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Estimation of Potential Greenhouse Gases from the Agriculture and Livestock Sectors

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ABSTRACT

Greenhouse gas emissions from the agricultural sector, including methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), contribute significantly to climate change. This study aims to estimate the potential greenhouse gas emissions from the rice agriculture subsector and livestock subsector in Sigi Biromaru District, Sigi Regency, Indonesia, and identify effective mitigation measures. A descriptive survey was conducted using questionnaires administered to farmers in the district. Data on agricultural practices, including water regime, fertilizer use, and manure management, were collected. Additionally, data on the number of livestock and the average weight of livestock were obtained from the Livestock and Animal Health Office of Sigi Regency, while data on the area of rice farming land was obtained from the Horticulture and Plantation Food Crops Office of Sigi Regency. The estimated potential greenhouse gas emissions from the agricultural sector in 2022 amounted to 24,277.39 tons of CO_2 eq, with the rice agriculture subsector contributing 14,538.08 tons of CO_2 eq (59.88%) and the livestock subsector contributing 9,739.31 tons of CO_2 eq (40.12%). Methane (CH_4) accounted for the largest proportion of emissions, reaching 22,911.45 tons of CO_2 eq (94.37%), followed by nitrous oxide (N_2O) at 1,303.64 tons of CO_2 eq (5.37%) and carbon dioxide (CO_2) at 62.30 tons of CO_2 eq (0.26%). The agricultural sector in Sigi Biromaru District is a significant source of greenhouse gas emissions, with methane from rice cultivation and livestock manure management being the major contributors.

1. INTRODUCTION

Global warming is a pressing global issue that has led to the formation of the 2015 Paris Agreement, which replaced the 2005 Kyoto Protocol. This agreement serves as a framework for collaboration between developed and developing countries to tackle the challenges of global warming and climate change. Under this agreement, every country, including Indonesia, is obligated to contribute to reducing greenhouse gas (GHG) emissions [1].

Indonesia is a significant contributor to GHG emissions from various sectors, with agriculture being a major source. Agricultural and animal husbandry practices are responsible for the release of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) [2]. These gases are naturally produced by living organisms, both plants and animals. The agricultural sector is a significant contributor to atmospheric GHG emissions [2]. Research has shown that the agricultural sector accounts for 10-12% of total anthropogenic GHG emissions, while the livestock sector contributes around 18-51% of anthropogenic GHG emissions, primarily in the form of methane (CH_4) [3].

Several studies have investigated GHG emissions from the agricultural sector in various regions. Mustikaningrum et al. [4] conducted a study in Tuban Regency, Indonesia, using the IPCC Tier-1 calculation method for 2006. Their findings indicated that the agricultural sector in Tuban Regency emitted 1,665.67 Gg CO_2-eq in 2019, with the agricultural sub-sector contributing 1092.50 Gg CO_2-eq and the livestock sub-sector contributing 573.17 Gg CO_2-eq. Similarly, Purnamasari et al. [5] employed the IPCC tier 1 method in 2006 to assess GHG emissions in Boyolali District, Indonesia and found that lowland rice cultivation accounted for as much as 53.64% of CH_4 emissions. In another study, Sasmita et al. [6] utilized the Tier1 IPCC method in 2006 to investigate GHG emissions in Kampar District, Indonesia and revealed that 97.92% of GHG emissions originated from the livestock sector.

Researchers have also examined changes in GHG emissions over time. Adinatha and Arif [7] studied GHG emissions in the city of Bogor, Indonesia, using Tier-1 IPCC in 2006 and found a decrease in emissions between 2014 and 2020. This reduction was attributed to a decline in activity due to the COVID-19 pandemic and the increasing dominance of land use for housing and parks. Similarly, Lintangrino and Boedisantoso [8] employed the IPCC Tier-1 method in 2006 to analyze GHG emissions in Surabaya City, Indonesia. Their findings indicated that the livestock sector contributed 89.92 Ton CO_2-eq/year, while the agricultural sector emitted 6.1 Ton CO_2-eq/year. The total GHG emission burden for Surabaya City was estimated to be 93 Ton CO_2-Eq/year.

While previous research has provided valuable insights into GHG emissions from the agricultural sector in various regions, there remains a need for further investigation to address specific gaps in the existing knowledge. One area that requires more attention is the identification of factors that contribute to variations in GHG emissions across different regions. Additionally, a more comprehensive understanding of the impact of different agricultural practices and livestock management systems on GHG emissions is needed.

The potential for the population to produce greenhouse gas emissions (GHG) is predicted to grow. The reason is the increasing population and the need for food caused by the use of marginal land and increased meat consumption [9]. Prevention of greenhouse gas emissions explosion requires attention to producing greenhouse gases (GHG) from the agricultural and livestock sectors. The first step in making a strategy to reduce greenhouse gas emissions is to carry out an inventory of emission estimates [10]. The emission inventory is a comprehensive recording of air pollutant parameters from sources within a certain area and period of time. According to Article 6, paragraph 4, Indonesian government regulation no 41 of 1999 contains provisions for the need for emission inventory activities.

