Organic Vs. Conventional Farming: Greenhouse Gas Emissions Analysis Through Life Cycle Assessment for Sustainable Rice Farming

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Abstract: - Asingan, Pangasinan, Philippines, is known for its annual celebration of the rice-based "Kankanen" festival, which relies heavily on local rice production. Since rice production is one of the major sources of greenhouse gas (GHG) emissions, this study will guide the farmers and policymakers in developing sustainable farming practices and mitigating the impacts of GHG emissions. The main goal of this study is to quantify the CO_2 emissions from the organic, combined, and conventional farming methods in the municipality, considering seasonal variations and irrigation methods using life cycle assessment. The agricultural inputs were obtained from the agriculturists of the municipality. The system boundary was set from cradle to gate, and kg of CO_2 emission per hectare of land was used as the functional unit. The results show that conventional farming consistently shows the highest emissions among the three farming methods. On the other hand, irrigated systems produced higher emissions than the rainfed irrigation method. To reduce GHG emissions, farmers should adopt organic farming with a more water-efficient irrigation system, and policymakers should strongly recommend supporting this.

Key-Words: - life cycle assessment, organic farming, conventional farming, greenhouse gas, rice cultivation, emission factor.

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1 Introduction

The average Filipino diet mainly includes rice. It provides half of their calorie requirements and one-third of their protein intake. Rice accounts for 20% of food expenditures for average households, which increases to 30% for households belonging to the bottom third of society, [1]. For these households, rice not only serves as the staple food but also a symbol of culture, hard work, and way of life.

The Philippines remains one of the top rice producers in the world, maintaining its eighth place behind China, Indonesia, India, and other Southeast Asian nations, [2]. However, with agriculture being the leading contributor to atmospheric methane emissions, the environmental implications of rice farming must be carefully considered. Methane emissions from agricultural sources are projected to be 3135.75 million tons (Mt) CO_2-equivalent (CO_2-eq) annually. This value makes the agricultural sector the biggest emitter, which is responsible for the majority of methane emissions from anthropogenic sources, [3]. The anaerobic decomposition during rice production and burning releases greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases significantly contribute to rising global temperatures, [4]. These gases, together with other components, such as ammonium (NH_3) and other nitrogen compounds, are usually generated in animal and agricultural activities, [4].

Total greenhouse gas emissions from rice production in the Philippines, including emissions from fertilizers, agricultural machinery, fuel, and water buffaloes (carabaos) used by local farmers, are estimated at 13.3 Teragram (Tg) CO_2 eq. yr^{-1}, comprising 3,920 kg CO_2-eq. ha^{-1} $crop^{-1}$ in irrigated areas and 1,381 kg CO_2-eq. Ha^{-1} $crop^{-1}$ in rainfed areas, [5]. In addition, the extensive use and application of pesticides and herbicides pose a great risk to the health of farmers, consumers, and the environment. Furthermore, detecting pesticide-contaminated products is also important to protect the ecosystem. One negative effect of synthetic pesticides, particularly organochlorinated and organophosphorus (OP) pesticides, is food contamination, which poses significant risks to human health in many regions, [6]. Additionally, the growing demand for rice products increases rice residues, such as rice straw, which are a major source of emissions. During harvest, rice straw is collected along with the grains and is either piled or spread across the field, depending on whether harvesting is done manually or with machines. The ratio of straw to paddy varies, ranging from 0.74–0.79, [7]. In this study, they evaluated 5480 ha of potential cropland for rice, estimated an annual generation of 4411 tons of rice straw, and calculated the overall carbon footprint to be 421.84 tons of CO_2-eq per year, equating to just 0.096 kg of CO_2-eq per kilogram of rice straw, [8]. The introduction of combine harvesters has made rice straw collection a major challenge and has brought bottlenecks to the rice straw supply chain, [9].

There are two types of rice farming in the Philippines: conventional and organic. Conventional farming includes a large amount of chemical fertilizer and pesticide use to increase the yields per hectare, [10]. In the organic farming system, chemical and synthetic fertilizers and pesticides are avoided to minimize their negative environmental impacts, [10]. Crop production (during the crop's life cycle) is done using a wide set of cultivation techniques and crop management, harvest, and postharvest procedures, [11]. The processes and relevant inputs and outputs are part of the life-cycle process. Rice production is typically characterized by three major phases: preplanting, plant growth, and postproduction, [11].

Rice is the second most widely grown cereal crop and the staple food for more than half the world's population, [12]. With the continuous growth of the global population, the demand for rice production is also rising. Rice production on a global scale is predicted to rise by 58 to 567 million tons (Mt) by 2030, [13]. Given these factors, rice farming has emerged as one of the least sustainable practices within the agri-food sector, highlighting the urgent need to focus on reducing its environmental impact, [14].

To minimize greenhouse gas emissions from rice production, it is necessary to identify and analyze the factors that contribute to these emissions. Life Cycle Assessment (LCA) helps analyze the contributors to GHG emissions. The LCIA methods are methodologies assessing the potential impact that the evaluated system will have on the environment (i.e., global warming, eutrophication, acidification), [15]. Life cycle assessment (LCA) has proven to be an appropriate assessment tool for analyzing agroecosystems by identifying, quantifying, and evaluating the resources consumed and released into the environment during rice cultivation, [16]. Assessing GHG emissions from rice cultivation is vital to help identify potential mitigation processes, [5]. Knowing the sources of emissions will help us better understand measures for mitigating environmental effects and formulate better management practices, [5]. This study addresses increasing concerns about greenhouse gas emissions from rice cultivation. It provides a comprehensive Life Cycle Assessment (LCA) of rice farming in Asingan, Pangasinan, evaluating the entire production system.

