

Review

# Rice Cultivation and Greenhouse Gas Emissions: A Review and Conceptual Framework with Reference to Ghana

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**Abstract:** Rice is an essential crop in Ghana. Several aspects of rice have been studied to increase its production; however, the environmental aspects, including impact on climate change, have not been studied well. There is therefore a gap in knowledge, and hence the need for continuous research. By accessing academic portals, such as Springer Open, InTech Open, Elsevier, and the Kwame Nkrumah University of Science and Technology's offline campus library, 61 academic publications including peer reviewed journals, books, working papers, reports, etc. were critically reviewed. It was found that there is a lack of data on how paddy rice production systems affect greenhouse gas (GHG) emissions, particularly emissions estimation, geographical location, and crops. Regarding GHG emission estimation, the review identified the use of emission factors calibrated using temperate conditions which do not suit tropical conditions. On location, most research on rice GHG emissions have been carried out in Asia with little input from Africa. In regard to crops, there is paucity of in-situ emissions data from paddy fields in Ghana. Drawing on the review, a conceptual framework is developed using Ghana as reference point to guide the discussion on fertilizer application, water management rice cultivars, and soil for future development of adaptation strategies for rice emission reduction.

**Keywords:** Ghana; rice production; greenhouse gas emissions; smallholder farming

## 1. Introduction

Developing countries currently account for about three-quarters of direct greenhouse gas (GHG) emissions and are expected to represent the most rapidly growing GHG emission sources in the future [1]. However, developing countries make up 70% of climate change mitigation potential for land use in agriculture and 52% of countries in this bracket have targeted the agricultural sector to reduce their climate change footprints [2]. The current knowledge of GHG emissions from land use systems in Africa is inadequate when the potential of the continent as both a source and sink for GHGs is considered. Furthermore, the lack of data on GHG emissions from agricultural lands and the absence of a thorough analysis of existing data hinder the progress of understanding the factors that influence GHG emissions on the continent [3–6]. Palm et al. [7] stated that in the face of the above stated difficulties, it is important to quantify baseline GHG emissions to understand the contributions of different land-use systems to GHG emissions.

In Ghana, rice cultivation has received a major boost from the government in recent years, primarily because current production levels only meet 30% of local demand and the huge gap of

the 70% deficit is filled through foreign rice imports with an annual bill of more than U.S. \$450 million. This has led to the intensification of rice cultivation across the country. Rice cultivation, however, has been identified as a source of GHGs, namely methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and carbon dioxide (CO<sub>2</sub>) [8–11]. Current cultivation methods are likely to impact negatively on the environment if sustainable systems are not developed to intensify rice cultivation in Ghana. This review therefore focuses on trends and analyses from various studies that have been carried out on rice cultivation and greenhouse gas emissions in Ghana and other tropical developing countries.

## 2. Yield-Scaled Global Warming Potential (Greenhouse Gas Intensity)

Evidence abounds through numerous studies on the importance of rice cultivation systems in relation to the emission of greenhouse gases, especially CH<sub>4</sub> and N<sub>2</sub>O [12–14]. Rice production intensification is essential considering the critical role it plays in feeding the world's growing populations, and for Ghana, where rice is a staple, a deficit in production has necessitated the intensification of rice production. Intensification of production, however, comes inevitably with a surge in GHG emissions. To be able to know how efficient a rice production system is, it has to be able to give optimum yield with low environmental impacts, such as low GHG emissions and its associated Global Warming Potential (GWP). The global warming potential of a greenhouse gas is an index computed to measure its radiative forcing following an emission of a unit mass of the specific gas, accumulated over a specific time period using carbon dioxide as a reference. Thus, carbon dioxide has a GWP of 1 [1]. The GWP therefore represents the combined effect of the differing times these substances remain in the atmosphere and their effectiveness in causing radiative forcing [15].

The use of the Yield-Scaled Global Warming Potential (GWPY) or Greenhouse gas intensity is one such method used to measure and identify the efficiency of rice production systems by linking grain yield with GWP of the system. Mosier et al. [16] referred to it as GHG intensity (GHGI) whilst Van Groenigen et al. [17] referred to this concept as Yield-scaled global warming potential (GWPY). It is a measure that can be used to identify efficient cropping systems that produce high grain yields with low GWP values. The authors explained that a positive GHGI value is indicative of a net source of CO<sub>2</sub> equivalent per kg of yield whilst a negative value indicates a net sink of GHG to the soil. GWPY studies have been conducted for rice cultivation systems and other arable cropping systems in various countries [17–20], but literature on such studies in Ghana and African rice cultivation systems is rare. For Ghana, the lack of adequate investments in the agricultural sector and the high percentage of smallholders who still employ rudimentary farming practices make it imperative for efficient farming systems which encourage optimal use of inputs to be developed. GWPY is one such tool that can help in the development of such systems, and for paddy rice systems it can be employed to give knowledge on optimal fertilizer and water/flooding levels that ensure high yields with low GHG emissions.