Central Sulawesi, especially Sigi Regency, has a large potential for greenhouse gas emissions because it has large farms and a wide area of rice fields [11]. In the process of facilitating the establishment of policies regarding the control of greenhouse gas emissions, the results of the emission inventory need to be mapped. Mapping the burden of greenhouse gas emissions using a Geospatial information system, namely mapping using maps by region with a color scale to make it easier to read [12]. With the mapping of the load of greenhouse gas emissions resulting from the inventory, a mitigation plan in the form of efficient greenhouse gas control in the area can be carried out.

Addressing the research gaps identified is crucial for developing effective strategies to mitigate GHG emissions from the agricultural sector. By gaining a deeper understanding of the factors influencing GHG emissions and the impact of various agricultural practices, policymakers and stakeholders can make informed decisions to reduce GHG emissions and contribute to climate change mitigation efforts. The primary objective of this study is to inventory the GHG emission burden from the agricultural sector, including the agriculture and livestock sub-sectors, in Sigi Biromaru District, Central Sulawesi, Indonesia, for the year 2022.

2. METHOD

This research was conducted in the Sigi Biromaru District, one of the districts in Sigi Regency, Central Sulawesi Province. The area reaches 289.6 km^2 [13]. Administratively it is within Sigi Regency. A detailed map of the research location is presented in Figure 1. The survey method was chosen as the most appropriate data collection method for this study as it allowed for the collection of detailed information on a wide range of variables related to agricultural practices and livestock management. The use of a structured questionnaire ensured that all participants were asked the same questions, facilitating consistent and reliable data collection. The Kreicjie & Morgan sample calculation formula was used to determine the sample size, ensuring that the sample was representative of the population of farmers and breeders in Sigi Biromaru District. Informed consent was obtained from all participants prior to their participation in the study. The anonymity and confidentiality of participants were protected throughout the research process.

Figure 1. Research location (kotakita.com)

Types of data and data sources can be seen in Table 1.

Data processing was carried out using Microsoft Excel 2016 software and the preparation of article manuscripts using Microsoft Office 2016 software. Descriptive methods were used to analyze the results of data processing. Data processing uses guidelines adopted from the IPCC Guidelines 2006 Tier-1. The data was cleaned and organized to ensure accuracy and consistency. Descriptive statistics, such as frequencies, means, and percentages, were used to summarize the data. The data was also analyzed to identify patterns and relationships between different variables.

One of the scientific institutions established by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP / United Nations Environment Program) is the IPCC [14]. This method was chosen as it is a widely recognized and accepted methodology for GHG emission estimation. The use of this methodology ensured that the results of this study were comparable to other studies that have used the same methodology. Tier 1 was designed for simple calculations, where equations and default parameter values (e.g., emission factors and change in carbon stock) are provided and can be used. This method required country-specific activity data, but for tier 1 there were often globally available sources of activity data (e.g., deforestation rates, livestock production statistics, etc.), although these were usually crude data [11].

Table 2 shows the three greenhouse gases' concentration periods and global warming potential values. Carbon dioxide has the longest residence time in the atmosphere among the three greenhouse gases, 5 to 2000 years. Nonetheless, N_2O has the highest global warming potential value, 298 times the potential of CO_2. So even though the amount of N_2O emitted into the atmosphere is smaller than CO_2, its greater global warming potential will cause a higher global warming effect than CO_2 or CH_4 [11].

Table 1. Sources of data and types of data used in this study

No.	Variable	Type of Data	Source of Data
1	Methane from Rice cultivation	**Secondary Data** • Land area according to irrigation (Ha) • Harvested area (Ha) • Rice emission factor **Primary data** • Water Regime Scale Factor • Rice Varieties • Fertilizer use	• TPHP Office of Sigi Regency • TPHP Office of Sigi Regency • IPCC Literature Study 2006 • Questionnaire • Questionnaire • Questionnaire
2	Direct and indirect emissions of N_2O from the ground	**Primary data** • N Fertilizer Composition (%) • Dosage of manure (Kg/Ha) • Dosage of Inorganic N Fertilizer (Kg/Ha) **Secondary Data** • Planted area (Ha) • N content in manure and inorganic fertilizers (%) • Emission factors for irrigated paddy fields • Dryland emission factors	• Literature review • Questionnaire • Questionnaire • TPHP Office of Sigi Regency • Literature review • IPCC Literature Study 2006 • IPCC Literature Study 2006
3	Urea fertilization	**Primary data** • Use of Urea **Secondary Data** • Extensive planting area • Urea Emission Factor	• Questionnaire • Department of Agriculture • IPCC 2006
4	Enteric Fermentation	**Secondary Data** • Livestock Population • Emission factors for enteric fermentation	• District PKH Office. Sigi • IPCC Literature Study 2006
5	Livestock waste processing	**Secondary Data** • Livestock population (beef cattle, dairy cows, buffaloes, goats, pigs, horses, sheep, free-range chickens, broilers, laying hens, ducks), in head unit. • Emission Factor of manure processing • Average weight of cattle (Kg) **Primary data** • Livestock manure management	• District PKH Office. Sigi • IPCC Literature Study 2006 • PKH Extension • Questionnaire

