 p-ISSN 2827-8585
e-ISSN 2827-8062

International Journal of Multidisciplinary Research and Literature
IJOMRAL
Vol. 3, No. 2, March 2024 pp. 268-282
Journal Page is available at http://ijomral.esc-id.org/index.php/home

METHANE GHG EMISSION ANALYSIS SUPPORTS REGIONAL ACTION PLANS FOR MITIGATION AND ADAPTATION TO THE IMPACTS OF CLIMATE CHANGE IN SITUBONDO REGENCY

Mochamad Thohiron[1*], Faez M. Hassan[2], Achmadi Susilo[3], Dwie Retna Suryaningsih[4*], Achmad Wicaksono[5]
[1,3,4]Agrotechnology Department, College of Agriculture, Wijaya Kusuma University, Surabaya, Indonesia
[2] Physics Department, College of Education, Mustansyiriah University, Baghdad, Iraq
[5]Accounting Department, College of Economics and Business, Nadlatul Ulama University, Sidoarjo, Indonesia
Email: surjaningsih@uwks.ac.id[4]

Abstract

The study aims to inventory and analyze GHG methane (CH_4) emissions to support RAD in mitigation and adaptation of PI Situbondo Regency. It is hoped that the results of the research can be used as input for the Regional Government in designing implementable mitigation and adaptation actions. The scope of the research in the Situbondo Regency area was six months. Research methods: 1) Tier-1 IPCC Guidlines (IPCC, 2006) for numerical equation analysis of methane gas, and 2) analysis of remote sensing and numerical spatial data on cloud-based digital platform Java script Google Earth Engine (GEE) and Google Colaboratory Research (GColab) 2023, image digitization and outlating in QGIS software. Research data: 1) activity data based on producing sectors, methane emission factors, and farmer group mitigation options questionnaires; and 2) remote sensing data access to the methane gas datasets Sentinel-5P OFFL CH_4: Offline Methane, and MOD11A1.061 Terra Land Surface Temperature and Emissivity Daily Global 1km. Research results: the transportation sector emits the highest methane gas (tons of CO_2 eq) at 378,486; agriculture 249,580.74; industrial energy 30,533.58; and the lowest livestock 6,364. Remote sensing results: an increase in methane gas emissions during the analysis period. The lowest CH_4 gas emissions were respectively in 2017, 2019 and 2021, respectively 0.74 g/m^2; 1.79 g/m^2; and 1.85 g/m^2; and the highest respectively at 4.56 g/m^2; 10.95 g/m^2; and 23.90 g/m^2 in the same year. The lowest temperature increased in 2017, 2019, then decreased in 2021 to 19ºC, 21ºC and 18ºC respectively. The highest temperature increased in 2017, 2019, and decreased in 2021 respectively 39ºC, 40ºC and 38ºC. Increasing methane gas emissions are correlated with the lowest and highest LST from 2017-2021 with a correlation of $R \geq 0.6$ (0.6-0.9).
***Keywords**: methane, mitigation, global warming, regional action plan*

INTRODUCTION

Global warming (Panwar et al, 2011), is the phenomenon of increasing global temperatures due to the greenhouse effect (ERK) from increasing emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2) and freon (CFC). Damayanti (2013), the release of solar thermal energy trapped by greenhouse gases (GHG) will increase temperatures. The average increase in global surface temperature of the earth is 0.74 ± 0.18 ºC in the last 100 years. Numberi (2009), there are two factors that cause global warming; 1) burning fossil energy for industry, motor vehicles, power plant; and 2) emissions of various gases from industrial activities such as the use and manufacture of CFCs. Humans contribute to global warming as the largest contributor of greenhouse gases.

ERK in the laws of physics (Wahyono, 2008), occurs because the wavelength of light emitted to an object depends on the temperature of the object. The higher the temperature of the object, the shorter the wavelength. The high temperature of the sun's heat emits short-wave rays. The low temperature of the earth's surface will emit long wave infrared rays. Infrared rays in the atmosphere will be absorbed by certain gases so that they are not released into space. Heat is trapped in the lower layer of the atmosphere (troposphere) due to the rise of the earth's surface, causing the air temperature to rise in the troposphere. If the trend of phenomena like this continues, the earth's surface air temperature (land surface temperature) in the future will rise by ± 2.3°C. Methane is one of the GHGs that triggers increasing heat on the earth's surface. The increase in GHGs that causes the greenhouse effect is the process of entering solar radiation which is trapped in the atmosphere and increases the temperature of the earth's surface.

Methane gas (CH4) is the simplest hydrocarbon compound in the form of a colorless and odorless gas, burning at levels of 5-15%; molecular weight 16.04; specific gravity 0.554; boiling point -161°C; and the solubility is 35 mg/l at 1 atm (Cunha et al, 2016). The process of anaerobic decomposition of solid waste and urban liquid waste, industrial liquid waste piles and composting of organic materials will emit methane gas and CO2. Storage of untreated urban wastewater that is discharged into seas, rivers, lakes, clogged sewers, city liquid waste processing (anaerobic, digester, septic tank, laterine), and industrial wastewater treatment facilities produce methane (Ministry of the Environment, 2012). There are ± 208 million tonnes/year of methane emissions into the atmosphere from several natural sources. Wetlands are the largest source of ± 170 Tg (170 million tons per year). Geological emissions are 42-64 million tons/year, lake emissions are ± 30 million tons/year, and plant emissions are ± 20-60 million tons/year (US-EPA, 2010). The negative impact of methane gas for humans is disruption of the respiratory system, for the environment it causes global warming because it is one of the GHGs that contributes to the depletion of the ozone layer. (Ratih et al, 2015).

