

Estimation of Greenhouse Gas Emissions from Household Waste in Banjarbaru City Using the IPCC Method

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ABSTRACT

The research aims to estimate greenhouse gas emissions from household waste in Banjarbaru City using the IPCC Tier 2 method. The calculation was carried out with three scenarios, namely: scenario 1 (BAU), scenario 2 (existing conditions according to Jakstrada policy), and scenario 3 (mitigation with 3R optimization). The results show that in 2024, the BAU scenario produces emissions of 6.02 Gg CO₂-eq. In the existing scenario, emissions decreased to 5.78 Gg CO₂-eq (down 4.11%), while in the mitigation scenario, emissions decreased more significantly to 5.55 Gg CO₂-eq (down 7.81%). The mitigation scenario is the most effective approach in efforts to reduce GHG emissions in Banjarbaru City in 2024. Scenario 3 is the best scenario in reducing GHG emissions, because it integrates sustainable waste management strategies and supports the achievement of Indonesia Zero Waste Zero Emission in 2050.

Keywords: Emissions, greenhouse gases, IPCC methods, Household waste

INTRODUCTION

Banjarbaru City, South Kalimantan Province, Indonesia, which initially had the status of an administrative city since 1982 and then became a municipality in 1999, has now developed into a new growth center after being designated as the capital city of South Kalimantan Province in 2022. The increase in population and economic activity has driven massive infrastructure growth and regional development. Banjarbaru City, which has an area of 305,153 km² and a population of 272,763 people with a growth rate of 2.71% (BPS Banjarbaru, 2024), is now facing various urban challenges, one of which is the problem of household waste management (Prihatin, 2020). Rapid population growth is directly proportional to the increasing amount and composition of household waste. Data from the National Waste Management Information System (2023) recorded that Banjarbaru City's waste generation reached 189.50 tons/day, with the household sector being the main contributor at 84.39%. Most of the waste still ends up in the Gunung Kupang Final Disposal Site, which is currently experiencing limited capacity (Manruni et al., 2023).

The waste management system is still linear and has not been optimal in supporting the principles of reduction and recycling. In an effort to overcome this problem, the Banjarbaru City Government has provided facilities such as waste banks, and set a target of reducing household waste by 30% and handling by 70% by 2025 (Banjarbaru Mayoral Regulation No. 32 of 2018). Banjarbaru City Regional Regulation Number 5 of 2023 also requires everyone to manage household waste in an environmentally friendly manner. In addition to being a cleanliness problem, household waste is now a concern because of its contribution to greenhouse gas emissions, especially through the decomposition and landfill processes (Chaerul et al., 2020).

Waste management activities have been proven to produce greenhouse gases such as methane (CH₄), carbon dioxide (CO₂), and nitrous oxide (N₂O). Landfilling of waste in landfills produces large amounts of methane, while open burning produces all three types of greenhouse gases (Prabowo et al., 2017). Even composting methods are not free from CH₄ and N₂O emissions (Kiswandayani et al., 2016). This potential danger is exacerbated by the fact that 1 ton of solid waste can produce 50 kg of methane gas, which is 28 times more damaging to the atmosphere than CO₂ (Ardhitama et al., 2017). The issue of increasing greenhouse gas emissions is a global challenge because it has an impact on climate change and global warming. The Indonesian government responded to this through the Enhanced Nationally Determined Contribution (ENDC) commitment with a target of reducing emissions by 31.89% unconditionally and 43.20% with international support by 2060 (Presidential Regulation of the Republic of Indonesia No. 98 of 2021).

In the domestic waste sector, Indonesia is targeting a reduction in greenhouse gas emissions of 40 million tons of CO₂-eq in order to achieve Zero Waste Zero Emission 2050 (KLHK, 2024). Thus, the waste sector,

especially households, is a strategic focus in climate change mitigation efforts. Factors that influence the amount of greenhouse gas emissions from waste include the amount of daily generation, the type of waste composition, and the management method used. Rizkiannur (2019) showed that the rate of domestic waste generation in Banjarbaru City reached 0.36 kg/person/day, with organic waste dominating at 61.67%. This information is important data in estimating greenhouse gas emissions released into the environment through household waste management activities, both directly and indirectly. The research aims to estimate greenhouse gas emissions from household waste in Banjarbaru City using the IPCC Tier 2 method.