Table 2. Value of global warming potential and residence time of greenhouse gases from agricultural land

Gases	Period of Concentration in the Atmosphere (Year)	Global Warming Potential (CO_2 Conversion Value)
CO_2	5-2.000	1
CH_4	12	23
N_2O	114	298

3. RESULTS AND DISCUSSION

3.1 Estimation of potential greenhouse gas emissions from the rice agriculture sub-sector

In the agricultural sub-sector, especially rice farming, the emission burden can be calculated in three categories: emission load from paddy field cultivation, the use of urea fertilizer, and soil management in paddy field cultivation. The sub-total estimated GHG emissions from the rice farming sub-sector in Sigi Biromaru District in 2022 can be seen in Table 3.

Table 3 shows the estimated emission load for the rice farming sub-sector, with a sub-total emission load of 14,538.08 Ton CO_2 eq in 2022 from a harvested area of 633.5 Ha, Obtained an average estimated emission load of 22.96 tons of CO_2 eq hectare. The largest estimated emission load is in Pombewe village, which is 4146.05 Ton CO_2 eq with an agricultural land area of 155 Ha, while the smallest estimated emission load is in Kalukubula village of 2223.72 Ton CO_2 eq with an agricultural land area of 95 Ha. In contrast, the villages of Ngatabaru, Jono, Sidondo 1, Sidondo 3, and Lolu do not have an estimate of the potential for greenhouse gases because these villages will not have rice farming land in 2022 due to difficulties. It obtains water from irrigation damaged by the earthquake natural disaster in 2018.

The estimated GHG emission load in the Sigi Biromaru district is above the average value of districts in Central Sulawesi, where the 2021 Central Sulawesi GHG inventory report obtained an estimated emission load of 1,214,890 tons of CO_2 eq with an average rate for each district in Central Sulawesi of 8,264.56 tons of CO_2 eq [11]. The high value of the estimated GHG emission load from rice cultivation in Sigi Biromaru Subdistrict is because the area of agricultural land owned by Sigi Biromaru subdistrict is above the average area of agricultural land owned by each subdistrict in Central Sulawesi Province [13].

Table 3 shows that the land area is directly proportional to the estimated emission load from the rice cultivation management. The study estimated the GHG emission load from rice cultivation in Mpanau Village, which is larger than Loru Village. The estimated emission load data in Loru Village in 2022 is 2455.65 Ton CO_2 eq with a planted area of 282.95 Ha, while in Mpanau Village, the estimated emission load in 2022 is 2575.50 Ton CO_2 eq with a planted area of 236.96 Ha. This is because, in Loru Village, some farmers grow varieties that produce fewer GHG emissions. Data can be seen in Appendix 4 of this study, and then farmers are already dominant in implementing an irrigation system with a regime of drying water and irrigation many times. Data can be seen in Appendix 3 of this study. The use of varieties and regime systems during rice cultivation greatly influences the potential for CH_4 emissions. The same thing was also stated by Nihayah et al. [15]. Rice varieties and water regime during cultivation will affect the process of CH_4 gas emission. Varieties with shorter ages will produce fewer emissions, and cultivation with a regular irrigation system can save water use and minimize the process of releasing CH_4 gas.

Rice plants release Greenhouse Gases through the plant aerenchyma vessels [16]. The ability to release CH_4 varies, depending on the characteristics of rice varieties, such as nature, age, and root activity. Rice with more tillers will increase the number of aerenkima, so the CH_4 gas emission will be greater. Long-lived varieties produce greater CH_4 emissions than short-lived varieties. This is related to the life cycle of rice plants. The longer the period of plant growth, the more exudate and root biomass are formed so that the CH_4 gas emission becomes higher.