## 3. Rice Production in Africa and Greenhouse Gas Emissions

### 3.1. Current Research in Africa

Research on African rice cultivation systems and how they contribute to greenhouse gas emissions is inadequate, and this is evidenced by the limited availability of literature on the subject in peer-reviewed journal publications. Eshun et al. [21] and Das and Baruah [22] agreed when they both asserted that the environmental impact of rice cultivation in the tropics, especially in Africa, has not received much attention from the research community. In summarizing recent available data on GHG emissions from sub-Saharan African natural and agricultural lands, Kim et al. [23] were able to cite only 2 out of 73 rice production studies. This and other similar studies reinforce the need for continuous research and knowledge generation, since rice cultivation contributes significantly to food security and employment in Africa.

The limited literature that is available employs mathematical modelling and qualitative research approaches in studying and predicting the levels of GHG emissions from rice cultivation systems.

This approach, however, needs quality field data specific to tropical developing countries. Quality data will ensure efficient scenario simulations. Currently in Ghana and other sub-Saharan African countries, quality data on rice cultivation and its impact on GHG emissions is not readily available because of inadequate research.

For instance, Farag et al. [24], in studying carbon footprints on rice cultivation in Egypt, used the Intergovernmental Panel on Climate Change (IPCC) guidelines for emissions estimation (emission factors) as function of parameters like soil type, temperature, and rice cultivar. Eshun et al. [21], in their work on greenhouse gas emissions and energy analysis of rice production systems in Ghana, employed a similar method to that of Farag et al. [24] to estimate the emission levels as a function of production activities carried out by farmers during the season. The authors cited non-availability of emission inventory data as a reason for using the emission factor method.

In their work, Farag et al. [24] and Kaba [25] also used the qualitative approach viz surveys and observations to study the impacts of climate change on crop production in Ghana. Inherent in the qualitative approach in studying GHG emissions from land use systems is the risk of predicting GHG emission levels which show high discrepancies with actual field measurements, as observed by Sheer et al. [26] and Kim et al. [23].

The qualitative approach gives a broader generic view of GHG emissions from crop production systems, but in providing specific data to aid in the setting up of a local GHG emissions database to help with the design of mitigation strategies to reduce emission levels, the quantitative approach is preferable based on the potential of the qualitative method to produce conservative figures [27]. Commonly used emission factors (EFs) are formulated based on assumptions mainly from Europe and thus, the disagreement is grounded in the fact that there is a gap in the production as well as climate dynamics between these two geographical locations, therefore, assumptions in Europe may not hold in the sub-Saharan Africa (SSA) context.

This paper disagrees with the use of the emission factor (EF) method as a means of quantifying GHG emissions, particularly in SSA for the reason above. The use of EFs will be more useful if they are formulated to be location specific.

Kim et al. [23] agreed with this paper's position by arguing that GHG estimations based on EF are not suited for tropical, developing countries because they are derived from models calibrated from measurements conducted under temperate, developed country conditions. Their position is further buttressed when they stated that the IPCC Tier 1, a commonly used GHG estimator for N<sub>2</sub>O emissions resulting from fertilizer application, was parameterized by using the results from a meta-analysis of data collected in temperate climates in an 1891 studies.

The authors also agree with this paper's position by further arguing that the use of EF may give conservative estimates of GHG emissions and hence a false representation of what pertains on the field. However, in Asia and the monsoon regions, substantial work has been carried out on the interactions between rice cultivation systems and GHG emissions using various methods, and this work intends to draw on lessons from the various studies from these areas to help to sustainably improve rice cultivation in SSA.