Presidential Regulation Number 71 of 2011, GHG Inventory is an activity to obtain data and information on the level, status and trend of changes in periodic GHG emissions from various emission sources (sources), sinks and carbon stocks (carbon stock). The Government's efforts to facilitate mitigation for reducing GHG emissions are carried out through the RAN for Reducing GHG Emissions (RAN-GRK), then by provincial regions throughout Indonesia with RAD-GRK. UNFCC (2005), mitigation is an effort to prevent, restrain the release of carbon, increase carbon absorption into forests or other carbon sinks, and slow down the effects of GHGs that cause global warming. Setiawan (2010), adaptation is an important response strategy approach in efforts to minimize the dangers caused by climate change. Adaptation has a role in reducing the impacts that immediately arise due to climate change that cannot be done by mitigation. The Indonesian government is trying to adapt through the RAN-API program (National Action Plan for Adaptation to Climate Change). Slamet (2015), PI adaptation strategy: reducing socio-economic and environmental vulnerability originating from climate change; increasing community and ecosystem resilience; and improving the welfare of local communities through poverty alleviation. Mitigation and adaptation to the impacts of climate change have been carried out both nationally through NAP and regionally through RAD. Each region is encouraged to carry out activities through RAD periodically. The methane GHG emissions analysis study was carried out to provide a baseline description of methane GHG producers and potential in efforts to mitigate and adapt to the impacts of climate change as a reference for RAD. It is hoped that the research results will become input for the Regional Government in designing implementing PI mitigation and adaptation actions.

The research aims to inventory and analyze GHG emissions of methane gas to support RAD for mitigating and adapting to the impacts of PI in Situbondo Regency.

MATERIALS AND METHODS

The research was carried out in the Situbondo Regency area at the astronomical position: 7°35'–7°44' south latitude and 113°30'–114°42' east longitude. The research period was carried out for six months from May to October 2023. The scope of the research included (1) exploration of sector activity data contributing to GHG emissions for the 2017 base year, and (2) remote sensing through exploration of Sentinel-5P satellite data for GHG methane gas.

The research method consists of: (1) quantitative method for numerical estimation of methane GHG emissions based on land sector: agricultural land; forestry; and livestock. The estimation of GHG gas emissions comes from changes in biomass or carbon storage on permanent/remaining land (same land use), and land changing to another land use (Ministry of the Environment, 2012). Land use transitions are calculated from carbon stocks at each land use category transition as the accumulated changes in carbon stocks (live biomass, dead biomass, and soil organic matter) or time averaged C stock (Hairiah et al., 2011; Agus et al., 2013; US-EPA 2012), as well as changes in land use categories, IPCC 2006 and the Ministry of Forestry (Bappenas, 2014) using the method of changing carbon stocks (stock difference). In this method, estimates of methane emissions are calculated by estimating differences in carbon stocks over a time interval. This method is also used by US-EPA (2012), Van Noordwijk et al., (2010) and Agus et al., (2013).

Land whose use does not change over a certain period of time is assumed to not emit (zero emissions) and land that experiences changes in cover emits carbon. The amount of carbon contained by the initial land cover minus the carbon reserves of the subsequent land cover is the change in carbon reserves emitted from an activity.

Where;

a) E (emissions) or (gas GHG absorption), namely:

E (S_GRK gas) = Activity Data (DA) x Emission Factor (FE)

b) SD (Stock Different) Changes in Land Use:

SD (PPL) = Change in Land Cover x (Previous Land Cover Carbon Stock – Current Land Cover Carbon Stock)

https://doi.org/10.53067/ijomral.v3i2.212

c) Rice fields refer to the Global Warming Potential (GWP) CO2 equivalent reference number (default) of 21 (IPCC, 2006). The reference number correction factor is used because the existing agroecological conditions of rice fields in Indonesia are diverse (irrigation water management, varieties, soil types) (IPCC, 1996; Setyanto et al, 2005; Prihasto et al, 2007 cit. BAPPENAS, 2014)

d) The global warming potential index for each type of GHG is used as a reference quantity to estimate the amount of emissions for each type of gas, and (2) remote sensing method for methane GHG projection analysis using Sentinel-5P satellite data access via the Google Earth Engine (GGE) platform on the dataset: (a) Sentinel-5P OFFL CO: Offline Carbon Monoxide, (b) Sentinel-5P OFFL CH4: Offline Methane, (c) Sentinel-5P OFFL NO2: Offline Nitrogen Dioxide, and (d) MOD11A1.061 Terra Land Surface Temperature and Emissivity Daily Global 1km which was then analyzed with Google Colaboratory. The following is a graph of the global warming index for each type of GHG emission.

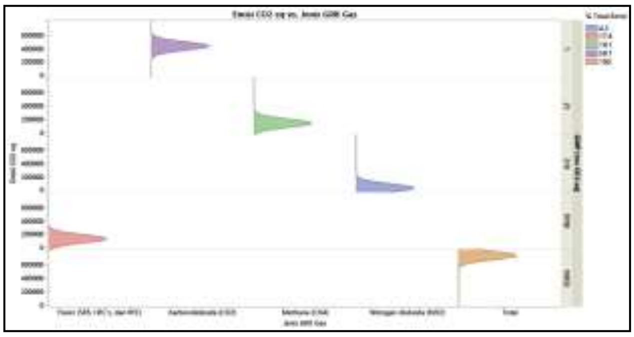

Figure 1. GHG Global Warming Potential Index in Indonesia

(Source: Ministry of the Environment, 2009. processed, 2024).

Numerical spatial analysis through remote sensing and five-year projections were carried out on the cloud-based digital platform Java script GGE, GColab and outlet on QGIS software. The following is a picture of the conceptual framework for the flow of stages in implementing remote sensing research.