Martono [17] stated that using urea fertilizer in agricultural cultivation causes the release of CO_2 bound during the fertilizer manufacturing process. Urea ($CO(NH_2)_2$) is converted to ammonium (NH_4^+), hydroxyl ion (OH^-), and bicarbonate ion (HCO_3^-) in the presence of water and the enzyme urease. Table 3 shows the estimated emission load for the rice farming sub-sector from the category of urea fertilizer use, resulting in a sub-total emission load of 62.30 Ton CO_2 eq in 2022 from a harvested area of 633.5 Ha. The estimated average emission load is 0.09833 Ton CO_2 eq per hectare. The largest estimated emission load is in Pombewe village, which is 17.54 Ton CO_2 eq with a harvested agricultural land area of 155 Ha, while the smallest estimated emission load is in Kalukubula village, about 8.8 Ton CO_2 eq with a land area of 95 Ha. The villages of Ngatabaru, Jono, Sidondo 1, Sidondo 3, and Lolu do not have an estimated emission load because these villages will not have rice farming land in 2022 due to the difficulty of obtaining water from irrigation that has been damaged by the earthquake natural disaster in 2018.

Table 3 shows that if the dosage of urea fertilizer is the same, the area of agricultural land is directly proportional to the estimated emission load from the use of urea fertilizer. Safitri [18]'s research on the potential for greenhouse gases in paddy rice fields in the western part of Sleman Regency, the Special Region of Yogyakarta, it was stated that districts that have a large dose of urea fertilizer will produce greater GHG emissions, while smaller doses of fertilization will result in a smaller estimated emission value. This happened in Pombewe Village, which obtained 17.54 Tons of CO_2 eq with an area of 155 Ha of harvested agricultural land with a dose of 216.65 kg/Ha of urea, while Sidondo 2 Village obtained 14.34 Tons.

Table 3 shows the amount of direct and indirect N_2O emissions from land management in Pombewe Village obtained 218.76 tons of CO_2 eq with an agricultural land area of 155 ha at a dose of 216.65 kg/ha of urea, while Sidondo 2 village obtained 178.25 tons of CO_2 eq with an area of 162 ha of harvested agricultural land at a dose of 212.47 kg/ha. Table 3 shows that if the fertilization doses are the same, the area of agricultural land is directly proportional to the estimated N_2O emissions from land management. However, a smaller fertilization dose will result in a smaller estimated emission value due to differences in fertilization doses. The research on inventorying greenhouse gas emissions in the agricultural sector in Boyolali Regency [5], where in the research, it was found that districts with less use of chemical fertilizers would produce smaller N_2O emissions, the use of NPK fertilizers could be reduced by increasing the use of organic fertilizers such as compost or manure as stated by Anggri Hervani [19] in the study of N_2O emissions on fallow green bean planting by hammer planting.

Table 3. Estimated sub-total GHG emissions from the agricultural sub-sector in Sigi Biromaru District in 2022 in units of Ton CO_2-eq

No	Village	Paddy Field Area (Ha)	Paddy Field Annual CH_4 Emissions	Annual CO_2 Emissions from Urea Fertilization	Direct N_2O Emission Annual from Land Management	Indirect N_2O Emission Annual from Land Management	Total Emissions from the Rice Farming Sub-Sector
1	Kalukubula	95	2098.88	8.80	96.77	18.27	**2222.72**
2	Mpanau	94	2575.50	9.73	103.66	19.61	**2708.51**
3	Pombewe	155	3909.75	17.54	183.93	34.84	**4146.05**
4	Sidondo II	162	2645.82	14.34	149.86	28.39	**2838.41**
5	Loru	127.5	2455.65	11.88	130.26	24.60	**2622.39**
6	Ngatabaru	0	0	0	0	0	**0.00**
7	Jono	0	0	0	0	0	**0.00**
8	Sidondo 1	0	0	0	0	0	**0.00**
9	Sidondo 3	0	0	0	0	0	**0.00**
10	Lolu	0	0	0	0	0	**0.00**
Sub Total		**633.50**	**13685.60**	**62.30**	**664.48**	**125.70**	**14538.08**
Estimated Average GHG Emissions per Ha of Paddy Land/ Year							**22.96**

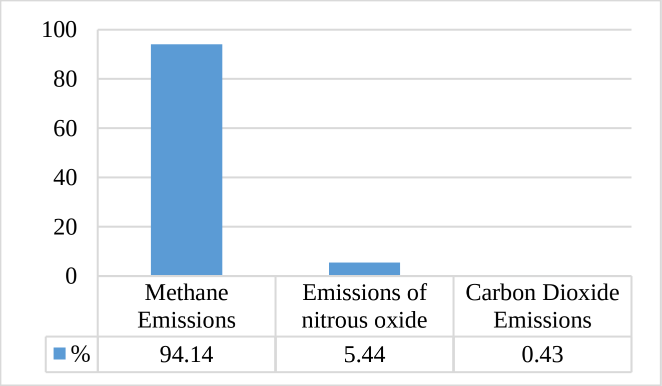

Figure 2. Diagram of GHG emission composition by type of emission gas in 2022 from the agricultural sub-sector in Sigi Biromaru District

Figure 2 shows that the percentage of methane gas (CH_4) emissions of 94.14% are the most greenhouse gas emitted from the rice farming sub-sector, followed by nitrous oxide (N_2O) gas emissions of 5.44% and finally, carbon dioxide gas (CO_2) emissions of 0.43%. Purnamasari et al. [5] research also showed the same thing but with different compositions due to differences in fertilization doses and types of varieties planted. CH_4 emissions result from annual methane emissions from rice cultivation. N_2O emissions result from land management, both directly and indirectly N_2O emissions. CO_2 emissions result from the use of urea fertilizer during rice cultivation.

