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Inventory of Greenhouse Gas Emissions in the Energy Sector in Gili Iyang Island, Sumenep Regency Using the IPCC 2006 Method

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Abstract. Global warming comes from many human activities, such as the burning of fossil fuels and the use of energy can produce greenhouse gases. The energy sector itself is the largest contributor of greenhouse gases in the world. This study aims to determine the greenhouse gas emissions produced in the energy sector on Gili Iyang Island. To be able to determine the greenhouse gas emissions produced in the energy sector on Gili Iyang Island, the IPCC 2006 calculation method was used. In this method, primary data is needed in the form of data on energy and fuel consumption activities of residents and secondary data in the form of the number of families on Gili Iyang Island. In the stationary source itself, CO_2 gas emissions are produced at 1,438,259.903 Kg/Year, CH_4 gas at 206.751 Kg/Year, and N_2O gas at 12.486 Kg/Year. Meanwhile, moving sources produce CO_2 gas emissions of 510,339.051 Kg/Year, CH_4 gas of 191.363 Kg/Year, and N_2O gas of 20.969 Kg/Year. As for mitigation actions that can be taken based on its topography and climate, Gili Iyang Island has the potential to use solar panels and biogas as alternative energy and fuel sources to meet daily needs.

Keyword:

Energy, Gili Iyang, greenhouse gases, IPCC 2006, SDGs

1. Introduction

The extreme climate change has an impact on very unpredictable weather changes in several areas. The cause of climate change itself is global warming. Global warming itself can be defined as an increase in the earth's temperature or an increase in the average temperature of the atmosphere, sea, and land of the earth [1]. The increasing greenhouse effect on earth itself is caused by an increase in greenhouse gas levels on earth. Greenhouse gases can be defined as gases in the atmosphere that have the ability to absorb and re-emit long-wave radiation in the form of infrared radiation [2]. In the UN Convention on Climate Change, there are six types of greenhouse gases (GHG): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs). Other gases such as nitrogen oxides (NOx), chlorofluorocarbons (CFCs), and non-metal volatile organic gases are also GHGs [3]. According to the Agency for Policy, Climate and Industrial Quality Assessment, CO_2 contributes more than 75% to global warming, followed by CH_4. Greenhouse gases are produced both naturally and by human activities [4].

The use of fossil fuels in the energy and transportation sectors has been the main contributor to greenhouse gas emissions since pre-industrial times [5]. In addition to industry, natural processes such as denitrification and nitrification in the soil also produce greenhouse gases, an example of which is N_2O from the agricultural sector [6]. The energy sector is the main contributor to global greenhouse gases, influenced by population growth that increases energy consumption [7]. Vehicle combustion contributes about 95% of emissions, while air conditioning usage contributes 5%. Although global fossil fuel use has decreased from 86% in 1970 to 81% in 2004, fossil fuels still dominate as an energy source (more than 80%). In Indonesia, around 75% of energy needs come from non-renewable sources such as oil, coal, and natural gas. The energy sector at the global level is divided into power generation (24%), industry (14%), transportation (14%), construction (8%), and other energy sources (5%).

Each type of Greenhouse Gas (GHG) has a different Global Warming Potential (GWP), which measures its potential to cause global warming relative to CO_2 [8]. For example, CH_4 has a GWP of 21, which means it is 21 times more effective than CO_2 in causing global warming. The accumulation of GHG causes the greenhouse effect, where heat reflected from the earth's surface is trapped in the atmosphere, increasing the overall temperature [9]. This mechanism is similar to the greenhouse effect in a house, where heat is trapped inside. The increase in atmospheric temperature due to the greenhouse effect can cause negative impacts, including rising sea levels and extreme climate change, as well as adverse impacts on human health such as increased disease outbreaks and stress [10].

The IPCC 2006 Guidelines for National Greenhouse Gas Inventories establish a scientifically rigorous framework for quantifying GHG emissions and removals across multiple sectors—such as energy, industry, agriculture, land use, and waste management. Produced by the Intergovernmental Panel on Climate Change (IPCC), this framework promotes methodological consistency, ensuring that countries can produce comparable, transparent emissions data critical for global climate analysis. The guidelines employ a tiered structure, where higher tiers involve more complex, data-intensive calculations for enhanced accuracy, while lower tiers offer default factors for regions or sectors with limited data availability. By standardizing inventory practices, the IPCC 2006 methodology has become instrumental in supporting national GHG inventories, informing climate-related policy development, and enabling nations to meet global climate objectives, including those outlined in the Paris Agreement.