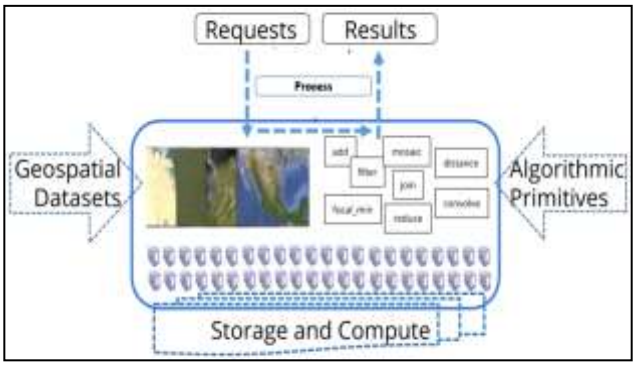

Figure 2. Conceptual framework for the flow of stages of remote sensing research for analysis of GHG methane emissions on the GEE and Google Colaboratory platforms.

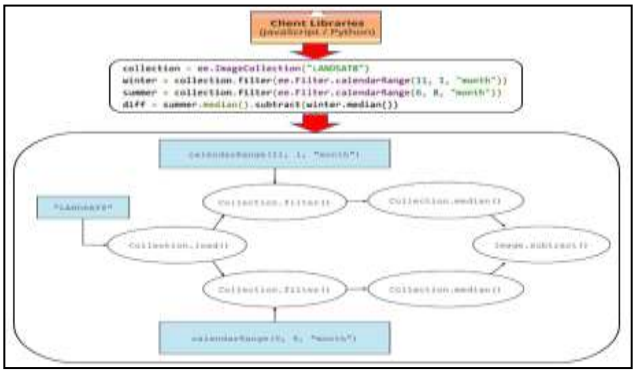

Figure 3. Accessing Datasets Sensory Analysis of Methane GHG Emissions.

(Source: Noel, G.; Matt, H. et al. 2017. Remote Sensing of Environment. GGE: Planetary-Scale Geospacial Analysis for Everyone. Science Direct. Elsevier).

Potential Mitigation and Adaptation Actions refers to methane GHG emissions after mitigation actions, namely reducing the base year emission figures by the emission figures after mitigation actions for each sector. Implementation of potential mitigation actions in Situbondo Regency through document studies (Agricultural Research and Development and Ministry of Agriculture according to IPCC Guidelines, 2006 cit. Susilawati et al., 2015). Farmers can determine implementing mitigation actions in the work area by considering costs, ease of work, and opportunities for facilitation by other parties.

RESULTS AND DISCUSSION

DA Numerical Equation Analysis.

DA analysis of methane gas GHG emissions in the agricultural, forestry and livestock sectors uses 2017 basic data (baseline). Based on the reference figure (default) for rice field emissions (IPCC, 2006) of 475 kg, then CH_4/ha/year is 475 kg CH_4 or 0.475 tons CH_4 x 21 CO2 eq/CH_4 = 10 tons CO2 eq/ha/year (with two assumptions planting season/year). The global warming potential of three types of GHGs is as shown in table 1.

Table 1. GHG Global Warming Potential Figures

Type GRK	Persistence in ATM (Year)	GWP (CO_2 eq)
CO_2	5 to 2000	1
CH_4	12	25
N_2O	144	298

Source: Intergovernmental Panel on Climate Change, 2006; Lintangrino & Boedisantoso, 2016.

Ministry of the Environment (2009), sector activities that are sources of GHG emissions that contribute to global warming in Indonesia are as shown in Figure 4.

https://doi.org/10.53067/ijomral.v3i2.212

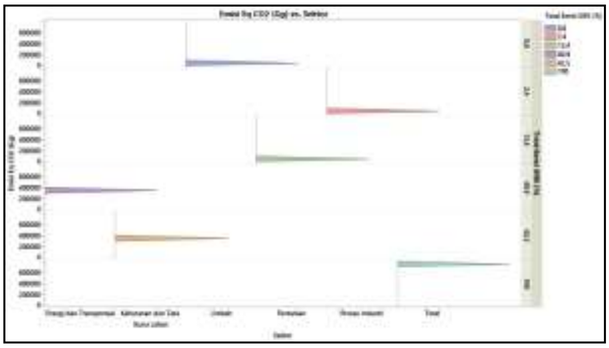

Figure 4. Sector Contribution to the Performance of Gas GHG Emissions in Indonesia
(Source: Ministry of the Environment, 2009. processed, 2024).

Meanwhile, for lowland rice (Oryza sativa L) plant varieties, correction factors are used as reference numbers for methane emission levels as shown in Figure 5.

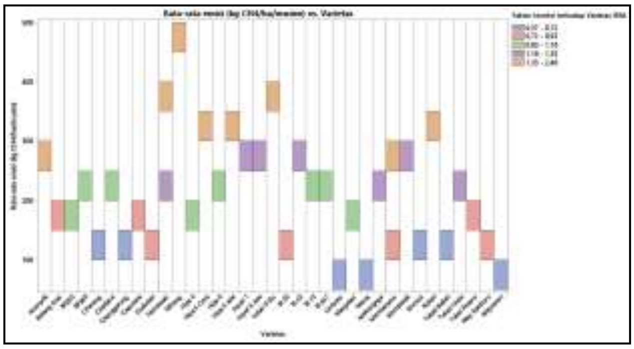

Figure 5. Average Methane GHG Emissions (kg CH_4/ha/season) of Rice Varieties Against the Correction Factor for Reference Figure Emissions for Rice Varieties IR 64
(Source: Setyanto et al., 2005. processed, 2024).

In Indonesia, emissions are estimated at 160 kg CH_4/ha/season or 6.72 tons CO2 eq/ha/season (Ministry of the Environment, 2012). The performance of existing rice field systems (water supply management, rice varieties and soil types) has different reference numbers for calculating methane gas emissions. The graph of the average methane emissions (kg CH_4/ha/season) for each variety as a reference number for the standard correction factor is the IR 64 variety of 1.0 or the equivalent of 1.0. From the picture above, the Gilirang, Fatmawati, Impari 9, Hipa 5 Ceva, Hipa 6 Jete, and Rokan varieties have high methane emissions while the other varieties vary. This indicates that varieties with high CH_4 emissions are not and/or less environmentally friendly. The contribution of the agricultural sector to the performance of GHG emissions of methane gas in Situbondo Regency is as shown in Figure 6.