MATERIALS & METHODS

This study uses a descriptive quantitative approach to estimate GHG emissions from household waste. The method used is the Intergovernmental Panel on Climate Change (IPCC) Tier 2 method, which is more detailed because it uses local activity data and default emission factors. Data collection was carried out through literature studies, interviews with the Banjarbaru Environmental Service, and documentation observations.

Research Location and Time

The study was conducted in Banjarbaru City, South Kalimantan, which consists of five sub-districts: Landasan Ulin, Liang Anggang, Cempaka, North Banjarbaru, and South Banjarbaru. The research time was carried out in 2024 by collecting secondary data from related agencies and reviewing relevant literature

GHG Emission Calculation Method

Calculating the estimate of greenhouse gas emissions from household waste, data on generation, composition and default parameters recommended by the IPCC are required. Calculation of CH₄, CO₂, N₂O emissions using the IPCC Tier 2 method,

household waste management from landfill activities in landfills, composting, and open burning. The results of Rizkiannur's research (2019), the composition of household waste in Banjarbaru City is dominated by organic waste 61.67%, wood 0.21%, paper 8.74%, plastic 14.08%, cloth/textile 11.60%, rubber 0.44%, metal 0.94%, glass 1.98%, electronic devices 0.31%, and other waste 0.03%. SRT composition diagram of Banjarbaru City. Scenarios used in calculating GHG emission estimates:

- The first scenario, estimated GHG emissions from household waste in 2024 with Business as Usual (BAU) conditions (without waste reduction).
- The second scenario, estimated GHG emissions from household waste in existing conditions in 2024 in accordance with the existence of the Banjarbaru City Jakstrada, with 3R activities (garbage dump 3R and Recycling Processing).
- The third scenario, GHG estimation from household waste according to mitigation conditions with the target of Indonesia Zero Waste Zero Emission in 2024 with the condition of 3R activities (garbage dump 3R and Recycling Processing) reaching ideal conditions.

GHG emissions are calculated in the form of CH₄, CO₂, and N₂O then converted to CO₂-equivalent (CO₂-eq) units using the Global Warming Potential (GWP) of each greenhouse gas according to IPCC AR5. The equation used to calculate GHG emissions from each type of household waste management:

a. Garbage is piled up in landfills

- Calculation of the mass of DDOCm deposited in year T

$$DDOCmd(T) = W(T) \times DOC \times DOCf \times MCF$$
- Calculation of the mass of undecomposed DDOCm deposited at the end of the deposit year T

$$DDOCmrem(T) = DDOCmd(T) \times e^{-(k \times (13-M)/12)}$$

- Calculation of the mass of DDOCm deposited that decomposed in the year of deposit T

$$DDOCmdec(T) = DDOCmd(T) \times (1 - e^{-(k \times (13-M)/12)})$$

- Calculation of the mass of DDOCm accumulated in the landfill at the end of year T

$$DDOCma(T) = DDOCmrem(T) + (DDOCma(T-1) \times e^{-k})$$

- Calculation of the mass of DDOCm decomposed in year T

$$DDOCmdecomp(T) = DDOCmdec(T) + (DDOCma(T-1) \times (1 - e^{-k}))$$

- Calculation of CH₄ formed

$$CH_4 \text{ generated}_T = DDOCmdecomp_T \times F \times 16/12$$

- Calculation of CH₄ emissions in landfills

$$= \sum_x CH_4 [generated_{x,T} - R_T] \times (1 - O_{X_T})$$

Description:

T: inventory year

DDOCmdT: mass of DDOC deposited in landfill in year T (Gg)

W(T): mass of solid waste deposited in year T (Gg)

DOC: fraction of degradable organic carbon in the year of waste deposition

DOCf: fraction of DOC that can be decomposed under anaerobic conditions

MCF: correction factor for aerobically decomposed CH₄ in the year of waste deposition

DDOCmdT: mass of DDOC deposited in year T, which is not decomposed by the end of year T

DDOCmdec(T): mass of DDOC deposited in year T, which is decomposed by year T

DDOCmaT: DDOCm accumulated in SWDS at the end of year T (Gg)

DDOCmaT-1: DDOCm accumulated in SWDS at the end of year (T-1) (Gg)

DDOCmdecompT: DDOCm entering landfill that can decomposed in year T

CH₄ generatedT: CH₄ formed in year T as a result of decomposition of organic components stored in waste (DDOC)

K: reaction constant

F: % fraction of CH₄ in landfill gas generated, F value based on default

IPCC is 50% or 0.5.