1.1 Objectives of the Study

1. To quantify and compare the total GHG emissions associated with each farming method, considering variations in seasons and irrigation methods.
2. To identify the largest contributor of GHG emissions among the three farming methods.

1.2 Scope and Delimitation

This study assesses and compares GHG emissions from organic and conventional rice farming across dry and wet seasons from 2020 to 2023, using different irrigation methods. A cradle-to-gate system boundary is applied, covering processes from land preparation to harvesting and threshing. Data were obtained from the Department of Agriculture in Asingan, and the functional unit used is kg CO_2 emissions per hectare for both farming systems. However, the study is constrained by limited data on farmers' actual inputs and machinery use, which may influence emission accuracy. Future studies may overcome these limitations by conducting field measurements, broadening data collection, using LCA software, and mapping GHG hotspots.

2 Methodology

In this study, cradle-to-gate life cycle assessment was conducted to evaluate the environmental impacts of two farming systems—organic and conventional—from land preparation to harvesting. Data were collected on various parameters, including the cultivated area, rice yield, types and quantities of fertilizers and pesticides used, machinery employed, and pesticides used. Emission factors were adapted from peer-reviewed studies to estimate GHG emissions, expressed in kilograms of CO_2 equivalent (kg CO2). Computation of all GHG emissions was performed using Microsoft Excel. Statistical analyses, including analysis of variance (ANOVA) and post hoc tests, were employed to compare the two farming systems and to determine the major contributors to GHG emissions within the municipality using the Statistical Package for the Social Sciences (SPSS).

2.1 Research Design

2.1.1 Proposed Procedure

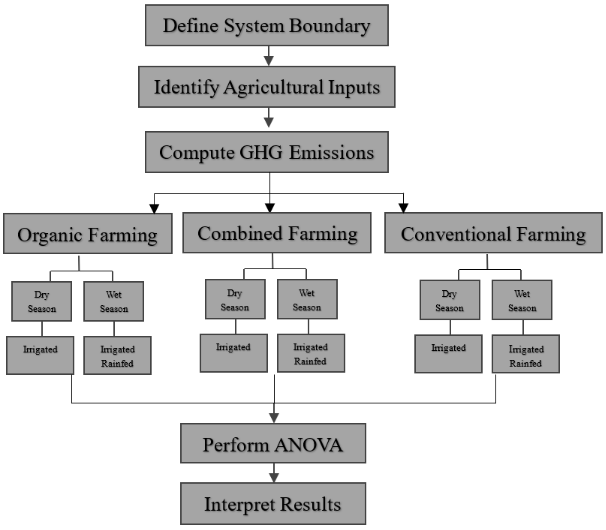

Fig. 1: Research Design of the Study
Source: created by the authors

Figure 1 presents the study procedure, starting with system boundary identification and agricultural input data collection. GHG emissions of the three farming methods (organic, combined, and conventional) under varying seasons and irrigation methods will be estimated using the IPCC guidelines and reviewed studies by multiplying agricultural inputs with their corresponding emission factors. Data will be analyzed using different statistical treatments. The results will be analyzed to determine which farming method and irrigation system significantly contribute to GHG emissions. Sensitivity analysis will also be performed to test for the robustness of the data.

2.1.2 System Boundary

The study adopted a system boundary covering the pre-planting to plant growth stages of rice production, including seed preparation, sowing, crop management, irrigation, and harvesting, as shown in Figure 2.

2.1.3 Functional Unit

The functional unit used in this study is kg of CO_2 emission per hectare of land to ensure standardized comparison of the farming methods, regardless of farm size.

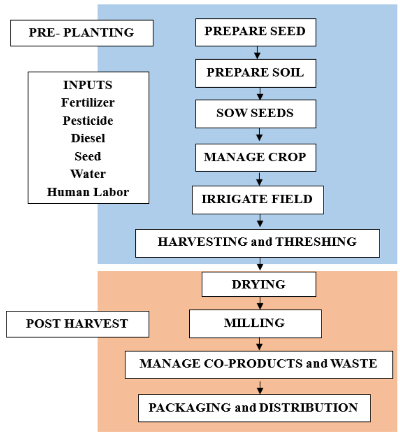

Fig. 2: Cradle-to-gate system boundary showing the stages of rice production and agricultural inputs
Source: created by the authors

2.1.4 Emission Factors

Emission factors were used in this study instead of LCA software to provide a simplified approach to estimate GHG emissions and to minimize software constraints. This is useful when primary data are limited. These emission factors are scientifically validated and make the study focus more on cross-scenario comparisons rather than absolute magnitudes. Future research may improve these estimates through actual field data measurements or the use of localized LCA databases once available.

2.2 Population and Locale of the Study

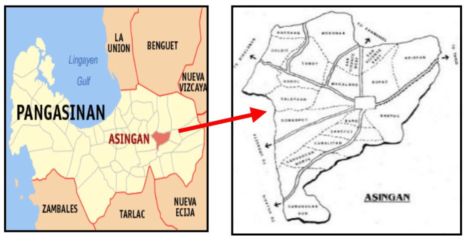

Fig. 3: Location map of Asingan with its barangays
Source: The Official Website of the Province of Pangasinan [12]

The study is conducted in the municipality of Asingan, where both organic and conventional farming are practiced under varying seasons and irrigation methods. Asingan, located in the eastern region of Pangasinan province and within the sixth congressional district, spans a total land area of 6,759 hectares and has a population of 57,811 according to the 2020 census, [17]. The municipality of Asingan is subdivided into 21 barangays as shown in Figure 3, [18].