### 3.2. Research in Other Continents

Zhang et al. [28] employed the Denitrification and Decomposition (DNDC) method to simulate the biogeochemical processes in rice paddies leading to greenhouse gas emissions, specifically methane (CH<sub>4</sub>) from soil. The method was used together with remote sensing to model the emissions over 1.44 million hectares of paddy rice fields in the Sanjiang Plain of north-eastern China. This method allowed the authors to model emission levels over a large area of rice paddies, and the results indicated that the total 1.44 million ha of rice paddies in the plain emitted 0.48–0.58 Tg·CH<sub>4</sub>·Cha<sup>-1</sup> with spatially differentiated annual emission rates ranging between 38.6–943.9 kg·CH<sub>4</sub>·Cha<sup>-1</sup>, which were comparable with that observed in Southern China. They attributed the high levels of emission to high

soil organic carbon (SOC) contents, long crop season, and high rice biomass enhanced CH<sub>4</sub> production in the cool paddies.

The method proves effective for large study areas if the data requirements such as the spatial distribution of the rice fields over a location and a local emissions database are available. For countries in SSA, including Ghana, where this type of data may not be readily available, the method's effectiveness will be challenged significantly.

Babu et al. [9] also employed the DNDC model to estimate CH<sub>4</sub> emissions from Indian rice fields, and they reported discrepancies between observed and simulated seasonal patterns of CH<sub>4</sub> emission. They also observed large discrepancies between simulated and observed the occurrence of seasonal fluxes at sites that used manual chamber flux measurements. The modelling methods are useful in the simulation of future scenarios of GHG emission levels, however, the input data should be close to field data to ensure quality output.

Weller et al. [29] investigated and compared differences in N<sub>2</sub>O and CH<sub>4</sub> emissions from traditional paddy rice, upland 'aerobic' rice, and maize systems in a dry subtropical climate by employing an automated static chamber method of GHG emission measurement. The study concluded that though CH<sub>4</sub> emissions from the upland rice were lower than the paddy rice system, yield was below average, and also a shift from the paddy system to the upland system will only amount to pollution swapping since N<sub>2</sub>O emissions were higher in the upland system.

It is important, therefore, to rather look at the contributory factors that enhance GHG emissions in both systems and the opportunities that are available to reduce emissions in both systems.

#### 4. Rice Cultivar (Variety) Impact on GHG Emissions

Rice varieties have been found in various field studies to affect GHG emissions, especially methane [20,30]. The physiology of rice plants regulates methane emissions by making available sources of methanogenic substrates through carbon in the roots, including exudates, and also by transporting CH<sub>4</sub> emissions through the aerenchyma [11,31–34]. Several studies have confirmed variations in the emission levels of different rice cultivars [21–39].

Butterbach-Bahl et al. [35] studied how rice genotypes influence CH<sub>4</sub> emissions by growing and measuring season long emission levels from five cultivars that are commonly grown by smallholder farmers and five high-yielding improved varieties grown in India. The results of the study showed lower emission levels for the improved high yielding varieties compared to the traditional cultivars which exhibited profuse vegetative growth linked with the enhancement of GHG emissions.

In another study, Baruah et al. [30] confirmed the results from Gogoi et al. [40] by analyzing CH<sub>4</sub> and N<sub>2</sub>O emissions in relation to plant and soil factors by studying ten popular rice varieties grown in India (five traditional cultivars and five high yielding improved varieties). The study showed that emissions of CH<sub>4</sub> and N<sub>2</sub>O were lower in the high yielding improved varieties compared to the traditional varieties. They further found that CH<sub>4</sub> and N<sub>2</sub>O both showed a significant positive correlation with root dry weight, leaf area, leaf number, and tiller number. The traditional varieties which are mostly characterized by profuse vegetative growth therefore recorded higher CH<sub>4</sub> and N<sub>2</sub>O emissions.

The results of this study have shown that making improved seed available to farmers will not only mitigate GHG emissions but also guarantee high yield. Ongoing research in sub-Saharan Africa should seek to compare the emission levels of local cultivars that are predominantly grown to new improved cultivars. This will give adaptation experts useful information on rice cultivars when formulating adaptation strategies.

Das and Baruah [22] examined the morpho-physiological characteristics of rice on methane emissions from a paddy system in India using a traditional and improved rice variety. The study recorded a higher seasonal flux for CH<sub>4</sub> in the traditional variety compared to the improved cultivar. This was attributed to the profuse vegetative growth in the traditional variety which was exhibited by the development of more leaves, tillers, leaf area, length, and root volume, but the more important

traits that influence yield, like increased photosynthate partitioning to panicles rather than roots, were greater in the improved variety. The authors assert that the traditional cultivar exhibited enhanced diversion of photosynthate to roots resulting in more substrate availability to methanogenic bacteria in the rhizosphere region. In addition, the prominent vegetative growth enhances the transport of CH<sub>4</sub> from the soil to the above ground atmosphere. The results from this study agree with the earlier findings of several authors who reached a similar conclusion [32,33,35,41].