RT: CH4 recovered for use or flare

OXT: oxidation factor in year T

Emission CO₂

$$= MSW \times \sum_i (WFi \times dmi \times CFi \times FCFi \times OFi) \times \frac{44}{12}$$

b. Open burning

- Emission CH₄

$$\text{Emission CH}_4 = \sum_i (M_i \times EF_i) \times 10^{-3} - R$$

- Emission N₂O

$$\text{Emission N}_2\text{O} = \sum_i (M_i \times EF_i) \times 10^{-3}$$

- Emission CO₂**

c. Composting

- Emission CH₄**

$$\text{Emission CH}_4 = \sum_i (IW_i \times EFi) \times 10^{-6}$$

- Emission N₂O**

$$\text{Emission N}_2\text{O} = \sum_i (IW_i \times EFi) \times 10^{-6}$$

The mass balance of each scenario can be seen in the figure below:

a. Mass balance scenario 1

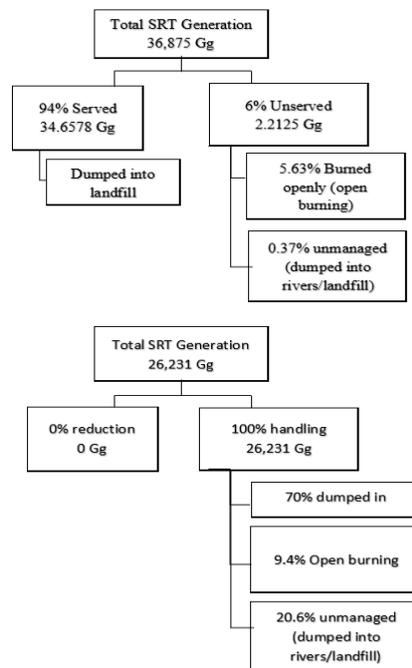


Figure 1. Mass balance scenario 1

b. Keseimbangan massa skenario 2

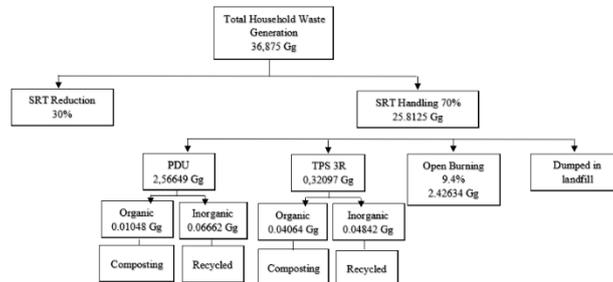


Figure 2. Keseimbangan massa skenario 2

c. Mass balance scenario 3

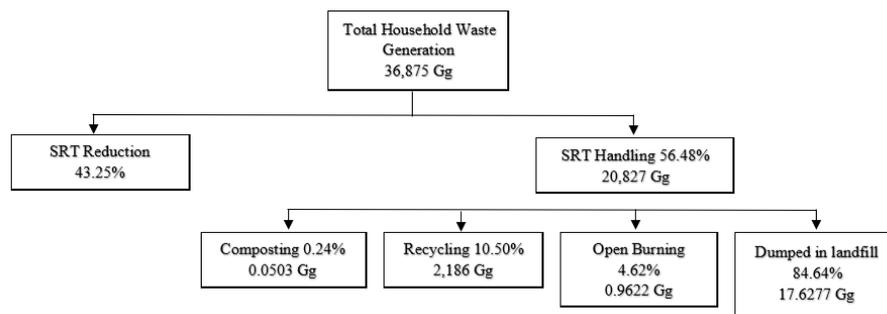


Figure 3. Mass balance scenario 3

RESULT AND DISCUSSION

The estimation of greenhouse gas emissions from household waste in Banjarbaru City in this study was calculated using the Tier 2 approach, in accordance with the 2006 IPCC Guidelines for the National Greenhouse Gas Inventory Volume 5 which discusses waste. The Tier 2 approach in calculating greenhouse gas emissions was chosen because it provides higher accuracy compared to Tier 1. Tier 1 usually uses global data or generalizations that do not specifically consider local conditions. The calculation in Tier 2 uses local data such as waste composition, DOC (degradable organic carbon) values and methane correction factors (MCF) in the study area. The use of local data allows for more representative greenhouse gas emission estimates and is in accordance with conditions in the area.