3.2 Estimation of potential greenhouse gas emissions from the livestock sub-sector

The livestock sub-sector comprises beef cattle, goats, pigs, pure chickens, laying hens, and broiler chickens. The emission load comes from livestock's enteric fermentation and management of livestock manure. The sub-total estimated GHG emissions from the livestock sub-sector in Sigi Biromaru District in 2022 can be seen in Table 4. Table 4 shows the estimated emission load for the livestock sub-sector, obtaining a sub-total emission load of 9739.31 Ton CO_2 eq in 2022. The largest emission load is in Jono village, 217.08 Ton CO_2 eq with 397 cows, 386 goats, 8006 pigs, and 1391 free-range chickens. The smallest estimated emission load value is in Ngatabaru village, namely 448.52 Tons of CO_2 eq with 227 cows, 227 goats, 0 pigs, and 1250 native chickens.

The estimated potential for greenhouse gases will be even greater if the number of cattle populations is greater; the same thing was stated by Herawati [20] on social reflections on mitigating greenhouse gas emissions in the livestock sector in Indonesia and Ishak et al. [21] in the estimation of greenhouse gas emissions from the livestock sector in 2016 in Central Sulawesi Province where it was stated that the population of cattle and goats greatly influences the potential for greenhouse gas emissions from the livestock sector, while pigs are not considered to be a major factor because the population of pigs in Central Sulawesi Province is not much compared to the population of cattle.

Table 4 shows the estimated emission load of the livestock subsector from the CH_4 subcategory from livestock manure management in 2022 in the Sigi Biromaru district, which obtained a subtotal emission load of 1510.2665 Ton CO_2 eq in 2022. The largest estimated emission load is in Jono village, 1300.69 Ton CO_2 eq with 397 cattle, 386 goats, 8006 pigs, 1 free-range chicken 391. The smallest estimated value of emission load is found in Ngatabaru village, namely 13.1532 tons of CO_2 eq with 227 cattle, 1454 goats, 0 pigs, and 1250 free-range chickens. Pigs play a major role in CH_4 emissions from manure management, so the amount of CH_4 emissions from manure management is directly proportional to the number of pigs in that location; the same thing was found in research by Lintangrino et al. [8] where the number of pigs is concentrated in one district so that the total emission burden from the livestock management sector from that district tends to be higher than the district that does not have a population of pigs.

Table 4 shows the estimated emission load of the livestock sub-sector from the direct N_2O subcategory from livestock manure management in 2022, and the Sigi Biromaru district obtained a sub-total emission load of 426.07 Ton CO_2 eq in 2022. The largest estimated emission load is in the village of Jono, namely 199.27 Ton CO_2 eq. The smallest estimated value of emission load is found in Sidondo village, namely 14.31 Ton CO_2 eq. The estimated emission load for the livestock sub-sector from the indirect N_2O subcategory from livestock manure management in 2022 in the Sigi Biromaru district obtained a sub-total emission load of 87.40 Ton CO_2 eq in 2022. The largest emission load estimate is in Jono village, which is 39.44 Ton CO_2 eq, while the smallest emission load estimate is in Sidondo 2 village, namely 2.50 Ton CO_2 eq.

Table 4. Sub-total Estimated GHG emissions from the livestock sub-sector in Sigi Biromaru District in 2022 in units of Ton CO_2-eq

No	Village	CH_4 Emission from Enteric Fermentation	CH_4 Emission from Sewage Management	N_2O Emissions from Directly from Stool Management	Indirect N_2O Emissions from Sewage Treatment	Sub Total Emissions Sub Husbandry
1	Mpanau	697.73	26.87	32.36	9.27	766.23
2	Kalukubula	903.28	31.23	34.90	9.66	979.07
3	Lolu	861.49	25.75	27.14	5.83	920.20
4	Loru	962.25	25.66	24.29	4.06	1016.27
5	Pombewe	1014.42	27.18	28.26	4.72	1074.58
6	Ngatabaru	412.60	13.15	19.75	3.02	448.52
7	Jono	657.69	1300.69	199.27	39.44	2197.08
8	Sidondo 1	1023.41	28.55	28.70	5.88	1086.54
9	Sidondo 2	723.93	17.85	17.09	2.50	761.36
10	Sidondo 3	458.80	13.33	14.31	3.01	489.45
Total						9739.31

