A STUDY OF THE EFFECTS OF INCREASING LOCAL RICE PRODUCTION ON GREEN HOUSE GAS EMISSIONS IN GHANA

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN APPLIED AGRICULTURAL ECONOMICS AND POLICY

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DEDICATION

This dissertation is devoted to my wife, MRS. ALICE ABENAA ANSAA BOATENG, for her unwavering support throughout the four-year program. I am incredibly grateful to her.

DECLARATION

I, Forster Kwame Boateng, the author of the thesis titled "A STUDY OF THE EFFECTS OF INCREASING LOCAL RICE PRODUCTION ON GREEN HOUSE GAS EMISSIONS IN GHANA" do hereby declare that with the exception of references to past and current literature duly cited, this thesis is a result of research solely conducted by me under the supervision of Professor Kwabena Asomanin Anaman, Professor Irene Susana Egyir, and Dr. Yaw Bonsu Osei-Asare, in the Department of Agricultural Economics and Agribusiness, College of Basic and Applied Sciences, University of Ghana, Legon, Accra, Ghana from August 2020 to October 2022. This work has never been presented either in whole or in part for any other degree of this university or elsewhere.

.... 26 October 2023

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…………………………………………

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ABSTRACT

This research was motivated by the government of Ghana's (GoG) initiative to boost local rice production to achieve self-sufficiency by 2025, in line with the country's commitment to meet its Nationally Determined Contribution (NDC) of a 15% reduction of the growth of Ghana's total greenhouse gas (GHG) emissions by 2030 relative to a Business as Usual (BAU) scenario. Rice production emits methane (CH_4) and nitrous oxide (N_2O), which have a relatively higher global warming potential (GWP) than carbon dioxide (CO_2). Increasing local rice production to achieve self-sufficiency could increase GHG emissions, making Ghana's NDC pledge to reduce CO_2, CH4, and N_2O unachievable. The government's policy of increasing local rice production brings about conflicting policy goals. GHG emissions resulting from paddy rice production are comprehensively discussed in many Sub-Saharan African studies, including in Ghana, but the emphasis has been on rice intensification to reduce food insecurity and poverty with little attention to environmental costs. The problem statement informed the four study objectives of this study. The first was to identify the macro drivers of GHG emissions in Ghana and the second objective was to identify the factors that contribute to the observed declining share of the total GHG emissions in Ghana attributed to the agricultural sector using time series regression analysis from 1990 to 2019. For the third objective, an environmentally extended input-output analysis was used to examine the direct and indirect GHG emissions arising from rice production and compare these emissions with the corresponding generation of incomes and employment. Using a random cross-sectional survey of farmers and qualitative research methods, the fourth objective dealt with the methods local rice farmers used to manage their production systems to deal with GHG emissions.

From the macro-level analysis in objectives one and two, it was determined that the total land area dedicated to rice production was a significant driver of total GHG emissions in the economy; a one percent increase in the land area dedicated to rice production would result in a 0.35% increase in total emissions. The study further showed that while increasing rice production was a significant long-term macro driver of total emissions, this was not the case in the short-term period. Using an environmentally extended input-output analysis to deal with the third objective, it was established that rice production was the second biggest GHG-impacting industry in the domestic economy, after the electricity generation industry, despite its relatively small share of total emissions, estimated at around two percent. The other three big GHG-impacting industries were transport, crude oil production, and all other agricultural industries (excluding rice production). Rice production generated broad-based income and employment impacts, both directly for the rice industry, and also indirectly for other industries in the economy. It was ascertained from the survey of rice producers that farmers had a modest understanding of climate change and GHG emissions. In response to climate change, rice producers were implementing agronomic practices such as soil fertility management, planting of early-maturing varieties, using improved seeds and drought-tolerant rice varieties, and employing no-till land preparation. However, their efforts to adapt to climate change were hampered by their limited understanding of the effects of GHG emissions, high labour costs, and low levels of extension officer contacts. All three analyses confirm that rice production is a significant emitter of GHG emissions. However, its share of the national total GHG emissions is relatively small compared to all other agricultural industries (excluding rice production), transport, crude oil production, and electricity generation.

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ABBREVIATIONS AND ACRONYMS

ADF	Augmented Dickey-Fuller
AFOLU	Agriculture, Forestry and Other Land Use
AWD	Alternate Wetting and Drying
BCE	Before the Common Era
BAU	Business as Usual
CF	Continuous Flooding
CFCs	Chlorofluorocarbons
CH_4	Methane
CO_2	Carbon dioxide
ECM	Error Correction Model
EE I-O	Environmentally-Extended Input-Output
EPA	Environmental Protection Agency
FBO	Farmer-Based Organization
FWI	Flooded and Wet Intermittent Irrigation
GHG	Greenhouse Gas
GNRDS	Ghana National Rice Development Strategy
GoG	Government of Ghana
GSS	Ghana Statistical Service
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
IFPRI	International Food Policy Research Institute
INDC	Intended Nationally Determined Contribution
I-O	Input-Output Analysis
IPPU	Industrial Production and Product Use
LM	Lagrange Multiplier test
MMDAs	Metropolitan, Municipal, and District Assemblies
MOFA	Ministry of Food and Agriculture
MPB	Marginal Private Benefit
MPC	Marginal Private Cost
MSB	Marginal Social Benefit
MSC	Marginal Social Cost
N_2O	Nitrous Oxide
PP	Phillips-Perron
MPC	Marginal Private Cost
SSA	Sub-Sharan Africa
SDGs	Sustainable Development Goals
SAM	Social Accounting Matrix
SFS	Sustainable Food System

MSC	Marginal Social Cost
TOFP	Tropospheric Ozone Forming Potential
UNFCCC	United Nations Framework Convention on Climate Change
VAR	Vector Autoregressive model

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

This study is in the area of resource and environmental economics. The key underlying aspect of this discipline is that the production of commodities by human beings entails externalities or side effects, for example pollution. These externalities are often not captured or considered by producers and/or consumers of the commodities (Jopke & Schoneveld, 2018). GHG emissions from rice production, a subject of this study, is a classic example of externalities.

Food is an essential need for the functioning and sustenance of human society. Consequently, the development of food systems has occurred in parallel with the advancement of human civilisation. Approximately 200,000 years in the past, people engaged in the activities of foraging, hunting, and scavenging as means of sustenance (Headrick, 2020). The cultivation of teff in the highlands of Ethiopia from about 9,000 BCE signified a shift from a subsistence strategy of hunting and gathering to one centred on agricultural practices for food and nutrition (Kreike, 2018). In Mexico, China, and the Middle East, societies changed as people tried to find new ways to feed themselves (Huntington, 2020). The food supply chain has undergone significant transformations due to population increase and commerce (Hobbs, 2021).

Many food production operations produce greenhouse gas emissions, aerosols, and albedo shifts that contribute to global warming and climate change, which have crippled agricultural communities (Smil, 2020). Climate change, biodiversity loss, and other environmental changes also threaten future generations health and wealth (Williams et al., 2021). To feed the 8.6 billion people expected in 2030, sustainable food production is essential (WHO, 2020). From the farm to the global food supply chain, food production systems must use less land, water, and inputs to produce more food sustainably and more resilient to changes and shocks (Queiroz et al., 2021).

Farmers and value chain actors underestimate the agriculture sector's contribution to global and national greenhouse gas emissions (Castro-Nunez et al., 2020; Ahmed et al., 2020). Land clearing, biomass burning, fertilizer application management, enteric fermentation, and rice cultivation produce a lot of CO_2, CH_4, and N_2O (Ahmed et al., 2020).

Developing nations account for three-quarters of direct greenhouse gas (GHG) emissions and will be the most rapidly expanding sources in the future (IPCC, 2014). Despite this, agricultural land use in these nations has a relatively high potential for mitigating climate change. In addition, a larger proportion of individuals have targeted agriculture to reduce their carbon footprints (CGIAR, 2015).

1.2 Why the Focus on Rice?

During the period from 2013 to 2019, agriculture accounted for an average of 20% of GDP in Ghana, while industrial and service sectors account for 22% and 48% respectively (GSS, 2020). Despite Ghana's vast agricultural potential, both basic and cash crop yields are among the lowest in the world. Ghana is a net importer of food, with an annual import bill of more than $2 billion, which is equal to the anticipated annual revenue from cocoa exports (World Bank, 2018).

Rice is a very important cereal grain cultivated globally, with its cultivation extending to many regions including Africa (Zenna et al., 2017). A significant number of individuals from the

African continent, especially the population of Ghana, depend on rice as a primary source of sustenance and nutritional intake. Based on statistics provided by the United States Department of Agriculture (USDA), it can be shown from Figure 1.1 that rice consumption in sub-Saharan Africa (SSA) is experiencing exponential growth, surpassing production levels. In the West African region, around 56% of Africa's overall rice output is grown across a landmass spanning 3.7 million hectares (Soullier et al., 2020). However, despite this significant cultivation, the sub-region relies on Asia for approximately 50% of its imports in order to satisfy local consumption needs (d'Amour & Anderson, 2020).

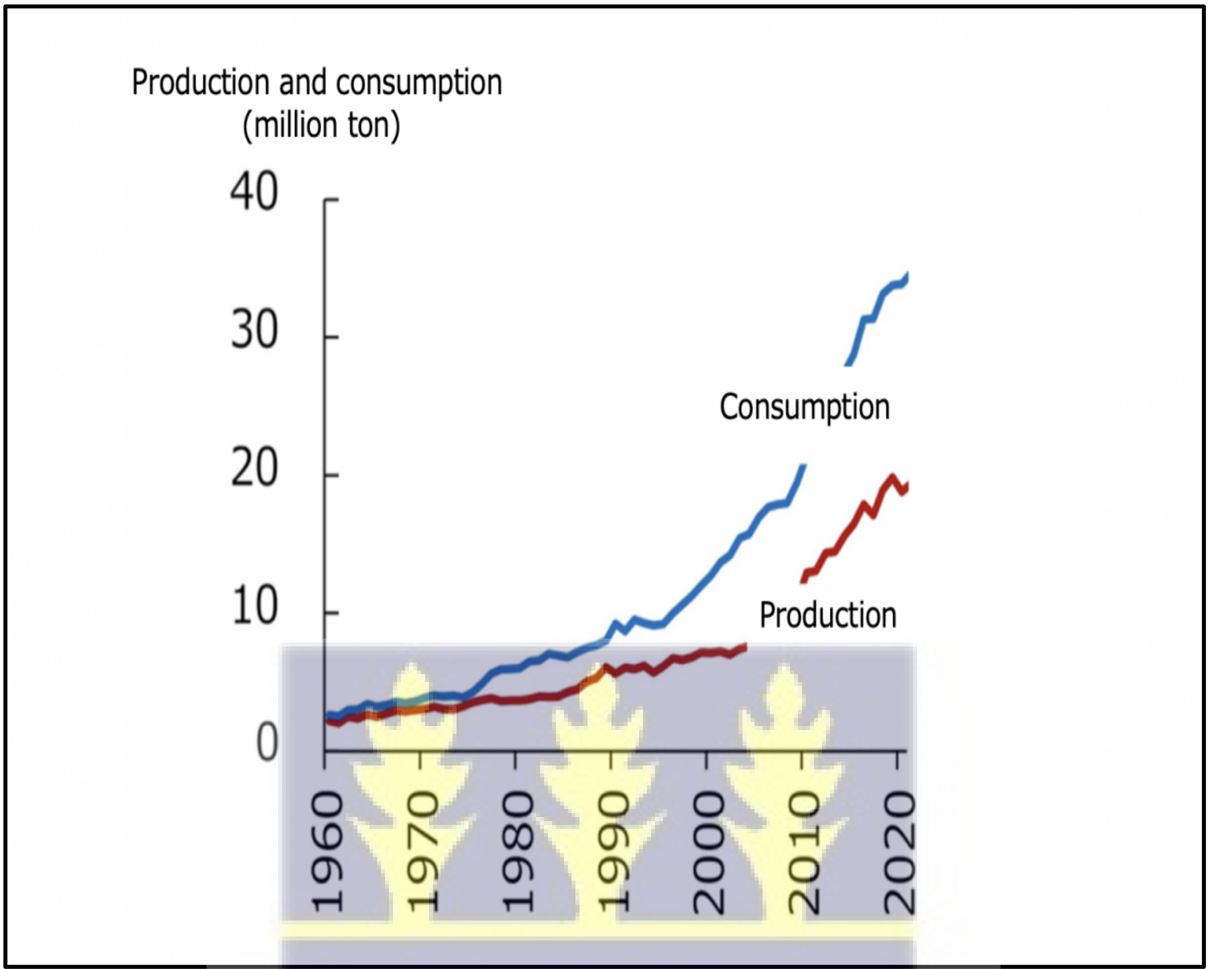


Figure 1. 1: Rice production (milled) and consumption in Sub-Saharan Africa
Source: USDA Production, Supply Distribution Online at https://apps.fas.usda.gov/psdonline/app/index.html#/app/home

Ghana grows rice for food and cash. Population growth, urbanization, and consumer habits increase rice consumption. According to MoFA-SRID (2020), paddy rice production ranged from 302,000 to 987,000metric tonnes (181,000 to 622,000 metric tonnes of milled rice) with large annual fluctuations as shown in Figure 1.2. In 2020, rice consumption in Ghana reached 1,450,000 metric tonnes at 45.0 kg per capita in comparison to the 2016 per capita consumption of 36.0kg. Ghana imports rice to make up for domestic shortages. As annual per capita consumption of rice has grown rapidly over time as a result of population growth, urbanization, and the fact that rice has a much longer shelf-life than other cereals, Government of Ghana

(GoG), as a policy, envisages rice self-sufficiency for Ghana through local cultivation to achieve greater food security. To ensure the sustainability and the comprehensive development of the rice crop, the Ministry of Food and Agriculture has facilitated the revision of the National Rice Development Strategy (NRDS) with a goal to achieve self-sufficiency. The government has in 2018 launched the rice chapter of its flagship project of Planting for Food and Jobs (PFJ) as a policy to boost local rice production to achieve self-sufficiency by 2025 for food security, import substitution, and foreign exchange savings. Since 2018, rice yield has steadily increased while other rice-producing regions in Ghana are expanding land area (IFPRI, 2020).

