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Methane Emission Inventory from Livestock and Rice Production in Cagayan Valley: Utilizing the IPCC Inventory Software

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ABSTRACT

This study evaluated methane (CH_4) emissions from livestock and rice cultivation in Cagayan Valley, Philippines, using the IPCC Inventory Software and the 2006 IPCC Tier 1 methodology to address the need for localized greenhouse gas (GHG) inventories. Using data from the Philippine Statistics Authority, CH_4 emissions for 2020 and 2021 were quantified, analyzed, and compared with national and international inventories. Results indicated a slight decline in emissions from 44.32 Gg in 2020 to 43.53 Gg in 2021 due to enteric fermentation, and a more notable decline, from 10.04 Gg in 2020 to 5.69 Gg in 2021 in manure management emissions, likely due to improved livestock management. However, rice cultivation emissions increased from 77.81 Gg in 2020 to 80.61 Gg in 2021, suggesting the need for targeted mitigation strategies. Cattle and buffalo were the primary livestock sources of CH_4, while swine contributed the most to manure management emissions. The findings emphasize the importance of accurate, region-specific GHG inventories for effective climate action. The study serves as a model for other agriculture-intensive regions seeking to quantify and reduce GHG emissions.

Keywords: *Methane emissions, greenhouse gas inventory, livestock management, rice cultivation, IPCC inventory software*

Introduction

The Philippines faces challenges in accurately quantifying greenhouse gas (GHG) emissions, particularly from agriculture. Rice cultivation and livestock are significant sources of methane (CH_4) emissions (Bautista et al., 2015; Francisco, 1996). The latest national GHG inventory for rice production used 1994 data, highlighting the need for updated assessments (Bautista et al., 2015). Developing countries often lack sufficient activity data and country-specific emission factors, hindering comprehensive GHG inventories (Ogle et al., 2013). To address these gaps, researchers recommended combining censuses and surveys for data collection, using a tiered approach for site-specific measurements, and employing advanced software systems for inventory compilation (Ogle et al., 2013). Recent estimates suggest that total GHG emissions from Philippine rice production are 13.3 Tg CO_2 eq. yr^{-1}, with soil processes being the largest contributor (Bautista et al., 2015). Improving GHG inventories is crucial for developing effective climate policies and sustainable agricultural practices in the Philippines.

The Cagayan Valley (Region 02) in the Philippines is a major agricultural hub, significantly contributing to national food production. However, its dominant farming activities—livestock rearing and rice cultivation—are substantial sources of methane (CH_4), a potent greenhouse gas (GHG) with a high global warming potential. Accurately quantifying CH_4 emissions from these sectors is crucial for informing climate policies and promoting sustainable agricultural practices. Despite global efforts to improve greenhouse gas inventories, data on methane emissions from Philippine agriculture, particularly at the regional level, remain limited. This study sought to address this gap by leveraging the Intergovernmental Panel on Climate Change (IPCC) Inventory Software to estimate CH_4 emissions from livestock and rice production in Cagayan Valley.

Several studies have emphasized the importance of comprehensive GHG inventories in developing effective mitigation strategies (FAO, 2019; IPCC, 2006). The IPCC Inventory Software is a widely recognized tool for calculating and reporting GHG emissions under the Agriculture, Forestry, and Other Land Use (AFOLU) sector. It employs tiered methodologies, from default emission factors (Tier 1) to more region-specific calculations (Tier 2 and Tier 3), facilitating the generation of transparent and internationally comparable emission reports. While many developing countries utilize this software to enhance their national inventories, its adoption in the Philippines remains limited due to technical constraints and a lack of awareness. Thus, strengthening local capacity in using this tool is essential for improving the accuracy and reliability of agricultural GHG inventories.

This study aimed to generate localized methane emission estimates from livestock and rice production in Cagayan Valley using the IPCC Inventory Software. By integrating region-specific agricultural data and employing the Tier 1 methodology, the research intends to contribute to more accurate and regionally relevant greenhouse gas (GHG) inventories. In doing so, it also sought to provide insights that could inform regional policy-making and support the Philippines' commitments to global climate change mitigation efforts through improved data quality, methodological transparency, and consistency with national and international inventory frameworks.

Methods

Participants and Samples

The participants in this study included technical personnel responsible for the installation, configuration, and operation of the IPCC Inventory Software. These individuals played a central role in setting up the system, defining superuser accounts, managing the database, and inputting the necessary data to generate greenhouse gas (GHG) emission estimates.

Data analysts and researchers were also key participants, tasked with extracting and structuring data from the Philippine Statistics Authority (PSA) and the Climate Watch Data Explorer. Their responsibilities included classifying the information according to IPCC categories and ensuring the data was accurate and ready for analysis. Local Government Units and regional stakeholders, although not directly mentioned, were implied participants due to the use of provincial-level data, especially in Cagayan Valley, and are likely involved in data provision and future policy implementation.

Furthermore, international benchmark groups, specifically the countries of China, India, and Brazil, were included as reference points for comparison. Their national GHG inventory data, compiled using the same IPCC guidelines, were used to contextualize the results of the Philippine inventory.

The samples used in the study consisted of structured datasets inputted into the IPCC Inventory Software. These included livestock population data for cattle (other cattle), buffalo, goat, and swine sourced from the PSA, which were used to estimate methane (CH_4) emissions under the livestock category, covering enteric fermentation and manure management.

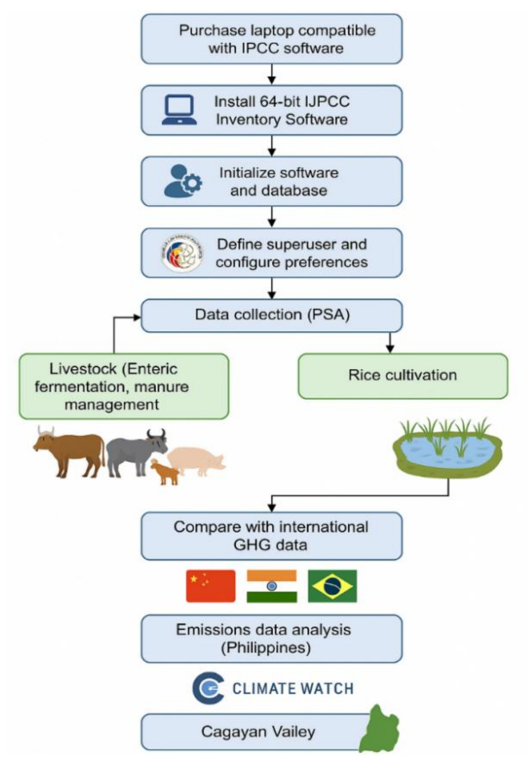

Figure 1. *Data Sources and Country Selection Criteria*

Additionally, data on the annual harvested area of rice cultivation, categorized by ecosystem, were used to estimate CH_4 emissions under the aggregate sources and non-CO_2 emissions category, specifically rice cultivation. To enhance regional relevance, the data were categorized by province within Cagayan Valley, allowing for a more localized analysis of emission sources. For a broader context, international data on historical GHG emissions were sampled from the Climate Watch website, focusing on top agricultural emitters such as China, India, and Brazil. These datasets enabled comparative analysis and helped identify best practices aligned with international standards.