Figure 3 shows that 95% of methane (CH_4) emissions are the most greenhouse gas emitted from the rice farming sub-sector, followed by 5% nitrous oxide (N_2O) emissions. CO_2 emissions are not generated from the livestock sub-sector. This composition also aligns with that stated by Akhadiarto and Rofiq [22], where methane gas dominates the potential for greenhouse gases from the livestock subsector. Methane (CH_4) is a potent greenhouse gas, contributing significantly to global warming. In the agricultural sector, methane emissions primarily originate from two sources: enteric fermentation in ruminant livestock and rice cultivation. Ruminant animals, such as cattle, sheep, and goats, have a unique digestive system that allows them to break down cellulose-rich plant matter. This process involves a complex microbial community in their rumen, which produces methane as a byproduct of digestion. Enteric fermentation is the primary source of methane emissions from livestock, accounting for approximately 50% of total agricultural methane emissions [4]. Rice cultivation is another major source of methane emissions in the agricultural sector. Submerged paddy fields, where rice is grown in flooded conditions, create an anaerobic environment that promotes the growth of methanogenic bacteria. These bacteria produce methane as a byproduct of their metabolic processes, leading to methane emissions from rice paddies.

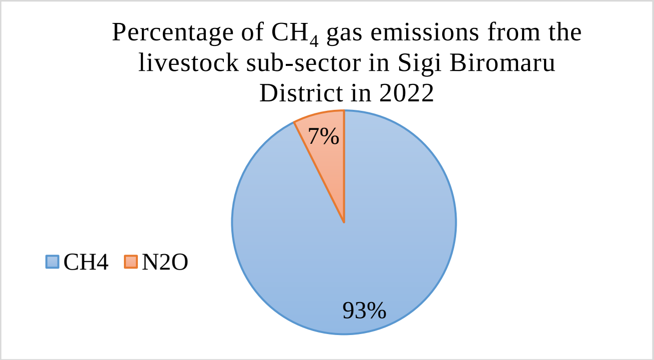

Figure 3. Diagram of the percentage composition of GHG emissions by type of emission gas in 2022 from the livestock sub-sector in Sigi Biromaru District

3.3 Total estimated potential greenhouse gas emissions from the agricultural sector

The agricultural sector consists of the rice farming sub-sector and the livestock sub-sector. Estimates of greenhouse gas emissions from the agricultural sector in the Sigi Biromaru district can be seen in Table 5.

Table 5 shows the estimated emission burden of the agricultural sector in the Sigi Biromaru District in 2022, a total emission load of 24,277.39 Ton CO_2 eq was obtained in 2022. The largest estimated emission load is in Pombewe village, about 3102.85 Ton CO_2 eq. The smallest estimated value of emission load is found in the village of Ngatabaru, namely 448.52 tons of CO_2 eq. When compared with the research conducted by Lintangrino and Boedisantoso [8]. Based on the estimation of several districts in the city of Surabaya in 2006 where the average of each district has a potential for greenhouse gas emissions of 4,321.20 tons of CO_2 eq, the Sigi Biromaru district is a district that has a large potential for greenhouse gas emissions. Hence, it is necessary to take mitigation steps to reduce the potential for greenhouse gas emissions. Mitigation steps that can be carried out in the Sigi Biromaru district can be seen in this study.

Table 5. Estimated emission burden of the agricultural sector in the Sigi Biromaru District in 2022

No.	**Village**	**Total Emissions from the Rice Farming Sub-sector (tons of CO_2 eq)**	**Total Emissions of Livestock Sub (tons of CO_2 eq)**	**Total Agricultural Sector GHG Emissions (tons of CO_2 eq)**
1	Mpanau	2708.51	766.23	**3474.74**
2	Kalukubula	2222.72	979.07	**3201.78**
3	Lolu	0.00	920.20	**920.20**
4	Loru	2622.39	1016.27	**3638.66**
5	Pombewe	4146.05	1074.58	**5220.64**
6	Ngatabaru	0.00	448.52	**448.52**
7	Jono	0.00	2197.08	**2197.08**
8	Sidondo 1	0.00	1086.54	**1086.54**
9	Sidondo 2	2838.41	761.36	**3599.77**
10	Sidondo 3	0.00	489.45	**489.45**
	Total	14538.08	9739.31	**24277.39**