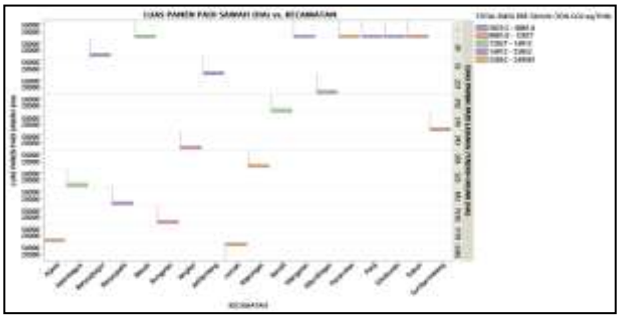

Figure 6. Contribution to Methane GHG Emission Performance in the Rice Food Agriculture Sector in Situbondo Regency.

Source: data analysis, 2023.

The total annual CO_2 equivalent methane emissions from rice fields (rice fields and rainfed) were the highest in Panarukan District, respectively, 28,004.79 tonnes CO_2 eq/yr; Kapongan 26,324.46 tonnes CO_2 eq/yr; and Arjasa 25,851.84 tonnes CO_2 eq/yr. The same results occurred in the pattern of spatial map analysis of methane gas emissions (g/m^2) in 2017, 2019 and 2021 (spatial map images 10, 11 and 12).

Figure 7. Development of Agricultural Land Methane GHG Emission Levels in the Base Year of Situbondo Regency.

Source: Bappeda Situbondo Regency 2017, Preparation of RAD for Reducing GHG Emissions. processed, 2023).

The graphic image above shows the development of methane gas emissions which increased every year in Situbondo Regency before the baseline. In the livestock sector, the most important greenhouse gas from livestock is methane gas released from the digestive process (enteric fermentation). Methane is also produced from the anaerobic oxidation process of animal waste, but the amount is less than emissions from the digestive process. There is 94 percent methane gas resulting from digestive fermentation of ruminant animals and 6 percent from fecal secretions, apart from Nitrous oxide (N_2O). Activity data to calculate methane emissions from the livestock sector uses the IPCC method (IPCC, 2006). Data on livestock population activity and linear projections for Situbondo Regency (BPS, 2017) and verified data from the Department were used. In Situbondo Regency the average growth rate of the ruminant livestock population is 7%/year and poultry 12.5%/year as a projected achievement target for the 2017-2022 livestock service strategic plan. The calculation uses livestock population data resulting

https://doi.org/10.53067/ijomral.v3i2.212

from an inventory of existing condition data. The amount of non-dairy cattle manure with an emission factor of 1.0 used as biogas material is 6,364,000 kg, so the GHG methane emissions from the livestock sector are 6,364,000 x 1 or 6,364,000 kg CO_2 eq or 6364 tons CO_2 eq.

In Situbondo Regency, the agricultural land and livestock sectors contribute the second largest to methane gas emissions after energy (transportation). The natural manifestation of methane emissions comes from the process of methanogenesis or biomethanation of agricultural biomass, namely the formation of methane by the methanogenic microorganisms Methanococcus, Mathanosarcina, and Methanobacterium in the Archaea domain. Archaea are phylogenetically different from eukaryotes and bacteria but are related in their lifestyle to anaerobic bacteria. Methane is the main metabolic product of a large number of microbes which convert the advanced products of the acidification stage into methane gas, water and carbon dioxide (Wahyuni, 2018). Methanogenesis is the final step in the process of decomposition of land, agricultural and livestock biomass. The energy methanogenesis process of several microorganisms is:

$$CO_2 + 8\,H^+ + 8\,e^- \rightarrow CH_4 + 2\,H2O$$

And then catalyzed by the enzyme *methyl-coenzyme M reductase* at the end of the process. Methanogenesis is a form of anaerobic respiration by organisms in landfills, ruminants and termites (Hamilton et al, 2010). Several factors influence the potential for methane (CH_4) emissions: type of irrigation, amount of organic material, and type of organic material applied to the land (Ghofur, 2019). In the energy sector, the contribution to GHG emissions is important because it is related to the supply and use of energy. The energy supply side includes activities; exploration and exploitation of primary energy sources; conversion of primary energy into secondary energy; and energy distribution. The energy use side includes activities; fuel use in stationary equipment; and mobile equipment. GHG emissions from energy for both industry and transportation are calculated as CO_2 equivalent gas emissions (tons CO_2 eq).

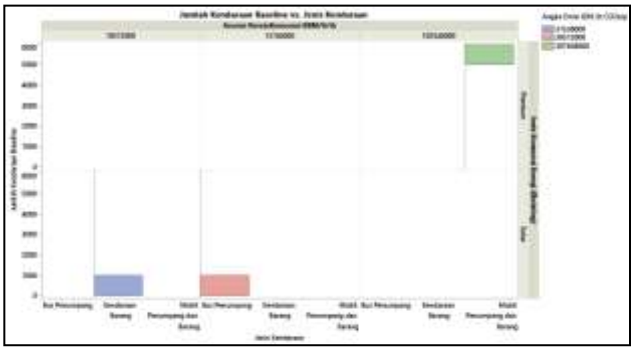

Figure 8. Development of Energy Sector Methane GHG Emission Levels in Situbondo Regency, analysis results, 2023).

From the graph above, it can be seen that the number of vehicles and high fuel consumption (lt/yr) and premium fuel will result in high levels of GHG emissions (lt CO_2 eq). Sectoral aggregation of GHG emissions as shown in the following figure.

