and traffic in Pekalongan City. CO_2 emissions are calculated using the Vehicle Kilometer Traveled (VKT) approach, which measures the length of trips per year. The initial stage of conducting an emission inventory involves collecting historical data to support the calculation of CO_2 emissions. The necessary historical data includes vehicle population and traffic counts on arterial and collector roads. These data are then projected until 2032. Projections estimate that by 2032, the vehicle population will reach 250,309 units across all vehicle categories. With the increase in vehicle population, traffic counts also rise, allowing the calculation of projected vehicle traffic in Pekalongan City using a percentage approach relative to the vehicle population. To find emissions based on vehicle population projections, it is necessary to multiply activity data (fuel consumption of each vehicle type) by the emission factor for each vehicle type and the calorific value of the fuel. After calculating the emission load for all vehicle types, the emissions are converted to CO_2e for each type of GHG emission using the Global Warming Potential (GWP) value.

The inventory of GHG emissions in the waste sector was analyzed using IPCC Tier-1 with a Business as Usual (BAU) scenario from 2022 to 2032. Emissions are calculated based on four categories of waste management: waste in landfills, biologically processed waste, open-burning waste, and unmanaged waste. To calculate GHG emissions, projections of waste generation for each category are needed based on population and waste generation rates in 2021. Projections follow the BAU method, with waste management distribution as follows: 70.4% to landfill, 17.6% to biological processing, 7.92% to open burning, and 4.08% unmanaged. Waste generation and GHG emissions are calculated using the IPCC formula. Figure 1 shows the results of an inventory of emissions from the waste sector. The calculations indicate an annual increase in emissions, as the distribution of waste management remains constant. Based on the results, GHG emissions will reach 27.87 Gg CO_2eq by 2032.

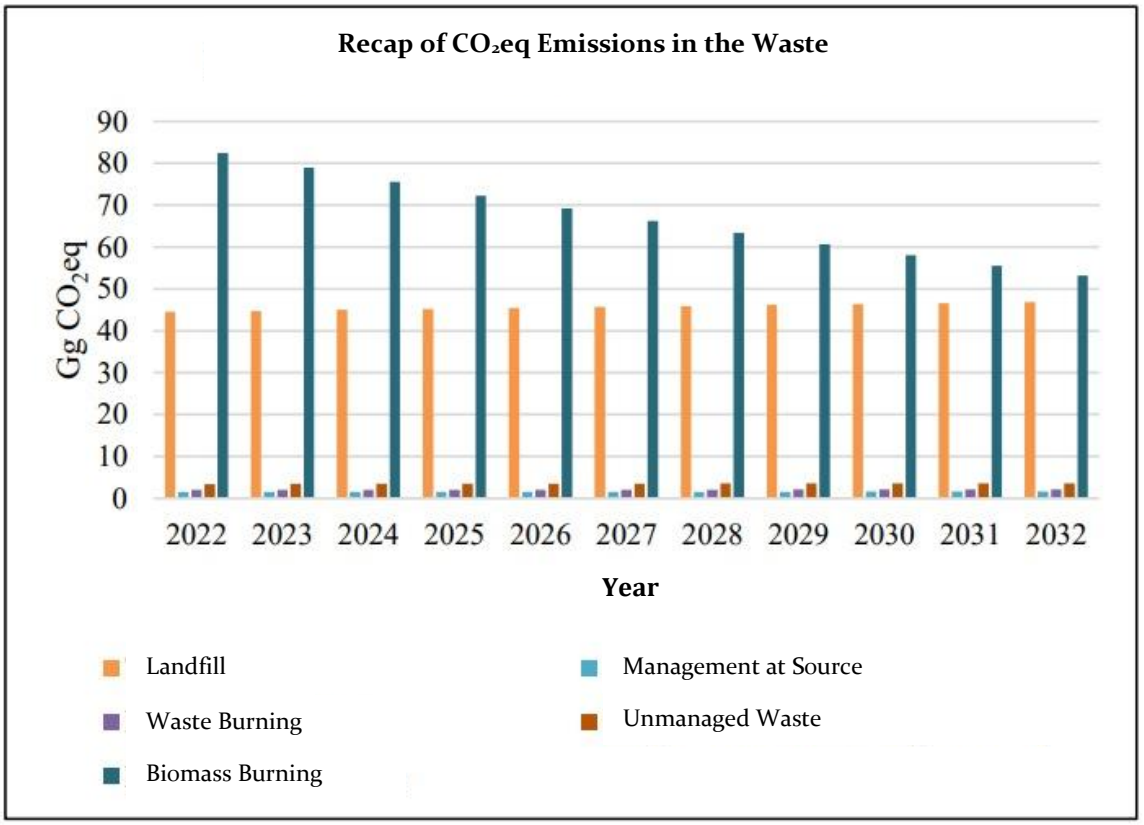
The inventory of GHG emissions in the domestic sector was analyzed using IPCC Tier-1 with activity data, specifically household-scale LPG fuel use. LPG usage data was obtained from questionnaires, with consumption categorized based on welfare stages: 2.71 kg/month/person for Pre-Prosperous Family, 2.65 kg/month/person for Prosperous Family I, and 2.21 kg/month/person for Prosperous Family II, III, and III+. To project GHG emissions, population projections based on welfare stages in each sub-district were obtained from BPS Pekalongan City.