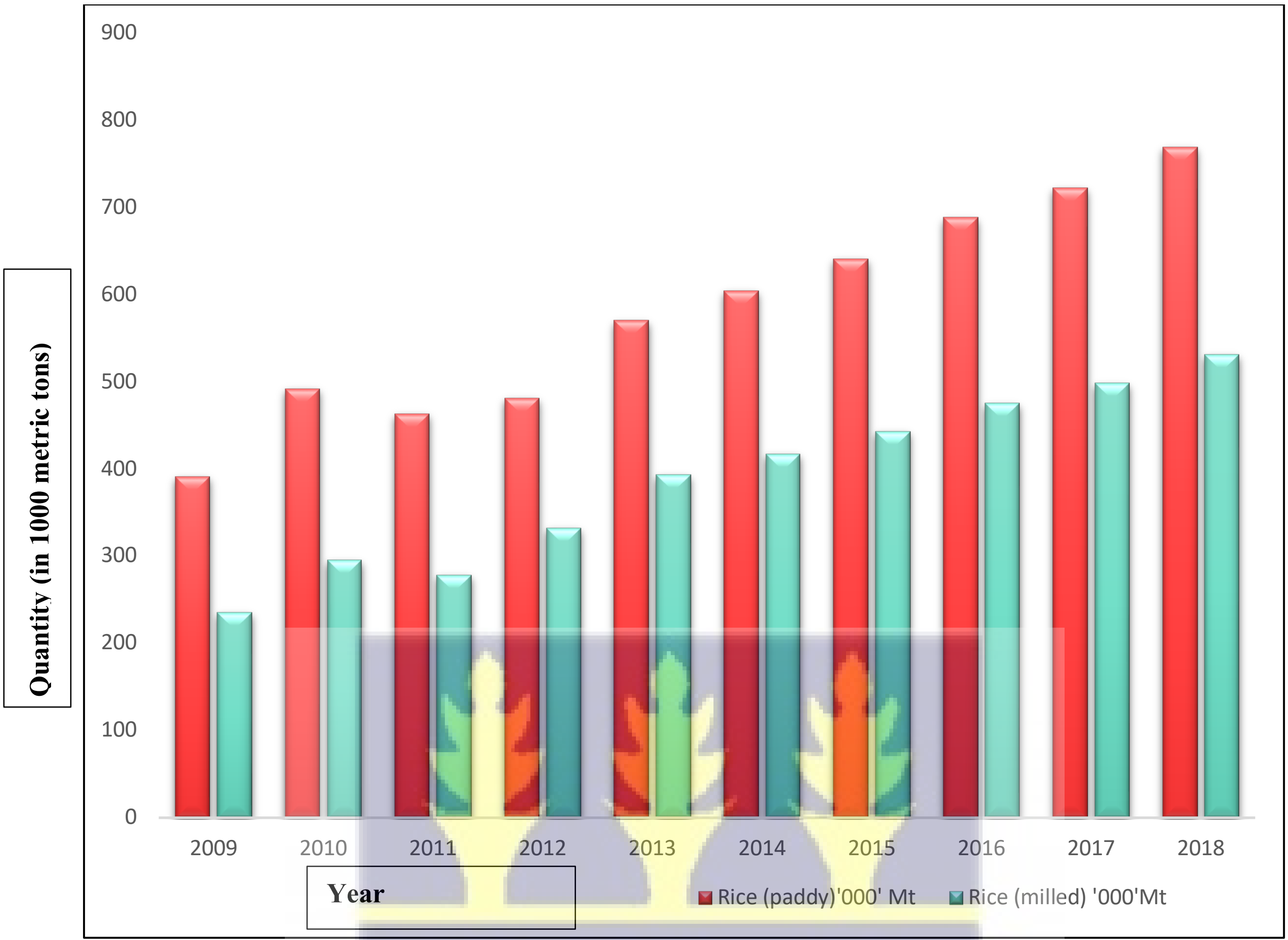


Figure 1. 2: Paddy & Milled Rice Production Quantities in Ghana, 2009 -2018
Source: MOFA-SRID (2020)

Rice cultivation is undertaken in all 16 regions of Ghana. On average, the Volta Region of Ghana is responsible for the production of around 40% of the country's paddy rice. According to Figure 1.3, it is evident that the top five areas responsible for rice production together accounted for 87% of the total output, so underscoring their significant contribution in this domain. In Ghana, rice producers are categorized based on their agro-ecological systems, which include irrigated, rain-fed lowland, and rain-fed upland cultivation methods. The distribution of agricultural land may be categorized into three main types: lowland rainfed systems, irrigated systems, and upland systems. On average, lowland rainfed systems occupy around 78% of the total arable land, while irrigated systems cover approximately 16%. Upland systems, on the other hand, account for approximately 6% of the arable land. According to the Ministry of Food and Agriculture-Statistics, Research and Information Directorate (MOFA-SRID), in 2018, an annual average of 118,000 hectares of land was used for rice cultivation.

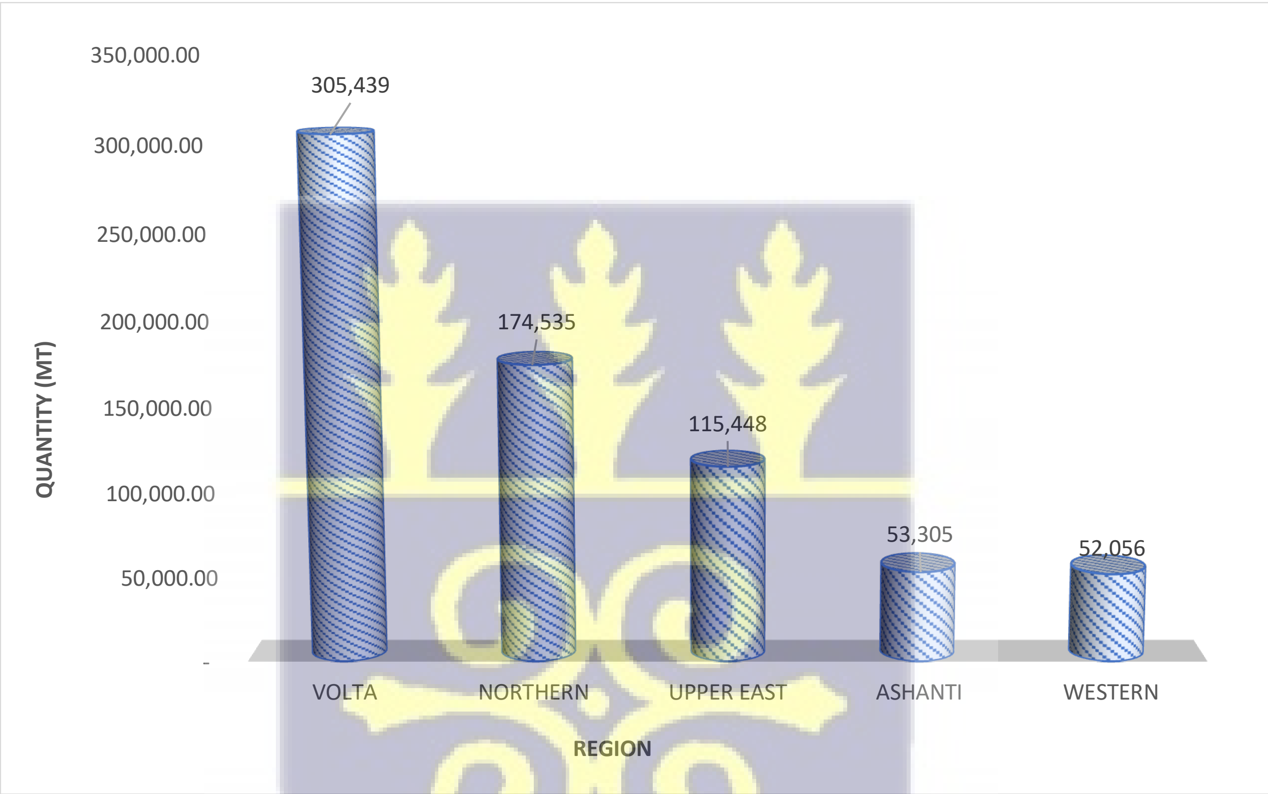


Figure 1. 3: Top Five Rice Production Regions in Ghana (Three Year Average, 2017-2019)
Source: MOFA-SRID (2018)

According to a study conducted by Li et al. (2021), the cultivation of paddy rice is responsible for around 3% of world greenhouse gas emissions. The primary gases that contribute to the phenomenon are carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). Rice farming is responsible for around 60% of global methane (CH4) emissions and 15% of global nitrous oxide (N2O) emissions. Methane (CH4) and nitrous oxide (N2O) have global warming potentials

(GWPs) that surpass carbon dioxide (CO2) by factors of 84 and 268, respectively (Gorh & Baruah, 2019). According to Boateng et al. (2017), the region of West Africa is responsible for about 66% of the overall greenhouse gas (GHG) emissions generated by paddy rice cultivation in sub-Saharan Africa (SSA). Figure 1.4 illustrates the yearly emissions resulting from rice cultivation in the Sub-Saharan Africa region.

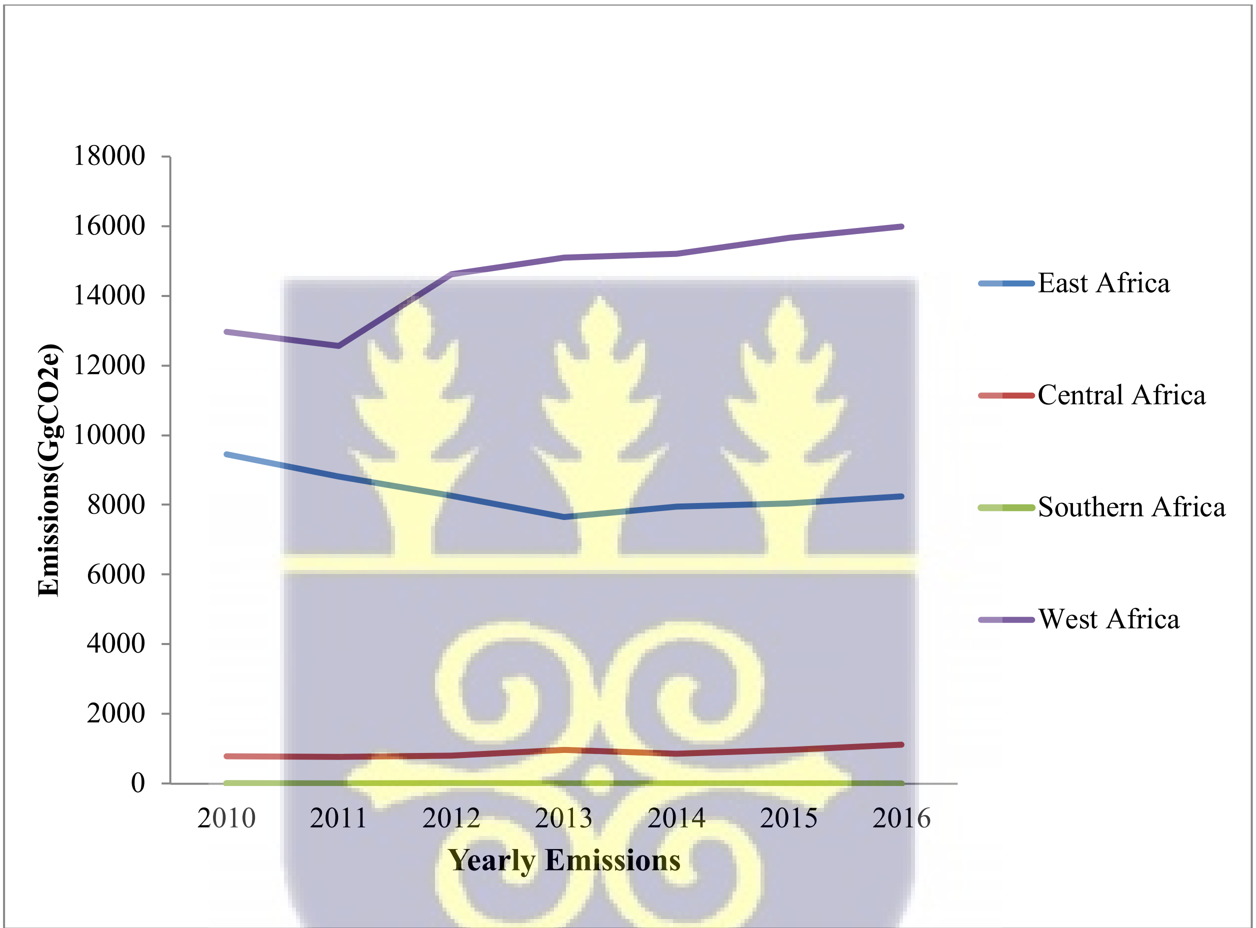


Figure 1. 4: Emissions from Rice Production in Sub-Saharan Africa
Source: (Boateng et al., 2017)

According to several scholarly sources, including Behnassi et al. (2022), Gholipour et al. (2021), Khan and Ullah (2019), Wang et al. (2019), Cassia et al. (2018), and Wolf et al. (2017), it is widely accepted among environmental experts that greenhouse gas (GHG) emissions are a significant contributor to the phenomenon of global warming and subsequent climate change. If greenhouse gas (GHG) emissions are not promptly mitigated, the adverse impacts of global warming and climate change on economies will become more apparent. Hence, it is vital to note that all member states of the United Nations have made a commitment to mitigate greenhouse gas (GHG) emissions, encompassing carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), by means of their nationally determined contributions (NDC) as outlined by the United Nations Framework Convention on Climate Change (UNFCCC) in 2021.