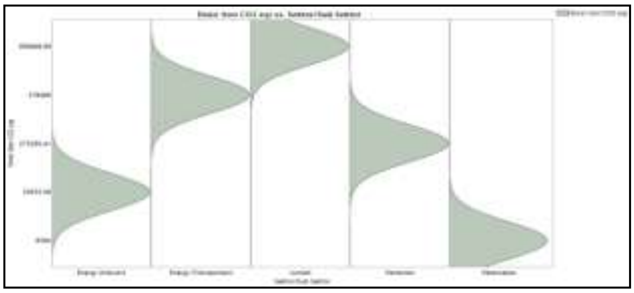

Figure 9. Sectoral Contribution to GHG Emissions in Situbondo Regency, analysis results, 2023).

The graph shows that sectoral aggregates produce varying levels of emissions. Respectively, the highest GHG emitting activity sectors (tons of CO_2 eq) are energy (transportation) at 378,486; agriculture 249,580.74; and energy (industry) 30,533.58; while the livestock sector emits the lowest methane at 6,364.

Remote sensing analysis.

The spatial map of the distribution of methane gas in Situbondo Regency in 2017, 2019 and 2021 is as shown in Figures 10, 11 and 12 below.

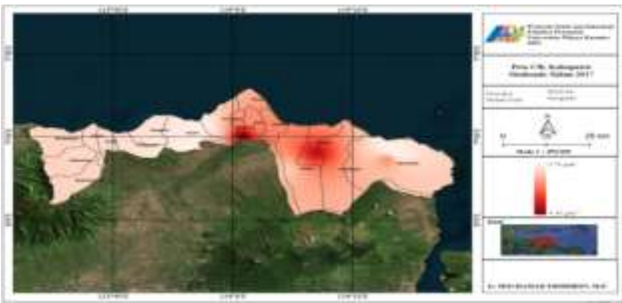

Figure 10. Distribution Map of Methane Gas GHG Emission Levels in Situbondo Regency, 2017.
Source: analysis results, 2023

Figure 11. Distribution Map of Methane Gas GHG Emission Levels in Situbondo Regency, 2019.
Source: analysis results, 2023

https://doi.org/10.53067/ijomral.v3i2.212

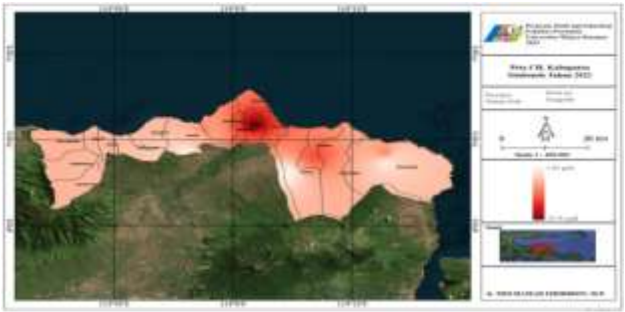

Figure 12. Distribution Map of Methane Gas GHG Emission Levels in Situbondo Regency, 2021.
Source: analysis results, 2023

The results of the numerical spatial analysis show that during the five years from 2017 to 2021, there was an increase in the concentration of GHG emissions of methane gas in Situbondo Regency. From the picture above, it can be seen that there is a similar pattern in the distribution of the lowest and highest GHG emissions of methane gas in 2017, 2019 and 2021 when the analysis was carried out, where the results are not much different from the results of the numerical equation analysis. The highest distribution pattern of methane gas GHG emissions is found in Panarukan, Kapongan and Arjasa Districts. The analyzed daily GHG emissions data for methane gas shows high fluctuations in 2017 and 2019, with a different pattern in 2021 as shown in the following picture.

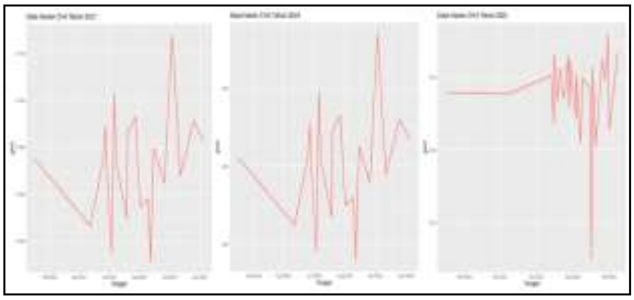

Figure 13. Distribution Pattern of Daily Methane Gas GHG Emission Levels per Year during 2017-2021 in Situbondo Regency.
Source: analysis results, 2023

The image above shows high fluctuations with different methane gas emission patterns, this is thought to be due to the dynamic nature of methane gas and changes in existing conditions that occur. From the results of the analysis of the GHG methane spatial map, it can be seen that emission levels have increased from 2017-2021. The lowest CH_4 gas emissions increased successively starting in 2017, 2019 and 2021, namely 0.74 g/m^2; 1.79 g/m^2; and 1.85 g/m^2. Meanwhile, the highest methane gas emissions in the same consecutive year also increased: 4.56 g/m^2; 10.95 g/m^2; and 23.90 g/m^2 or average annual methane emissions: 2017; 2019 and 2021 is 3.02 g/m^2; 7.22 g/m^2; and 13.8 g/m^2. The area of Situbondo Regency is 1,638.50 km^2 or 163,850 Ha, equivalent to 1,638,500,000 m2, so the total methane GHG emissions are: 2017; 2019; and 2021 is: 4,948.27 tons; 11,829.97; and 22,611.30 tons. The increase in methane emissions occurs due to the dynamic nature of methane gas and increased activity in existing regional sectors.