Figure 1 also shows the results of an inventory of emissions from the domestic sector, indicating an annual increase in GHG emissions. This increase is attributed to population growth, which influences the amount of energy consumption, specifically LPG use, thereby increasing emissions (National Energy

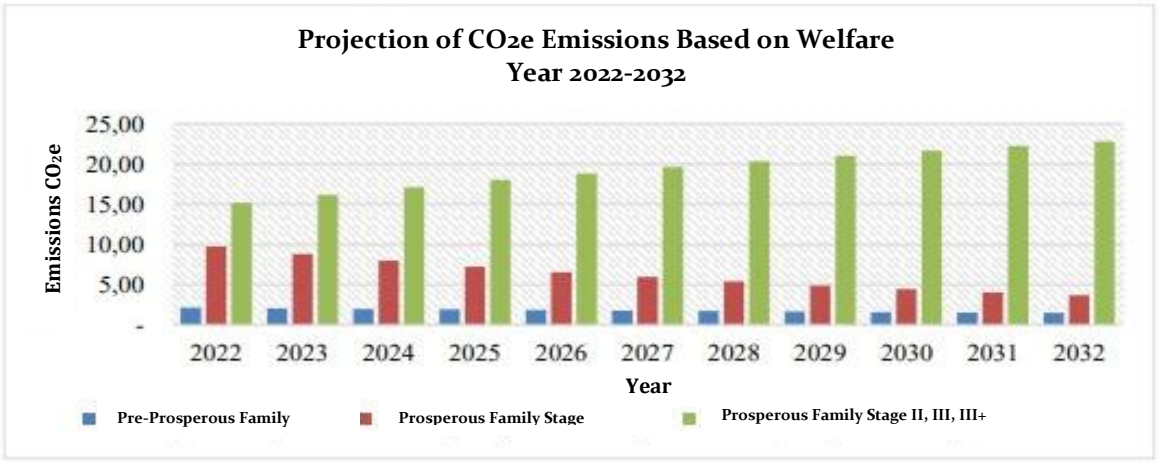
Council 2019). Emissions in 2021 were 26.98 Gg CO2eq, rising to 27.97 Gg CO2eq by 2032, representing a 3.7% increase in emissions from the domestic sector.



(a)



(b)



(c)

Figure 1. CO2eq emission graph (a) transportation sector; (b) waste sector; (c) domestic sector

3.2 Greenhouse Gas Emission Reduction Strategy Priority for Transportation, Waste, and Domestic Sectors

GHG emission reduction strategies are determined by considering factors that can affect the chosen strategy. These factors were then analyzed using the SWOT and QSPM to determine the scores and quadrants (I, II, III, and IV) for each planned strategy. Strategy determination is based on the analysis of existing government policies and programs, such as RAN-GRK, RAD-GRK Central Java Province, RPJMD Pekalongan City, RPJPD Pekalongan City, and data from related agencies. The results of the SWOT and QSPM analyses, including the quadrant for each program, are presented in Table 1.

Table 1. Quadrant determination result

No	Strategy	IFAS Coordinate	EFAS Coordinate	Quadrant
Transportation Sector				
1	Optimization of green open space as a pollution buffer	0.133	-0.088	II
2	Public Transportation Rejuvenation	0.098	-0.016	II
3	Bus Rapid Transit (BRT) Development	0.144	-0.035	II
Waste Sector				
1	Increasing the Coverage of Waste Services at the Degayu Landfill in Pekalongan City	0.068	0.034	I
2	Optimizing Available Waste Facilities (TPS3R)	0.048	0.048	I
3	Utilizing Biogas from Household Organic Waste	0.034	0.069	I
Domestic Sector				
1	the Development of Livestock Biogas of Community Origin (BATAMAS)	0.180	0.169	I
2	Utilizing Biogas from Household Organic Waste	0.196	0.058	I
3	the Utilization of Biogas from MCK Plus ++ Facilities	0.087	0.001	I