Scenario 1: Business As Usual (BAU)

The Business As Usual (BAU) scenario represents the condition of household waste management in Banjarbaru City which is running without any policy intervention or changes in community behavior patterns in waste management. The waste produced by the community is considered to be directly disposed of without being sorted from the source, not reused, and not processed through official management facilities such as the Reduce-Reuse-Recycle Waste Processing Site (garbage dump 3R) or Recycling Processing. The entire burden of waste management depends on conventional mechanisms, namely landfilling at the Final Processing Site and open burning carried out

by some people independently. The total estimated household waste generation in 2024 is estimated to reach 36.87 Gg (gigagrams) per year. Of this total, 34.6578 Gg is disposed of at the Final Processing Site and 2.2125 Gg is burned openly. The accumulation of organic waste in the Final Processing Site, which takes place under anaerobic conditions, produces methane gas (CH₄) of 0.21966 Gg. CH₄ is a greenhouse gas that has a global warming potential (GWP) 25 times stronger than carbon dioxide (CO₂) over a period of 100 years.

This anaerobic condition is very common in landfills that are not managed as sanitary landfills, where there is no gas recovery system or adequate daily cover. Open burning contributes carbon dioxide emissions of 0.51335 Gg and nitrous oxide (N₂O) of 0.00044 Gg. N₂O has a global warming potential of 298 times that of CO₂, making it one of the most powerful greenhouse gases even in very small amounts. This open burning activity is carried out outside the official management system and is usually not accompanied by emission control technology, so that all gas is released directly into the atmosphere. After converting all gas emissions into CO₂-equivalent (CO₂-eq) units according to the GWP value of each gas, the total GHG emissions from the BAU scenario reached 6.02 Gg CO₂-eq. This value illustrates the highest emission potential of the three scenarios analyzed. Emissions from methane from landfills are the largest contributor, around 55% of total emissions. This shows that environmentally unfriendly final disposal methods are the main contributors to

emissions in an unmanaged waste management system. With no technical or social intervention in this scenario, waste generation continues to increase linearly with population growth. A major challenge for the city government because in addition to having an impact on GHG emissions, waste accumulation also causes other environmental problems such as soil pollution, untreated leachate, and unpleasant odors. The BAU scenario not only has high environmental risks, but also hinders efforts to achieve the national GHG emission reduction target listed in Indonesia's Nationally Determined Contribution (NDC) document.

Scenario 2: Existing (Jakstrada Policy)

The existing scenario describes the projection of household waste management in Banjarbaru City in 2024 if the waste management policy stated in Jakstrada (Regional Policy and Strategy for Waste Management) has been partially implemented in the field. This scenario assumes that the policy of reducing waste by 30% and handling by 70% through strengthening the garbage dump 3R (Reduce-Reuse-Recycle Waste Processing Site) and Recycling Processing facilities has been implemented, although not yet fully optimal. The existence of garbage dump 3R and Recycling Processing has an impact on changes in the waste flow path. Not all waste is directly disposed of at the Final Processing Site or burned, but some is processed first through composting, sorting, and recycling. This causes the proportion of waste dumped at the Final Processing Site to decrease from the previous 34.6578 Gg (in the BAU scenario) to 24.193 Gg. The reduction in the volume of the landfill also reduced CH₄ emissions from the landfill to 0.1958 Gg, down compared to the first scenario. The volume of open burning also decreased, from 2.2125 Gg to 1.41 Gg.

This practice has not been completely stopped because there are still obstacles in implementing the burning ban at the

household level. Emissions resulting from this burning include CO₂ of 0.363 Gg, CH₄ of 0.00917 Gg, and N₂O of 0.00013 Gg. All three still contribute significantly to total GHG emissions because they occur without control. This scenario is the role of composting that has begun to run through the 3R garbage dump. Organic waste of 0.0511 Gg is processed biologically, producing CH₄ emissions of 0.000204 Gg and N₂O of 0.000102 Gg. Composting does produce small amounts of GHG gas, but its contribution is relatively low compared to landfilling because it takes place in aerobic conditions (exposed to oxygen), which tend to be more environmentally friendly. Based on all emission sources in the existing scenario, the conversion results to CO₂-eq units produce a total emission of 5.78 Gg CO₂-eq.

Compared to the BAU scenario which produces 6.02 Gg CO₂-eq, there is a decrease of 4.11%. This decrease shows that the implementation of waste management policies, although still in the early stages and not yet comprehensive, has had a real impact on reducing greenhouse gas emissions from the domestic waste sector. The potential for reducing emissions in this scenario has not reached its optimal point. Technical obstacles in the field such as limited capacity of garbage dump 3R, inconsistent Recycling Processing operations, and minimal community participation in sorting and processing waste from home are challenges in themselves. Not all areas of Banjarbaru City have equal access to waste management infrastructure, resulting in spatial disparities in the achievement of emission reductions between sub-districts. This condition shows that the success of the existing scenario is highly dependent on the consistency of policy implementation, program sustainability, and cross-sector synergy between the government, private sector, and the community. Without continuous supervision and support, the implementation of this strategy can stagnate or run half-heartedly, which ultimately reduces its

effectiveness in supporting the national target of reducing GHG emissions.