Findings from the studies demonstrate the possibility of employing biological mitigation strategies to control methane emission from rice production systems.

Typical among smallholder farmers in sub-Saharan Africa, access to improved and high yielding rice cultivars is a challenge. Therefore, if progress is to be made regarding the reduction of GHG emissions via improved seeds, access to seeds which are high yielding and low on emissions must be improved and made affordable.

## 5. Rice Production Management Practices Influence on GHG Emissions

### 5.1. Organic versus Conventional

The management practices that are employed in rice cultivation are key to the emission of greenhouse gases. Methane and nitrous oxide emissions are impacted directly by water management and fertilizer application respectively.

It has been estimated that rice production will increase by around 70% over the next quarter of a century if the demand for the growing human population is to be met [42]. The use of fertilizer has therefore assumed great importance in the effort to boost production, but the downside to the use is the potential of fertilizers to aggravate methane emissions.

Methane emissions from rice cultivation are projected to shoot up from 1990 levels of 97 Tg·year<sup>-1</sup> to 145 Tg·year<sup>-1</sup> by 2025 [43].

Studies done by various authors confirmed that the majority of the practices that are carried out during the growing phase of rice cultivation affect GHG emissions and that they can be manipulated to reduce emissions [32,41,44]. A lot of work has been done to study the mechanisms through which these management practices influence GHG emissions.

Linquist et al. [45] did a quantitative review and analysis of fertilizer management practices and GHG emissions from rice cultivation systems. In their research they studied the emission levels associated with different fertilizer management practices and concluded that there is a positive correlation between fertilizer management practices and GHG emissions. The study suggested the need to investigate options for combining mitigation practices and also to determine the economic viability of these practices.

Sampanpanish [46] studied the impact of organic and inorganic fertilizers on the emission levels of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O). The results of the study indicated a higher rate of emissions from chemical fertilizers when compared with emissions from organic fertilizers and therefore the use of organic fertilizers was recommended.

### 5.2. Optimization of Fertilizer Application

The use of organic fertilizers may reduce emissions, but there is the need to determine their performance on a large scale as well as their economic viability. There is also the need for effective farmer education to gradually wean them off chemical fertilizers which have guaranteed yields for years.

Lin et al. [47], employing the Life-cycle assessment method, expected that organic farms would have less GHG by avoiding synthetic fertilizers, but the results of the study proved otherwise. They cited the high availability of methanogenic substrate present in organic fertilizers as a potential reason for the high CH<sub>4</sub> emissions in the organic fields. The use of pesticides in conventional farms and

their inhibiting effect (side effect) on CH<sub>4</sub> producing microbes was also cited as a probable reason for the low methane emissions from the conventional farms.

The effects of organic materials on methane emissions was also studied by Khosa et al. [48]. The research measured the emission levels from straw, farmyard manure, green manure, and rice-straw amended plots over two farming seasons. The study showed a high methane seasonal flux for all treatments except rice-straw compost amended plots, which showed a significantly lower emissions level. The authors attributed the differential effect to the carbon (C):Nitrogen (N) ratio of the material. The authors suggested the use of humified organic materials which have a lower C:N ratio for rice cultivation since it could minimize GHG emissions and also increase soil fertility and crop productivity. Nungkat and Kusuma [49] agreed with the above results when in their study to determine the effects of the use of organic manure on methane emissions from rice paddies in Indonesia they found no correlation between the use of organic fertilizers and methane emissions.

However, there exist contrasting reports on the emission levels associated with conventional and organic rice fields.

Dubey [50] intimated that fertilizer effect on emissions, especially CH<sub>4</sub>, depends on rate, type, and mode of applications. Urea application was found by Dubey [50] and Wang et al. [51] to enhance CH<sub>4</sub> emissions over the growing season which is likely a result of increases in soil pH following urea hydrolysis and a decrease in redox potential. These two processes have been found to enhance methanogenic activities.

A decrease in the emission rate of CH<sub>4</sub> due to the competitive inhibition of nitrate in favor of methane production in ammonium nitrate applications has been reported by Wang et al. [51].