Materials and Tools

The primary tool used in this study was the IPCC Inventory Software Version 2.93 (64-bit), developed by the IPCC Task Force on National Greenhouse Gas Inventories. This software was installed on a Windows-based laptop that met the required system specifications, including a 64-bit operating system and compatible Microsoft Office software (preferably the 64-bit version). The laptop served as the central device for managing the GHG inventory system, storing the database, and performing data input and analysis.

Data for greenhouse gas emissions were primarily sourced from two platforms. National data were obtained from the Philippine Statistics Authority (PSA) through its online portal https://openstat.psa.gov.ph/, which provided essential statistics on livestock population and rice cultivation area, both critical to calculating emissions under IPCC categories of livestock and aggregate sources and non-CO2 emissions sources on land. For international comparisons, the Climate Watch Data Explorer tool https://www.climatewatchdata.org, a platform maintained in partnership with the United Nations Framework Convention on Climate Change (UNFCCC), was used to gather historical greenhouse gas emissions data from countries such as China, India, and Brazil.

Additional tools included a flowchart for software installation decision-making, which guided the user through identifying the correct version of the IPCC software based on system architecture and Office compatibility. The IPCC software itself provided built-in worksheets and drop-down fields with default values aligned with Tier 1 methodology, simplifying data entry and ensuring compliance with international standards. Internet access was also essential for downloading the software, accessing data sources, and conducting background research. Furthermore, user credentials (login name and password) were created to manage access to the inventory system securely.

Together, these materials and tools supported a structured and systematic approach to collecting, organizing, and analyzing greenhouse gas emissions data for the agriculture sector in the Philippines.

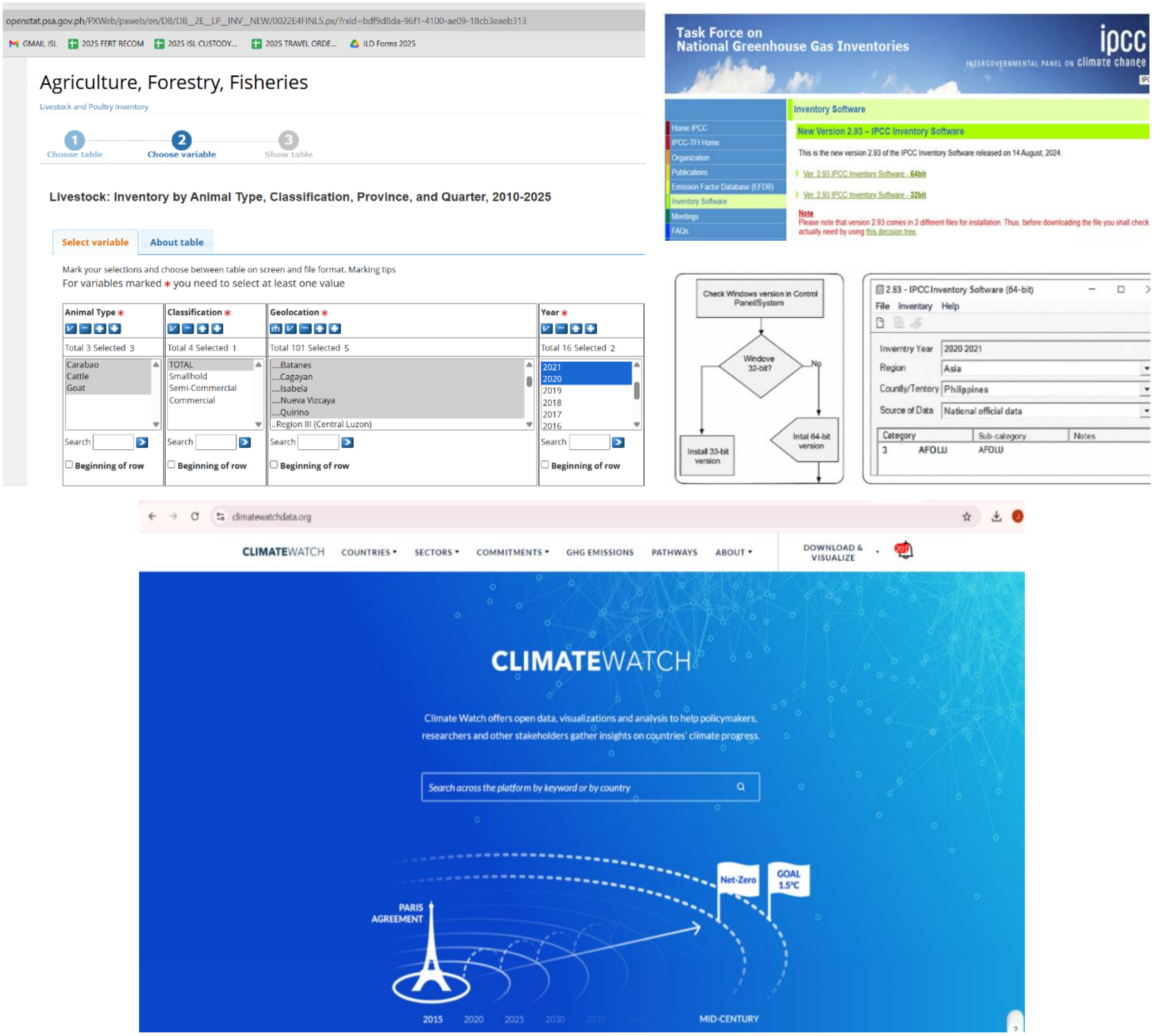

Figure 2. *Software Environment and Interface Used for GHG Accounting*

Data Collection

Data collection began with the installation and setup of the IPCC Inventory Software, where initial configurations such as units of measurement, emission factors, and inventory year were defined. Data on livestock populations and rice cultivation for the years 2020 and 2021 were manually retrieved from PSA and entered into the corresponding worksheets within the software. The entries were categorized under the agriculture, forestry, and other land use (AFOLU) sector, specifically within the enteric fermentation, manure management, and rice cultivation categories. Geographical segmentation ensured that emissions could be tracked by province. Additionally, global data was gathered from the Climate Watch platform for India, Brazil, and China, allowing for contextual benchmarking of emissions patterns.