The IPCC 2006 Guidelines for National Greenhouse Gas Inventories are especially significant in studying greenhouse gas (GHG) emissions on small islands, where environmental sensitivity and resource limitations present unique challenges. These guidelines offer a standardized and adaptable framework that allows for accurate, scalable GHG estimation despite the varied and often limited data available on small islands. The tiered approaches within the IPCC method are particularly beneficial here, as they enable researchers to utilize both default emission factors and more precise, localized data where possible, providing flexibility. Small islands, often highly vulnerable to climate change impacts, can use this methodology to monitor emissions from sectors crucial to their economies and environments—such as agriculture, land use, and waste—more effectively. By adopting the IPCC 2006 methods, small islands can produce reliable emissions inventories, aiding in climate mitigation strategies, and also contributing valuable data to global climate assessments. This consistent, credible data helps drive informed policy decisions tailored to small island needs, facilitating their efforts to participate in international climate commitments and improve resilience to climate change impacts.

This study is aimed to determine the greenhouse gas emissions produced in the energy sector on Gili Iyang Island. This study was conducted using the 2006 IPCC Tier-1 greenhouse gas calculation method, which is a standard for inventorying greenhouse gas emissions and absorption from various sectors [11]. This method, issued by the UN IPCC, is the standard used by countries that ratify the UNFCCC. IPCC 2006 requires activity data and emission factors to calculate greenhouse gas emissions [12]. Tier-1 was chosen based on the availability of existing primary and secondary data [13]. This study is important to be conducted on Gili Iyang Island, so that the community and the Sumenep Regency government can determine mitigation actions to maintain the sustainability of Gili Iyang Island.

2. Methodology

2.1 Data Collection

The research, conducted from February to April 2024, integrated both primary and secondary data sources to evaluate greenhouse gas emissions on Gili Iyang Island. Over a two-week period, primary data were gathered through questionnaires distributed among randomly selected local residents. These questionnaires captured information on activities directly or indirectly contributing to emissions, focusing on key variables such as vehicle type and fuel used, type of cooking fuel, monthly electricity consumption, and fuel usage. From this, a sample size of 100 respondents was determined. Secondary data from the Central Bureau of Statistics (BPS) in Sumenep provided essential demographic data, including the total number of families residing on the island, enabling accurate population-based assessments.

2.2 Data Analysis

Following data sampling, this study advances to processing the collected primary and secondary data, obtained through direct sampling and surveys. Data processing employs the IPCC 2006 guidelines, using the default calculation formula specified for Tier-1 methodology. This approach ensures consistency with international standards and provides a foundational level of accuracy for emission estimations. The selected formula applies standardized factors to quantify the data accurately, allowing for reliable comparisons with similar studies. The processed results will then inform the study's analysis, ensuring that findings are supported by methodologically sound data interpretation aligned with the IPCC's environmental assessment framework.

$$\text{GHG} = \text{Energy Consumption} \times \text{Emission Factor} \quad (1)$$

GHG : $CO_2/CH_4/N_2O$ emission (kg/year)

Energy consumption : The amount of fuel consumed (Tj/year)

Emission factor : Emission factor of $CO_2/CH_4/N_2O$ based on the fuel type (kg/Tj)

The equation was applied across several sectors to estimate greenhouse gas emissions, providing a comprehensive assessment of environmental impacts. It was used to calculate CO_2 emissions specifically in the road transportation sector and to estimate CH_4 and N_2O emissions within the same sector. Additionally, the equation was employed to evaluate CO_2, CH_4, and N_2O emissions in the water transportation sector. For the household sector, the formula assessed emissions of CO_2, CH_4, and N_2O as well. Lastly, it was used to estimate emissions of CO_2, CH_4, and N_2O resulting from electricity consumption, ensuring a robust cross-sectoral emissions analysis. Emission factors refer to values established by IPCC 2006.