USEPA (2014), higher temperatures occur in urban and suburban areas compared to remote rural environments. The average annual air temperature difference in cities with a population of ≥ 1 million people can reach 1.8-5.4°F (1-3°C) and even 22°F (12°C) which is warmer than the surrounding area with varying impacts. Differences in city temperature vary with city size, reaching 22°F (12°C) for most cities, or even less, although the effect varies with city size. The increase in methane emissions in Situbondo Regency was followed by an increase in land surface temperatures. The map of the distribution of land surface temperatures in Situbondo Regency is as shown in the following image.

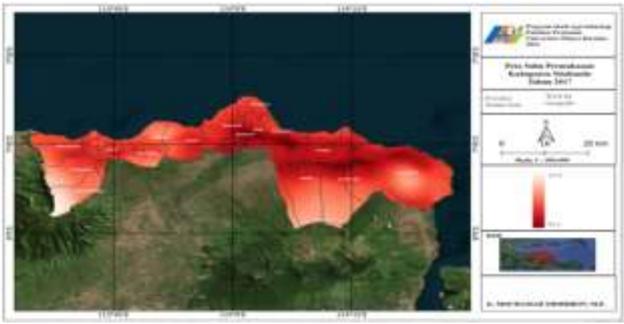

Figure 14. Map of Land Surface Temperature Distribution in Situbondo Regency, 2017.
Source: analysis results, 2023).

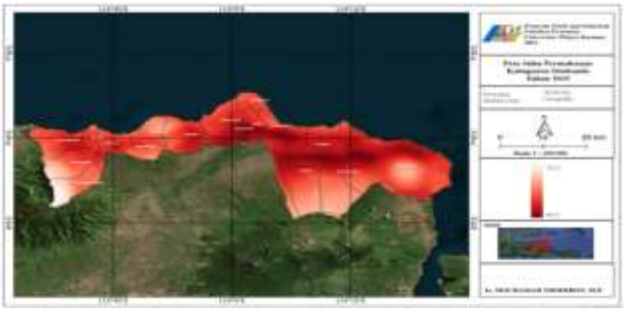

Figure 15. Map of Land Surface Temperature Distribution in Situbondo Regency, 2019.
Source: analysis results, 2023).

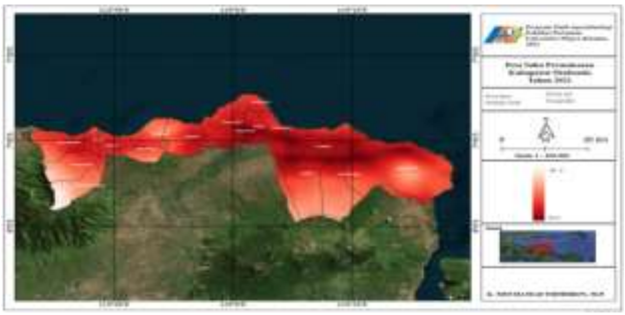

Figure 16. Map of Land Surface Temperature Distribution in Situbondo Regency, 2021.
Source: analysis results, 2023).

https://doi.org/10.53067/ijomral.v3i2.212

From the LST map, it can be seen that the distribution pattern of land surface temperatures is the same from 2017-2021. This is thought to be due to the same pattern of changes in existing conditions during that period. The sub-districts with the lowest land surface temperatures are in parts of Sumbermalang, Jatibanteng, Bungatan, Banyuputih, Arjasa and Asembagus sub-districts. The highest land surface temperatures were successively in several areas of Situbondo District: Panarukan, Panji, Kapongan and Anchor. The distribution of daily average annual land surface temperatures for 2017, 2019 and 2021 is as shown in the following figure.

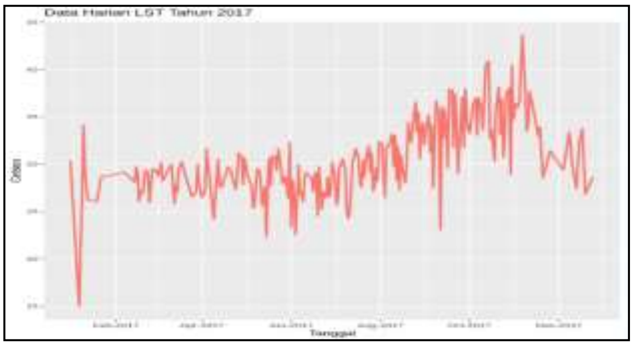

Figure 17. Distribution Map of Average Daily Land Surface Temperature in Situbondo Regency, 2017.

Source: analysis results, 2023

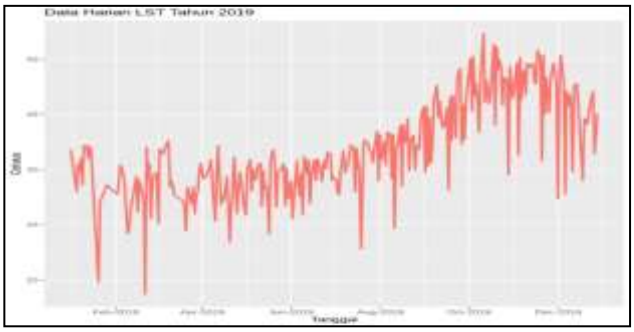

Figure 17. Distribution Map of Average Daily Land Surface Temperature in Situbondo Regency, 2019.

Source: analysis results, 2023

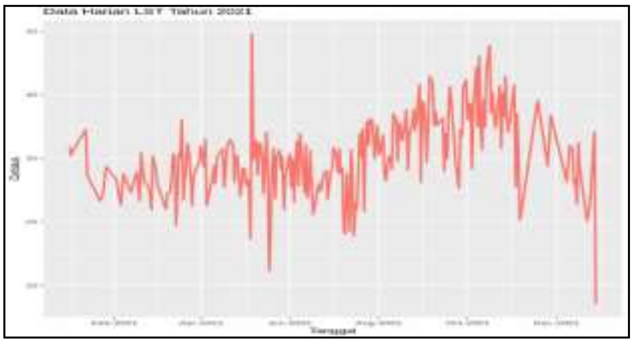

Figure 17. Distribution Map of Average Daily Land Surface Temperature in Situbondo Regency, 2021.