Philippine Statictics Authority (PSA) Data
(Livestock: Inventory by Animal Type, Province and Year)

Animal Type	Province	Unit of Measure	Year 2020	Year 2021
Cattle	Batanes	head	15,468	16,284
	Cagayan	head	44,330	40,404
	Isabela	head	256,575	266,820
	Nueva Vizcaya	head	36,282	35,846
	Quirino	head	23,781	23,575
Carabao (Buffalo)	Batanes	head	7,425	7,773
	Cagayan	head	184,204	182,873
	Isabela	head	155,397	148,338
	Nueva Vizcaya	head	50,574	51,419
	Quirino	head	41,828	41,878
Sheep	Batanes	head	-	0
	Cagayan	head	-	0
	Isabela	head	-	23
	Nueva Vizcaya	head	-	172
	Quirino	head	-	6,645
Goat	Batanes	head	9,223	10,254
	Cagayan	head	76,669	70,120
	Isabela	head	43,785	39,035
	Nueva Vizcaya	head	30,355	31,276
	Quirino	head	26,536	26,509
Horse	Batanes	head	-	385
	Cagayan	head	-	0
	Isabela	head	-	724
	Nueva Vizcaya	head	-	579
	Quirino	head	-	0
Swine	Batanes	head	6,185	10,435
	Cagayan	head	812,740	403,393
	Isabela	head	342,550	134,245
	Nueva Vizcaya	head	196,520	179,427
	Quirino	head	168,917	82,036

Ecosystem	Province	Unit of Measure	Year 2020	Year 2021
Irrigated Palay	Batanes	hectare	0	0
	Cagayan	hectare	179,823	187,462
	Isabela	hectare	269,960	270,670
	Nueva Vizcaya	hectare	53,966	62,338
	Quirino	hectare	22,656	24,007
Rainfed Palay	Batanes	hectare	79	49
	Cagayan	hectare	41,290	44,100
	Isabela	hectare	16,969	19,024
	Nueva Vizcaya	hectare	2,611	2,768
	Quirino	hectare	2,363	2,703

Figure 3. *PSA Data Entries for Livestock Population and Rice Ecosystem Classification*

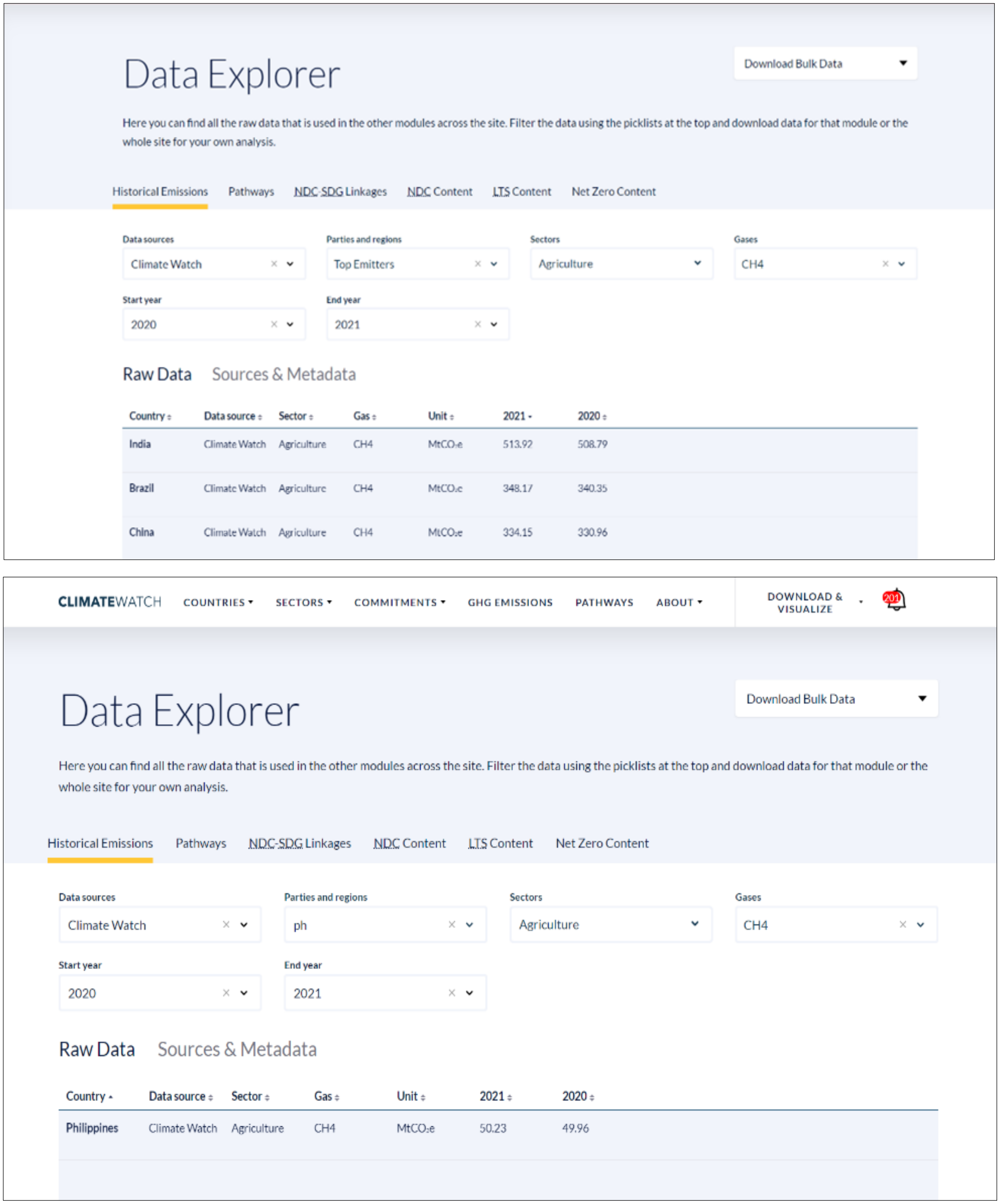

Figure 4. *Climate Watch Comparison Dashboard for Agricultural Emissions*

Livestock and rice cultivation data from PSA were encoded into the software's worksheets. The software's default emission factors were reviewed and used under the

Tier 1 approach. Fields irrelevant to Tier 1 methodology were excluded to streamline data entry. Retrieving agriculture-related CH_4 emission data from China, India, and Brazil, which were then compared using filters for sector, gas type, and year, a usability assessment of PSA and Climate Watch platforms, where recommendations for platform enhancements—such as interface improvements, automated reporting, and stakeholder training—were formulated.

Data Analysis

GHG emissions were estimated using the Tier 1 methodology from the 2006 IPCC Guidelines. Methane emissions were calculated in gigagrams (Gg) using default emission factors provided by the software. Regional analysis focused on provincial disaggregation within the Cagayan Valley for more granular insights. Comparative analysis involved descriptive statistics and graphical visualization of agricultural GHG trends among the Cagayan Valley, China, India, and Brazil.