2.3 Data Gathering Procedure

Data were obtained through interviews with the municipal agriculturist, who provided actual data on harvested area, cultivation days, and yield. They also provided the recommended fertilizer and pesticide inputs, which vary depending on the season and irrigation type, as well as the duration of machinery use for land preparation and water pumping. Additionally, combined harvester usage per hectare and recommended fertilizer rates for nitrogen, phosphorus, and potassium were also given, alongside details on the type and suggested amounts of organic fertilizers. A limitation of this study is the unavailability of actual inputs; only recommended values were provided. These standardized inputs are necessary to compare the three farming methods under different seasons and irrigation methods consistently. Each farming method has its own pumping practices depending on the season and irrigation method. These are indicated in the appendix. Conventional seeds are used instead of hybrid varieties, with the quantity varying by season.

2.3.1 Harvested Area and Rice Yield Data from 2020 to 2023

The data shows the harvested area and yield for each season (dry and wet) and irrigation method (irrigated or rainfed) from the years 2020 to 2023. These data were provided by the Department of Agriculture and are included in the appendix.

2.3.2 Recommended Agricultural Inputs for Asingan

The data includes recommended agricultural inputs for various irrigation methods and seasons. It covers the type and number of conventional seeds used for direct seeding, the quantities of nitrogen (N), phosphorus (P), and potassium (K) in inorganic fertilizers, and the recommended herbicides and insecticides. Using 40 kg of high-quality rice seeds per hectare is sufficient to achieve high yields, [19], [20]. The agriculturist computed the mass of the insecticides and herbicides. The mass was determined using the density of the chemicals. Specifications for the chemicals include Sofit, with a density of 1.073 g ml^{-1}, [21], applied 2 to 3 times per season, and Stampede, with a density of 1.020 g ml^{-1}, [22], applied 2 to 4 times per season. Fuel consumption, pumping hours, and machine usage time were also estimated by the agriculturists. A 7 HP 4×4 self-priming centrifugal pump and a hand tractor with a 7–10 HP water-cooled diesel engine were also considered.

2.3.3 Estimation of Greenhouse Gases

The quantity of GHG emissions from rice cultivation was estimated using the data from the IPCC guidelines for national greenhouse inventories, [23]. Other sources provided the emission factors, [5], [24], [25], [26], [27], [28], [29]. Emission factors (EF) indicate the potential of specific waste or wastewater types to produce particular gases [23]. The GHG emissions for each agricultural input were computed using the general equation by multiplying the activity data obtained from the Department of Agriculture in the municipality and the emission factors. The total GHG emissions for each type of farming were computed by adding all the GHG emissions from each category.

2.3.3.1 Seed Input

The seed rate is quantified in terms of kg ha^{-1}, while the emission factor, EF for seed, is quantified as kg CO_2 eq kg^{-1}. This is computed using equation (1).

2.3.3.2 Inorganic Fertilizer Input

Farmers use various fertilizers, such as ammophos, urea, muriate of potash, and foliar fertilizer, on their farms. These fertilizers contain varying amounts nitrogen, phosphorus, and potassium (N, P, K) and

$$CO_2 \text{ seed input} = \text{Seed rate x EF seed} \quad (1)$$

can be computed using equation (2).

where:

$$\begin{aligned} CO_2 \text{ fertilizer} = {} & (\text{NFerRate x EF } CO_2\text{-}N_2O) + \\ & (\text{NFerRate x EF } CO_2\text{-N}) + \\ & (\text{PFerRate x EF } CO_2\text{-P}) + \\ & (\text{KFerRate x EF } CO_2\text{-K}) \end{aligned} \quad (2)$$

CO_2 fertilizer = total amount of CO_2 emissions from fertilizer
NFerRate = amount of Nitrogen fertilizer application kg N ha^{-1}
EF CO_2-N_2O (kg CO_2-eq. kg^{-1} N) = direct emission factor of N_2O emission from N fertilizer,
EF CO_2-N (kg CO_2-eq. kg^{-1} N) = is the indirect CO_2 emission from N fertilizer
PFerRate = amount of phosphorus in the fertilizer, EF CO_2-P is the emission factor for phosphorus fertilizer (kg CO_2-eq. kg^{-1} P)
KFerRate = amount of potassium in the fertilizer
EF CO_2-K = emission factor for potassium fertilizer (kg CO_2-eq. kg^{-1} K).

The emission factor for the direct emission of nitrogen depends on the type of flooding.