1.3 Problem Statement

Increasing local rice production to achieve self-sufficiency in Ghana will increase GHG emissions, making the country's NDC pledge to reduce CO_2, CH4, and N_2O unachievable. The Ghanaian government's policy of increasing local rice production brings about conflicting goals. The policy maker is confronted with two conflicting goals to be managed to meet the food needs of the growing population (Saray, et al., 2022; Pereira et al., 2020). In the Ghanaian case, the two goals are: production maximization to improve economic welfare related to food security, jobs, and incomes; and GHG emissions growth minimization to achieve a 15 percent reduction in the growth of total national GHG emissions by 2030, based on business-as-usual scenario. GHG emissions resulting from paddy rice production are discussed in many Sub-Saharan African studies, including Ghanaian works, but the emphasis has been on rice intensification to reduce food insecurity and poverty with little attention to environmental costs.

Environmental issues are often analyzed based on the three natural environmental media: air, land and water. Air pollution includes particulate matter, sulphur dioxide and greenhouse gases (GHGs). Water pollution is the contamination of water sources through causes such as poisoning with cyanide used in illegal mining. Land pollution relates more to soil erosion, and environmental sanitation. For this study, the focus is on air pollution (GHG emissions).

According to Hisschemöller & Hoppe (2018) when policy conflicts arise in policymaking, a conflict analysis is required. The policymaker requires hard empirical evidence in order to select the optimal combination of policy instruments for evidence-based decision making. This is precisely what this study aims to address.

1.4 Research Questions

The study aimed to investigate relevant questions that emerged from the Ghanaian government's policy of enhancing domestic rice production. This policy is designed to promote economic well-being, enhance food security, generate employment opportunities, raise incomes, and mitigate environmental pollution in alignment with the country's NDC related to the reduction of the growth of GHGs. The overarching research question is, what are the effects of increasing local rice production on total greenhouse gas (GHG) emissions in the economy and how can these emissions be managed? Specifically, the study sought to respond to the following questions:

1. What factors drive the production of GHG emissions in the overall economy of Ghana?
2. What factors contribute to the observed declining share of the total GHG emissions attributed to the Agricultural Sector?
3. How would increasing local rice production affect the total GHG emissions in terms of both direct and indirect effects based on the linkages between the rice industry and all other industries in the economy?
4. How do local rice producers manage their production systems to deal with GHG emissions?

1.5 Objective of the Study

The main objective of this study was to ascertain the influence of increasing local rice production on total GHG emissions in the economy through the effects on other industries and economic sectors.

The specific objectives were:

1. To identify the macro drivers of GHG emissions in Ghana.
2. To identify the factors that contribute to the observed declining share of the total GHG emissions attributed to the agricultural sector.
3. To examine the direct and indirect GHG emissions arising from rice production based on the linkages between the rice industry and all other industries in the economy.
4. To assess how local rice farmers manage their production systems to deal with GHG emissions.

1.6 Relevance of the Study

The policy continuum is an essential component of any public policy, consisting of the policy problem, policy objectives, and a set of instruments to achieve the policy objectives. In light of the foregoing, policymakers are faced with an optimization challenge: maximizing welfare in terms of food security, job creation, and income growth by increasing local rice production while minimizing production externalities. When such conflicts arise in policymaking, a conflict analysis is required. Examining paired policy scenarios and informing policymakers of potential policy conflicts is what policy conflict analysis entails. The policymaker requires credible empirical evidence in order to select the optimal combination of policy instruments for evidence-based decision making (Hisschemöller & Hoppe 2018). However, there is a scarcity of information on how policymakers might resolve the policy dilemma.

In order to forecast the results of a policy experiment, as per the Lucas critique, it is necessary to construct a model that incorporates the "deep parameters" including preferences, technologies, and resource limitations, which are posited to influence individual behaviour (Caldwell, 2019). Consequently, an analysis was conducted on both macroeconomic and microeconomic interdependencies. Hence, the primary value of this work is in its comprehensive analysis of policy conflicts across several levels, including macro, meso, and micro.

First, the study examined Ghana's macro level GHG emission drivers and identified the most important ones for policy consideration. Using environmentally extended input-output (EE I-O) methods, based on the 2018 Ghana Social Accounting Matrix (GSS & IFPRI, 2020), the effects of increasing local rice production on other industries' GHG emissions were examined. The EE I-O analysis emphasizes the industry effects of the externality and potential policy trade-offs. Adaptation is essential to combating climate change. Volta Region, the leading producer of paddy rice among Ghana's top five regions, was used as a case study to assess smallholders' management strategies for reducing GHG emissions in rice production at the micro level. The data from the field survey can be incorporated into Ghana's policy on climate change adaptation.

Last but not least, the author compiled Ghana's first enhanced total GHG emissions panel data for various industries and economic sectors, from a secondary source, developed by the Environmental Protection Agency of Ghana, which were originally classified into five sectors: agriculture, forestry and other land use (AFOLU), energy, industrial production and product use (IPPU), and waste. This ground-breaking information may inform future research.

1.7 Organization of the Thesis Report

This thesis is organised in seven chapters. The first chapter is the introductory chapter and discusses the background of the study, problem statement, objectives, relevance of the study as well as the organization of the study report. The second chapter is a review of the literature focusing on definition of key concepts relevant to the research objectives, findings of empirical research on AFOLU sector and GHG emissions, rice production at the global, regional and national level and GHG emissions, how farmers across the globe and Africa in particular are adapting and /or mitigating GHG emissions in rice fields. Further, the review identifies several gaps in the literature which also drive the objectives of the current study and important information on the methodological approaches used in determining macroeconomic drivers of GHG emissions, and analysing the inter-relationship between environmental pollution and economic activities. The third chapter is a presentation of the theoretical and conceptual framework used for the study, the data collection and sampling procedures and model specifications utilized for the analysis of the data, linked to the specific objectives of the study. The fourth chapter is devoted to the presentation of the results and discussions of the study undertaken to identify the macroeconomic determinants of GHG emissions in Ghana involving the use of time series macroeconomic data from 1990 to 2019. The results and discussion of the input-output analysis of GHG emission in the economy of Ghana are presented in chapter five. The sixth chapter focusses on the results and discussion of the analysis of rice farmers' understanding of climate change issues and their management responses in reducing GHG emissions. The final chapter of the main text of the thesis report, chapter seven, provides a summary, conclusions and policy recommendations arising out of the study. The references cited in the text and appendices follow.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This literature review is organized under six main sections. The second section after the introduction defines a few concepts relevant to the research objectives. The third section summarizes empirical research on agriculture, forestry and other land use (AFOLU) sector and greenhouse emissions. The fourth section is devoted to rice production at the global, regional and national level and GHG emissions. The fifth section is devoted to how rice farmers across the world and in Africa are mitigating greenhouse gas emissions. The sixth section is focused on review of the methodological approaches used in determining macroeconomic drivers of GHG emissions, and analysing the inter-relationship between environmental pollution and economic activities. The seventh and final section, summarizes the findings of the literature review and the gaps that exist in the literature.

2.2 Definition of Concepts

Environmental quality

The term "environmental quality" refers to how clean or dirty the air, water, and land are. Environmental quality refers to how free land, air, and water are from human-produced pollutants and deterioration (Chu & Karr, 2017; Zhang et al., 2022). Environmental quality is further defined in this research study as the amount of greenhouse gas (GHG) emissions produced and released into the atmosphere. Existing literature (e.g., Zhang et al., 2022; Khan and Ullah, 2019) demonstrates that greenhouse gas (GHG) emissions generally contribute to global warming and climate change.

Global warming potential (GWP)

For policy discussion and target setting, greenhouse gases are measured by global warming potential (GWP), a measure of how much energy one tonne of gas emissions will absorb during a given period relative to one tonne of carbon dioxide emissions. GWP is calculated for a 100-year period.

Public goods

Public goods are non-excludable and non-rivalrous in nature. An additional use of a public good has no marginal cost. These items cannot be denied for non-payment. Also, one person's use of a resource does not limit others' access to it (Chen, 2021). Multiple people can use the goods simultaneously without a reduction in their quality and quantity.

Externality

Arthur Pigou, a prominent economist during the 1920s, is credited with the conceptualization and development of the economic concept known as externality. An externality refers to the indirect costs or benefits experienced by a third party as a result of the actions of another party (Ekici et al., 2022). Pollutants may be seen as externalities in the context of environmental economics. An illustrative instance may be seen in the context of motorized transportation, where manufacturers and customers of such vehicles do not bear the costs associated with the air pollution produced from the vehicles. This phenomenon has detrimental effects on society, as it fails to incentivize responsible behaviour, thereby exemplifying a typical manifestation of negative externality. A positive externality is said to occur when a positive advantage is experienced by a party other than those directly involved in a transaction or activity. The promotion of positive externalities may be facilitated by the government through the provision of subsidies for products and services that provide spill-over benefits. Conversely, the mitigation of negative externalities can be achieved by imposing Pigouvian tax on goods and services that result in spill-over costs (Lauer et al., 2023).

Agri-food systems

FAO (2018) defines a food system as a complex web of activities involving the production, aggregation, processing, distribution, consumption, and disposal of food products derived from agriculture, forestry, or fisheries, as well as components of the broader economic, social, and natural environment, as illustrated in Figure 2.1. Food systems produce food and affect everything else, including food security, nutrition, social equity, and sustainability. Human-made food systems affect the environment. However, sustainable food system generates net additional income for people, financial returns for investors, government revenue, and consumer benefits and also benefit other non-human animal species (Adhikari et al., 2021).

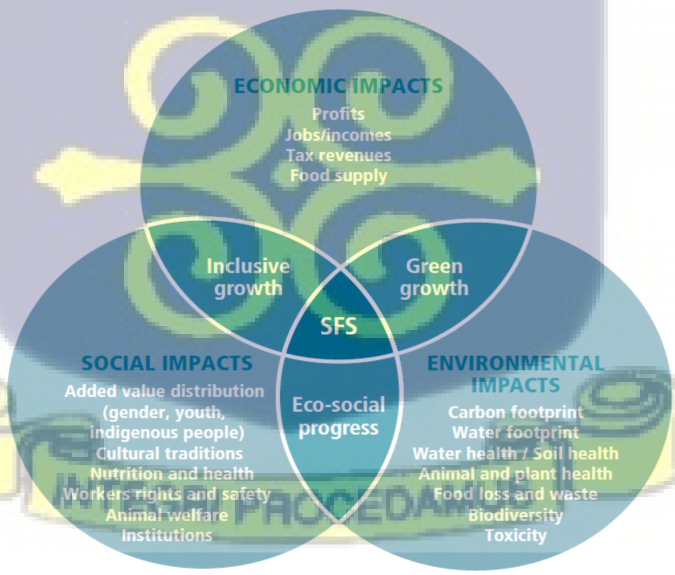


Figure 2. 1: Sustainability in Food Systems
Source: Adapted from FAO, 2018

2.3 Empirical Review

Air pollution is an environmental concern. Heinrich et al. (2020) assert that air pollutants consist of greenhouse gases (GHG), acidification contributing pollutants (ACID), and tropospheric ozone forming potential (TOFP). ACID and TOFP have less of an effect on climate change than GHG, according to Wang et al. (2021). A rise in greenhouse gas concentration causes climate change.

Gases help regulate Earth's temperature. By absorbing solar radiation, these gases regulate Earth's temperature (Kweku et al., 2018). Human activities like fossil fuel consumption, solid waste disposal, wood and coal production, and agricultural and industrial processes, like cement manufacturing, emit greenhouse gases (Hussain et al., 2019). Human-produced greenhouse gases include carbon dioxide (CO2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). CFCs, HFCs, HCFCs, PFCs, SF_6, methane, and nitrous oxide have a higher GWP than CO_2, forcing temperature increases over time (Delevingne et al., 2020). Excess greenhouse gas emissions cause global warming. High-GWP gases trap more heat per unit of mass than CO_2.

Despite the fact that greenhouse gases help keep the planet warm enough for humans' survival, too much greenhouse gas in the atmosphere depletes Earth's resources. Nonetheless, human activity has increased greenhouse gas concentrations since 1750 (Yoro & Daramola, 2020). According to Woolf et al. (2021) some greenhouse gases can last in the atmosphere for 100 years. Policymakers and researchers are therefore concerned about rising GHG emissions, since they cause global warming resulting in climate change (Islam et al., 2022). GHG emissions harm agriculture, health, and energy security.