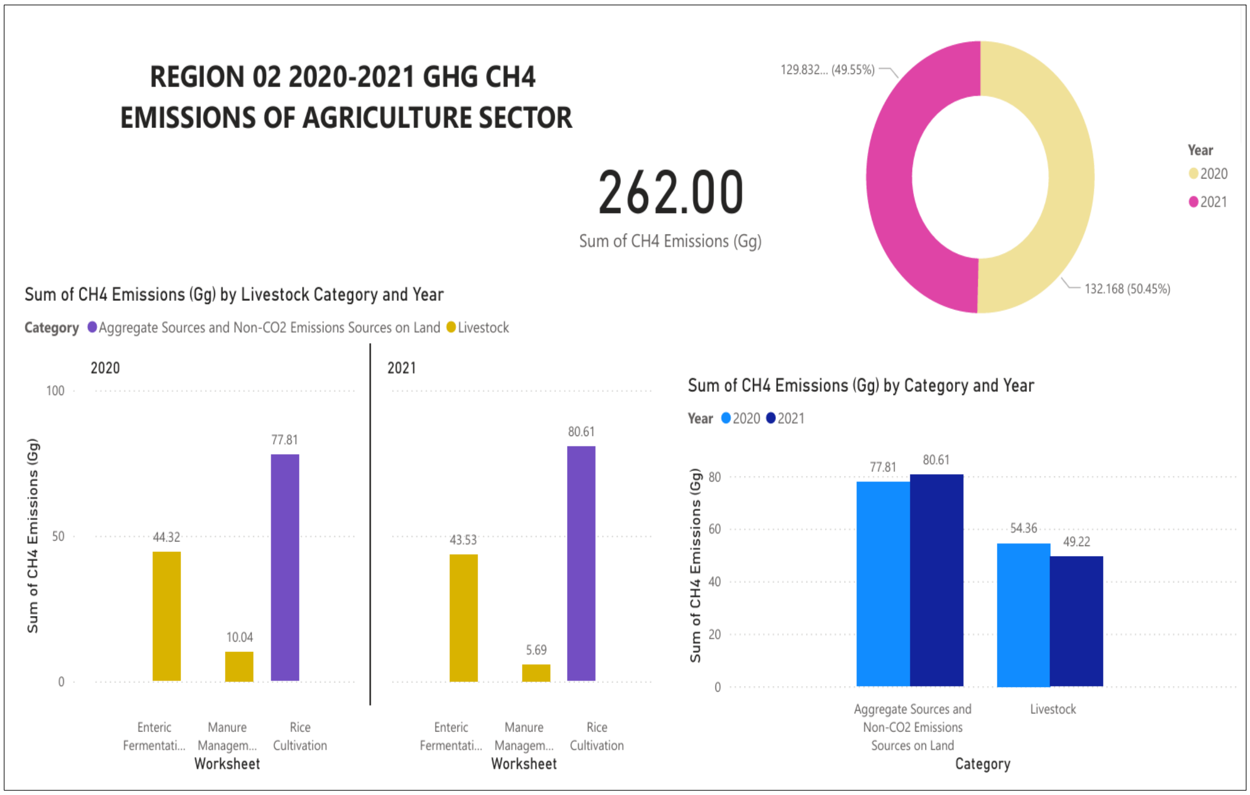

Figure 5. *Computed CH_4 Emissions for Livestock and Rice Cultivation in the Cagayan Valley*

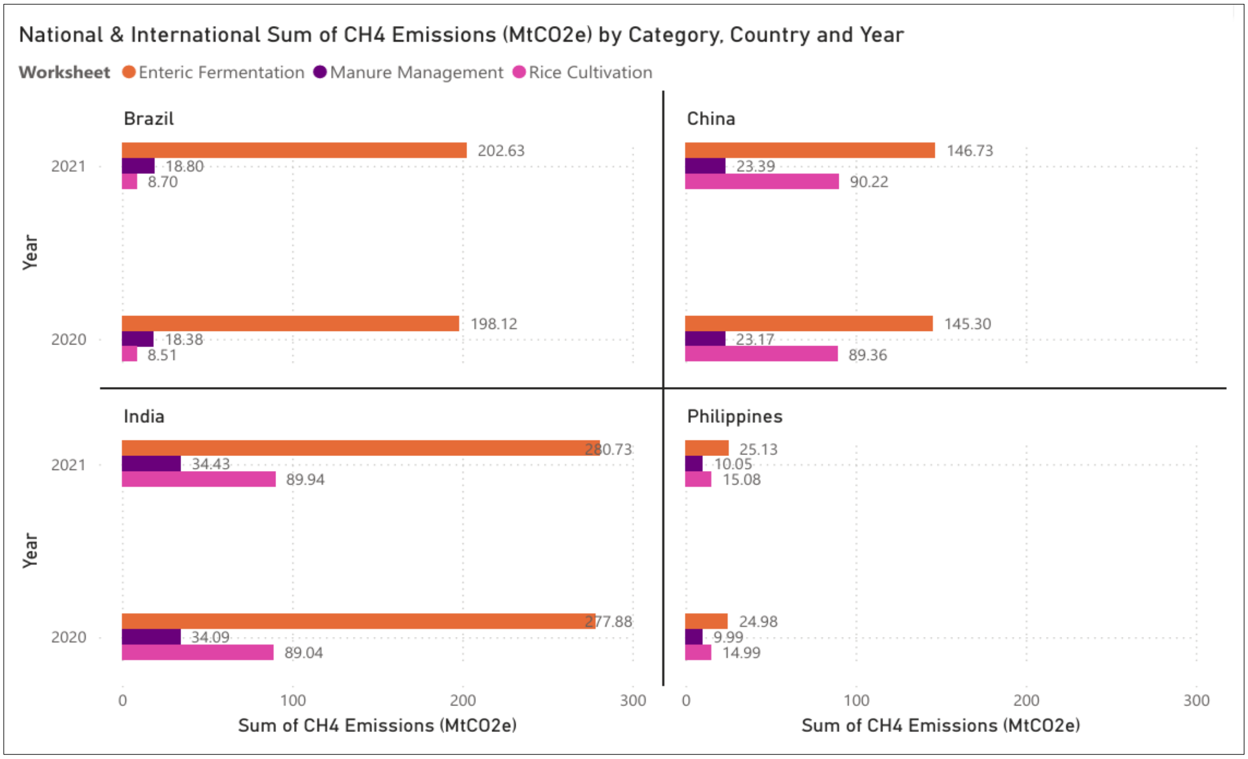

Figure 6. *National and International Comparison of Agricultural CH_4 Emissions – Philippines, China, India, Brazil*

Ethical Considerations

Ethical considerations were rigorously observed throughout the study. All data utilized were publicly accessible and derived from verified governmental and international organizations, ensuring both transparency and reliability. There was no personal or confidential data involved, thus eliminating any need for informed consent or ethical clearance. The software used was obtained legally through the official IPCC website, adhering to all licensing requirements. To maintain transparency and reproducibility, all procedures—from software setup to data entry and analysis—were documented thoroughly. This ensured that the study's methodology could be reviewed or replicated in future assessments.