2.3.3.3 Organic Fertilizer

Organic fertilizers which include materials and manures derived from plant or animal wastes or by-products, such as cattle or poultry manure, composted rice straw, other crop residues, sewage sludge, oil cakes, green manures, and legume clippings [30] are computed using equation (3).

$$CO_2 \text{ organic fertilizer} = (\text{OrgFert x EF } CO_2\text{-OrgFert}) \quad (3)$$

where:
OrgFert = rate of any organic amendment used
EF CO_2-OrgFert = emission from any organic fertilizer

2.3.3.4 Pesticides and Herbicides

GHG emissions from the production and processing of pesticides and herbicides can be calculated using the equation (4).

$$CO_2 \text{ pest and herb} = (\text{Pest Rate x EF Pest}) + (\text{Herb Rate x EF Herb}) \quad (4)$$

where:
CO_2 pest and herb = CO_2 emission from the production of pesticides
Herb rate = amount of herbicide applied per hectare
Pest rate = amount of pesticide applied per hectare
EF pest = emission factor pesticides
EF herb = emission factor of herbicide

2.3.3.5 Rice Cultivation Due to CH_4 Emissions from Soil

The GHG emissions from irrigated and rainfed areas were calculated separately for each season under both organic and conventional farming using equation (5). These methane emissions were converted into CO_2-eq based on the scaling and emission factors from the IPCC Tier methodology [23], as well as the conversion factor for CH_4 to CO_2, [25].

$$CO_2 \text{ soil} = (t)\,(EF_{CH4})\,(34.16) \quad (5)$$

where:
CO_2 soil = CO_2 emission converted from CH_4 emissions in rice farms from the soil
EF $_{CH4}$ = emission factor for CH_4 from irrigated or rainfed rice
t = time of cultivation period
34.16 (kg CO_2-eq. ha^{-1} d^{-1}) = is the conversion factor from CH_4 to kg CO_2-eq

2.3.3.6 GHG Emissions from Machines during Seedbed and Land Preparation

GHG emissions from seedbed preparation and land cultivation were assessed based on fuel use in tractors and other equipment, which depends on the total machinery operating hours. The time spent on machine operation is converted into energy units (62.7 MJ h^{-1}), [29]. Fuel usage is also further converted into carbon dioxide emissions using an emission factor of diesel (2.76 kg CO_2-eq. L^{-1}) [28]. These are computed using equation (6).
where:
CO_2 machine = CO_2 emission from machinery
$Fuel_{machine}$ = amount of fuel used by the machine in liters per hectare

$$CO_2 \text{ machine} = (Fuel_{machine} \text{ x } EF_{fuel}) + (\text{MachineTime x } CF_{Machine} \text{ x } EF_{Machine}) \quad (6)$$

Machine Time = amount of time the machine is used, $CF_{Machine}$ = machinery conversion factor
$EF_{Machine}$ = emission factor of the machine

2.3.3.7 Combined Harvester and Thresher

In the municipality of Asingan, combine harvesters are used for harvesting. The GHG emissions from harvesting and threshing are calculated based on fuel usage and machine operation time using equation (7).

$$CO_2 \text{ comb harvester} = (Fuel_{machine} \text{ x } EF_{Fuel}) + (Operation_{TimeMachine} \text{ x } CF_{Machine} \text{ x } EF_{Machine}) \quad (7)$$

where:
CO_2 comb = CO_2 emission from using the combined harvester and thresher
$Fuel_{machine}$ = amount of fuel in Liters during the time of operation
EF_{Fuel} = emission factor for fuel
$Operation_{TimeMachine}$ = time of operation in hours, $CF_{Machine}$ = conversion factor of the machine
$EF_{Machine}$ = emission factor of machinery usage

2.3.3.8 Water Pumps

In the municipality, the predominant irrigation method employed is using pumps. Equation (8) is used to calculate the emissions associated with the water irrigation method:
where:
CO_2 pump = CO_2 emission from pumps
$Fuel_{pump}$ = amount of fuel used by the machine in

$$CO_2 \text{ pump} = (Fuel_{pump} \text{ x } EF_{fuel}) + (\text{MachineTime x } CF_{pump} \text{ x } EF_{pump}) \quad (8)$$

Liters per hectare
Machine Time = the amount of time the pump is used
CF_{pump} = pump conversion factor
EF_{pump} = emission factor of pump

2.3.4 Baseline Scenario Analysis

The baseline scenarios used in the study are the following:

1. Organic Farming with Irrigation in the Dry Season
2. Organic Farming with Irrigation in the Wet Season
3. Organic Farming Utilizing Rainfed Methods in the Wet Season
4. Conventional Farming with Irrigation in the Dry Season
5. Conventional Farming with Irrigation in the Wet Season
6. Combined Farming with Irrigation in the Dry Season
7. Combined Farming with Irrigation in the Wet Season
8. Combined Farming Utilizing Rainfed Methods in the Wet Season

3 Results and Discussion

This result has two main parts, the first comparing emissions across farming methods and season–irrigation combinations (dry-irrigated, wet-rainfed, and wet-irrigated).

1. Organic farming
2. Conventional farming
3. Combined farming

The second part compares the three farming methods under the same seasonal and irrigation conditions.

1. Comparison under dry-irrigated conditions,
2. Comparison under wet-irrigated conditions, and
3. Comparison under wet-rainfed conditions.

3.1 Comparison of Emissions Among Three Farming Practices by Season and Irrigation

This section discusses GHG emissions for each farming method across seasons and irrigation types, identifying which combination produces the highest emissions. Tables A1 to A3 in Appendix A present the detailed results. The dry season with irrigation showed the highest CO_2 emissions (37–39 million kg CO_2), followed by the wet season with irrigation (33–36 million kg CO_2), whereas the wet season under rainfed conditions recorded the lowest emissions (below 1 million kg CO_2).

3.2 Comparison of the Three Methods under the Same Seasonal and Irrigation Combinations

This part presents a detailed comparison of GHG emissions among the three farming methods under the same seasonal and irrigation conditions.