Climate change has caused rising sea levels, ocean acidification, floods, droughts, land degradation, and the extinction of millions of plant and animal species (Talukder et al., 2021). Climate change and biodiversity loss may be more costly than COVID-19 (McElwee et al., 2020). Thus, many studies have examined greenhouse gas effects on crop yield, particularly climatic change (Agba et al., 2017). Kukal & Irmak (2018) state that climate change will harm the world's food supply. Greenhouse gases harm food and health. Its regional impact varies, like food production. Climate change caused by GHG emissions increases crop and animal pests and diseases. These measures fit a specific climate. Weather changes may affect pest resistance. Increased GHG emissions therefore endanger humans. Climate change in Africa and Asia causes malaria, cholera, and heat stress (Watts et al., 2018).

Some studies have presented findings that demonstrate a positive relationship between greater greenhouse gas (GHG) emissions and certain outcomes, which contradicts the prevailing body of research indicating that such emissions contribute to global warming, reduced crop yields, diminished availability of arable land, and increased prevalence of animal diseases. On the contrary, Harris et al. (2017) found that elevated levels of greenhouse gases (GHGs) in the atmosphere have a positive impact on agricultural productivity, result in decreased heating expenses in temperate regions, and contribute to a reduction in mortality rates associated with cold weather.

Agriculture, forestry, and other land use change (AFOLU) is essential to the global economy, food security, and sustainable development in all nations, but particularly in developing nations (Mbow et al., 2017). Increased AFOLU-related activities have resulted from population growth and rising food demand. The world population is projected to reach 9.7 billion by 2050 (Gu & Dupre, 2021). The anticipated increase in the global population might potentially lead to a substantial rise in the demand for food. The AFOLU sector is responsible for between 20% to 27% of global greenhouse gas emissions, making it the second largest emitter (Xu et al., 2021; Ahmed & Almeida, 2020). AFOLU is both a major climate change contributor and carbon sink. AFOLU activities release CO_2 and non-CO_2 emissions, such as CH_4 and N_2O, which have higher atmospheric forcing and longer life cycles (Allen et al., 2022).

Land use emits greenhouse gases and stores carbon in forests and the atmosphere. Clearing plants and soil contributes to climate change (Fearnside, 2019). Clearing tropical forests for farm development (in Africa, Asia, and Europe) and intensive animal farming (in South America) accounted for between 12-25 percent of total GHG emissions. Changes to the earth's surface affect climate, food security, and sustainable development (Rogers, 2021). Total net agriculture, forestry, and other land use (AFOLU) emissions increased from 7,497 million tons of CO2 equivalent in the 1990s to 8,103 million in the 2000s due to agricultural operations (50%), woodland conversion (38%), peat degradation (11%), and biomass fires (1%). Stavert et al. (2022) report that livestock, rice production, and biomass burning produce 80% of agricultural methane emissions. Fertilizer application causes 80% of global agricultural N2O emissions (Zhou et al., 2017). The agricultural sector feeds the world. As population and food needs increased, more land was farmed (Ahmed & Almeida, 2020).

Agriculture's GHG emissions have been studied extensively. There have been studies on cattle (Wang et al., 2017; FAO, 2019). Tillage and irrigation, however, are the most important sources of CO_2 emissions because they rely on fossil fuels and are now widely employed globally as recommended management methods to boost yields (Jaiswal & Agrawal, 2020).

2.3.1 Rice production and GHG emission at the global level

Every day, millions of individuals in low-income and developing nations consume rice for food and nutrition (Biswas et al., 2020). As the importance of rice in human diets grows, producing countries regard it as a cash crop (Chirinda et al., 2018). Asia produces 90% of the world's rice, while Africa produces only 2%. Rice yields have increased in tandem with farmland and population growth (FAO, 2018). An estimated 47.6 million tonnes of rice were to be exported in 2017 (FAO, 2018). Rice yields are increasing as a result of high-yielding, short-duration rice varieties and irrigation (Acharjee et al., 2019).

The phenomenon of global warming, which is caused by the release of greenhouse gases (GHGs), has been extensively studied and recorded in scientific literature. It has been observed that the severity and frequency of global warming events have been on the rise due to the escalating concentrations of GHGs resulting from human activities (Baker, 2022). The agricultural sector is well recognized as a significant contributor to greenhouse gas (GHG) emissions among various human activities (Gao et al., 2022). It is estimated that the agricultural sector accounts for around 11% of the overall GHG emissions (Masson-Delmotte et al., 2021). The current emphasis in the field of agriculture is on maintaining food production levels while also reducing greenhouse gas (GHG) emissions (Sun et al., 2020).

Many nations are experiencing energy shortages and environmental damage from extractive agricultural production (Baruah et al., 2004; Nagothu, 2018; Naz et al., 2019). Thus, environmental disasters, land degradation, and global food insecurity alarm policy makers and researchers worldwide (Gathala, 2020). In Asia, heavy tillage, uneven fertilizer usage, excessive irrigation, and energy consumption may raise greenhouse gas (GHG) emissions by 37% by 2050 (Frank et al., 2019).

As a major source of the greenhouse gas methane, rice farming both contributes to global warming and is affected by it. Methane emissions from rice fields are estimated to be around 12%, with wetlands and flooded rice fields contributing the most (Wang et al., 2023). There is evidence that rice contributes far more to global warming than wheat and maize, both of which are widely consumed staples (Elbasiouny & Elbehiry, 2020). Nonetheless, rice is a major staple for millions of people around the world, and as food demand rises, more rice production is needed to feed the world. Several countries, particularly in Asia and Africa, have already tried to increase rice output.

Rice production emits greenhouse gases. Rice cultivation relies on a human-dominated or, in some cases, human-induced environment that uses natural wetland controls and good agronomic techniques like irrigation and fertilizer use (Cohen & Teytelboym, 2019). Most farmers choose flooded terrain for rice farming because of the high soil fertility and nutrients requirements for rice production. The presence of water on the soil reduces oxygen and carbon dioxide, causing anaerobic fermentation thereby emitting methane and nitrous oxide into the atmosphere (Emmerling & Junk, 2020). The rate and pattern of organic/chemical fertilizer input and degradation in the soil also affects methane and nitrous oxide production rates. Methane is emitted into the atmosphere immediately after the floodwater recedes on paddy rice farms (Saha et al., 2022).

Irrigated rice fields emit more methane than rice wetlands. Consistent water supply and soil preparation produce high yields in rice fields (Pal & Debanshi, 2022). Farming rice on flooded lands is sustainable and has fewer environmental impacts than dry land or elevated rice farming (Tran et al., 2021). In the context of upland rice cultivation, it has been reported that there is a decrease in methane emissions. However, it is important to note that this reduction in methane emissions is accompanied by an increase in nitrous oxide emissions (Ali & Amin, 2019). This phenomenon, known as "emission swapping," leads to a situation where greenhouse gas emissions are not effectively reduced. For every kilogram of paddy rice produced from dryland, Yodkhum et al. (2017) reported that 0.58kg of carbon dioxide is emitted. In comparison, rice exhibits relatively modest greenhouse gas (GHG) emissions. Nevertheless, it is important to note that the global warming potentials (GWPs) of methane (CH_4) and nitrous oxide (N_2O) are projected to be 34 and 298 times more than that of carbon dioxide, respectively (Gupta et al., 2021).

Islam et al. (2022) suggest agriculture's GHG emissions contribute to global warming and climate change. Thus, field tests at the Bangladesh Rice Research Institute Farm Research Institute in Gazipur, Bangladesh, were needed to determine rice production GHG emissions reduction measures. The project focused on nitrogen fertilizer efficiency and water-saving alternate wetting and drying (AWD). Four fertilizer treatments—control (no N), prilled urea (PU), urea deep placement (UDP), and the integrated plant nutrient system (IPNS), a combination of poultry manure and PU, in combination with two irrigation systems—AWD and continuous flooding—were tested during the dry seasons of 2018, 2019, and 2020. The study found that AWD irrigation with enhanced fertilizer application techniques reduced pollution, including GHG emissions, compared to continuous flooding (CF) irrigation.

Vo et al. (2023) performed research which revealed that rice cultivation in Vietnam contributes to around 15% of the country's total greenhouse gas (GHG) emissions. The objective of this study was to explore strategies for mitigating greenhouse gas emissions associated with rice cultivation. The research centred its attention on the modification of agricultural techniques and the use of alternative rice cultivars as means to mitigate emissions stemming from rice cultivation. The study was conducted in the Mekong Delta (VMD) in Vietnam to evaluate the performance of 20 rice varieties under two irrigation methods: continuous flooding (CF) and alternating wetting and drying (AWD). The study spanned a duration of two years and used the closed chamber technique to measure greenhouse gas (GHG) emissions. The findings of the study provided confirmation that the most significant source of variance in methane (CH4) emissions under conventional farming practices was due to differences in crop varieties. In the context of various types, methane (CH4) emissions shown greater significance compared to nitrous oxide (N2O) emissions. The impact of different rice types on greenhouse gas levels was shown to be influenced by water management practices. Therefore, it is essential to consider the appropriate choice of variety when implementing mitigation strategies. This consideration may either be included as an extra step to optimize the impact of alternate wetting and drying (AWD) during periods of low rainfall, or as an independent mitigation option in situations when AWD is not feasible.

A four-year (2012–15) field experiment by Yadav et al. (2020) examined the energy use pattern, carbon footprint (CF), and economic viability/feasibility of tillage and mulches on direct-seeded upland rice cultivation at the India Council of Agricultural Research for the Northeastern Hill Region, Lembucherra, Tripura, India. Compared to conventional tillage, no-till (NT) reduced energy usage by 48.50%, specific energy by 49.63%, CF by 16.48%, and cost of cultivation by 35%. It also improved energy use efficiency and benefit-to-cost ratio. Mulching improved energy consumption efficiency, economic productivity, net returns, and benefit-to-cost ratio over no mulch. The findings showed that NT with mulch is an ecologically clean production technique that improves energy efficiency and reduces CF in direct-seeded upland rice production in the Eastern Himalayas and other ecoregions. The research found that no-till-based direct-seeded rice used 48.5% less energy and 16.5% less CO2-e than traditional tillage without affecting yield. No-till had 35% lower production expenses and 12.8 times higher net return than conventional till. No-till improved energy efficiency, decreased continuous flow, and boosted direct-seed rice output and profitability.

According to Singh, et al. (2021) pollution from rice farming is also caused by open-field rice straw burning. As much as 7300 kg CO2-eq/ha−1 of GHGs and pollutants from straw burning may harm soil, biodiversity, and human health. Global rice straw production is 731 million tons (MT), of which India contributed 126.6 MT. An estimated 60 percent of rice straw is burnt in the field. Stopping open burning reduces CH4 and N2O and helps the environment.

2.3.2 Rice production in Africa and greenhouse gas emissions

Rice has been farmed in Africa for over 3000 years and feeds millions (Rodenburg et al., 2006; Zenna et al., 2017). Africa produces 2.6% to 4.6% of the world's rice (Ibrahim & Wopereis, 2021). Over 50 percent of Africa's rice growers are smallholders. Africa produced around 24 million metric tons of rice in the 2017/2018 trade year. However, domestic rice production meets 60% of local demand (Zenna et al., 2017). Akpoti et al. (2022) conducted a study which revealed that the majority of rice cultivation in Africa occurs in upland drylands (38%), rain-fed wetlands (33%), irrigated land (20%), and deep-water and mangrove swamps (9%).

West African countries import almost a third of the world's rice each year (Nasrin et al., 2015; Norman and Kebbe, 2015). To meet expanding rice demand, governments have explored different wetlands for rice cultivation, bred high-yielding cultivars for Africa, and trained growers in rice production. (Makihara et al., 2018). Rice is the fastest-growing cereal in Africa (Makokha et al., 2017). However, agriculture, especially rice farming, will increase Africa's GHG emissions (Ntinyari & Gweyi-Onyango, 2021).

Farag et al. (2013) estimated the carbon footprints of Egyptian paddy rice using life cycle analysis and IPCC recommendations. They evaluated rice field emissions by analysing emissions from rice cultivation, mechanical operations such as irrigation, tillage, and harvesting, nitrogen fixation, and rice straw combustion. The findings revealed that rice farming was responsible for approximately 53% of total methane emissions, rice straw burning for approximately 35%, nitrogen fertilizer application for approximately 1%, and mechanical operations for approximately 1%. However, the contribution of rice production to Africa's total GHG emissions has not been studied in depth. Concerns about climate change, the intensification and expansion of rice production, and methods for increasing rice production are common themes in academic research on rice.

Nyamadzawo et al. (2013) examined Zimbabwe's intermittently flooded rice fields' emissions. The study sampled conventional tillage, no tillage, tied ridges, tied fallows, and mulched fields. No tillage, mulched fields, and tied ridges had the highest nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2) emissions, respectively. Rice fields release CO_2, CH_4, and N_2O during cropping season. Osabohien et al., (2019) examined West African food production and GHG emissions. Their study found that GHG emissions decreased crop yields. Thus, social protection programs should compensate farmers for GHG-related crop losses and other risks. Their study focused on food crop production rather than paddy rice cultivation, which emits large amounts of GHGs directly and indirectly and is affected by them (climate change).

GHG emissions in rice and maize production affected food security in Ghana, Senegal, Benin, and Côte d'Ivoire, according to Ba (2016)'s value chain analysis and greenhouse model. Nitrogen fertilizers increased maize cultivation's GHG emissions. Rice production emits more methane in flooded systems.

By 2025, African governments plan to increase food production, particularly rice, which will increase fertilizer use and agricultural GHG emissions (Adegbeye et al., 2020). Van Loon et al. (2019) examined how rice intensification affects GHG emissions in ten countries using different management techniques. Regardless of cereal output, all countries studied will increase GHG emissions by 2025. GHG emissions rise when countries turn forests and grasslands into cereal farms.