Scenario 3: Optimal Mitigation

The third scenario projects the best management conditions, open burning practices continue to decrease and all 3R garbage dump facilities and Recycling Processing is operate optimally. The community actively sorts waste from the source, especially for organic waste which is then processed through composting. The volume of waste dumped in the Final Processing Site is reduced to 20.827 Gg with CH₄ emissions of 0.18169 Gg. There are no emissions from open burning because this activity has been completely stopped. The composting process produces CH₄ emissions of 0.000201 Gg and N₂O of 0.000085 Gg from a total of 0.0503 Gg of organic waste. The conversion of all GHG emissions in the mitigation scenario produces a total of 5.55

Gg CO₂-eq, indicating a decrease of 7.81% compared to the BAU scenario. This decrease is the most significant among the three scenarios. These results prove that with integrated management and active community participation, emissions from the waste sector can be substantially reduced.

Emission Conversion to CO₂ (eq)

The calculation results of GHG emissions from waste managed through landfill and open burning, which include CO₂, CH₄, and N₂O are then converted into carbon dioxide equivalent units (CO₂-eq) using the Global Warming Potential (GWP) value. This conversion aims to simplify and unify the impact of the three gases on global warming into a uniform unit. Based on IPCC guidelines (AR5), 1 ton of CO₂ is equivalent to 1 ton of CO₂-eq, 1 ton of CH₄ gas is equivalent to 28 CO₂ -eq and 1 ton of N₂O gas is equivalent to 265 tons of CO₂ -eq.

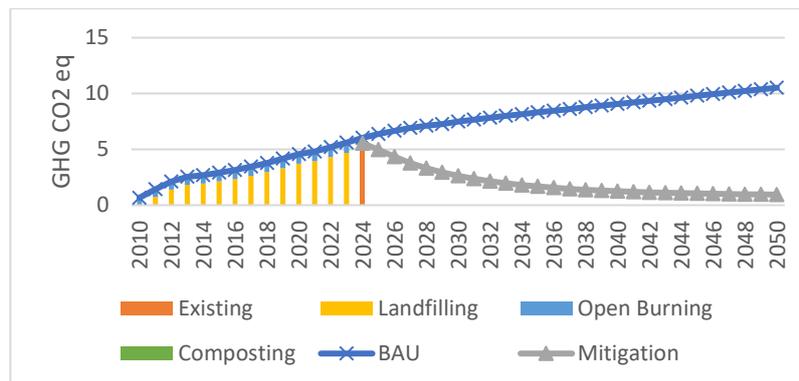


Figure 4. BAU and Projection of GHG Emissions from Household Waste 2010 - 2050 in Banjarbaru City

Calculation of GHG emission conversion resulting from household waste management in scenario 1 as BAU conditions with landfill and open burning, shows an increase every year as seen in the graph. Landfill waste disposal produces higher GHG emissions than open burning. The increase in CH₄ emissions has consistently occurred from 2010 to its peak in 2050, landfill disposal produces 9.114 Gg CO₂ eq and open burning produces 1.402 Gg CO₂ eq. In scenario 2 in 2024 as the existing condition, with composting activities in Recycling Processing and garbage dump 3R. The

contribution of composting to total GHG emissions is relatively small, namely 0.033 Gg CO₂ eq. GHG emissions from landfill disposal are higher than open burning, where in scenario 2 there is a decrease in emissions from open burning to 0.655 Gg CO₂ eq, this shows the initial impact of sustainable household waste management policy interventions. In scenario 3 in 2024-2050, there is a decrease in emissions from open burning reaching 0.95 Gg CO₂ eq in 2050, in line with the assumption that open burning activities continue to decrease every year. Composting activities fluctuate continuously

in terms of both the amount and contribution of emissions.