This study did not involve human subjects and, therefore, did not require IRB approval. However, the following ethical research principles were strictly observed:

1. Use of Secondary Data – All data were publicly available and obtained from official sources (PSA and Climate Watch). No private, sensitive, or personally identifiable information was collected.
2. Data Confidentiality – Only aggregated datasets were used, with full citation and acknowledgment of sources.
3. Research Integrity – Transparency in methodology, honest reporting of findings, and responsible data management were ensured throughout the study.

Results and Discussion

Cagayan Valley Livestock Emissions

Agriculture is a major source of methane emissions, contributing 145 Tg CH4 y−1 in 2017 (Smith et al., 2021). The primary agricultural sources include livestock enteric fermentation, livestock manure management, rice cultivation, and residue burning (Smith et al., 2021; Wu et al., 2023). These emissions have increased by 17% since 1990 (Benbi, 2013). Despite methane's short atmospheric lifetime, urgent action is needed to reduce all greenhouse gas emissions, including methane (CH4) (Smith et al., 2021).

In terms of enteric fermentation, total CH_4 emissions across Cagayan Valley slightly declined from 44.32 Gg in 2020 to 43.53 Gg in 2021. Among the provinces, Isabela recorded the highest emissions, with 13.55 Gg in 2020 and 12.85 Gg in 2021. This corresponds to its large populations of cattle and carabaos, both of which are known to produce high levels of methane through digestion. Cagayan followed as the second-largest contributor, with 10.13 Gg in 2020 and a nearly unchanged 10.06 Gg in 2021. Interestingly, while Cagayan's total livestock population dropped, the stable emissions suggest a higher proportion of ruminants, which are more methane-intensive. Moreover, Nueva Vizcaya and Quirino reported moderate emissions, with around 2.7 to 2.8 Gg and 2.3 Gg, respectively, also due to their cattle and carabao populations. On the other hand, Batanes, with its relatively small livestock inventory, had the lowest emissions from enteric fermentation at 0.73 Gg in 2020 and 0.77 Gg in 2021.

In addition, enteric fermentation in ruminants, particularly cattle, is a significant source of methane emissions, accounting for about 20% of anthropogenic methane in the United States (Mangino et al., 2003). Various strategies can mitigate these emissions, including dietary manipulation, animal breeding, and improved production systems (Lascano et al., 2011). Methane emissions are positively correlated with dry matter intake, milk production, and average daily gain in both dairy and beef cattle (Min et al., 2022). Mitigation efforts focus on reducing emissions per unit of product, such as energy-corrected milk or live weight gain (Lascano et al., 2011). Potential mitigation strategies include using ionophores, organic acids, oils, and plants containing secondary metabolites like tannins and saponins (Lascano et al., 2011). However, adoption of these strategies depends on regulatory requirements and economic incentives (Meale et al., 2012). A holistic, life cycle assessment approach is crucial when evaluating the effectiveness of any abatement strategy (Meale et al., 2012).

For manure management, methane emissions showed a more notable decline, from 10.04 Gg in 2020 to 5.69 Gg in 2021. This was mainly due to a sharp reduction in the swine population, particularly in the provinces of Cagayan, Isabela, and Nueva Vizcaya. Cagayan's emissions dropped from 4.88 Gg in 2020 to 2.44 Gg in 2021, which aligns with the decrease in its swine population from 812,740 to 403,993. Similarly, Isabela saw a decline in emissions from 3.16 Gg to 2.06 Gg, and Nueva Vizcaya from 0.59 Gg to 0.54 Gg. These reductions indicate either a decrease in the number of confined swine or possible changes in manure handling practices. The provinces of Batanes and Quirino, having smaller swine populations, recorded much lower emissions from manure management. Other animal types, such as goats, sheep, and horses, had minimal contributions to overall methane emissions, reflecting their smaller populations and less methane-intensive waste output.

Methane emissions from livestock manure management are a significant contributor to greenhouse gas emissions. Various mitigation strategies have been studied to reduce these emissions. Changing from liquid to solid-liquid separation systems, coupled with other measures, can reduce GHG emissions by 65% and ammonia emissions by 78% (Wang et al., 2017). Reducing storage time, lowering manure temperature, and capturing and combusting methane during storage are effective practices (Montes et al., 2013). Anaerobic digestion with gas combustion reduces methane emissions but may increase N2O emissions after land application (Montes et al., 2013). Methane recovery systems can significantly reduce emissions, even in less favorable conditions (Gallo et al., 2015). Factors such as livestock population, water availability, and farming practices influence emission patterns across regions (Maze et al., 2024). While sheep and goats may have higher populations, buffalo and cattle contribute more to emissions from both enteric fermentation and manure management (Maze et al., 2024).

Overall, the data showed that Isabela is the top contributor to methane emissions in Cagayan Valley, mainly due to its substantial populations of cattle, carabaos, and swine. Cagayan, while experiencing a decrease in total livestock population, maintained high levels of methane emissions, likely due to a shift towards more ruminant animals. The significant drop in manure management emissions across the region points to a reduction in swine populations and possibly improved manure practices. The smaller provinces—Batanes, Quirino, and to a lesser extent Nueva Vizcaya—contributed less to regional methane totals but maintained relatively consistent emission levels. These findings highlight the importance of targeted mitigation strategies, especially in provinces with high ruminant populations and intensive swine farming, to reduce methane emissions from the agriculture sector.