In quantitatively reviewing and analyzing fertilizer management practices and greenhouse gas emissions from rice systems, Linguist et al. [10] showed that farmyard manure increased CH<sub>4</sub> emissions by 26% when compared with urea applied at the same rate. Green manure (*Sesbania*, used in the study), which is mostly nitrogen fixing plants grown on the field and incorporated into the soil prior to planting, also increased CH<sub>4</sub> emissions by as much as 192%, although the authors pointed out that different green manure species can have variable effects on CH<sub>4</sub> emissions. The study also showed that low application rates of inorganic fertilizers averaging 79 kg·N·ha<sup>-1</sup> increased CH<sub>4</sub> emissions by 18% compared to non-application of nitrogen fertilizers. Higher application rates (average of 249 kg·N·ha<sup>-1</sup>), on the other hand, decreased CH<sub>4</sub> by 15%.

The review also reported that ammonium sulfate reduced CH<sub>4</sub> emissions by 40% compared to urea applied at the same rate. The reason ascribed to the reduction in emission levels according to authors was likely a result of the addition of sulfate.

Zhang et al. [45] investigated the impact of three levels of nitrogen fertilizer application viz high (300 kg·ha<sup>-1</sup>), moderate (219 kg·ha<sup>-1</sup>), and low (150 kg·ha<sup>-1</sup>) CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions from paddy fields. The conclusion of the study showed that the emission levels of all the gases of interest were higher for the 300 kg·ha<sup>-1</sup> fertilizer application, which represented the dominant practice employed by the local farmers. This work demonstrated the potential use of optimized fertilizer application as a means of overcoming high emission levels in rice systems, especially N<sub>2</sub>O, and the study showed that encouraging optimized fertilizer application is feasible since the yield in this study was maintained at normal levels.

Optimized fertilizer application will ensure efficient utilization of nutrients by the rice, thereby leaving very little residue for nitrification/denitrification and thereby reducing N<sub>2</sub>O emissions. For smallholder farmers with limited access to farm inputs, optimized fertilizer application will not only help in the reduction of N<sub>2</sub>O emissions but will also make it possible for the farmers to make savings for other farm activities and their families.

Gogoi [52] studied the seasonal and temporal variations associated with N<sub>2</sub>O emissions under different regimes (doses) of fertilizer and also sought to identify the best combination for fertilizer application which can reduce N<sub>2</sub>O emissions but give a higher yield potential. Results from the study showed that temporal fluxes were positively correlated to fertilizer application. They found

that applying N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O in a ratio of 40:20:20 kg·ha<sup>-1</sup> as urea, single super phosphate, and muriate of potash without farm yard manure was able to sustain yield levels, whereas N<sub>2</sub>O emissions were lowered.

It is important to note that different soils may produce different reactions to different fertilizer amendments, and so for rice fields in Ghana it will be important to study the effects of different fertilizer combinations on GHG emissions with a view of making organic fertilizers an integral part.

Studies on emissions from both conventional and organic fields have not been carried out in Ghana or most other rice producing countries in Africa. This makes it difficult to assess the effect of synthetic and organic fertilizers on GHG emissions under tropical conditions.

### 5.3. Water Management and Research Efforts

Xu et al. [53] studied how effective different water regimes could conserve water, reduce GHG emissions, and maintain yields in rice production systems. They used two rice varieties in a no-till paddy under three different water systems viz (a) continuous flooding (CF) (b) flooded and wet intermittent irrigation (FWI), and (c) flooded and dry intermittent irrigation (FDI).

In regards to emission reduction, the study reported that the CF and (FWI and FDI) strategies reduced CH<sub>4</sub> emissions by 60% and 83%, respectively, while CO<sub>2</sub> and N<sub>2</sub>O emissions increased by 65% and 9%, respectively. CO<sub>2</sub> emissions increased by 104% under the FWI system, and N<sub>2</sub>O emissions increased by 11% under the FDI system.

The highest emission reduction for CH<sub>4</sub> (83%) was achieved under systems where there was a period of non-flooding (FWI and FDI), and consistent with methane production, which is more pronounced in anaerobic conditions, the FWI and FDI systems provided limited anaerobic conditions for methanogenesis—hence the 80% relative reduction in CH<sub>4</sub> emissions. The study also brought to the fore the issue of pollution swapping, where practices which reduce one pollutant tend to increase the production of another. This was demonstrated in the study by the increase in CO<sub>2</sub> and N<sub>2</sub>O emissions by 104% and 11% respectively in the same system which reduced CH<sub>4</sub> emissions.