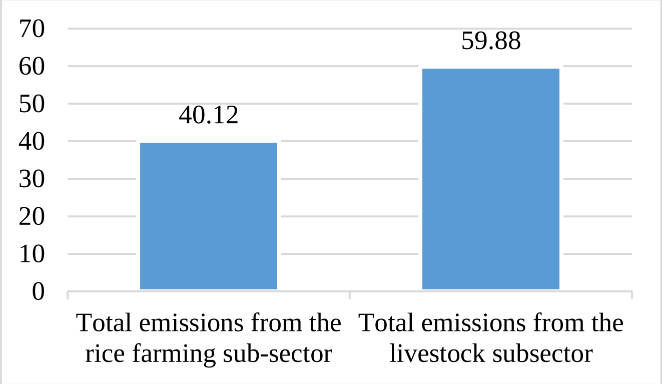

Figure 4. Diagram of the contribution of the rice farming sub-sector and the livestock sub-sector in producing GHG emissions from the agricultural sector in Sigi Biromaru District in 2022

The rice farming sub-sector and livestock sub-sector in Sigi Biromaru District both play a large role in estimating greenhouse gas emissions from the agricultural sector. Figure 4 Diagram shows the contribution of the rice farming sub-sector and the livestock sub-sector in producing GHG emissions from the agricultural sector in Sigi Biromaru District in 2022. The rice agriculture sub-sector contributes 59.88% of the estimated greenhouse gas emission burden, while the livestock sub-sector contributes 40.12%. It is the same with the research of Mustikaningrum et al. [4], where the rice farming sector produces higher greenhouse gas emissions than the livestock sector; this is because, in this study, the agricultural land is much larger than the existing livestock. But different from the research conducted by Lintangrino and Boedisantoso [8], where the livestock sector provides more emissions than rice farming.

3.4 The contribution of each type of greenhouse gas in the agricultural sector

The agricultural sector can produce gas emissions in the form of methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). The contribution of each type of gas to the agricultural sector in the Sigi Biromaru district in 2022 can be seen in Table 6. Table 6 shows the contribution of each type of GHG emitted from the rice farming sub-sector and the livestock sub-sector. The most methane emissions produced in the agricultural sub-sector are in Pombewe village since it has wider agricultural land, while in the livestock sector, the village that emits the most methane is Jono village because Jono village has more livestock.

The contribution of each type of gas in Ton CO_2 eq shows that methane greenhouse gas emissions dominate the agricultural sector, both from the rice farming sub-sector and from the livestock sub-sector. Mustikaningrum et al. [23] also put forward the same thing where the agricultural sector will produce more potential for greenhouse gas emissions.

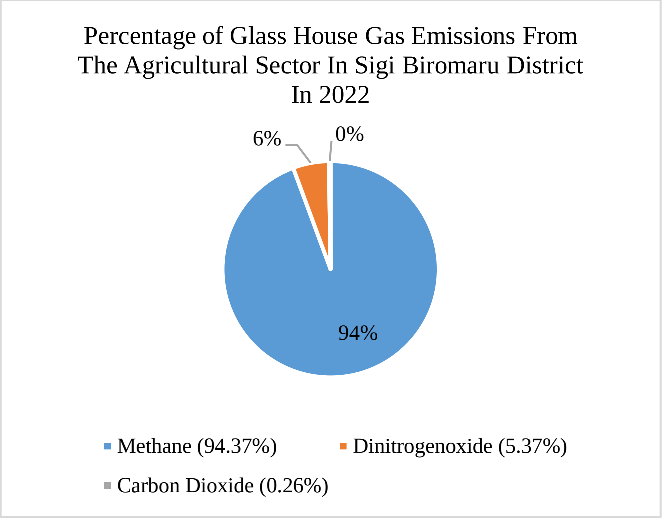

Figure 5. Diagram of the contribution of each type of gas to the agricultural sector in the Sigi Biromaru district in 2022

Figure 5 shows the contribution of each type of gas to the agricultural sector in the Sigi Biromaru District in 2022. The largest contribution from each type of greenhouse gas produced by the agricultural sector is methane gas (CH_4), which is 92%. The second largest is the emission of Nitrogen Oxide (N_2O) gas of 7% and finally the emission of Carbon Dioxide (CO_2) gas of 1%. CH_4 emissions result from annual methane emissions from rice cultivation, enteric fermentation and manure management. N_2O emissions result from N_2O emissions from land management and livestock manure, both directly and indirectly. CO_2 emissions are only generated from the use of urea fertilizer during rice cultivation in the rice farming sub-sector. Converting livestock manure into biogas can significantly reduce greenhouse gas emissions by capturing and utilizing methane, a potent greenhouse gas with a global warming potential 25 times greater than carbon dioxide [24]. Biogas production from livestock manure can reduce methane emissions by up to 90%, offering a substantial mitigation opportunity for the livestock sector [25].