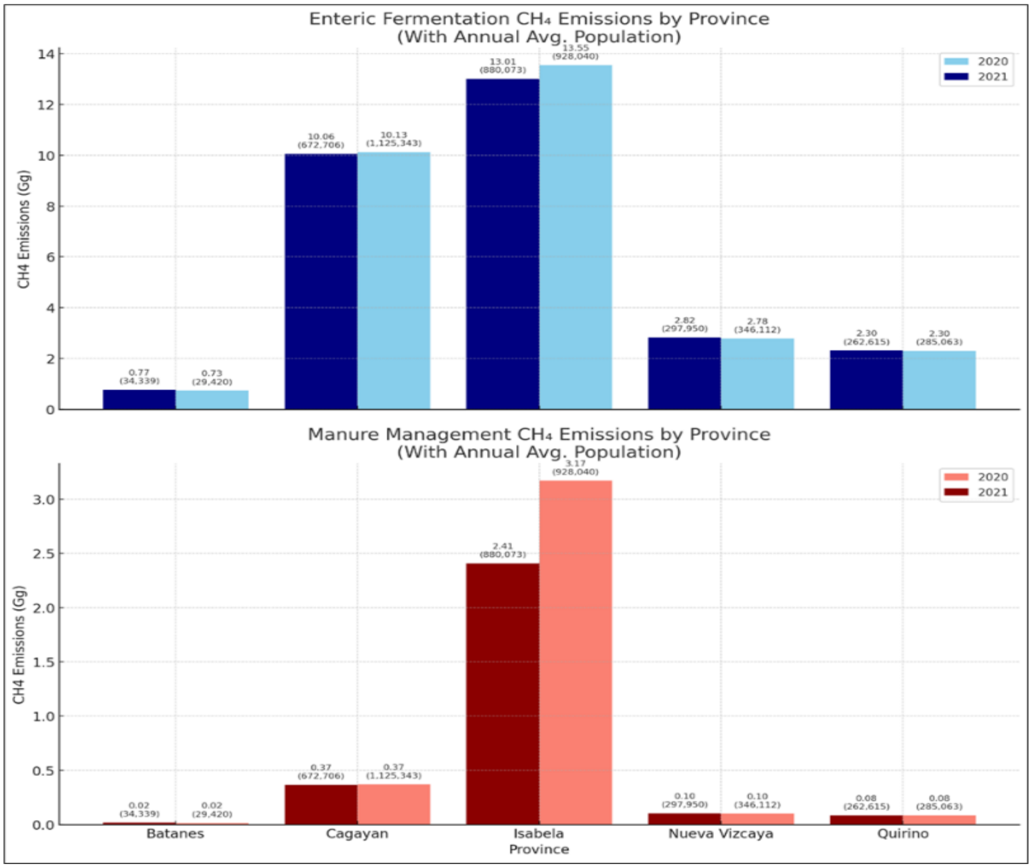

Figure 7. *Livestock CH4 Emissions by Province with Annual Average Population*

Cagayan Valley Rice Cultivation Emissions

The data and visualizations highlight significant trends in rice cultivation and associated methane (CH_4) emissions across the provinces of Cagayan Valley for both irrigated and rainfed systems in 2020 and 2021.

Overall, irrigated rice cultivation dominates the region in terms of area and emissions. Provinces such as Isabela and Cagayan have the largest irrigated areas, consistently exceeding 250,000 and 180,000 hectares, respectively, in both years. These provinces also exhibit the highest CH_4 emissions from irrigated systems, with Isabela contributing approximately 38.6–38.7 Gg and Cagayan around 25.7–26.8 Gg. The increase in harvested areas from 2020 to 2021 is mirrored by a corresponding rise in CH_4 emissions, indicating a direct relationship between land use intensity and greenhouse gas emissions.

For rainfed systems, while the harvested areas and CH_4 emissions are considerably lower than irrigated systems, a similar pattern of increase is observed. Cagayan again leads in the rainfed area, increasing from 41,290 hectares in 2020 to 44,100 hectares in 2021, with emissions rising from 1.65 Gg to 1.77 Gg. Isabela and the rest of the provinces showed modest growth in both harvested area and emissions. Notably, Batanes remained negligible in irrigated rice cultivation and recorded minimal values under rainfed systems as well, indicating its limited contribution to both rice production and methane emissions in the region.

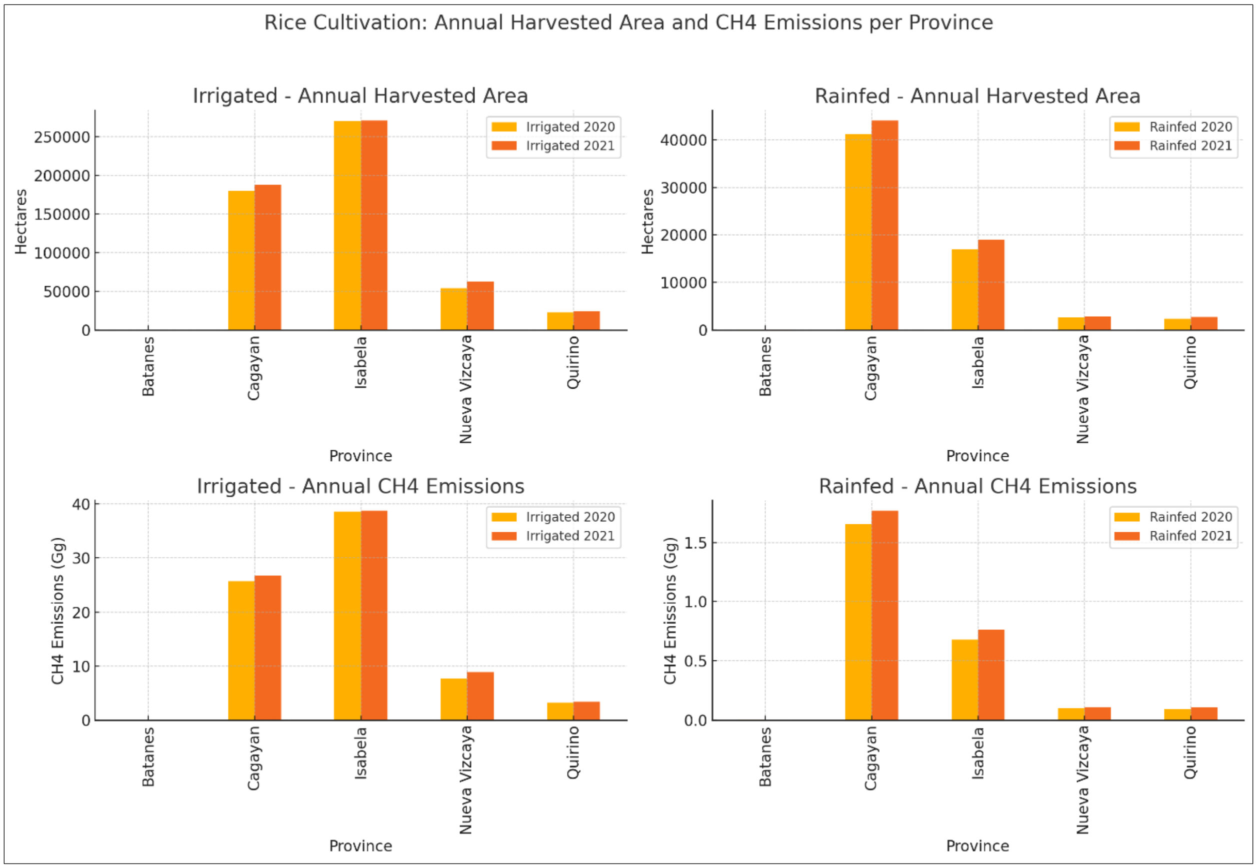

Figure 8. *Rice Cultivation CH4 Emissions by Province with Annual Harvested Area*

Rice cultivation is a significant source of greenhouse gas emissions, particularly methane (CH4), due to flooded field conditions (Rennenberg et al., 1992; Wassmann et al., 2009). Global CH4 emissions from irrigated rice were estimated at 625 million metric tons of CO2 equivalent in 2000 (Wassmann et al., 2009). In Vietnam, rice cultivation accounts for 49.7 million tons of CO2 equivalent annually (Hao et al., 2023). Emissions are influenced by water management, organic inputs, soil type, and agricultural practices (Rennenberg et al., 1992; Wassmann et al., 2009). Alternate Wetting and Drying (AWD) and the System of Rice Intensification (SRI) have shown potential in reducing CH4 emissions compared to conventional rice cultivation (Dahlgreen & Parr, 2024; Hao et al., 2023). While these methods may increase nitrous oxide and carbon dioxide emissions, SRI also improves yield, further reducing emissions per kilogram of rice (Dahlgreen & Parr, 2024). Implementing such techniques could simultaneously address climate change and food security concerns.