3.3 Transportation Sector Emission Reduction Strategy

Based on projected calculations, transportation sector emissions will continue to increase until 2032. The potential increase in emissions is caused by an increase in the population. The following is a proposed strategic plan for reducing greenhouse gas emissions in Pekalongan City, which is prepared based on applicable policies and regulations:

3.3.1. RTH Optimization

The RTH (green open space) planning in Pekalongan City aims to help absorb greenhouse gas emissions from the transportation sector. This plan targets the East Pekalongan District, an area with dense settlements, and refers to the spatial pattern plan map in the 2009-2029 Pekalongan City RTRW, which identifies available areas for utilization. Once the planning location is determined, the next step is calculating the required number of plants. The Trembesi tree, which can absorb 28.45 tons of CO_2 per year (Ghifary, 2017), has been chosen for this purpose. The plan calls for planting 192 trees. The RTH development is planned to begin in 2023 and is expected to reach full maturity by 2025. Once the trees have grown and reached their maximum absorption capacity, the strategy is projected to reduce emissions by 1.2% by 2032 compared to emission levels before the implementation of this action.

3.3.2. Public Transportation Rejuvenation

The Pekalongan City Transportation Office plans to improve urban transportation services and revive public interest in using public transportation through a transportation rejuvenation plan. Each year, at least 2% of the total number of buses will be rejuvenated. By rejuvenating transportation, fuel consumption in older vehicles can be reduced, enhancing public confidence to switch to public transportation and reducing the use of private vehicles, thus lowering greenhouse gas emissions in the transportation sector. According to research by Nugroho & Fazzry (2016), the rejuvenation of AKDP transportation in East Java can reduce fuel consumption by up to 5.89%. This reduction is attributed to the decreased total fuel consumption from rejuvenated transportation, subsequently reducing greenhouse gas emissions. The percentage decrease in fuel consumption is used as an assumption for calculating the reduction in this project. After comparing the emission reduction to the amount of emissions before the action, it is estimated that this strategy can reduce emissions by 0.003% by 2032.

3.3.3. Bus Rapid Transit (BRT) Development

One of the proposed efforts to control GHG emissions in the transportation sector in Pekalongan City is the development of Bus Rapid Transit (BRT) to incentivize the public to shift from private vehicles to public transportation. The development of BRT is supported by Governor Regulation Number 51 of 2012 concerning Regional Action Plans for Reducing Greenhouse Gas Emissions in Central Java Province. Implementing BRT is expected to address the shift from private vehicles to public transportation, leading to a decrease in private vehicle usage and subsequently reducing greenhouse gas emissions. The chosen BRT route, the Pekalongan - South Pekalongan Terminal route, traverses densely populated commercial and residential areas, ensuring high vehicle occupancy and public interest. After analyzing circulation and waiting times, a fleet of 7 medium buses and fifteen stop points along the planned BRT route have been determined. Emission reduction is calculated by comparing emissions from vehicles that have not shifted to BRT with emissions from BRT units per trip. After calculating the emission reduction compared to emissions before the action, it is estimated that this strategy can reduce emissions by 0.006% by 2032.

3.4. Waste Sector Emission Reduction Strategy

The results of GHG emission calculations in the waste sector show an increase in GHG emissions every year, so efforts need to be made to control GHG emissions. GHG emission control programs planned for the waste sector based on existing policies and development directions, including:

3.4.1. Increasing the Coverage of Waste Services at the Degayu Landfill in Pekalongan City

Currently, Pekalongan City operates 13 waste collection Points and 20 depots, but proper management is needed for some of these facilities. Additionally, there are several unserved villages in the North Pekalongan and South Pekalongan Districts. Therefore, it is necessary to establish a new container depot to extend waste services to these areas. Due to the small waste generation in unserved villages, Type III transfer depots with a capacity of 10 m^3 are proposed. The plan requires 10 container units by the end of the planning year, with procurement scheduled for 2024. To enhance waste service coverage, it is assumed that there will be a 1% increase in the percentage of waste entering landfills and undergoing biological processing. As a result of this plan, there is an anticipated reduction in emissions of 2,076 Gg CO2eq or 7.45% by the final year of the planning period.

3.4.2. Optimizing Available Waste Facilities

Pekalongan City currently operates 21 integrated waste management facilities, although 3 of them will become inactive in 2021. There are still facilities in need of improvement, and the target for depositing fertilizer at several TPS3Rs has not been met. The plan for revitalizing and repairing TPS3Rs is scheduled for implementation from 2023 to 2032. Each TPS3R is designed to serve 400 households within a 200 m^2 area. To enhance waste management at TPS3Rs, it is assumed that there will be a 1% increase in the percentage of waste undergoing biological treatment. As a result of this plan, there is an anticipated reduction in emissions of 2,263 Gg CO2eq or 8.12% by the final year of the planning period.