3. Results

This study was conducted with the aim of determining the amount of Greenhouse Gas (GHG) emissions resulting from the activities of the Gili Iyang Island community in the energy sector. The Greenhouse Gas (GHG) parameters analyzed in this study include CO_2, CH_4, and N_2O gases. The study was conducted using a questionnaire approach that was distributed to 100 samples of Gili Iyang Island residents from the two villages on Gili Iyang Island to track the use of fuels other than liquid petroleum gas (LPG) and to determine the average fuel consumption in each family, as well as distributing questionnaires to grocery stores as providers of energy sources or fuel oil and gas to determine data on fuel oil and gas consumption on Gili Iyang Island. In addition, this study also conducted an interview session with the manager of the Diesel Power Plant (PLTD) of Gili Iyang Island to obtain data on energy consumption and electricity generated by the PLTD as the primary source of electricity for Gili Iyang Island residents.

3.1 Greenhouse Gases from Stationary Sources

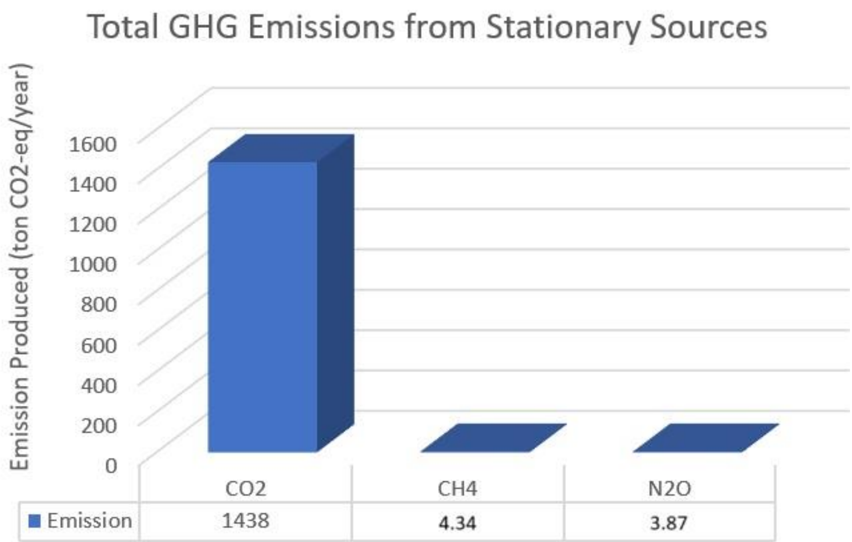

Figure 1. GHG emissions estimated from stationary sources

Based on the results of processing Greenhouse Gas (GHG) emission data on each fuel use for each Greenhouse Gas (GHG), it shows that the Greenhouse Gas emissions produced at stationary sources are mostly CO_2 gas with a value of 1,438,259.903 Kg/Year or 1,438

Tons/Year. Then followed by CH_4 gas of 206.751 Kg/Year or equivalent to 4,341.77 Kg CO_2-eq or 4.34 Tons CO_2-eq, and finally N_2O gas of 12.486 Kg/Year or equivalent to 3,870.30 Kg CO_2-eq or 3.87 Tons CO_2-eq, with total CO_2-eq emissions of 1,446,472.382 CO_2-eq or 1,446 Tons CO_2-eq. The high CO_2 Greenhouse Gas emissions are the result of fuel combustion activities to meet the energy needs of residents. In addition, the high CO_2 emission factor value in the energy sector also affects the CO_2 gas emissions produced. Where, this shows that in the energy sector, the most greenhouse gas emissions are CO_2 gas.