Based on the results presented in Tables A.4 to A.6 in Appendix A, conventional farming consistently showed the highest CO_2 emissions, averaging between 757,345.76 and 36,833,255.00 kg CO_2, followed by combined farming, while organic farming produced the lowest emission levels, ranging from 583,080.54 to 33,590,727.32 kg CO_2.

3.3 Statistical Analysis

Analysis of Variance (ANOVA) was used to determine significant differences in CO_2 emissions among organic, conventional, and combined farming systems under dry-irrigated, wet-irrigated, and wet-rainfed conditions. A Scheffé post hoc test identified which farming methods significantly differed from one another.

3.3.1 Performing Analysis of Variance (ANOVA) and Scheffé Post Hoc Test

This section evaluates significant differences in CO_2 emissions among the three farming methods across the three farming conditions.

The ANOVA results for dry-irrigated, wet-rainfed, and wet-irrigated farms are presented in Tables B.1 to B.3 of Appendix B. Significant differences in CO_2 emissions among organic, conventional, and combined farming systems were observed under dry-irrigated ($F = 51.27$, $p = 0.000$) and wet-irrigated ($F = 18.03$, $p = 0.001$) conditions, with large effect sizes of 0.919 and 0.800, respectively. In both cases, conventional farming recorded the highest emissions. In contrast, no significant differences were found under wet-rainfed conditions ($F = 0.82$, $p = 0.472$), as supported by the small effect size (0.154) and similar mean emissions across farming systems.

3.3.2 Assessment of the Difference in the Overall CO_2 Emissions Among Organic, Conventional and Combined Farming Systems

ANOVA was used to assess the impact of farming systems on overall CO_2 emissions.

The results in Table B.4 of Appendix B show a highly significant difference in CO_2 emissions among organic, conventional, and combined farming systems ($F = 54.84$, $p = 0.000$). The large effect size (0.924) indicates a strong practical effect, with conventional farming recording the highest mean emissions, followed by combined and organic systems. The superscripts confirm that all three means differ significantly.

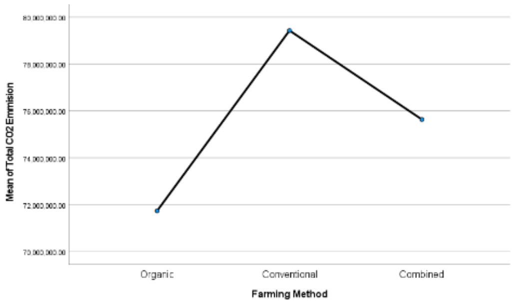

Fig. 4: Profile Plot of the Difference in CO_2 Emissions (in kg CO_2) between Organic, Conventional, and Combined Farming Systems
Source: created by the authors

As shown in Figure 4, the profile plot presents the differences in CO_2 emissions among the three farming systems. The observed trends indicate that each system contributes differently to overall emissions, reflecting the impact of management practices.

3.3.3 Summary of Findings

These findings highlight that irrigation and conventional farming methods generate a significant amount of greenhouse gases in rice production. Furthermore, the findings indicate that the irrigation method during both the dry and wet seasons has contributed substantially to higher carbon emissions compared to the rainfed system only. In the Philippines, this study found that emissions from irrigated areas are higher than those from rainfed areas, with values of 140 kg CO_2-eq ha^{-1} $crop^{-1}$ and 111 kg CO_2-eq ha^{-1} $crop^{-1}$ for irrigated and rainfed areas, respectively, [5]. LCA findings from the study, [31], revealed that irrigation is the main cause of the environmental problem in rice production, having a more significant impact than the other stages in 15 out of 18 categories (83%), including 12 out of 15 stages with impacts greater than 75%. This is also supported by the study [32], which states that for conventional cultivation, the main environmental impacts are attributed to irrigation (49.6%) and fertilizers (40.2%), with machinery contributing 10.2%. Irrigation impact is dominated by electricity consumption and agricultural machinery, which are responsible for 27.1% and 10.8% of the total environmental impact, respectively, [32]. Among the three farming methods, conventional farming was identified as the highest contributor to GHG emissions in rice production. CO_2 emissions in organic rice production were 32.7% lower than in conventional production, and the amounts of N_2O and CH_4 emissions in organic rice production were 152.2% and 122.7%, respectively, higher than in conventional production, [33]. Nitrogen is released through the process of nitrification followed by denitrification, which is created by microbial interactions in the soil under aerobic and anaerobic conditions, [34]. Results show that low inorganic fertilizer N rates (averaging 79 kg N ha^{-1}) increased CH_2 emissions by 18% relative to when no N fertilizer was applied, while high N rates (average of 249 kg N ha^{-1}) decreased CH_4 emissions by 15%, [35].

3.3.4 Sensitivity Analysis

Sensitivity analysis was performed to examine how variations in agricultural input levels (low, medium, and high) influence total CO_2 emissions from rice production. One-way ANOVA tests whether the emissions produced by different levels of each input are statistically different from the baseline (average input). The replication was carried out over the years 2020 to 2023 with the wet season under the irrigated farming method. A Post-Hoc test (Turkey's HSD) was performed to compare the means of all possible pairs of groups (baseline vs. low, baseline vs. medium, baseline vs. high, low vs. medium, low vs. high, medium vs. high) to determine where the differences lie.