Source: analysis results, 2023

From the picture above, the distribution of average daily land surface temperatures per year during 2017 and 2019 fluctuated and began to increase in October. Meanwhile, in 2021, daily fluctuations will be seen throughout the year. Voogt and Oke (2003), the difference in average surface temperatures during the day in urban and rural areas is around 5-10°C and at night it is higher, around 10-15°C. The correlation of methane GHG emissions with land surface temperature is presented in the following figure.

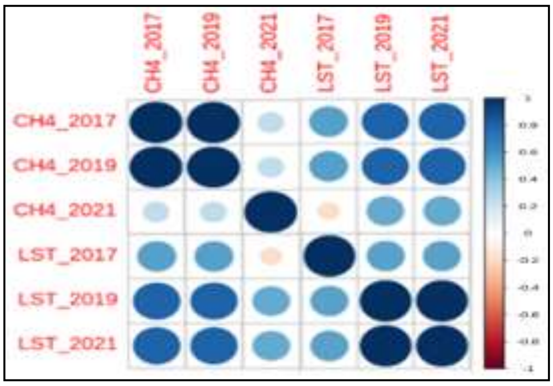

Figure 20. Correlation of GHG Methane Emissions with Land Surface Temperature (LST) in Situbondo Regency, 2017, 2019 and 2021.

Source: analysis results, 2023

From the picture above, the increase in methane emissions is followed by an increase in the lowest and highest temperatures of the land surface starting from 2017-2019, although it will decrease in 2021, which correlates with $R \geq 0.6$ (0.6-0.9). The lowest temperature increased in 2017, 2019, and decreased in 2021 respectively 19°C, 21°C, and 18°C. The highest temperature increased in 2017, 2019, and decreased in 2021 respectively 39°C, 40°C and 38°C.

Potential Mitigation Actions.

Methane GHG mitigation action options that can be developed (Susilawati et al, 2020), namely the Agricultural Research and Development Agency (Ministry of Agriculture) include: (1) reducing CH_4 emissions from paddy fields; (2) balanced fertilization of rice plants; (3) increasing soil carbon stocks (through the use of organic fertilizer, soil conservation, processing of organic matter, use of biochar); (4) mitigating CH_4 emissions through zero-burn agriculture; (5) mitigating enteric CH_4 emissions through improving animal feed quality; and (6) mitigating CH_4 emissions through the use of livestock manure biogas. Meanwhile, the mitigation options most likely to be accepted by farmers are balanced fertilizer doses, use of low-emission rice varieties (Ciherang variety). Mulyadi and Wihardjaka (2014), the Ciherang variety is able to reduce methane GHG emissions compared to other varieties.

CONCLUSION

The transportation sector emits the highest methane gas (tons of CO_2 eq) at 378,486; agriculture 249,580.74; industrial energy 30,533.58; and the lowest livestock 6,364. Meanwhile, remote sensing results show an increase in methane gas emissions during the analysis period. The lowest CH_4 gas emissions were respectively in 2017, 2019 and 2021, respectively 0.74 g/m^2; 1.79 g/m^2; and 1.85 g/m^2;

and the highest respectively at 4.56 g/m^2; 10.95 g/m^2; and 23.90 g/m^2 in the same year. The lowest temperature increased in 2017, 2019, and decreased in 2021 respectively 19ºC, 21ºC, and 18ºC, the highest temperature increased in 2017, 2019, and decreased in 2021 respectively 39ºC, 40ºC, and 38ºC. The increase in methane gas emissions was followed by an increase in the lowest and highest ground surface temperatures from 2017-2021 with a correlation of $R \geq 0.6$ (0.6-0.9). Balanced fertilizer doses, use of low-emission rice varieties (Ciherang varieties) are the mitigation options most likely to be accepted by farmers. Active community participation is needed in developing PI mitigation and adaptation actions as a joint community movement. Further research needs to be carried out to calculate the potential for reducing emissions of other types of GHGs through several existing mitigation options to obtain implementable mitigation actions for consideration by several interested parties. Community understanding and agency operational steps are very much needed in disseminating information on the impact of PI.

REFERENCES

Agus, F., Santosa, I., Dewi, S., Setyanto, P., Thamrin, Y., Wulan, C., & Suryaningrum, F. (2013). *Pedoman teknis perhitungan baseline emisi dan serapan gas rumah kaca sektor berbasis lahan: Buku I landasan ilmiah.* Jakarta: Badan Perencanaan Pembangunan Nasional, Republik Indonesia.

Arisandi, F. D., Setyanto, P., & Ardiarini, N. R. (2018). Heritabilitas dan karakteristik tanaman padi rendah emisi gas metana. *Jurnal Produksi Tanaman*, 6(6), 1042–1047.

Bappeda, (2017). *Badan Perencanaan Pembangunan Daerah*. Penyusunan Rencana Aksi Daerah Penurunan Gas Rumah Kacah Kabupaten Situbondo.

Bappenas, (2014). *Badan Perencanaan Pembangunan Nasional RI. Pedoman Teknis Perhitungan Baseline Emisi dan Serapan GRK Sektor Berbasis Lahan SNI 7654:2010*.

Bappenas, (2015). *Badan Perencanaan Pembangunan Nasional RI. Pedoman Umum, Petunjuk Teknis, dan Manual Perhitungan Pemantauan, Evaluasi dan Pelaporan (PEP) Pelaksanaan RAN dan RAD GRK Bidang Berbasis Lahan*.