2.3.3 Rice production and GHG emissions in Ghana

The government has focused on rice production in Ghana in recent years due to the high cost of importing rice to meet the 70% deficit from local production (Boateng et al., 2017). If Ghana's rice cultivation methods are used to increase rice production, they may negatively impact climate change mitigation. The research done by Narh et al. (2020) revealed that the use of inorganic fertilizer during rice production in northern Ghana is associated with the largest share of greenhouse gas emissions, at 72% of the overall emissions. The results support a previous, comparable research carried out by Eshun et al (2013). According to the study, the transportation of paddy by vehicle emerges as the second most significant contributor (10%) to greenhouse gas emissions within the rice-producing industry. In the southern part of Ghana, where a significant number of farmers transport their paddies to milling facilities, there is a possibility for this share to increase.

Oladele et al. (2019) investigated Ghanaian lowland rice farmers' adoption of alternate wet and dry (AWD) methods. They surveyed 120 rice producers in Tema. They gathered information regarding the socioeconomic status, AWD usage, and climate-smart agriculture knowledge of producers. The majority of producers in the study were unaware of AWD and did not employ it. AWD adoption was also found to be influenced by contact with agricultural extension officers, farm size, rice cultivation experience, and production technique. Although this study did not measure greenhouse gas emissions from farms, it identified this as an area for future research.

2.3.4 Rice trade and GHG emissions

Individuals and countries obtain their needs via commerce. As the population of a country grows, it becomes more dependent on other nations to satisfy its requirements that cannot be satisfied or created domestically. Countries spend extensively in industrialisation to create and sell more goods than they consume. The international commerce operations of producing and transporting goods and services result in the discharge of greenhouse gases into the environment (Cristea et al., 2013). The previous section of this review examined rice production and greenhouse gas emissions. This portion of the literature study will concentrate on the worldwide rice trade and its greenhouse gas (GHG) footprints.

Trade is one of the means through which an economy expands, but it is also related with an increase in greenhouse gas emissions (Lee & Erickson, 2017). Lee & Erickson (2017) discovered that while global economic production has grown since 1990, this trend has been accompanied by a rise in greenhouse gas emissions. Emissions of greenhouse gases effect commerce in the same way that increases in GHG emissions impact trade. Loss of arable land due to rising sea levels has a negative impact on agricultural productivity (Zhang & Cai, 2011). Increased GHG emissions influence commerce: they impact agriculture, labour productivity, the supply chain, and transportation systems, such as the impacts of severe weather and rising sea levels on shipping, which accounts for around 80% of world trade (Dellink et al., 2017). Agriculture and public health are impacted by increased greenhouse gas emissions, which has an effect on commerce. These resources (such as land and labor) are exploited to produce commodities that are traded on both local and international marketplaces.

As mentioned, Asia produces more than two thirds of the world's rice, a staple. Rice consumption has increased worldwide, especially in Africa, where most urban residents eat rice as their main food (Hegde & Hegde, 2013). Despite the high demand for rice, only 7% of all rice produced is traded internationally, mostly because most of it is eaten in the country of production and Asian countries, the largest producers, have policies to ensure national food security and protect farmers' incomes (FAO, 2006). Thailand, Vietnam, Pakistan, USA, India, Italy, Uruguay, China, UAE, Benin, Argentina, and Brazil export 90% of rice worldwide (Tubiello et al., 2014). Many developing countries like Ghana import large amounts of rice to meet their food and dietary needs. Due to comparative advantage, South American and East Asian countries are more likely to produce more food and export, while the Middle East, Africa, and South Asia are more likely to become net food importers (Schmitz et al., 2011).

The transportation of rice plays a vital role in facilitating its distribution, including both intra-national movements within producing nations and inter-national movements between producers and importing nations. When considering the whole supply chain, including the journey from the farm gate to factories, markets, and consumers, it becomes evident that transportation of agricultural products has the potential to emerge as a significant contributor to greenhouse gas (GHG) emissions. The predominant emphasis of contemporary research on greenhouse gas (GHG) emissions and international trade revolves on the examination of emissions stemming from the production of commodities, as well as the analysis of how trade activities contribute to the dispersion of carbon footprints across participating nations. (Tian et al., 2022).

2.3.5 Rice Farmers' adaptation options to reduce GHG emissions.

Rice cultivation releases methane and other greenhouse gases. Understanding the adaptation strategies of rice farmers to reduce greenhouse gas emissions is crucial for national policymaking. This review's objective is to evaluate farmers' adaptation strategies using case studies from Africa and Asia.

Hussain et al. (2020) found that rice field greenhouse gas emissions can be reduced by alternating wetting and drying, intercropping with short-term vegetation, limiting chemical fertilizers by precise farming, using rice cultivars with low methane emissions, improved tillage, recycling farm waste into organic fertilizers, and developing integrated rice farming systems. Boateng et al. (2017) classified rice emission reduction adaptation strategies in Ghana as fertilizer application, water and soil management, and drought-resistant rice cultivars. According to Esiobu et al. (2020) rice farmers in Nigeria use alternate wetting and drying (AWD) to mitigate greenhouse gas emissions. Similarly, Arunrat et al. (2018) recommended that some of the most effective strategies for reducing greenhouse gas emissions for Thai rice farmers include the use of zero-tillage systems, ammonium sulfate rather than urea, mid-season drainage, and site-specific nutrient management.

Opoku Mensah (2023) found that smallholders' main strategies for minimizing climate change's impact on yield were changing planting date, planting early maturity varieties, and applying organic fertilizer. Hasan (2013) also found that Egyptian smallholders adapted by using short-duration rice varieties and good water and fertilizer management. Hussain et al. (2022) found that many Singaporean rice farmers used fertilizer combinations and the integrated management system to reduce greenhouse gas emissions and increase yield potential by changing tillage, nitrogen fertilization, irrigation, and organic and fertilizer inputs. Win et al. (2021) suggested resistant rice varieties, organic manure, and water management to reduce rice field greenhouse gas emissions. Islam et al. (2021) reported that most Bangladeshi rice farmers use water-saving irrigation. In non-tilled paddy fields in the central lowlands of China, Xu et al. (2015) reported water-saving irrigation and drought-resistant rice varieties.

Human capital is essential for all industries including rice farming (Kim et al., 2018). The efficiency of the workforce on any given farm can increase the output of the agriculture industry. A study conducted by Almoussawi et al. (2022) highlighted among the findings, the importance of human capital's influence on agricultural productivity for Iraq's sustained economic growth. In a country-specific study, Zhang et al. (2021) investigated how natural resources, human capital, and economic growth affected environmental degradation in Pakistan from 1985 to 2018 using the autoregressive distributed lag method (ARDL). The analysis results show that human capital and natural resources negatively impact CO2 in the long run. They concluded that adopting new production processes via using new technology by human intellectual capital plays a critical role in resource utilization, resulting in the mitigation of environmental degradation. Similarly, Pata & Caglar (2021) reported that anthropogenic production and consumption activities pollute the air, soil, and water, endangering human health and long-term development. Hence, countries have implemented various measures and technologies to reduce and control GHG emissions, especially CO2 emissions. They revealed that human capital is crucial in reducing environmental degradation in China using annual time series data from 1980 to 2016.

The aforementioned findings provide support for the human capital theory of economic growth proposed by Theodore Schultz (1961). This theory posits three key components: firstly, nations lacking sufficient human capital face challenges in effectively utilizing physical capital; secondly, economic growth can only be achieved when both physical capital and human capital experience simultaneous growth; and thirdly, human capital is the primary factor that tends to impose limitations on growth. The ability of rice farmers to mitigate greenhouse gas (GHG) emissions through adaptation measures is contingent upon their human capital, including factors such as education, training, and experience.

2.4 Methodological Approaches for Analysing GHG Emissions

Several academics used econometric analysis to examine greenhouse gas emissions and their causes. Khan & Ullah, (2019) and Boateng, (2020) all estimated overall economy, sector, and industry GHG emissions using the production function. The selection of analytical procedures and instruments is determined by the subject area (environmental economics or biology), study objective and the availability of specific data types. The econometric approach only estimates coefficients that are direct. The approach is incapable of capturing interdependencies across sectors and industries; hence, projections based on these estimations may be misleading and inaccurate. Environmental economists calculate the economic and environmental impacts of GHG emissions using various methods, according to the literature. Most approaches use input-output (IO) analysis, computable general equilibrium models, or a combination of I-O analysis and linear programming (Ribeiro et al., 2018; Nguyen et al., 2019; Moon et al., 2020).

IO analysis was used to identify sustainable Korean industries based on CO2 emissions and to examine indirect CO2 emissions in China's construction industry, GHG missions, and Brazil's livestock industry (Moon et al., 2020). In recent years, the international community's focus on environmental issues has led to the measurement of the flows and changes in a country or region's resources, energy, and emissions using the I-O framework (Cai et al., 2020). GSS-IFPRI (2020) examined COVID-19's effects on Ghana's agriculture, industry, and services using the I-O framework.

Leontief's assumption of the constant input coefficient of production and the constant returns of scale and technology restricts input-output analysis when it is used for forecasting beyond five years. A stationary economy presupposes continual returns to scale, but a stationary technology assumes a constant technique of production. The model is based on difficult-to-find equations. Identify the mathematical pattern first, then the enormous data. Equations need significant mathematics and difficult-to-locate data. The input-output paradigm gets convoluted and abstract, which is why some researchers avoid using it.

Leontief's (1986) input-output (I-O) analysis is used to analyse economic structure, global and local trade, energy, and environmental issues. The IO Inter-industry environmental impact analysis examines international trade and consumption (Daly 1968; Ayres and Kneese 1969; Chang and Lin 1998; Proops et al., 1999). Total output equals intermediate consumption plus final consumption (Leontief, 1985). Primary and intermediate texts discuss input-output analysis methods (Miller & Blair, 2009; Zhang et al., 2011; Ten Raa, 2017; Leontief, 2018; Ribeiro et al., 2018; Moon et al., 2020).

The I-O table is an exhaustive statistics table that illustrates the inter-industry trade ties of all products and services generated in a particular year. An I-O table comprises a link between the main input factor sector and industry as well as the number of transactions between the final output sector and each industry (Miller and Blair 2009). This demand table contains demand for intermediate commodities—inputs such as labor, earnings, and taxes—as well as demand for final products, including consumer goods and services and exports (Moon et al., 2020)

Table 2. 1: The structure of an Input-Output Table

Producing Sector	Intermediate Goods and Services						Total Intermediate Demand	Total Final Demand	Total Output
	R_1	R_2	R_3	R_4	…..	R_n			
R_1	X_{11}	X_{12}	X_{13}	X_{14}	…..	X_{1n}	RX_{1n}	D_1	X_1
R_2	X_{21}	X_{22}	X_{23}	X_{24}	….	X_{2n}	RX_{2n}	D_2	X_2
R_3	X_{31}	X_{32}	X_{33}	X_{34}	….	X_{3n}	RX_{3n}	D_3	X_3
R_4	X_{41}	X_{42}	X_{43}	X_{44}	…..	X_{4n}	RX_{4n}	D_4	X_4
…..	Quadrant I						……	Quadrant II …..	
R_n	X_{n1}	X_{n2}	X_{n3}	X_{n4}	….	X_{nn}	RX_{nn}	D_n	X_n
	Total Purchase								
		Value Added							
		Total Input							

Source: Moon et al. (2020)

In Quadrant I, goods are transferred from one sector of manufacturing to another. Rows R1 through Rn in Quadrant I show the different industrial sectors that contribute to economic production. The sum of each column indicates the overall number of intermediate resources accessible to a particular sector. In contrast, the industries in the columns use the outputs of the manufacturers in the rows as inputs for their own goods. Total intermediate demand for each industry is the sum of the sectors in their respective columns. In the second quadrant, is the ultimate demand, which comprises of purchases made by consumers, governments, and export enterprises, but not the manufacturing sector. The output of an industry is the total of all its inputs, from raw materials to completed products. Three factors make up value added: wages and salaries, taxes on production and imports less subsidies, and gross operating surplus. Total industrial input equals intermediate demand plus output with added value.

Miller and Blair (2009) calculated each sector's output as $X = (I-A)^{-1} Y$. A is the technology matrix showing how much input each sector needs to make one product in Ri. Technical coefficients are calculated by dividing each I-O table entry by its column total (aij = xij/Xj). The identity matrix is I, and the inverse Leontief matrix is $(I-A)^{-1}$. External demand is Y, and sector output is X. When sector j as a buyer and seller increases, so does its production. I-O analysis divides linkages into backward and forward effects.

Forward and backward linkage measure a sector's relationship to the sectors from which it buys inputs and sells output, respectively (Rasmussen, 1956; Miller and Blair 2009; Moon et al., 2020). Leontief inverse $(I-A)^{-1}$ measures economic sector links. Choe et al., 2023, Quan et al., 2020, and Moon et al. (2020) define the backward linkage effect as power of dispersion (POD) and the forward as sensitivity (SOD).

Rasmussen (1956) calculated POD and SOD index formulae. Quan et al. (2020) calculated the inter-sectoral and effects-induced effects of final demand on output, value-added, and GHG emissions in Korea and Vietnam using IO analysis. The POD and SOD are defined below.