3.4.3. Utilizing Biogas from Household Organic Waste

The current organic waste processing at integrated waste management facilities in Pekalongan City primarily involves composting, with no alternative methods currently in place. To alleviate the burden on landfills, converting organic waste into biogas through integrated waste management facilities presents a feasible solution. The plan entails the development of 5 units of organic waste biogas digesters at integrated waste management facilities. These digesters will utilize fixed dome biogas technology with a capacity of 50 m^3 and require a land area of 95 m^2. It's estimated that 253.33 kg of organic waste per day will be required to operate these digesters efficiently. By harnessing biogas derived from household organic waste, the plan assumes a reduction in the proportion of waste processed biologically. As a result of this initiative, there is an anticipated reduction in emissions of 0.081 Gg CO2eq or 0.29% by the final year of the planning period.

3.5. Domestic Sector Emission Reduction Strategy

The calculation of GHG emissions in the domestic or household sector shows an increase in GHG emissions every year, so efforts to control GHG emissions are necessary. GHG emission control programs planned for the domestic sector based on existing policies and development directions, including:

3.5.1. The Development of Livestock Biogas of Community Origin

Currently, Pekalongan City already operates 2 units of biogas digesters at the Eka Muncul Cattle Summit in Degayu Village. In this plan, considering the available livestock potential, it is proposed to develop 1 unit of livestock biogas digester every year starting in 2024. These digesters will utilize fixed dome biogas technology with a capacity of 12 m^3 each, requiring a land area of 40 m^2. To operate efficiently, each digester will need approximately 110 kg of cow dung per day, equivalent to the waste from approximately 9-12 cows per digester unit. With a capacity of 12 m^3, each biogas digester is capable of producing 4.5 m^3 of biogas per day (BIRU, 2014), resulting in an annual total production of approximately 1,643 m^3 of biogas. This amount of biogas can substitute approximately 755.5 kg of LPG annually.

3.5.2. Utilizing Biogas from Household Organic Waste

The biogas utilization program from household organic waste also contributes to reducing GHG emissions from the domestic sector by replacing LPG with biogas as a fuel source. Each digester unit produces 3699 m^3 of biogas annually, which is equivalent to 1701.04 kg of LPG per year. By utilizing biogas in households, emissions from LPG usage can be effectively reduced.

3.5.3. The Utilization of Biogas from MCK Plus^{++} Facilities

MCK Plus++ refers to an MCK facility equipped with a wastewater treatment unit, specifically a biodigester. According to SNI 03-2399-2002, a typical MCK can accommodate a maximum of 200 people or approximately 50 households. Thus, the biodigester capacity in this plan is set at 5 m^3. Based on calculations from the DEWATS Handbook (Sasse, 1998), a biodigester with a capacity of 5 m^3 can produce approximately 2.7 m^3 of biogas per day or 982.06 m^3 per year. Therefore, each unit of MCK Plus++ can utilize biogas equivalent to 451.75 kg of LPG per year. The plan is to develop 1 unit of MCK Plus++ annually, starting in 2024, specifically targeting slum areas in Pekalongan City.

4. Conclusions

Regarding on the results of the greenhouse gas emissions inventory in Pekalongan City under a Business as Usual (BAU) scenario, the emissions in 2022 from the transportation sector were 342.093 Gg CO2eq, from the waste sector were 26.50 Gg CO2eq, and from the domestic sector were 27.01 Gg CO2eq. The projected greenhouse gas emissions for 2032 in Pekalongan City are estimated to be 455.084 Gg CO2eq for the transportation sector, 27.88 Gg CO2eq for the waste sector, and 27.97 Gg CO2eq for the domestic sector. Additionally, the SWOT and QSPM analysis, there are three programs that have been identified from the transportation, waste, and domestic sectors to reduce greenhouse gas emissions in Pekalongan City. The strategies to reduce emissions in the transportation sector include Green Open Space Optimization, Public Transportation Rejuvenation, and BRT Development. In the waste sector, the strategies entail increasing the coverage of waste services to the Degayu Landfill in Pekalongan City, optimizing available waste facilities (TPS3R), and utilizing biogas from household organic waste. Finally, the strategies to reduce emissions in the domestic sector involve the utilization of biogas from household organic waste, the development of community-origin livestock biogas (BATAMAS), and the utilization of biogas from MCK Plus++ facilities.

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