Tarlera et al. [19] also studied how water management impacts both CH<sub>4</sub> and N<sub>2</sub>O emissions from rice paddies under two irrigation systems viz conventional water management (continuous flooding) and an alternative system (controlled deficit irrigation allowing for wetting and drying, AWDI). The results of the study showed that the AWDI system emitted 55% less CH<sub>4</sub> emissions compared to the continuous flooding system. There were no significant differences between N<sub>2</sub>O emissions from the two systems. The authors further demonstrated through yield-scaled global warming potential analysis that the AWDI system allowed for lower emissions by obtaining optimum yields, but they warned that though the system may present an opportunity for reducing CH<sub>4</sub> emissions, it can also increase N<sub>2</sub>O emissions (pollution swapping) and reduce crop yields.

Sander et al. [48] studied how variations in soil water regimes before the onset of rice cultivation and residue management during the fallow period influenced CH<sub>4</sub> and N<sub>2</sub>O emissions and affected methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) emissions during the subsequent rice cropping season. They used three treatments, flooded fallow, dry and wet fallow, as well as dry and dry-tillage fallows for their work and concluded that fallow treatments greatly influenced GHG emissions during rice growth.

They observed that the flooded fallow period recorded high emission levels during the rice growth period. The dry and wet fallow period produced intermediate emissions with the dry and dry-tillage treatment recording the lowest levels of emissions. Regarding the effect of residues, they observed that the GWP was higher in the fields with residues across all the fallow treatments.

Irrigation systems are not widely used for rice production in Ghana, except for a few large-scale commercial producers. Most small-scale rice farms are rain-fed and so any significant variation in rainfall is bound to have serious implications for yield. Research efforts should therefore be geared toward the development of resilient rice cultivation systems that can cope with little (intermittent) water regimes or drought conditions.

The rice variety used in the study which was drought resistant maintained yields and emitted less GHG emissions under the FWI system in the study by Xu et al. [53] when compared to the dominant cultivar used by farmers in the study area. Therefore, there is the need for current research to vary the dominant variety grown in Ghana as well as farmer practices, including water management, and compare their influence on GHG emissions and yield.

## 6. Conceptual Framework

At the smallholder rice cultivation level, many variables affect the major factors that determine the level of GHG emissions, and to better understand the nexus between these factors, a conceptual framework is presented in Figure 1. The major factors that determine the level of GHG emissions include fertilizer application, the water/flooding management process, soil characteristics, and the type of rice variety cultivated. These determinants have widely been recognized as the four major factors that account for GHG emissions from rice cultivation systems, and it is through their manipulation that emissions could be reduced [19,54].