Power of Dispersion (POD) = $\sum_i \cup_{ij} = \frac{\frac{1}{n}\sum_i B_{ij}}{\frac{1}{n^2}\sum_{ij} B_{ij}}$

Sensitivity of Dispersion (SOD) = $\sum_j \cup_{ij} = \frac{\frac{1}{n}\sum_j B_{ij}}{\frac{1}{n^2}\sum_{ij} B_{ij}}$

where n is the number of industries and Bij is the sum of the Leontief inverse matrix

$B = (I-A)^{-1}$ column elements. To meet a one-unit increase in final demand for industry products, the entire system of industries must increase output. The back link increases demand for inputs from other sectors, and the forward link changes output sensitivity to other sectors, according to Guo and Hewings (2001).

2.5 Summary of the Major Findings from the Review of the Literature

This literature review was conducted to find out the contribution of rice production to GHG emissions and how production systems are being managed to deal with GHG emissions. Among the key findings are:

1) The contribution of the agricultural sector to greenhouse gas (GHG) emissions is well acknowledged, however its comprehension remains limited. It is a fact that approximately one quarter of global greenhouse gas (GHG) emissions are attributed to the sectors of agriculture, forestry, and land-use change. Furthermore, as the global population grows and the need for food increases, these emissions are projected to rise if nothing is done about them.
2) Several researchers have conducted empirical research on this topic, with results indicating the net increase in production from the sector (Tubiello et al., 2014), sources of GHG emissions within the AFOLU sector (Foley et al., 2005; Houghton, 2003; Mammadova et al., 2020), forms of GHGs released by the sector (Lambin et al., 2003; Foley et al., 2005), and the effects of land use change.

3) The sources of GHG in agriculture can be divided into three categories: crop production, transportation and processing, and farm equipment purchases (Gifford, 1984; Lal et al.,2004; Farag, 2013). Several studies on cereal production and GHG emissions have been conducted. These studies usually focus on maize, wheat, and rice.

4) Global rice production has increased, which affects methane and nitrous oxide emissions. The literature review found that most empirical rice studies are from Asia. Also, many of these studies focused on GHG emissions and cropping systems (Bouman et al., 2017; Cai et al., 2020; Linquist et al., 2012; Zhou et al., 2017)

5) A significant number of studies also evaluated water management systems, while others analyzed both water management systems and fertilizer application (see for instance, Linquist et al., 2015; Xu et al., 2015). Some studies also focused on the use of fertilizer on rice fields and greenhouse gas emissions (Zhong et al., 2016; Snyder et al., 2009).

6) From the review, it was determined that, despite the fact that some studies on rice production and GHG emissions have been conducted on the African continent, the proportion of studies conducted in Africa relative to the rest of the world is extremely low. Moreover, research on the continent examined cropping systems and water management systems (Farag et al., 2013; van Loon et al., 2019; Osabohien et al., 2019).

7) Similarly, Ghanaian research has focused on cropping systems (Boateng et al., 2017), water management (Oladele et al., 2019), and GHG emissions in the rice production chain (Boateng et al., 2017; Oladele et al., 2019), and (Eshun et al., 2013). Although Eshun et al. (2013) examined transportation and greenhouse gas (GHG) emissions in rice production, their focus was on transportation from mills to the market.

8) In Asia, environmental impact studies focused on inter-industry analysis to examine how changes in final demand affect economic production and the environment (Ha, 2021;

Firdaus & Wijayanto, 2020; Moon et al., 2020; Ha & Trinh, 2018; Temursho, 2016). In lieu of regression analysis, they utilized an environmentally-extended input-output (EE I-O) technique to examine indirect greenhouse gas emissions, specifically carbon dioxide, in their respective industries. EE I-O builds on I-O in order to determine the hidden, indirect, or embodied environmental and/or social effects of an upstream economic event (Kitzes, 2013).

2.6 Gaps in the Literature

Among the gaps identified in literature are:

1) The literature on the negative production externalities such GHG emissions associated with paddy rice production in Africa has received little attention. In research studies, the emphasis has been on rice intensification to reduce food insecurity.
2) Studies on the impacts of rice production in Africa tend to focus on the direct effects of GHG emissions, ignoring the indirect effects of these emissions caused by industry interdependence. This emphasis is primarily due to the use of regression analysis, which is inadequate to explain industry interdependence.
3) In the allocation of total GHG emissions in an economy, outputs of industries as a proportion of total economic output are frequently used to calculate total GHG emissions produced by each industry (Ha, 2021; Firdaus & Wijayanto, 2020; Moon et al., 2020; Ha and Trinh, 2018; Ribeiro et al., 2018; Temursho, 2016). Even though this method is simple, it could be misleading and give wrong estimates of the emission coefficients for different industries.
4) The literature on drivers of GHG emissions frequently uses total trade as a measure of openness without distinguishing between imports and exports, which could have opposing effects on GHG emissions.

5) Input-output analysis studies frequently employ total output and total value-added multipliers and effects and do not distinguish between labour income and capital owner income effects. These studies tend to ignore income inequality issues, which are pertinent to political economy discourse, particularly in countries like Ghana where income inequality among the population is increasing. The causes and effects of GHG emissions, as perceived by policymakers and elites, and as indicated by farmers are not simultaneously addressed in studies of these emissions.

This study aims to identify the direct, hidden, indirect, embodied environmental, and economic and social benefits of Ghana's policy of increasing local rice production. This study will also examine the macro drivers of GHG emissions and the externalities in terms of GHG emissions produced in the domestic economy based on inter-industry interactions to determine which industries in the economy generate higher total value-added multipliers at relatively low levels of pollution in response to a unit increase in final demand. In addition, the study will disaggregate the total value-added multipliers into labour income and capital owner income effects in order to identify the policy's winners and losers. Overall, the study will generate evidence for policymakers to make informed decisions about increasing local rice production to achieve self-sufficiency while meeting the country's GHG mitigation commitments in accordance with its declared NDC linked to the reduction in the growth of GHG emissions.

CHAPTER THREE

METHODOLOGY AND PROCEDURES USED FOR THE STUDY

3.1 Introduction

This chapter describes in details the theoretical underpinnings and the conceptual framework of the study. It also discusses the methodology and procedures of the study under the three different objectives.

3.2 Theoretical Framework

The theory underpinning this research is externality theory based on economics of negative production externalities. Externalities cause market failure if the price mechanism does not take account of social costs and benefits of production and consumption. Market failure leads to an inefficient allocation of resources and dead weight loss of economic welfare. For this typology of externalities, a firm's production reduces the well-being of others who are not compensated by the firm. In this case, marginal social cost (MSC) is greater than marginal private cost (MPC) due to marginal damage cost (MDC). Marginal damage cost (MDC) is the additional cost associated with the production of the good that are imposed on others but that producers do not pay. The social marginal cost (MSC) is therefore comprised of the marginal private cost (MPC) to producers plus marginal damage cost (MSC=MPC+MDC).

MSB – Marginal Social Benefit

MPB – Marginal Private Benefit

3.2.1 Theory of externality (firm and industry)

In an economy that operates on market principles or exchange mechanisms, the production of a particular item, such as rice, is undertaken by a distinct entity referred to as the producer. Subsequently, the consumption of this commodity is carried out by a separate entity known as the consumer. The process of producing a commodity gives rise to externalities, which are unintended consequences in economic terminology. Neither the producer nor the consumer internalizes or captures these externalities. The use of the social cost of production concept is often necessary in the management of externalities.

Figure 3.1 depicts a competitive rice production industry characterized by a multitude of producers and consumers. The producers are represented by an individual supply curve denoted as S1, while the overall demand for rice in the industry is represented by the aggregate demand curve, D. At the point of equilibrium quantity Q1, individual rice farmers optimize their profits. At this point of equilibrium quantity, the marginal private benefit (MPB) is equal to the marginal private cost (MPC). If environmental factors are taken into account, the supply curve S1 experiences a leftward shift. The introduction of the new supply curve, denoted as S2, results in the establishment of a new equilibrium quantity, represented as Q2. The equilibrium level of output, when externalities are included, is lower compared to the scenario when externalities are not taken into consideration, as shown in Figure 3.1

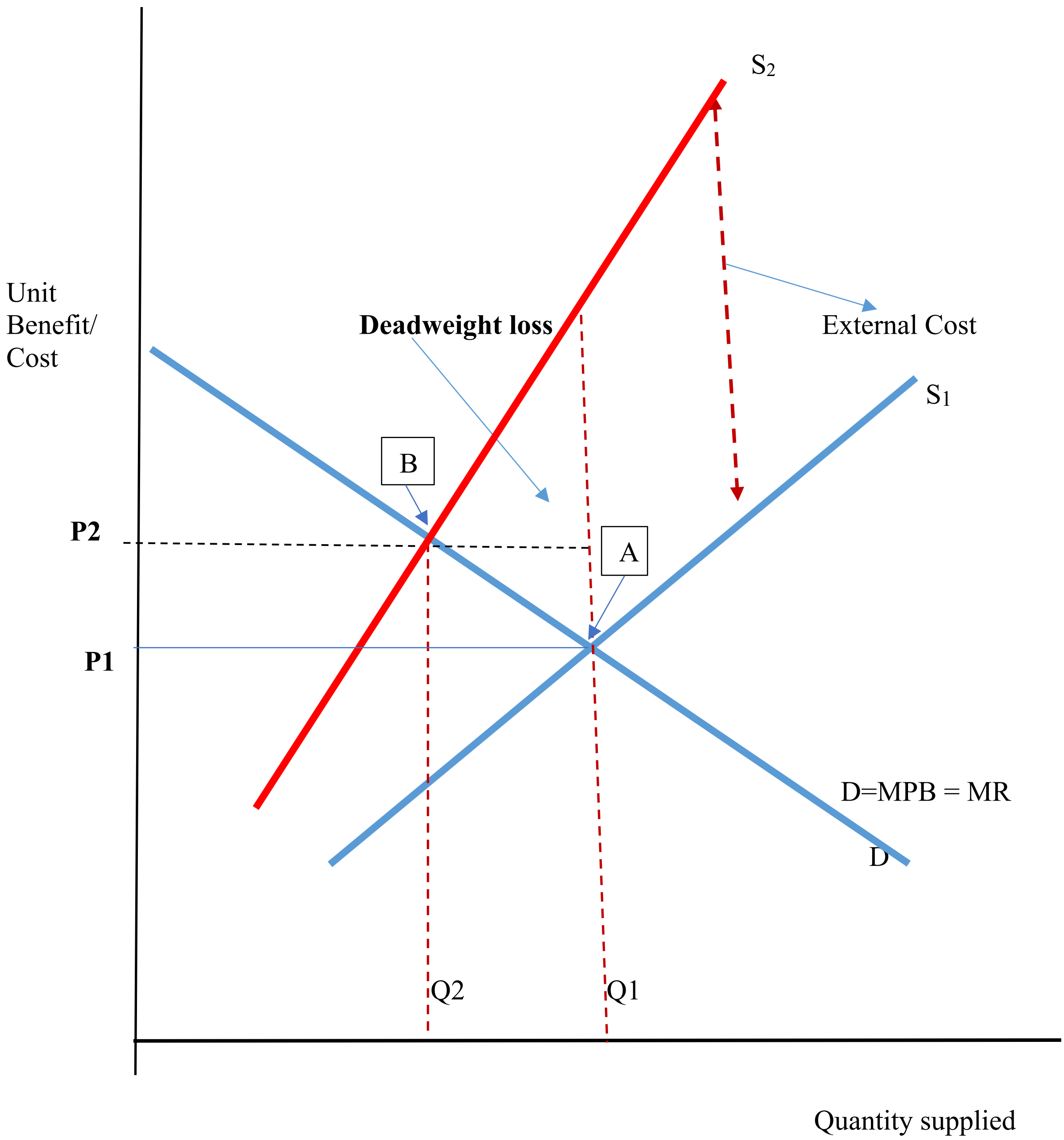


Figure 3. 1: Negative Production Externalities
Source: Author's adaptation from Pigou (2017)

3.2.2 Theory of externality (global common resource)

From a theoretical perspective, as illustrated in Figure 3.2, the natural environment is regarded as a global common resource. Initially, it was perceived as indivisible and nonexclusive entity, a pure public good, accessible to all individuals without any detrimental impact on the environment's capacity to sustain itself. The aforementioned feature is discernible inside the interval between point O and point B, as seen in Figure 3.2. Greenhouse gas (GHG) emissions are emitted into the Earth's atmosphere by producers of rice and other agricultural and non-agricultural commodities on a global scale. The global atmosphere is not under the exclusive control of any one corporation or government.

From the onset of the human revolution approximately 200,000 years ago until 1750 AD, which marked the advent of the industrial age, the collective greenhouse gas (GHG) emissions generated by the human population did not exert a discernible impact on the overall composition of the Earth's atmosphere. This observation is depicted graphically in Figure 3.2, where the trajectory from point O to point B illustrates that the marginal cost associated with pollution was negligible. From the year 1750 AD onwards, the escalation of greenhouse gas (GHG) emissions has resulted in a decline in the overall quality of the Earth's atmosphere, particularly after a certain point referred to as "B." This decline is associated with the observation of rising marginal costs. There is concern that by the year 2050, the global atmosphere may reach its limit in terms of its ability to effectively absorb the growing emissions of greenhouse gases (GHGs). This might result in irreparable harm, as shown by point C in Figure 3.2.