3.2 Greenhouse Gases from Mobile Sources

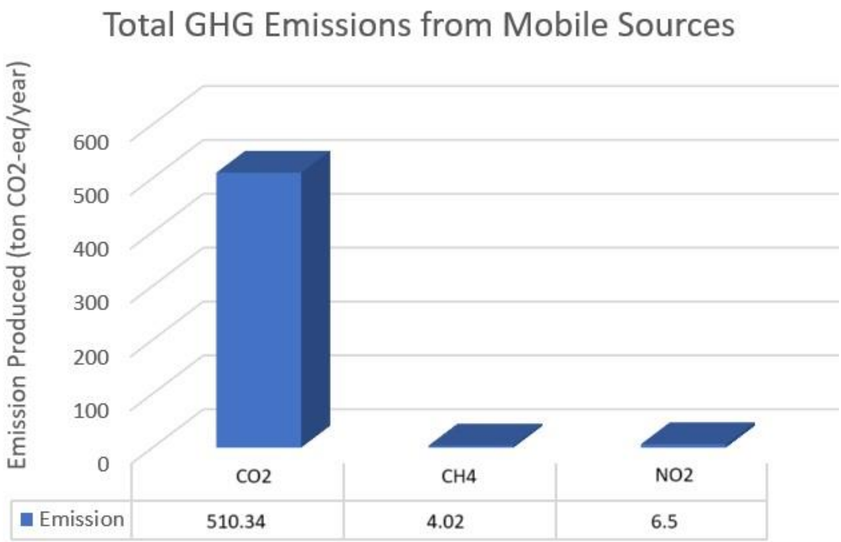

Figure 2. GHG emissions estimated from mobile sources

Based on the diagram produced, it shows that carbon dioxide gas is the highest greenhouse gas produced from moving sources (transportation). Where, CO_2 gas emissions from moving sources themselves are produced by 510,339.051 Kg/Year or 520.34 Tons/Year. This is because there is a combustion process in transportation engines. The combustion activity itself mostly produces carbon dioxide gas and a small amount of methane and nitrous oxide. The second largest greenhouse gas emissions produced by moving sources is CH_4 gas, with a value of 191,363 or equivalent to 4,018.63 Kg CO_2-eq or 4.02 Ton CO_2-eq. The greenhouse gas with the smallest amount in mobile sources is N_2O gas, with an amount of 20.969 Kg/Year or equivalent to 6,500.46 Kg CO_2-eq or 6.5 Ton CO_2-eq. The total greenhouse gas emissions in mobile sources on Gili Iyang Island are 520,858.146 Kg CO_2-eq or 520.858 Ton CO_2-eq.

4. Discussion

4.1 Impacts of Greenhouse Gas Emission on Gili Iyang Island’s Sustainability

Gili Iyang Island, often dubbed the "Island of Oxygen" for its exceptionally clean air, stands as a natural haven with a distinct ecological and social identity. However, the island's sustainability faces increasing threats from its surge in greenhouse gas (GHG) emissions. This discussion explores the multifaceted impacts of GHG emissions on Gili Iyang Island, focusing on environmental, social, and economic dimensions.

One of the most immediate consequences of increased GHG emissions would be the alteration of Gili Iyang’s climate. Rising global temperatures, driven by carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), have led to changes in local weather patterns [14].

These changes include shifts in rainfall intensity and frequency, exacerbating both drought and flooding risks. For an island community reliant on agriculture and freshwater from rain-dependent systems, such variability threatens water availability and crop productivity [15]. Prolonged droughts strain limited freshwater reserves, while intense rains increase the likelihood of soil erosion and flooding, disrupting local livelihoods [16].

Sea-level rise, a direct consequence of global warming, is likely to present a significant threat to Gili Iyang's coastal integrity [17]. The melting of polar ice caps and thermal expansion of seawater have led to gradual encroachment of the sea onto low-lying coastal areas. This process results in the loss of arable land and habitats for local biodiversity. Saltwater intrusion further aggravates freshwater scarcity, affecting both human consumption and agricultural activities [18]. As a small island, Gili Iyang has limited capacity to adapt to such changes, making it particularly vulnerable to even modest increases in sea levels.

Biodiversity on Gili Iyang, a key component of the island's ecological sustainability, is also prone to suffering under the weight of GHG emissions. Changes in temperature and precipitation patterns disrupt habitats and migration patterns of local flora and fauna [19]. For example, mangrove forests, which act as natural buffers against coastal erosion and support marine life, face degradation due to rising sea levels and increased salinity [20]. Similarly, coral reefs surrounding the island experience bleaching events driven by warmer ocean temperatures [21]. These ecosystems' decline not only impacts biodiversity but also diminishes the island's natural defenses against environmental hazards [22].

Social implications of GHG emissions on Gili Iyang are equally profound. The island's reputation as a health and wellness destination, rooted in its pristine air quality, is bound to face challenges as global emissions affect air and water quality. Pollution from its own area and transboundary pollution from neighboring regions with increased levels of particulate matter pose risks to respiratory health [23], undermining the island's unique identity. Furthermore, changes in climate conditions necessitate adaptive strategies among the local population. Traditional agricultural practices, which have sustained generations, may become obsolete as crop yields decline and pest infestations rise [24], forcing communities to seek alternative livelihoods.

Economic repercussions are intertwined with these environmental and social challenges. Tourism, a significant contributor to Gili Iyang's economy, is highly sensitive to climate change [25]. The island's allure lies in its natural beauty, clean air, and biodiversity. However, degradation of coral reefs, coastal erosion, and declining biodiversity deter tourists, leading to revenue losses [26]. Moreover, increased costs of adaptation—such as investing in seawalls, freshwater desalination systems, and sustainable agricultural practices—place additional financial burdens on the local government and community.