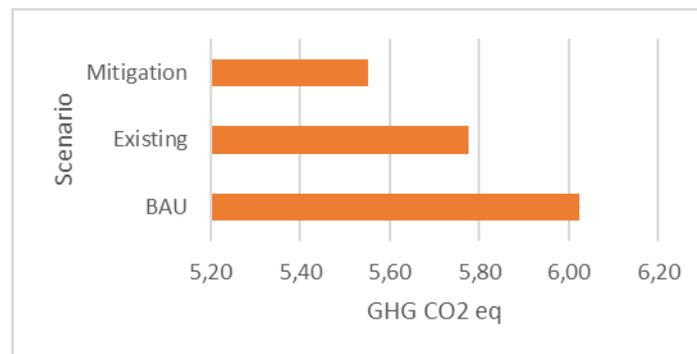


Figure 5. Comparison of GHG Emissions for Each Scenario in 2024

The calculation of the estimated GHG emissions analyzed from the three waste management scenarios, it can be concluded that scenario 1 (BAU) produces the highest GHG emissions, which is 6.02 Gg CO₂ eq in 2024. This occurs because in scenario 1 (BAU), the amount of household waste dumped in the landfill is quite high and the practice of open burning is still carried out with a percentage of 5.63%, which produces methane gas (CH₄), carbon dioxide (CO₂) and nitrous oxide (N₂O). Open burning alone contributes 0.936 Gg CO₂ eq. Scenario 2 (existing), GHG emissions are projected to reach 5.78 Gg CO₂ eq which shows a decrease of 4.11% in 2024 compared to the BAU scenario. This decrease in emissions comes from the implementation of the Banjarbaru City Jakstrada with a reduction in household waste by 30% and handling of household waste by 70% and management of organic waste through composting in Recycling Processing and garbage dump 3R. In line with the research results of Paramitadevi et al., (2022), it shows that waste reduction with the composting process at garbage dump 3R can reduce GHG emissions by 0.16%.

Scenario 3 (mitigation) the percentage of household waste reduction continues to increase every year and the percentage of open burning decreases, increasing composting and recycling. GHG emissions are projected to be lower, namely 5.55 Gg CO₂ eq This scenario has succeeded in

reducing GHG emissions by 7.81% from the BAU scenario. This shows that the implementation of sustainable waste management will have an impact on reducing GHG emissions that can be achieved significantly.

From the results of the analysis of greenhouse gas (GHG) emission calculations, scenario 3 (mitigation) which maximizes composting and recycling activities through 3R facilities at Recycling Processing and garbage dump 3R, is the best scenario that can be recommended. The implementation of this activity has been shown to have a significant influence in reducing the amount of waste dumped in the Final Processing Site. Effective waste management through composting organic waste and recycling non-organic waste has been proven to reduce greenhouse gas (GHG) emissions.

Data from the Ministry of Environment and Forestry, if all Indonesian people compost organic waste independently, around 10.92 million tons of organic waste will not enter the landfill and can contribute to reducing GHG emissions by 6.834 million tons of CO₂ eq each year (KLHK, 2023). This finding is in line with Lestari's research (2017), which shows that composting can reduce GHG emissions by 10.83% in 2030, as one solution to address the impacts of climate change. Also stated that the recycling and composting processes can reduce GHG emissions by 62.34% from BAU conditions,

which shows the great potential of both processes in reducing the contribution of the waste sector to global warming. Similar research was conducted by Romawati (2018), a case study in Bulak District estimated GHG emissions with the implementation of an ideal scenario through composting and recycling can reduce GHG emissions from 616.54 tons to 321.84 tons of CO₂ eq per year. Scenario 3 not only contributes to reducing GHG emissions, but also supports the achievement of Indonesia's Zero Waste Zero Emission goal in 2050. Therefore, a household waste management strategy is needed in Banjarbaru City in order to realize a household waste management system that is in line with scenario 3, which focuses on reducing the amount of waste dumped in landfills by increasing composting and recycling. To realize a more effective household waste management strategy in Banjarbaru City, a comprehensive analysis is needed regarding the factors that influence the implementation of household waste reduction, composting, and recycling at the local level. SWOT analysis can identify the strengths, weaknesses, opportunities, and challenges in implementing scenario 3.

CONCLUSION

The estimation of GHG emissions from household waste in Banjarbaru City using the Tier 2 approach shows that scenario 3 (mitigation) which optimizes composting and recycling through 3R facilities, has a significant impact on reducing GHG emissions from household waste in Banjarbaru City, with emission reductions of up to 7.81% in 2024 and an estimated 0.01283 Gg CO₂ eq in 2050. Scenario 3 is the best scenario in reducing GHG emissions, because it integrates sustainable waste management strategies and supports the achievement of Indonesia Zero Waste Zero Emission in 2050.

Declaration by Authors

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