Comparison to International Agricultural Emissions

The agricultural CH_4 emissions from Cagayan Valley (Cagayan Valley) were evaluated alongside emissions from China, India, and Brazil—countries with significantly larger agricultural sectors. In 2021, Cagayan Valley emitted approximately 129.83 Gg of CH_4, primarily from rice cultivation and enteric fermentation. In contrast, China reported agricultural CH_4 emissions exceeding 260 $MtCO_2e$, while India and

Brazil emitted around 270 $MtCO_2e$ and 220 $MtCO_2e$, respectively. This stark difference illustrates how emissions in Cagayan Valley, though gradually increasing, remain marginal on a global scale.

Cagayan Valley's CH_4 emissions accounted for just 0.5% of the national total, underscoring the region's potential to maintain low emission levels through proactive mitigation strategies. The growing emissions trend in Cagayan Valley emphasizes the need for early intervention. By adopting low-emission agricultural practices—such as improved manure management, optimized fertilizer application, and agroecological farming—the region can help curb emissions before they escalate.

While China, India, and Brazil face greater challenges due to the scale of their agricultural systems, Cagayan Valley has the opportunity to serve as a model for sustainable agricultural development. Strengthening local monitoring efforts and prioritizing land use management will be essential to align with national and global emission reduction goals.

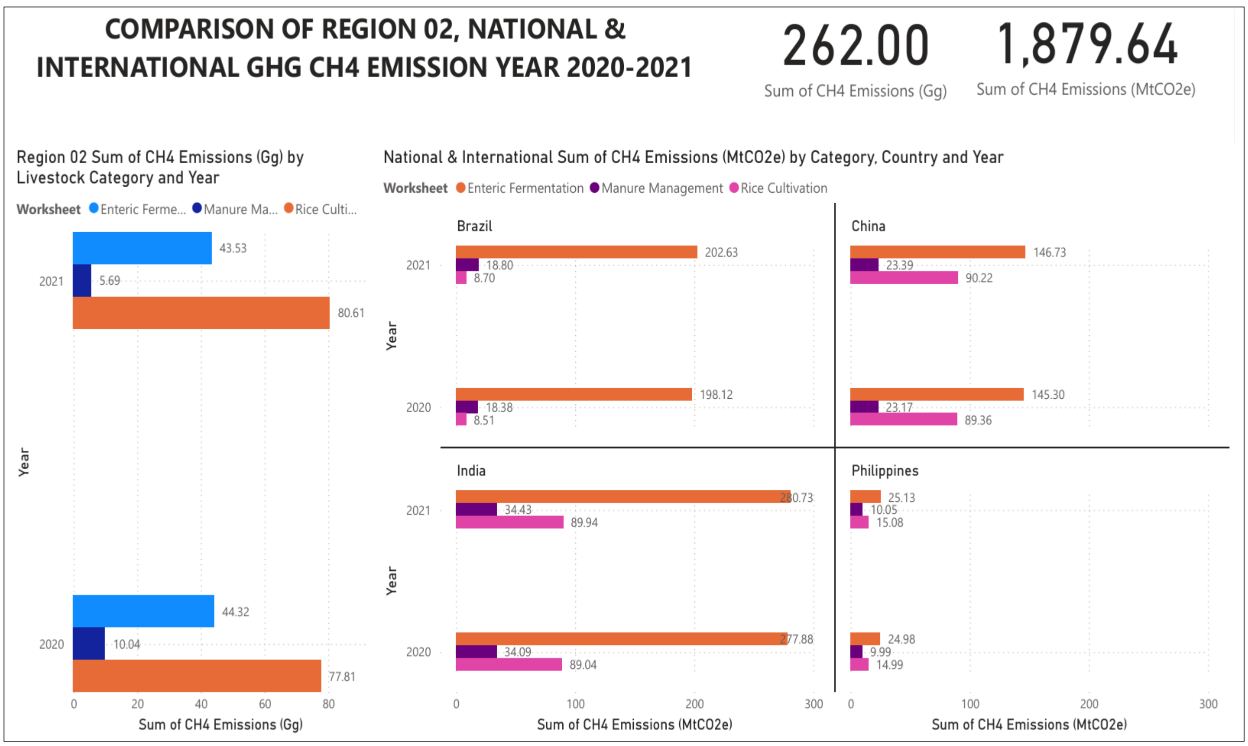

Figure 9. *Comparative Analysis of CH_4 Emissions from Agricultural Sectors in Cagayan Valley, China, India, and Brazil*

Conclusion and Future Works

This study provides an inventory assessment of greenhouse gas (GHG) emissions from agricultural activities in Cagayan Valley, focusing on methane emissions from livestock and rice cultivation. The findings suggest that while emissions from the region are relatively lower compared to major agricultural countries like China, India, and Brazil, they still represent a significant source of methane, particularly from livestock and rice fields. These results underscore the need for targeted mitigation strategies such as improved livestock management and modified rice cultivation practices, such as alternate wetting and drying (AWD), to reduce methane emissions.

Moreover, the comparison of emission profiles across countries highlights the unique position of Cagayan Valley within the broader global context, with opportunities for improving agricultural practices that align with both national and international climate goals. The study also identified the importance of enhancing data platforms, such as the Philippine Statistics Authority (PSA) and Climate Watch Data Explorer, to facilitate more efficient and accessible emission tracking and reporting.

Despite the contributions of this study, certain limitations should be acknowledged. The data used were based on secondary sources, and although these were reliable, they may not fully capture the regional variability in agricultural practices and emissions. Further research could incorporate primary data collection, including field studies and direct emissions measurements, to provide more granular insights into emission sources and their variability within the region.

Additionally, while this study focused on livestock and rice cultivation, future work could explore other agricultural sectors, such as crop cultivation (e.g., maize, sugarcane) and forestry, which may also contribute to GHG emissions. Future research could also explore the potential of integrated mitigation practices across multiple agricultural sectors to reduce the overall carbon footprint of farming in Cagayan Valley, as underscored in the studies of Erana et al. (2024) and Tasani and Barcellano (2024).