Ghofur, A. (2019). *Estimasi Potensi Gas Metan (CH_4) dan Karbon Dioksida (CO_2) Pada Lahan Sawah System of Rice Intensificatiom (SRI) dan Konvensional di Kecamatan Imogiri, Kabupaten Bantul, D.I. Yogyakarta*. Universitas Gadjah Mada.

Hairiah, K., Ekadinata, A., Rika, R, S., dan Rahayu, S. (2011). *Petunjuk Praktis Pengukuran Stok Karbon dari Tingkat Lahan ke Bentang Lahan. Edisi Ke 2 Bogor World Agroforestry Centre*. ICRAF SEA Regional Office. Universitas of Brawijaya (UB), Malang, Indonesia xx p. Bogor. 88 hal.

Hamilton, S.W., Edward, J.D., Jeffery, A.M., Jeremy, L., Frank, M. M. (2010). Greenhouse Gas, Animal Performance, and Bacterial Population Structure Responses to Dietary Monensin Fed to Dairy Cows. First published: 01 January 2010. Available at : https://doi.org/10.2134/jeq2009.0035.

IPCC. (2001). Climate Change 2001. *Impacts, adaptation and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK, and New York, Cambridge University Press.

IPCC. (2006). Intergovermental Panel on Climate Change. IPCC Guidelines for National Greenhouse Gas Inventories – a primer. In H. S. Eggleston., K. Miwa., N. Srivastava., & K. Tanabe (Ed.), *Prepared by the National Greenhouse Gas Inventories Programme*. Japan: IGES.

Kartikawati, R., Yulianingrum, H., Wihardjaka, A., & Setyanto, P. (2018). Upaya adaptasi terhadap perubahan iklim pada lahan tadah hujan melalui budidaya padi rendah emisi metana. *Prosiding* Balai Besar Penelitian Tanaman Padi (BB Padi), November, 165–257.

Kementerian Lingkungan Hidup. (2012). Pedoman Penyelenggaraan Inventarisasi Gas Rumah Kaca Nasional, Buku I, *Pedoman Umum*.

Lintangrino, M. C., dan Boedisantoso, R. (2016). Inventarisasi emisi gas rumah kaca pada sektor pertanian dan peternakan di Kota Surabaya. *Jurnal Teknik ITS*, 5(2), 53–57. doi:10.12962/j23373539.v5i2.16528.

Mulyadi, M., dan Wihardjaka, A. (2014). Emisi gas rumah kaca dan hasil gabah dari tiga varietas padi pada lahan sawah tadah hujan bersurjan. *Jurnal Penelitian Pertanian Tanaman Pangan*, 33(2), 116-121. doi:10.21082/jpptp.v33n2.2014.p116-121.

Oogt, J.A. and Oke, T.R. (2003). : Urban Climate Analysis with Remote Sensing and Climate Observations: A Case of Morogoro Municipality in Tanzania. *Thermal Remote Sensing of Urban Climates. Remote Sensing of Environment*, 86, 370-384. https://doi.org/10.1016/S0034-257(03)00079-8.

Prihasto, S., Irsal Las dan Achmad M. Fagi. (2007). Kekhawatiran Pengaruh Pemanasan Global Terhadap Produksi Pertanian dalam buku *"Pengelolaan Lingkungan Pertanian Menuju Mekanisme Pembangunan Bersih".* Balai Penelitian Lingkungan Pertanian, Jakenan, Pati.

Setiawan, B. (2010). *Kajian Awal Adaptasi dan Mitigasi Perubahan Iklim di Indonesia: Peluang dan Tantangan.* Teknik Sipil. Universitas Sriwijaya. Palembang.

Setyanto, P., Rosenani, A. B., Makarim, A. K., Che Fauziah I., Bidin, A., & Suharsih, S. (2002). Soil controlling factors of methane gas production from flooded rice fields in Pati District, Central Java. *Indonesian Journal of Agricultural Science*, 3(1), 1-11. doi:10.21082/ijas.v3n1.2002.p1-11.

Setyanto, P. (2015). *Teknologi mengurangi emisi gas rumah kaca dari lahan sawah*. Iptek Tanaman Pangan.

Slamet, B. (2015). Analisis Kebijakan Land Use Land Use Change Forestry (LULUCF) dan Skenario Mitigasi dan adaptasi Perubahan Iklim. *Research Gate*, Juli 2015.

Susilawati, H.L., Setyanto, P., Makarim, A.K., Ariani, M., Ito, K., and Inubushi, K. (2015). Effects of steel slag applications on CH_4, N_2O and the yields of Indonesian rice fields: a case study during two consecutive rice-growing seasons at two sites. *Soil Sci Plant Nutr 61*: 704–718.

UNFCCC. (2005). *Kyoto Protocol to the United Nations Framework Convention on Climate Change*. Germany.

USEPA. (2006). *Greenhouse Gas Inventory. Inventory of U.S*. Greenhouse Gas Emissions and Sinks: 1990-2006. USA.

USEPA. (2010). U.S. *Environmental Protection Agency (EPA) Decontamination Research and Development Conference.* U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-11/052, 2011. Diakses, 10 Januari 2023.

USEPA. (2014). U.S. Environmental Protection Agency (EPA). *Reducing Urban Heat Islands: Compendium of Strategies Urban Heat Island Basics.* Sumber : (http://www.epa.gov/heatisland/resources/pdf/BasicsCompendium.pdf). Diakses 10 Januari 2023.

Van Noordwijk, M., S. Dewi, N. Khasanah, A. Ekadinata, S. Rahayu, J.P. Caliman, M. Sharma, and R. Suharto. (2010). Estimating the carbon foot print of biofuel production from oil palm: Methodology and results from two sites in Indonesia. *International Conference on Oil Palm and Environment*, Bali, Indonesia, 23-25 February 2010.

Wahyuni, S. (2018). *Panduan Praktis Biogas*. Penebar Swadaya. Jakarta Timur. 116 halaman.