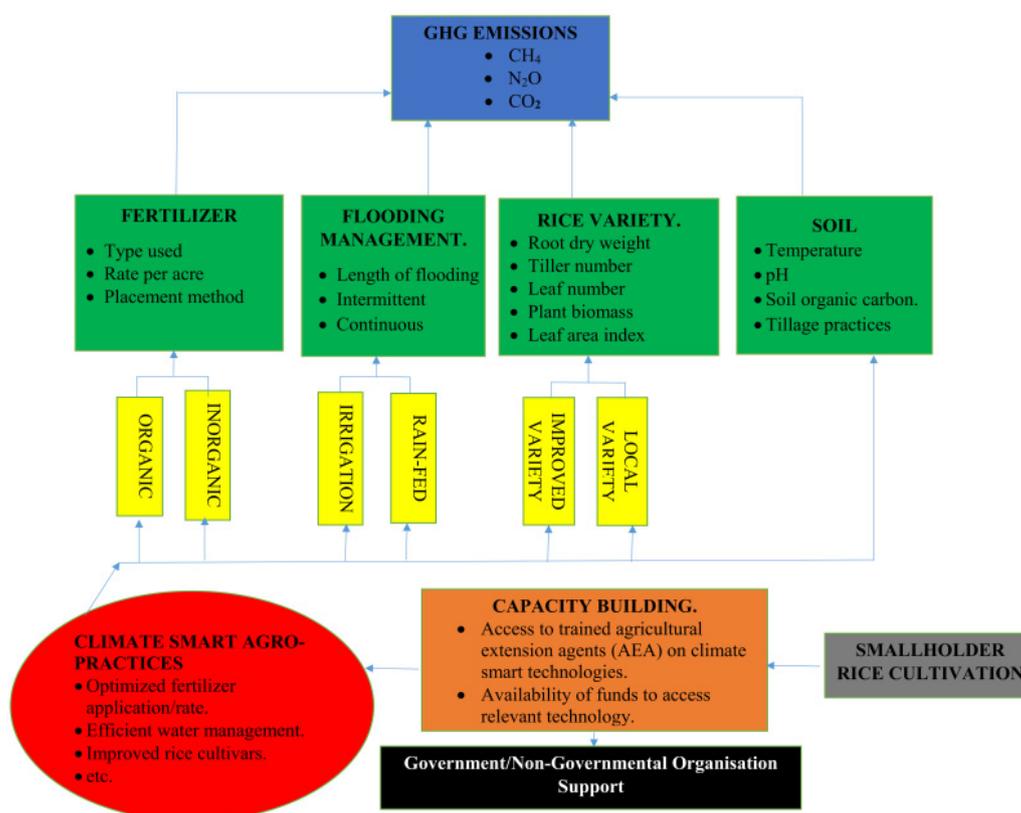


Figure 1. Conceptual framework.

The green boxes in Figure 1 represent the four major factors (sampling points) that will show how high or low levels of GHGs will be emitted from rice cultivation, and the red oval shape depicts how climate-smart agricultural practices involving the major factors are carried out.

According to the Consultative Group on International Agricultural Research (CGIAR) [2], climate-smart agriculture (CSA) is an integrative approach aimed at addressing relevant interlinked challenges of food security and climate change. The approach has three main objectives which include:

1. sustainably increasing agricultural productivity in order to support equitable increases in farm incomes, food security, and development;

2. adapting and building resilience of agricultural and food security systems to climate change at multiple levels;
3. reducing greenhouse gas emissions from agriculture (including crops, livestock, and fisheries).

The government of Ghana through its Ministry of Food and Agriculture (MOFA) has adapted the Climate Change, Agriculture and Food Security (CCAFS) programme to suit it locally by launching a programme termed the National Climate-Smart Agriculture and Food Security Action Plan which seeks to develop climate-resilient agriculture and food systems for all agro-ecological zones in the country.

To achieve this objective, the action plan seeks to develop climate-resilient agriculture and food systems for all agro-ecological zones, develop human resource capacity for climate-resilient agriculture, and to elaborate on the implementation framework and the specific climate-smart agricultural activities to be carried out at the respective levels of governance [2].

It is perceived in this review that climate-smart agricultural practices will have a significant effect on levels of GHGs emitted from paddy rice fields, and the framework presented in Figure 1 puts into context the major factors and variables at play at the smallholder level which will determine the level of GHGs emitted. For instance, building the capacity of agricultural extension agents to effectively train farmers on how to adopt and implement climate smart agro-practices will be essential in bringing down GHG emissions at the smallholder farming level.

The orange box depicts factors that will directly impact how farmers are able to adopt and effectively apply proven climate smart technologies which may involve optimal fertilizer application, efficient water/flooding management processes, and improved rice varieties, etc. At the smallholder level, where farm investments are limited to the farmer with little external support, a deliberate effort by government through its agricultural development agencies, as well as non-governmental organizations to assist farmers, will be important if any progress is to be made on reducing GHG emissions from rice paddies. The red oval represents the relevant climate smart technologies which will influence the choice of the factors depicted in the yellow boxes. The four major sampling points in measuring GHG emissions are illustrated with the green boxes, and finally the blue box represents the type of GHG emissions that will be measured.

## 7. Gaps Identified in Literature

Table 1 below presents gaps that were identified during the review of literature. The identified gaps make a strong case for further research to be conducted in these research areas for tropical regions, especially in sub-Saharan Africa.

**Table 1.** Identified gaps in reviewed literature.

Area	Identified Gaps
Emissions Estimation	Use of emission factors calibrated using temperate conditions which do not suit tropical conditions. Insufficient measurements for the development of a localized emissions database for continuous research on rice induced emissions in Ghana.
Location	Majority of studies on rice induced GHG emissions carried out in Asia with little to no input from African rice production.
Crops	Unavailability of emission data collected in situ from paddy rice fields in Ghana.

Emission reporting in most developing countries relies on generic default emission factors (EFs) provided primarily by the UN Intergovernmental Panel on Climate Change (IPCC) to prepare their mitigating strategies (if any) and also for reporting progress on emissions. This method is inherently problematic due to the difference in emission determining conditions in Africa and Europe, upon which

conditions the emission factor calibrations were done. As presented by Kim et al. [24], there is the high potential to either under or over-estimate emission levels employing the emission factor method.