The compounding effects of GHG emissions also exacerbate social inequalities on the island. Vulnerable groups, including small-scale farmers and fishers, bear the brunt of environmental changes due to their dependence on natural resources [27]. Limited access to financial and technical resources further constrains their ability to adapt, increasing disparities within the community. Additionally, migration from Gili Iyang to mainland regions in search of better opportunities could lead to the erosion of cultural heritage and traditional knowledge unique to the island [28].

4.2 Greenhouse Gas Emission of Other Small Islands in Tropical Regions

The greenhouse gas emissions profile of Gili Iyang Island, consisting of 510,339.051 kg/year from mobile sources and 1,438,259.903 kg per year from stationary sources, highlights a relatively modest emission level compared to larger tropical islands. In small tropical islands, GHG emissions often vary significantly based on population size, infrastructure, and economic activities [22]. For instance, islands with extensive industrial or tourism sectors generally exhibit higher emissions from stationary sources, such as power generation and industrial facilities [29]. Conversely, islands with high population density and transportation demands may report elevated emissions from mobile sources, such as vehicles and boats [30].

Compared to Gili Iyang, which relies on smaller-scale activities and retains a relatively low emission footprint, other tropical islands like the Maldives, Fiji, and Mauritius face greater challenges due to their reliance on fossil fuels for energy production and transportation [31]. The Maldives, for example, emits higher levels of CO_2 per capita due to its dependence on diesel generators for electricity and extensive aviation-based tourism. With its chain of small islands catering to global tourism, energy demands are substantial, and infrastructure is heavily reliant on imported fossil fuels [32]. Similarly, Fiji's transportation sector contributes significantly to its overall emissions, given its geographic reliance on inter-island shipping and air travel. A large percentage of emissions in Fiji arise from maritime transportation, which is integral to the movement of goods and people across its many islands [33].

Mauritius, another tropical island heavily dependent on tourism, faces a distinct emissions challenge. It generates the bulk of its electricity from coal and oil, leading to high stationary source emissions [34]. The sugarcane industry, a major economic contributor, also adds to emissions through energy-intensive processes and methane release from agricultural practices [35]. Despite efforts to integrate renewable energy, such as wind and solar, these sources still constitute a minority share of the energy mix.

In the Caribbean, islands like Jamaica and Barbados also offer a point of comparison. Jamaica's stationary source emissions are predominantly linked to energy production from fossil fuels, as the island imports nearly all its energy needs. The industrial sector, particularly bauxite and alumina production, contributes additional emissions [36]. Mobile source emissions, although moderate, are compounded by the heavy reliance on imported vehicles, often with outdated emission standards. In Barbados, the tourism-driven economy similarly relies on fossil fuel-based electricity and significant air travel emissions [37]. The small size of the island limits the viability of large-scale renewable energy projects, further entrenching reliance on fossil fuels.

While Gili Iyang's emissions are lower than these examples, they are not negligible in the context of its sustainability. The combination of 510 ton per year from mobile sources and 1,438 ton per year from stationary sources reflects a growing need to transition toward renewable energy and cleaner transportation options. Reducing emissions from stationary sources could involve scaling up solar or wind energy, given the island's favorable climatic conditions. The steady availability of sunlight and wind positions Gili Iyang to adopt renewable energy technologies more effectively than islands with less predictable weather patterns. Investing in microgrid systems powered by renewable energy could provide a sustainable and resilient alternative to conventional fossil fuel-based power systems.

Mobile emissions on Gili Iyang are primarily attributed to vehicles and small boats used for local transportation and fishing activities. These emissions could be curbed through the adoption of electric vehicles and the promotion of non-motorized transport systems, such as bicycles. Introducing electric motorboats or hybrid-powered vessels for fishing and inter-island travel could significantly reduce dependence on fossil fuels. Furthermore, enhancing public transportation options, such as electric minibuses, could reduce individual vehicle use and associated emissions.

The broader comparison of tropical islands underscores the diversity of challenges and opportunities in managing GHG emissions. For instance, Seychelles has made significant strides in integrating renewable energy into its energy mix despite its small size. Government incentives and international partnerships have facilitated the installation of solar panels and the development of wind farms [38]. While Seychelles' emissions remain relatively low, these proactive measures highlight the potential for small islands to become models of sustainability.