Table B5 of Appendix B shows the total CO_2 emissions across baseline, low, medium, and high input levels, revealing a highly significant difference in emissions ($Fc = 262.74$, Sig. = 0.000). Baseline emissions are statistically different from all input levels. Low input levels produce significantly lower emissions, while high input levels result in the highest emissions. The effect size of 0.985 highlights the significant impact of input levels on total CO_2 emissions.

As shown in Figure 5, the profile plot illustrates the differences in total emissions between the baseline and the three input levels (low, medium, and high). The results indicate that emission levels vary with input intensity, reflecting the influence of agricultural inputs on overall greenhouse gas emissions.

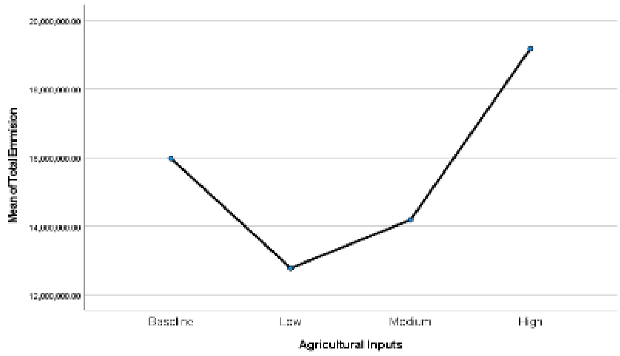

Fig. 5: Profile Plot of Emission Differences (Baseline vs. Low, Medium, High Inputs)
Source: created by the authors

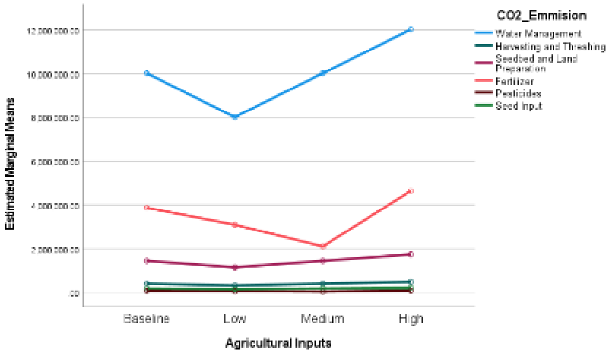

Fig. 6: Profile Plot of Sources of CO_2 Emission
Source: created by the authors

Figure 6 shows the estimated marginal means of CO_2 emissions across various agricultural input levels for different agricultural activities: water management, harvesting and threshing, seedbed and land preparation, fertilizer, pesticides, and seed input. Water management shows the largest variation, with emissions decreasing at low input levels and increasing sharply at high levels. Fertilizer emissions also rise noticeably under high input conditions. In contrast, seed input, pesticides, and harvesting and threshing display minimal changes, indicating stable emissions regardless of input variation. Overall, results show that water management, fertilizer, seedbed and land preparation are highly influenced by agricultural inputs, while other activities remain consistent. This is similar to the findings of the study, [24], which states that soil and water management were the biggest contributors to GHG emissions, accounting for 64.8% of the total GHG emissions. Inorganic fertilizer management accounted for 14.4% of total GHG emissions. Soil and water management were identified as the highest contributors to GHG emissions in this study, [24], supporting the present findings.

4 Conclusion

This study compared CO_2 emissions from the three farming methods (organic, combined, and conventional) across seasons and irrigation methods over the years 2020 to 2023 to identify the highest contributor of GHG emissions. It was found that conventional farming consistently produces the highest emissions, mainly due to fertilizer use and soil management, especially in dry and wet-irrigated systems. In contrast, wet-rainfed systems resulted in the lowest emissions and showed no significant differences among methods. Methane, one of the main GHGs emitted through anaerobic decomposition of organic matter in submerged rice fields, is emitted less in rainfed rice fields than in irrigated ones, [36]. Organic and combined systems showed reduced emissions, particularly organic farming, which minimizes high-impact inputs like pesticides and fertilizers. In terms of agricultural inputs, soil emissions were found to be the largest contributor across systems. Soil emissions, accounting for about 76.85% of total CO_2 equivalents, were confirmed as the dominant source of GHGs in rice farming, [27]. Future studies could explore how scaling up wet-irrigated areas affects emissions and conduct longer-term monitoring to better understand seasonal and irrigation effects, helping identify practices that lower emissions under irrigated conditions. Sensitivity analysis was also performed to strengthen the reliability of the results by demonstrating how variations in agricultural inputs affect GHG emissions. Baseline, low, medium, and high input levels reveal a highly significant difference in emissions. Baseline emissions are statistically different from all input levels. The effect size of 0.985 demonstrates the significant impact of input levels on total CO_2 emissions. In conclusion, this study found that irrigation and conventional farming methods are the major contributors to GHG emissions in rice farming. These findings will help policymakers promote more water-efficient irrigation techniques, such as alternate wetting and drying (AWD), and encourage farmers to adopt low-emission farming methods, such as the use of combined organic and inorganic fertilizers, through seminars and incentives. There is a need to establish best management practices for sustainable farming that include measurements of land use management, identification and selection of farming systems that are ecologically efficient, and strategies for strengthening the capacity to adapt to climate change in the future, [37]. Lastly, this study can be used as a reference for the development of a simulation app using emission factors to compute GHG emissions and generate graphs.