Efforts are, however, under way in some African countries to curtail the use of the EF method through the setting up of the Mazingira laboratory in Kenya. This is a collaboration between the Center for International Forestry Research (CIFOR), Germany's Karlsruhe Institute of Technology (KIT), and the International Livestock Research Institute (ILRI). The laboratory has started churning out data 'made in Africa for Africa' and through the scaling up of such laboratories across the different ecological zones on the continent, the emission data gap will eventually be bridged.

Due to the lack of data on rice paddy emissions in Ghana and most countries in the sub-Saharan region, the table below serves as a guide to the levels of emissions that may be recorded in field research. To broaden the spectrum of data, emission levels data from countries in both developing and developed world are presented in Table 2.

**Table 2.** Emission levels from various studies.

	Location	Emission	Emission Level	Reference
1	India	CH <sub>4</sub>	18.63 g/m <sup>2</sup>	[44]
		N <sub>2</sub> O	14.33 g/m <sup>2</sup>	
2	China	N <sub>2</sub> O	23.10 <sup>a</sup> , 40.10 <sup>b</sup> , 71.10 <sup>c</sup> mg/m <sup>2</sup>	[55]
3	China	CO <sub>2</sub>	0.45–8.62 μmol·m <sup>-2</sup> ·s <sup>-1</sup>	[56]
4	China	N <sub>2</sub> O	0.089–0.21 kg·N·ha <sup>-1</sup>	[15]
5		CH <sub>4</sub>	34.6–51.7 kg·Cha <sup>-1</sup> ·year <sup>-1</sup>	
6	China	N <sub>2</sub> O	0.11–0.68 kg·N·ha <sup>-1</sup>	[55]
		CH <sub>4</sub>	135–467 kg·Cha <sup>-1</sup>	
7	India	N <sub>2</sub> O	1.09–1.64 kg·Cha <sup>-1</sup>	[57]
8	Philippines	CH <sub>4</sub>	75.55–86.81 kg·CH <sub>4</sub> -C·ha <sup>-1</sup> ·s <sup>-1</sup>	[30]
		N <sub>2</sub> O	0.64–0.90 kg N <sub>2</sub> O-N·ha <sup>-1</sup> ·season <sup>-1</sup>	
9	Italy	CH <sub>4</sub>	0.16–0.38 g·CH <sub>4</sub> ·m <sup>-2</sup> ·day <sup>-1</sup>	[58]
10	Indonesia	CH <sub>4</sub>	19–123 mg·CH <sub>4</sub> ·m <sup>-2</sup> ·day <sup>-1</sup>	[59]
11	Indonesia	CH <sub>4</sub>	–399.63 to 459.94 kg·CH <sub>4</sub> /ha	[52]
12	USA	N <sub>2</sub> O	90–171 g·N·ha <sup>-1</sup>	[60]
13	USA	CO <sub>2</sub>	2.4–21.1 kg·C·ha <sup>-1</sup> ·day <sup>-1</sup>	[61]
		N <sub>2</sub> O	0.20–6.7 g·N·ha <sup>-1</sup> ·day <sup>-1</sup>	
		CH <sub>4</sub>	–0.97 to 0.04 g·C·ha <sup>-1</sup> ·day <sup>-1</sup>	

<sup>a</sup>, <sup>b</sup> and <sup>c</sup> represents low, medium and high nitrogen fertilizer application respectively.

## 8. Conclusions

There is a chronic lack of data on rice cultivation and GHG emissions in Ghana and other African countries and as such the net effects of emissions are not known. This makes the design of mitigation measures to suit local conditions difficult. It emerged from this review that, in most cases, management practices of rice production systems played a critical role in the emission of greenhouse gases, especially fertilizer and flooding regimes. Rice cultivar/variety as a biological means of mitigating GHG emissions from rice cultivation systems is essential, but it should be used in collaboration with emission reduction proven water and fertilizer regimes to get the expected results. The conceptual framework had presented a visual representation of how various factors such as fertilizer application, water management practices, crop variety, and soil type inter-relate to explain the factors that influence the level of greenhouse gas emissions from rice fields. We conclude that research in sustainable rice cultivation should be given attention in Ghana and other African countries to ensure continuous generation of knowledge and an understanding of the potential methods that can contribute to intensify rice cultivation and reduce greenhouse gas emissions.

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