Finally, the development and implementation of local emission reduction policies based on the findings of this study will require multi-stakeholder engagement, including government agencies, local farmers, and environmental organizations. Future work should focus on promoting the adoption of sustainable agricultural practices and exploring the role of policy interventions in supporting the transition to low-emission farming systems.

In conclusion, this study lays the groundwork for future research that can enhance understanding of agricultural emissions in Cagayan Valley and inform practical solutions to mitigate their impact on climate change. It also encourages further exploration into more comprehensive, region-specific emission inventories and mitigation strategies that could serve as models for other areas facing similar agricultural challenges.

References

[1] Bautista, E., & Saito, M. (2015). *Greenhouse gas emissions from rice production in the Philippines based on life-cycle inventory analysis*. https://www.researchgate.net/publication/273636139_Greenhouse_gas_emissions_from_rice_production_in_the_Philippines_based_on_life-cycle_inventory_analysis

[2] Benbi, D. K. (2013). Greenhouse gas emissions from agricultural soils: Sources and mitigation potential. *Journal of Crop Improvement, 27*(6), 752–772. https://doi.org/10.1080/15427528.2013.845054

[3] Climate Watch. (n.d.). *Data Explorer tool*. https://www.climatewatchdata.org/

[4] Dahlgreen, J., & Parr, A. (2024). Exploring the impact of alternate wetting and drying and the system of rice intensification on greenhouse gas emissions: A review of rice cultivation practices. *Agronomy, 14*(2), 378. https://doi.org/10.3390/agronomy14020378

[5] Erana, I., Bareng, J. L., Balderama, O., Naval, R., Taracatac, A., Labuanan, F. R., Bose, W., Jr, Awisen, M., & Dingoasen, S. M. (2024, June 30). Development of integrated solar-powered wireless smart IoT-based water level monitoring embedded system. *The Journal of Emerging Research in Agriculture, Fisheries and Forestry (TJERAFF)*. https://www.isujournals.ph/index.php/tjeraff/article/view/30

[6] Francisco, R. V. (1996). Greenhouse gas inventory of the Philippines: Interim report. In *Environmental Science and Technology Library* (pp. 189–199).

[7] Gallo, M., Del Borghi, A., & Strazza, C. (2015). Analysis of potential GHG emissions reductions from methane recovery in livestock farming. *International Journal of Global Warming, 8*(4), 516.

[8] Hao, D. P., Binh, N. T., & Anh, L. H. (2023). Current situation and solutions for methane (CH_4) emission in paddy rice cultivation in Vietnam. *VNU Journal of Science: Earth and Environmental Sciences, 39*(1).

[9] IPCC. (2019). *2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories*. https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

[10] IPCC. (2019, May 13). IPCC updates methodology for greenhouse gas inventories — IPCC. https://www.ipcc.ch/2019/05/13/ipcc-2019-refinement/

[11] Lascano, C. E., Carulla, J. E., & Vargas, J. (2011). *Strategies for reducing methane emissions from ruminants*. [Unpublished manuscript].

[12] Mangino, J., Peterson, K. A., & Jacobs, H. (2003). *Development of an emissions model to estimate methane from enteric fermentation in cattle*. [Unpublished manuscript].

[13] Maze, M., Taqi, M. O., Tolba, R., Abdel-Wareth, A. A. A., & Lohakare, J. (2024). Estimation of methane greenhouse gas emissions from livestock in Egypt during 1989 to 2021. *Scientific Reports, 14*(1). https://doi.org/10.1038/s41598-024-63011-0

[14] Meale, S. J., McAllister, T. A., Beauchemin, K. A., Harstad, O. M., & Chaves, A. V. (2012). Strategies to reduce greenhouse gases from ruminant livestock. *Acta Agriculturae Scandinavica, Section A – Animal Science, 62*(4), 199–211. https://doi.org/10.1080/09064702.2013.770916

[15] Min, B., Lee, S., Jung, H., Miller, D. N., & Chen, R. (2022). Enteric methane emissions and animal performance in dairy and beef cattle production: Strategies, opportunities, and impact of reducing emissions. *Animals, 12*(8), 948. https://doi.org/10.3390/ani12080948

[16] Montes, F., Meinen, R., Dell, C., Rotz, A., Hristov, A. N., Oh, J., Waghorn, G., Gerber, P. J., Henderson, B., Makkar, H. P. S., & Dijkstra, J. (2013). Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. *Journal of Animal Science, 91*(11), 5070–5094. https://doi.org/10.2527/jas.2013-6584

[17] Ogle, S. M., Buendia, L., Butterbach-Bahl, K., Breidt, F. J., Hartman, M., Yagi, K., Nayamuth, R., Spencer, S., Wirth, T., & Smith, P. (2013). Advancing national greenhouse gas inventories for agriculture in developing countries: Improving activity data, emission factors and software technology. *Environmental Research Letters, 8*(1), 015030. https://doi.org/10.1088/1748-9326/8/1/015030

[18] Philippine Statistics Authority. (n.d.). *OpenSTAT portal*. https://openstat.psa.gov.ph/

[19] Rennenberg, H., Wassmann, R., Papen, H., & Seiler, W. (1992). Trace gas exchange in rice cultivation.

[20] Smith, P., Reay, D., & Smith, J. (2021). Agricultural methane emissions and the potential for mitigation. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 379*(2210). https://doi.org/10.1098/rsta.2020.0451

[21] Tasani, A., & Barcellano, E. (2024, June 30). Diversity and utilization of wild plants and macrofungi: Its contribution to rural livelihood in Cabagan, Isabela, Philippines. *The Journal of Emerging Research in Agriculture, Fisheries and Forestry (TJERAFF)*. https://www.isujournals.ph/index.php/tjeraff/article/view/36

[22] Wang, Y., Dong, H., Zhu, Z., Gerber, P. J., Xin, H., Smith, P., Opio, C., Steinfeld, H., & Chadwick, D. (2017). Mitigating greenhouse gas and ammonia emissions from swine manure management: A system analysis. *Environmental Science & Technology, 51*(8), 4503–4511. https://doi.org/10.1021/acs.est.6b06430

[23] Wassmann, R., Hosen, Y., & Sumfleth, K. (2009). Reducing methane emissions from irrigated rice.

[24] Wu, X., Zhang, Y., Han, Y., Zhang, Y., Zhang, Y., Cheng, X., Zhong, P., Yuan, X., Zhang, Y., & Li, Z. (2023). Advances in methane emissions from agricultural sources: Part I. Accounting and mitigation. *Journal of Environmental Sciences*. https://doi.org/10.1016/j.jes.2023.08.029

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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