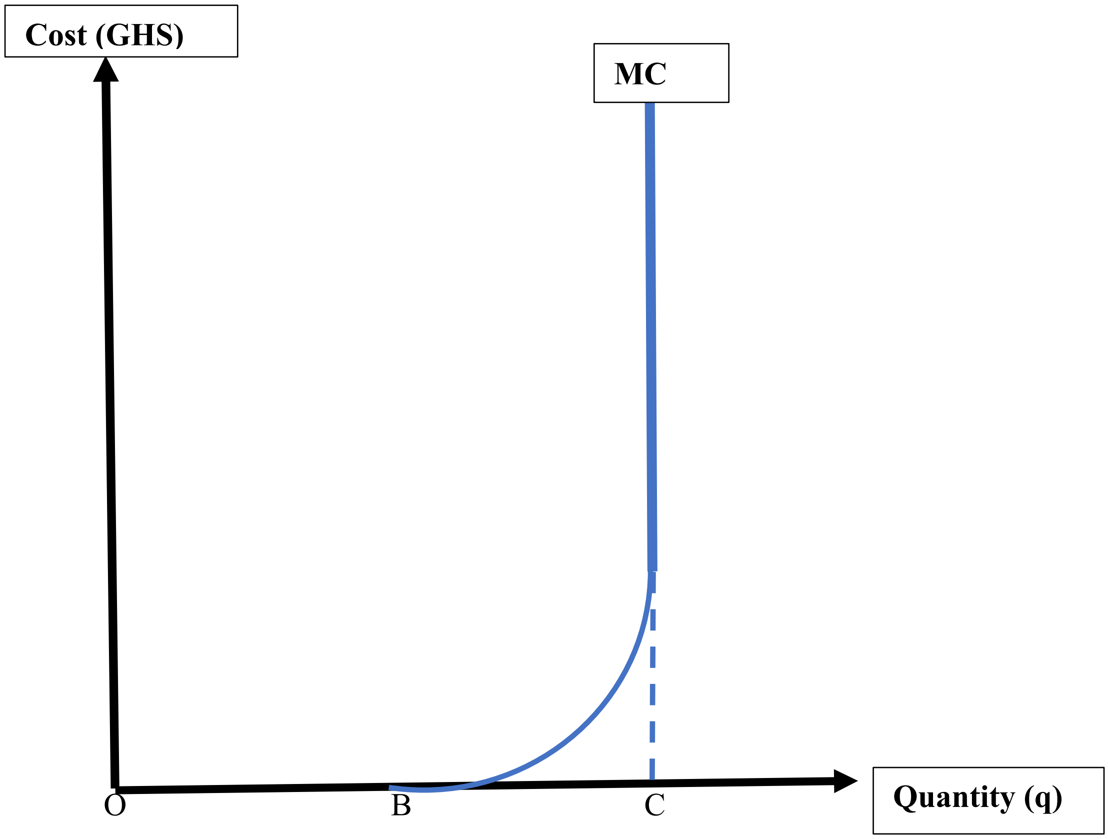


Figure 3. 2: Conceptual Depiction of the Use of the Natural Environment
Source: Author's adaption from Thampapillai (2002)

3.3 Conceptual Framework

According to Scheidel et al. (2018), Hsu et al. (2016), and Lenschow et al. (2016), the occurrence of environmental degradation and its subsequent unsustainable outcomes may be ascribed to the existence of deficiencies in economic development. The study examines the relationship between economic growth, namely the increase of local rice production, and its impact on environmental quality with respect to greenhouse gas (GHG) emissions. Furthermore, this study examines different strategies used by rice farmers to control greenhouse gas (GHG) emissions within their production systems. The conceptual framework, as seen in Figure 3.3, outlines the four objectives of this study, which are approached using a three-tier analytical methodology: macro, meso, and micro.

At the macroeconomic level, the aggregate greenhouse gas (GHG) emissions of a country are influenced by several economic activities, one of which is rice cultivation. This particular activity, carried out by rice farmers within the broader economy, is of particular relevance. As a result, the aggregate production of all the sectors and industries that make up the whole economy defines the direct emission drivers, and this in turn determines the total greenhouse gas (GHG) output.

According to the Leontief input-output model, the economy is divided into sectors where each sector produces goods and services not only for itself but also for other sectors. These sectors are dependent on each other and the total input always equals the total output. In the context of the meso level of analysis, it becomes imperative to assess the direct and indirect effects of macro drivers on the overall greenhouse gas (GHG) emissions within the wider economy. These emissions are a result of interdependencies that exist across different industries. A given industry's output functions as an intermediary input for another industry.

In order to minimize the micro-level effect of greenhouse gas emissions from rice production, farmers' management activities are determined according to the degree of their adaptation, which is a reflection of their preferences and choices. The study assumes the farmer's decision-making behaviour is rational. Consequently, the farmer's decision to implement a particular strategy or strategies to reduce GHG emissions will be influenced by the anticipated benefits of those strategies. A farmer chooses to implement a strategy that will deliver maximum utility.

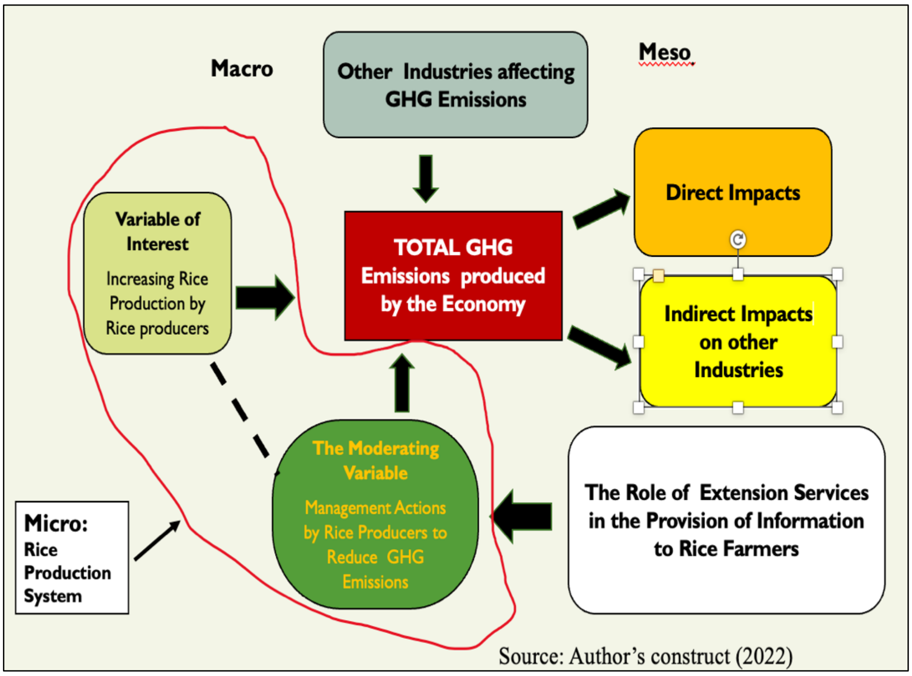


Figure 3. 3: Conceptual Framework of the Study

3.4 Empirical Models

In developing countries, economic growth generally impacts environmental degradation where output increases and decreases with environmental pollution due to the inefficient technologies used. The impact of economic growth on emissions is in literature (Boateng, 2020; Abokyi et al., 2019; Kwakwa and Alhassan, 2018). The study derives three empirical models as follows:

a) Cobb–Douglas production function for the macro level study as written in Equation 3.1;

$$Y_t = f(Z_t K_t L_t) \qquad \text{Equation 3.1}$$

where Y is desired output to be produced and Z, K, and L are the factors employed to produce the output. Consequently, air pollution (GHG emissions), a proxy for environment degradation, is a result of economic activities. Total greenhouse gas emissions = f (derivers of macroeconomic growth). To determine how to reduce total emissions while improving quality of life through sustainable development, it is necessary to examine the macrolevel causes of GHG emissions in Ghana;

b) Leontief input-output (I-O) model is utilized in this study at the meso-level to analyze the effect of enhancing local rice production on the overall greenhouse gas (GHG) emissions. This analysis considers both direct and indirect effects by examining the interconnections between the rice industry and all other sectors within the economy. The mathematical representation of this model is presented as Equation 3.2. The utilization of the Input-Output (I-O) model is justified by a series of studies conducted by Ribeiro et al. (2018) wherein the I-O model was employed to calculate the greenhouse gas (GHG) emissions multipliers of the Brazilian economy in 2009. These findings were then linked to the employment and income multipliers in the agriculture sector. Similarly, Moon et al. (2020) employed I-O analysis to identify the eco-friendly and highly interconnected industries in Korea, thereby providing an objective representation of sustainable development. Furthermore, Nguyen (2021) utilized the I-O model to examine the intersectoral linkages, or the interdependence of industries, in Vietnam's economy from 2000 to 2012.

$$X = [1 - A]^{-1} Y \qquad \text{Equation 3.2}$$

where X is the gross domestic output matrix, A is the direct intermediate input coefficient matrix, $[1 - A]^{-1}$ is the technical coefficient of the economy and Y is the domestic final demand matrix.

c) Multiple regression model for the micro level study to assess how local rice farmers manage their production systems to deal with GHG emissions. This was motivated by

Jingchao et al. (2019) who applied the same model in the evaluation of the of coal quality-based household energy choices in rural Beijing. In Kenya, Mwaura et al. (2021), the employed the same model to evaluate the socioeconomic determinants of adoption intensity of selected organic-based technologies. Debie & Anteneh (2022) use the multiple regression model to investigate how the joint use of indigenous and introduced soil management practices impacted the development of smallholders' livelihoods in the Goso watershed in northwest Ethiopia.

The empirical model for the adaptation intensity was specified using Equation 3.3.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon_i \qquad \text{Equation 3.3}$$

The adaptation intensity score by farmers to address greenhouse gas (GHG) emissions from rice production is denoted as Y. The intercept is represented by β_0, while the regression coefficients (marginal utilities) of the independent variables X_1, X_2, ..., X_n, which are socioeconomic factors influencing the adaptation intensity score, are denoted as β_1, β_2, ..., β_n, respectively. The error term is represented byε_i.

3.5 Methodology for Analysing Macro Level Determinants of GHG Emissions in the Economy

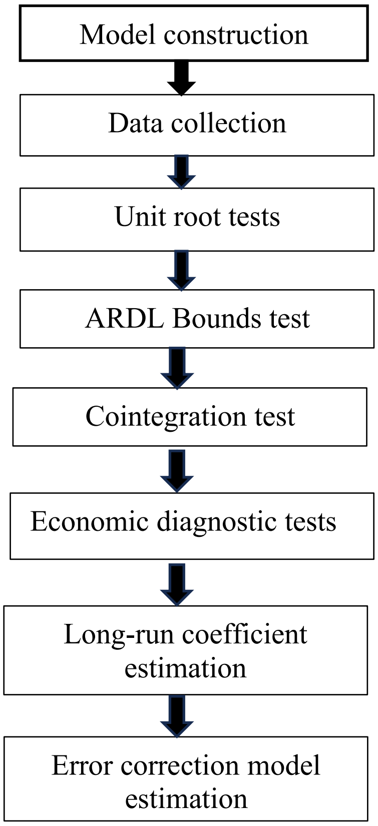
The previous studies on Ghana (Boateng, 2020; Abokyi et al., 2019; Sarkodie & Strezov, 2018; Aboagye, 2017; Asumadu-Sarkodie & Owusu, 2016; Twerefou et al., 2016) focused on drivers of CO_2 emissions. The objective of this study is therefore to examine the key drivers of total greenhouse gas (GHG) emission in Ghana based on evidence generated by the available secondary data from the Environmental Protection Agency (EPA) of Ghana report (2021), Ghana Statistical Service (GSS) (2020), Bank of Ghana, Ghana Metrological Agency, Agricultural

Facts and figures (MOFA-SRID 2019), Agriculture Census report (2019), and World Development Indicators published on Ghana produced by the World Bank.

3.5.1 Methodology

Time series econometric methodology was employed in identifying the drivers of total greenhouse gas emissions in Ghana using an empirical model based on the constant returns to scale Cobb–Douglas production function presented in Equation 3.4. The approach was based on the hypothesis that total greenhouse gas emissions (TGHG) as a dependent variable is influenced by per capita real Gross Domestic Product (PCRGDP), per capita real Gross Domestic Product Square (PCRGDPSQ), real interest rate (RINTRATE), export Gross Domestic Product ratio (EXPGDPR), import Gross Domestic Product ratio (IMPGDPR), total land area planted to rice (RICEAREA), and energy shock related to the occurrence of severe El Nino events (ENERGYS). Other variables like total land area devoted to the production of the twenty major crops in Ghana and total land area devoted to the production of crops other than rice were also considered, however, these other variables, when included in the models did not have produce valid cointegration among the variables.

The Environmental Protection Agency (EPA) of Ghana estimates that agriculture, forestry, and other land use (AFOLU) produce 43.4 percent of total GHG emissions in Ghana. However, the energy industry has continuously been the largest contributor of GHG emissions, trailing only the AFOLU sector (EPA 2021). Agriculture used to be the largest source of GHG emissions, but it has been steadily declining. Because the agriculture sector is one of Ghana's primary sources of emissions, it is critical to understand the factors driving the decline in order to reduce overall emissions. The study also examined the share of Ghana's agriculture sector to the overall greenhouse gas emissions. This was done on the basis of the hypothesis that the AFOLU share of total GHG emissions (SAFOLUt) is a dependent variable that is influenced by the agricultural sector share of GDP in year t (SHAREAGt), the amount of land devoted to rice production in time t (RICEAREAt), flaring in the crude oil production industry (FLAREDUMt). The methodological approach of the study is illustrated in Figure 3.4



Source: Author's construct (2022)

Figure 3. 4: Flow chart of the methodological approach

3.5.2 Data sources and description of variables of interest

This study used annual time series data from the EPA (2021) version spanning the years 1990 to 2019. This period was chosen since data on total GHG emissions in Ghana were only available for the time period under consideration. Furthermore, the data spans the period when Ghana changed from a low-income to a middle-income country, as well as the beginnings of crude oil production. The data source and description of variables of interest used in the study for the whole economy and the agricultural sector are captured in Table 3.1.