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Declaration of Generative AI and AI-assisted Technologies in the Journal Writing Process

The authors acknowledge the assistance and usage of AI tools such as ChatGPT and Grammarly in the rephrasing and improvement of the readability and language of the manuscript. The authors made sure that a thorough review and editing were done and take full responsibility for the content of the manuscript.

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APPENDIX A

A.1. Total CO_2 Emissions from Organic Farming Using Irrigated and Rainfed Methods

Year	Dry-Irrigated	Wet-Rainfed	Wet-Irrigated
2020	36,817,697.85	666,377.7575	33,324,576.36
2021	37,628,414.05	666,377.7575	32,705,620.63
2022	37,628,414.05	666,377.7575	33,976,543.05
2023	38,187,528.67	333,188.8788	34,356,169.23
Mean	37,543,105.38	583,080.5378	33,590,727.32

A.2. Total CO_2 Emissions from Combined Farming Using Irrigated and Rainfed Methods

Year	Dry-Irrigated	Wet-Rainfed	Wet-Irrigated
2020	38927612.84	768038.0075	34966592.71
2021	39784788.83	768038.0075	34317138.91
2022	39784788.83	768038.0075	35650684.05
2023	40375944.68	384019.0038	36049015.72
Mean	39718283.8	672033.2566	35245857.85

A.3. Total CO_2 Emissions from Conventional Farming Using Irrigated and Rainfed Methods

Year	Dry-Irrigated	Wet-Rainfed	Wet-Irrigated
2020	41004653.54	865538.0075	36541412.71
2021	41907565.43	865538.0075	35862708.91
2022	41907565.43	865538.0075	37256314.05
2023	42530263.28	432769.0038	37672585.72
Mean	41837511.92	757345.7566	36833255.35

A.4. CO_2 Emissions of Three Farming Practices under Dry-Irrigated

Year	Organic	Conventional	Combined
2020	36817697.85	41004653.54	38927612.84
2021	37628414.05	41907565.43	39784788.83
2022	37628414.05	41907565.43	39784788.83
2023	38187528.67	42530263.28	40375944.68
Mean	37565513.66	41837511.92	39718283.80

A.5. CO_2 Emissions of Three Farming Practices under Wet-Rainfed

Year	Organic	Conventional	Combined
2020	666377.7575	865538.0075	768038.0075
2021	666377.7575	865538.0075	768038.0075
2022	666377.7575	865538.0075	768038.0075
2023	333188.8788	432769.0038	384019.0038
Mean	583080.5378	757345.7566	672033.2566

A.6. CO_2 Emissions of Three Farming Practices under Wet-Irrigated

Year	Organic	Conventional	Combined
2020	33324576.36	36541412.71	34966592.71
2021	32705620.63	35862708.91	34317138.91
2022	33976543.05	37256314.05	35650684.05
2023	34356169.23	37672585.72	36049015.72
Mean	33590727.32	36833255.00	35245857.85

APPENDIX B

B.1. Difference in CO_2 Emissions (in kg CO_2) Among Organic, Conventional, and Combined Farming Systems for Dry – Irrigated Farms

Farming Systems	Mean	Std. Deviation	Fc	Sig.	Effect Size
Organic	37,565,513.66^c	563,927.91	**51.27****	**0.000**	0.919
Conventional	41,837,511.92^a	628,058.52			
Combined	39,718,283.80^b	596,244.98			

***Highly Significant Means with the same superscript do not differ significantly at a 5% level of significance.*
Source: created by the authors

B.2. Difference in CO_2 Emissions (in kg CO_2) Among Organic, Conventional, and Combined Farming Systems for Wet-Rainfed Farms

Farming Systems	Mean	Std. Deviation	Fc	Sig.	Effect Size
Organic	583,080.54^a	166,594.44	0.82^{ns}	0.472	0.154
Conventional	757,345.76^a	216,384.50			
Combined	672,033.26^a	192,009.50			

^{ns}Not Significant Means with the same superscript do not differ significantly at a 5% level of significance.
Source: created by the authors

B.3. Difference in CO_2 Emissions (in kg CO_2) Among Organic, Conventional, and Combined Farming Systems for Wet-Irrigated Farm

Farming Systems	Mean	Std. Deviation	Fc	Sig.	Effect Size
Organic	33,590,727.32^c	727,783.23	**18.03****	**0.001**	0.800
Conventional	36,833,255.35^a	798,036.48			
Combined	35,245,857.85^b	763,643.61			

***Highly Significant Means with the same superscript do not differ significantly at a 5% level of significance.*
Source: created by the authors

B.4. Assessment of the Difference in the Overall CO_2 Emissions among the Three Farming Systems

Farming Systems	Mean	Std. Deviation	Fc	Sig.	Effect Size
Organic	71,739,321.51^c	998,202.61	**54.84****	**0.000**	0.924
Conventional	79,428,113.02^a	1,077,135.98			
Combined	75,636,174.90^b	1,038,100.71			

***Highly Significant Means with the same superscript do not differ significantly at a 5% level of significance.*
Source: created by the authors

B.5. Difference in Total CO_2 Emissions between the Baseline and the Three Input Levels

Input Level	Mean	Std. Deviation	Fc	Sig.	Effect Size
Baseline	15,980,167.82^b	346,229.42	**262.74****	**0.000**	0.985
Low	12,784,207.52^d	276,985.13			
Medium	14,185,920.22^c	307,354.91			
High	19,176,168.83^a	415,474.60			