3.5 Mitigation measures to reduce greenhouse gas emissions in the agricultural sector

Determination of mitigation measures is carried out by discussing through group discussion forums (FGD) with agricultural and livestock extension workers. The discussion results are several mitigation steps that can be carried out in the agricultural sector in the Sigi Biromaru district. Things that can be done as a mitigation measure to reduce the burden of greenhouse gas emissions include the following:

1) The use of lower rice varieties results in Methane (CH_4) emissions. Ciherang, Inpari 1, and Inpari 6 varieties have low methane emissions based on research conducted by Mulyadi and Wihardjaka [26].
2) Improving the quality of water regime management before planting until the time of rice cultivation by conducting intermittent irrigation (watering and drying multiple times). Irrigation with intermittent irrigation is believed to be better than continuous irrigation or single aeration irrigation. According to Kartikawati and Nursyamsi [27], intermittent irrigation, besides saving water, can also increase rice agricultural production.
3) Maximizing the use of rice straw in compost, animal feed, or immersing it in paddy fields at least 30 days before planting. The use of rice straw as animal feed has also been put forward by Is and Widiawati [28] as a way to mitigate greenhouse gas emissions from the livestock sector.
4) Optimizing fertilizers by following the recommended doses for rice farming. Using urea fertilizer can emit CO_2 gas through volatilization during land processing, directly and indirectly producing N_2O gas emissions.
5) Organic fertilizers and manure from farms are utilized for application in paddy fields. The use of organic fertilizers in the form of compost or manure will reduce synthetic fertilizers, indirectly reducing emissions from rice farming land. Organic fertilizers can also increase soil fertility.

Table 6. Contribution of each type of GHG emitted from the rice farming sub-sector and the livestock sub-sector

No	Village	Composition of GHG Emissions in the Livestock Subsector			Composition of GHG Emissions in the Rice Agriculture Subsector		
		CH_4	N_2O	CO_2	CH_4	N_2O	CO_2
1	Mpanau	724.60	41.63	0.00	2575.50	123.28	9.73
2	Kalukubula	934.51	44.56	0.00	2098.88	115.04	8.80
3	Lolu	887.24	32.97	0.00	0.00	0.00	0.00
4	Loru	987.91	28.36	0.00	2455.65	154.86	11.88
5	Pombewe	1041.60	32.99	0.00	3909.75	218.76	17.54
6	Ngatabaru	425.75	22.77	0.00	0.00	0.00	0.00
7	Jono	1958.38	238.71	0.00	0.00	0.00	0.00
8	Sidondo 1	1051.96	34.59	0.00	0.00	0.00	0.00
9	Sidondo 2	741.77	19.59	0.00	2645.82	178.25	14.34
10	Sidondo 3	472.13	17.31	0.00	0.00	0.00	0.00
Total		**9225.85**	**513.46**	**0.00**	**13685.60**	**790.18**	**62.30**

Use of livestock manure for Bioenergy (Biogas) and organic fertilizer. Using livestock manure in biogas is the best solution for handling livestock manure. Methane emissions resulting from livestock manure management can be used as fuel to reduce methane emissions. Efforts to use livestock manure in bioenergy are still not popular with the community; this can be seen from its application's lack of community response. The problems in applying bioenergy from livestock manure include the need for expensive and sophisticated equipment and technology and complicated operation and maintenance.

4. CONCLUSION

The total estimated potential emission load from the agricultural sector in the Sigi Biromaru district in 2022 is 24,277.39 tons of CO_2 eq consisting of the rice farming sub-sector of 14,538.08 tons of CO_2 eq or 59.88%, and the livestock sub-sector of 9,739.31 tons of CO_2 eq or 40.12%. The contribution of each type of greenhouse gas from the estimation of the potential emission load shows that methane gas (CH_4) is 22,911.45 tons CO_2 eq or 94.37%, nitrous oxide gas (N_2O) is 1,303.64 tons CO_2 eq or 5.37% and carbon dioxide gas (CO_2) is 62.30 tons CO_2 eq or 0.26%.

This study has some limitations that should be considered when interpreting the results. The use of default emission factors and activity data from the IPCC Guidelines 2006 Tier-1 methodology may not fully represent the specific conditions in Sigi Biromaru District. This could lead to some uncertainty in the emission estimates. Additionally, the survey method may have been subject to non-response bias, as not all farmers and breeders in the district were willing to participate in the study. This could also introduce some uncertainty into the findings.

Despite these limitations, this study provides valuable insights into the greenhouse gas emission profile of the agricultural sector in Sigi Biromaru District. The findings can inform the development of mitigation strategies to reduce GHG emissions and contribute to climate change mitigation efforts.

The findings of this study have several implications for policy and practice in the agricultural sector. The identification of the major sources of GHG emissions in the district can guide the development of targeted mitigation strategies. For instance, the high contribution of methane emissions from rice farming suggests that the adoption of low-emission rice cultivation practices could be an effective mitigation measure. Additionally, the promotion of organic fertilizers and the utilization of livestock manure into biogas could help to reduce emissions from the livestock sub-sector.

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