Kiribati, another small island nation, offers a stark contrast. With minimal industrial activity, its emissions are among the lowest globally. However, the nation faces existential threats from sea-level rise and climate change, underscoring the disproportionate impact of global emissions on vulnerable island communities [39]. Kiribati's government has taken steps to raise international awareness and advocate for stronger global commitments to reduce emissions.

The success stories of islands like Seychelles demonstrate that Gili Iyang can similarly leverage its strengths to transition toward a sustainable future. Partnerships with international organizations could provide technical and financial support for renewable energy projects and emissions reduction initiatives [40]. Additionally, local policies that incentivize clean energy adoption and sustainable transportation could create a foundation for long-term sustainability.

While Gili Iyang's GHG emissions are modest compared to many other tropical islands, the island must remain proactive in addressing its environmental footprint. The combination of renewable energy integration, cleaner transportation options, and community-driven initiatives can position Gili Iyang as a leader in sustainability among small islands. By drawing lessons from other tropical islands and leveraging its unique ecological and cultural assets, Gili Iyang can ensure a resilient and sustainable future in the face of global climate challenges.

4.3 Potential Mitigation Actions

Small islands often face unique challenges due to their size, geographic isolation, and limited resources [41]. They are particularly vulnerable to the impacts of climate change, such as rising sea levels, extreme weather events, and biodiversity loss [42]. Therefore, effective mitigation strategies are crucial for their sustainable development. Specific mitigation actions include installing hybrid solar panels, biogas utilization, and maximizing the use of LPG [43].

Hybrid solar panels are systems that combine photovoltaic (PV) panels, which convert sunlight into electricity, with other technologies, such as solar thermal panels, which capture heat from the sun [44]. For small islands, harnessing solar energy can be highly beneficial due to their abundant sunlight [45]. By maximizing energy production and providing both electricity and heat, hybrid solar panels can significantly enhance energy efficiency. This can reduce reliance on imported fossil fuels, which are often costly and difficult to obtain [46]. Furthermore, the use of hybrid solar panels can lower greenhouse gas emissions and improve energy security for small island communities.

Biogas is produced from the anaerobic digestion of organic matter, such as agricultural waste, manure, and food scraps, and serves as a renewable energy source [47]. Small islands often generate significant amounts of organic waste, which can be converted into biogas [48]. Utilizing biogas provides a sustainable energy source and helps manage waste effectively. This process reduces methane emissions from landfills, contributing to environmental conservation [49]. Additionally, biogas production can enhance energy independence and resilience for small island communities.

LPG is a cleaner-burning fuel compared to traditional biomass or coal, and it can be used for cooking, heating, and other household energy needs [50]. Transitioning to LPG in households can significantly reduce indoor air pollution and greenhouse gas emissions [51]. For small islands that may rely heavily on wood or other biomass for cooking, LPG offers a more sustainable and health-friendly alternative [52]. The shift to LPG can improve air quality and reduce the health risks associated with indoor pollution. Using LPG helps to preserve local ecosystems by reducing the need for biomass collection [53].

By adopting these technologies, small islands can reduce their dependence on imported fossil fuels, which are often costly and subject to supply disruptions. These actions help lower greenhouse gas emissions, contributing to global efforts to combat climate change and protecting the fragile ecosystems of small islands. Investing in renewable energy and biogas can create local jobs and stimulate economic growth [54]. Efficient waste management and energy systems can lower overall costs in the long term [55]. Enhancing energy efficiency and sustainability can improve the resilience of small island communities against climate change impacts and other external shocks.

4. Conclusion

Greenhouse gas emissions in the energy sector on Gili Iyang Island itself are generated from two sources, stationary and mobile sources. Stationary sources produce CO_2 greenhouse gas emissions of 1,438,259.903 Kg/Year, CH_4 gas of 206.751 Kg/Year, and N_2O gas of 12.486 Kg/Year which are produced through food producing activities and the use of diesel engines to meet electricity needs. Mobile sources produce CO_2 greenhouse gases of 510,339.051 Kg/Year, CH_4 gas of 191.363 Kg/Year, and N_2O gas of 10.969 Kg/Year which are produced through driving activities or combustion in vehicle engines. Mitigation actions that can be taken according to greenhouse gas estimation information are installing hybrid solar panels, biogas utilization, and maximizing the use of LPG as fuel in the household sector.

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