***Highly Significant Means with the same superscript do not differ significantly at a 5% level of significance.*
Source: created by the authors

APPENDIX C

C.1. Summary of the Emission Factors for Agricultural Input

Parameters	Emission Factor	Source
Conventional seeds	1.12 kg CO_2 eq. kg^{-1}	Wassmann et al., 2021
Hybrid seeds	2.24 kg CO_2 eq. kg^{-1}	Wassmann et al., 2021
Herbicides	6.30 kg CO_2 eq. kg^{-1}	Lal, 2004
Insecticides	5.10 kg CO_2 eq. kg^{-1}	Lal, 2004
Fertilizer production, N	1.3 kg CO_2 eq. kg N^{-1}	Pathak 2007, Schlesinger 1999
Fertilizer production, P	0.2 kg CO_2 eq. kg P^{-1}	Pathak 2007, Schlesinger 1999
Fertilizer production, K	0.2 kg CO_2 eq. kg K^{-1}	Pathak 2007, Schlesinger 1999
Direct emission from N in continuous flooding	1.41 kg CO_2 eq. kg^{-1} N	Wassmann et al., 2021
Direct emission from N in intermittent drainage	2.34 kg CO_2 eq. kg^{-1} N	Wassmann et al., 2021
Farmyard Manure	0.21 kg CO_2 eq. kg^{-1}	IPCC 2006
Compost	0.17 kg CO_2 eq. kg^{-1}	IPCC 2006
Diesel oil	2.76 kg CO_2 eq. L^{-1}	(Dyer & Desjardins, 2003).
Machinery Conversion Factor (time to energy)	62.7 MJ hr^{-1}	(Canakci et al., 2005)
Machine Emission factor	0.07 kg CO_2 eq. MJ^{-1}	(Dyer & Desjardins, 2003)
Irrigated rice cultivation w/ straw amended after harvest	2.08 kg CH_4 d^{-1} ha^{-1}	IPCC 2006, Corton et al. (2000)
Rainfed rice cultivation w/ straw amended after harvest	0.51 kg CH_4 d^{-1} ha^{-1}	IPCC 2006, Corton et al. (2000)
Irrigated rice cultivation w/o straw amended	1.3 kg CH_4 d^{-1} ha^{-1}	IPCC 2006, Corton et al. (2000)
Rainfed rice cultivation w/o straw amended	0.35 kg CH_4 d^{-1} ha^{-1}	IPCC 2006, Corton et al. (2000)
Rice straw burning	2.7 g CH_4 kg^{-1}	IPCC 2006
Carbon dioxide emission converted from methane emission	34.16 kg CO_2 eq. ha^{-1}	Wassmann et al., 2021

C.2. Recommended Agricultural Inputs for Asingan

	Dry-Irrigated	**Wet-Irrigated**	**Wet-Rainfed**
Seed Input			
Conventional Seed	35 kg ha^{-1}	40 kg ha^{-1}	40 kg ha^{-1}
Inorganic fertilizer			
Nitrogen	120 kg ha^{-1}	100 kg/ ha^{-1}	100 kg ha^{-1}
Phosphorus	30 kg ha^{-1}	30 kg ha^{-1}	30 kg ha^{-1}
Potassium	60 kg ha^{-1}	60 kg ha^{-1}	60 kg ha^{-1}
Organic fertilizer			
Compost	500 kg	1000 kg	1000 kg
Pesticides			
Herbicides	1.073 kg ha^{-1}	2.146 kg ha^{-1}	2.146 kg ha^{-1}
Insecticide	0.306 kg ha^{-1}	0.612 kg ha^{-1}	0.612 kg ha^{-1}
Seedbed and Land Preparation			
a. Plowing			
Machine hours	12 hrs ha^{-1}	16 hrs ha^{-1}	16 hrs ha^{-1}
Fuel Consumption	23.4 L ha^{-1}	31.2 L ha^{-1}	31.2 L ha^{-1}
b. Harrowing			
Machine hours	9 hrs ha^{-1}	10 hrs ha^{-1}	10 hrs ha^{-1}
Fuel Consumption	14.4 L ha^{-1}	16 L ha^{-1}	16 L ha^{-1}
c. Leveling			
Machine hours	13 hrs ha^{-1}	14 hrs ha^{-1}	14 hrs ha^{-1}
Fuel Consumption	16.25 L ha^{-1}	17.5 L ha^{-1}	17.5 L ha^{-1}
Harvesting and Threshing			
Machine hours	2.67 hrs ha^{-1}	2.67 hrs ha^{-1}	2.67 hrs ha^{-1}
Fuel Consumption	34.16 L ha^{-1}	34.16 L ha^{-1}	34.16 L ha^{-1}
Pump			
Machine hours	400 hrs ha^{-1}	267 hrs ha^{-1}	67 hrs ha^{-1}
Fuel Consumption	700 L ha^{-1}	467.25 L ha^{-1}	117.25 L ha^{-1}

C.3. Cultivated Area and Yield Across Different Seasons and Irrigation Methods

Cropping Year	**Wet Season**				**Dry Season**	
	Irrigated (ha.)	**Yield (kg)**	**Rainfed (ha.)**	**Yield (kg)**	**Irrigated (ha.)**	**Yield (kg)**
2020	4038	21807300	250	1143750	3951	26739800
2021	3963	12859310	250	994250	4038	23524800
2022	4117	20361100	250	1001000	4038	24023850
2023	4163	18841400	125	500000	4098	22718370