Table 3. 1: Data sources and variables

Variable	Description	Source
Dependent		
TOTAL GHG_t	Total emissions of all greenhouse gases measured, in carbon dioxide equivalent, in time t, in giga grams with data sourced from the Ghana Environmental Protection Agency (2021).	Ghana's Third Biannual Update Report to the United Nations Climate Change, prepared and published in August 2021 by EPA Ghana.
$SAFOLU_t$	Share of the total greenhouse emissions of Ghana attributed to the agricultural sector in year t.	
Independent		
$PCRGDP_t$	Per capita gross domestic product in time t.	Ghana Statistical Service (GSS), April 2022 based on the rebased GDP with 2013 as base year.
$RINTRATE_t$	Real interest rate, defined as the nominal interest rate, adjusted for by inflation, at time t.	Bank of Ghana (nominal interest rate data released in March 2022) and GSS (inflation data)
$EXPGDPR_t$	Total exports divided by GDP at time t.	GSS data supplemented by World Bank data.
$IMPGDPR_t$	Total imports divided by GDP at time t.	
$RICEAREA_t$	The amount of land devoted to the production of rice in time t.	Agricultural Facts & Figures from MOFA (2019), 2017-2018 Agricultural Census published in 2019 by GSS
$GSHAREAG_t$	Growth of agriculture share of GDP in year t.	Ghana Statistical Service (GSS) GDP data (April 2022), based on the rebased GDP with 2013 as base year.
$ENERGYS_t$	Energy shock related to the occurrence of severe El Nino events which generate severe droughts in the country in time t. Specified as dummy variable with a value of 1 for years for severe El Nino occurrences and zero for all other years.	Data on weather-based energy shocks related to El Nino weather phenomenon based on data from Ghana Meteorological Agency
$FLAREDUM_t$	A dummy variable with a value of 1 for the years, 2011 and 2017, when there was increased flaring in the crude oil production industry due to the start of production from new oil fields. The value of zero was assigned to other years	Ghana's Third Biannual Update Report to the United Nations Climate Change, prepared and published in August 2021 by EPA Ghana.

Source: Author's construct (2022)

3.5.3 Empirical model for macro level analysis

The general functional forms of the models constructed for the study based on the literature review are presented as Equations 3.4 and 3.5. The total GHG emissions is written as a function of economic activities as follows:

$$TGHG_t = f(PCRGDP_t\ PCRGDPSO_t\ RINRATE_t\ \mathrm{EXPGDPR}_t \mathrm{IMPGDPR}_t\ \mathrm{RICEAREA}_t\ \mathrm{ENERGYS}_t)$$

Equation 3.4

$$\mathrm{SAFOLU}_t = f(\mathrm{GSHAREAG}_t\ \mathrm{RICEAREA}_t\ \mathrm{FLAREDUM}_t)$$ Equation 3.5

Regression analysis as a statistical method was used to examine the relations between dependent variable and the explanatory variables of interest. Instead of Fully Modified OLS method used in Kwakwa & Alhassan (2018), this study employed the cointegration technique. Many cointegration procedures are used to analyse long-run relationships among first-order variables I (1). Engle and Granger developed the first popular cointegration method in 1987. Johansen (1991) developed a better cointegration method. Phillips and Ouliaris (1990) cointegration test, Boswijk's (1994) structural error correction model (ECM), and Banerjee et al. (1998) t-test cointegration technique are other well-known cointegration tests.

The study conducted by Abokyi et al. (2019) presents a critical analysis of conventional cointegration approaches, despite their widespread use and acceptance in the field. According to Shahbaz et al. (2018), conventional cointegration methods may provide ambiguous empirical findings. Bayer and Hanck (2013) proposed a novel integrated cointegration methodology to overcome the limitations of prevailing cointegration methodologies, which tend to introduce bias in empirical findings. Bayer & Hanck (2013) integrated the findings of Engle and Granger (1987), Johansen (1991), Boswijk (1994), and Banerjee et al. (1998) in order to augment the statistical power of their tests. In order to adhere to academic conventions, it is necessary to use first-order variables. Additionally, the approach employed in this study involves the application of combined cointegration.

The study used the ARDL-bound test cointegration approach to assess the robustness of the cointegration results. This method was chosen over traditional cointegration techniques because it gives efficient and consistent results for small samples. It works for I (0), I (1), and mutually cointegrated variables. This study's use of ARDL is consistent with existing literature in environmental economics and international trade that shows a relationship between the macroeconomy and environmental resource deployment (Mirza and Kanwal, 2017; Mikhaylov et al., 2020; Abokyi et al., 2019; Khan and Ullah, 2019; Boateng, 2020).

3.5.4 Method of analysis

In order to make interpretation easier by obtaining elasticity, the variables were transformed to their natural log forms. The log-linear versions of the models were therefore used because they outperformed their linear versions on basic econometric diagnostic tests and model power measured by R^2. Equations 3.4 and 3.5 are rewritten as Equations 3.6 and 3.7.

$$\mathrm{LTGHG}_t = H_0 + H_1\mathrm{LPCRGDP}_t + H_2\mathrm{LPCRGDPSQ}_{\ t} + H_3\mathrm{LRINTRATE}_t + H_4\mathrm{LEXPGDPR}_t + H_5\mathrm{LIMPGDPR}_t + H_6\mathrm{LRICEAREA}_t + H_7\mathrm{ENERGYS}_t + V_t \qquad \text{Equation 3.6}$$

$$\mathrm{LSAFOLU}_t = F_0 + F_1\mathrm{GSHAREAG}_t + F_2\mathrm{LRICEAREA}_t + F_3\mathrm{FLAREDUM}_t + X_t \qquad \text{Equation 3.7}$$

Where $LTGHG$, $LPCRGDP$, $LPCRDPSQ$, $LRINTRATE$, $LEXPGDPR$, $LIMPGDPR$, $LRICEAREA$, $LSAFOLU$, and $GSHAREAG$ are natural logarithms of $TGHG$, $PCRGDP$, $PCRGDPSQ$, $RINTRATE$, $EXPGDPR$, $IMPGDPR$, $RICEAREA$, $SAFOLU$, and $SHAREAG$, respectively; H_0 and $F_0$are intercepts, H_1, H_2, H_3, H_4, H_5, H_6, H_7, F_1, F_2, and F_3 are parameters to be estimated, and V_t, and X_t are error terms initially assumed to have zero means and constant variances.

3.5.5 Unit root tests

Using the Time Series Processor (TSP) program, the unit root test was applied to each variable in the log-linear function to check for stationarity based on the augmented Dickey-Fuller test (ADF) (Dickey and Fuller, 1981), the Phillips–Perron test (PP) (Phillips & Perron, 1988) and (Hall & Cummins, 2009). The null hypothesis was the model has a unit root. The optimal lag length was calculated using the Schwarz Bayesian Criterion, akin to Khan & Ullah (2019), and Boateng (2020), Adikari et al. (2023).

3.5.6 Existence of cointegration

Cointegration exists if all the variables in a model (both the dependent and independent variables) have the same order of integration (Engel & Granger, 1987). This study employed the autoregressive distributed lag (ARDL) method (bound testing approach) to check for a long-run relationship among the variables in the model. A good attribute of the ARDL method is that it can be applied to the model whether the variables are stationary or non-stationary; further it establishes a maximum of only one long-run cointegration relationship.

3.5.7 Long-run relationship among the variables

The study employs a vector autoregressive (VAR) model that checks for the existence of a long-run relationship between the dependent and explanatory variables of the two models. The ARDL method involves the bounds test using a correctly specified model (Abokyi et al., 2019; Khan and Ullah, 2019; and Boateng, 2020). The null hypothesis of the bounds test specifies that the coefficients of the lagged terms of the unrestricted error correction model are jointly equal to zero. The existence of a long-run relationship among the variables is proven if the test statistic lies above the upper bound critical value.

The long-run optimal ARDL cointegration models were assessed using four different econometric diagnostic tests. The Ransey RESET Test (Ramsey 1969) was applied to verify its correct model specification. For normality of the equation error term, the Jarque-Bera test (Jarque and Bera 1987) was used. The Breusch-Godfrey serial correlation test (Breusch 1978; Godfrey 1978) was also applied to check that the ARDL model was free from the problem of serial correlation. Finally, the Lagrange-Multiplier (LM) test was used to establish the presence or otherwise of the problem of heteroscedasticity (refer to Pesaran et al., 2001). For this study, the optimal ARDL cointegration models are specified as in Equations 3.8 and 3.9

$$\mathrm{LTGHG}_t = \beta_0 + \beta_1\mathrm{LPCRGDP}_t + \beta_2\mathrm{LPCRGDPSQ}_t + \beta_3\mathrm{LRINTRATE}_t + \beta_4\mathrm{LEXPGDPR}_t + \beta_5\mathrm{LIMPGDPR}_t + \beta_6\mathrm{LRICEAREA}_t + \beta_7\mathrm{ENERGYS}_t + U_t \quad \text{Equation 3.8}$$

$$\mathrm{LSAFOLU}_t = C_0 + C_1\mathrm{GSHAREAG}_t + C_2\mathrm{LRICEAREA}_t + C_3\mathrm{FLAREDUM}_t + Z_t \quad \text{Equation 3.9}$$

Once the autoregressive distributed lag (ARDL) model has established the existence of a cointegration among the variables, the subsequent step involves the derivation of the long-run regression equations which are similar to those expressed in Equations 3.8 and 3.9. The short run error corrections models are also determined from the underlying long run regression equations. The error correction models are discussed in the next section.

3.5.8 Error correction models (ECM)

The ECM procedure makes it possible to deal with non-stationary data series and separates the long short run effects. The error correction models for the whole economy and the agricultural sector are shown in Equations 3.10 and 3.11.

$$\Delta \text{LTOTALGHG}_t = E_0 + E_1 U_{t-1} + E_2 \Delta \text{LTOTALGHG}_{t-1} + E_3 \Delta \text{LPCRGDP}_t + E_4 \text{LRINTRATE}_t + \beta_4 \Delta \text{LPCRGDPSQ}_t + E_5 \Delta \text{LRINTRATE}_t + E_6 \Delta \text{LEXPGDPR}_t + E_7 \Delta \text{LIMPGDPR}_t + E_8 \Delta \text{LRICEAREA}_t + W_t \qquad \text{Equation 3.10}$$

$$\Delta \text{LSAFOLU}_t = G_0 + G_1 Y_{t-1} + G_2 \Delta \text{LSAFOLU}_{t-1} + G_3 \Delta \text{GSHAREAG}_t + G_4 \Delta \text{LRICEAREA}_t + G_5 \Delta \text{FLAREDUM}_t + Y_t \qquad \text{Equation 3.11}$$

where W_t, and Y_t are error terms of Equations 3.10 and 3.11, respectively.

3.6 Data Sources and Methodology for Determining the Effect of Rice Production on Total National GHG Emissions

The study seeks to respond to how the Government's rice self-sufficiency policy, directly and indirectly, affects the total GHG emissions based on the linkages between the rice industry and all other industries in the economy. For this reason, an Environmentally-Extended I-O analysis was first conducted using the Input-Output (I-O) table for Ghana derived from the 2018 Social Accounting Matrix (SAM) (GSS & IFPRI 2020). The results of the EE I-O analysis show the linkage effects that industries have on the Ghanaian economy. Having a great linkage effect means that those industries have great impacts on the national economy and therefore they are considered as strategic industries in the national economy.

3.6.1 Methodology

The I-O table for 20 industries in the domestic economy was first derived from the 2018 Social Accounting Matrix (SAM) of Ghana developed by the International Food Policy Research Institute (IFPRI). The IFPRI SAM is based on the core domestic economy having 76 industries, including the rice production industry. The researcher worked with the major supervisor to develop a 20-industry I-O table from the 76-industry 2018 SAM. The 20-industry I-O table had rice production as one industry. The remaining 19 industries are all other agricultural industries (29 industries combined), crude oil production, other mining and quarrying, electricity generation, water and sewage production, construction, and 13 services industries.

The researcher also constructed a 20 by 20 table of the domestic economy's technical coefficients. Technical coefficients are a measure of the fixed relationships between a sector's output and its inputs. This study follows Miller & Blair (2009), Ribeiro et al. (2018), Moon et al. (2020), and Shmelev & Brook (2021). The total value added out-put multipliers decomposed into total labour income, and capital owners' income multipliers were then derived using the Leontief inverse matrix based on one unit change of final demand of the 20 industries. Production externality multipliers; total, direct, and indirect GHG emissions multipliers based on one unit change of final demand of the 20 industries were also derived. Similarly, following Miller and Blair (2009), Ribeiro et al. (2018), and Vasconcellos & Couto (2021), the employment-output multipliers derived in this study assessed the effects of changes in a sector's final demand on the number of jobs created based on the assumption that employment levels within an industry are closely tied to the amount of output generated. The employment-output ratios of the 20 industries measured as numbers of jobs per million Ghana cedis of output produced were first estimated. To obtain the employment-output multipliers, the employment-output ratios were pre-multiplied by the Leontief inverse matrix. The process of calculating the technical coefficients and the multipliers is illustrated in Figure 3.5.

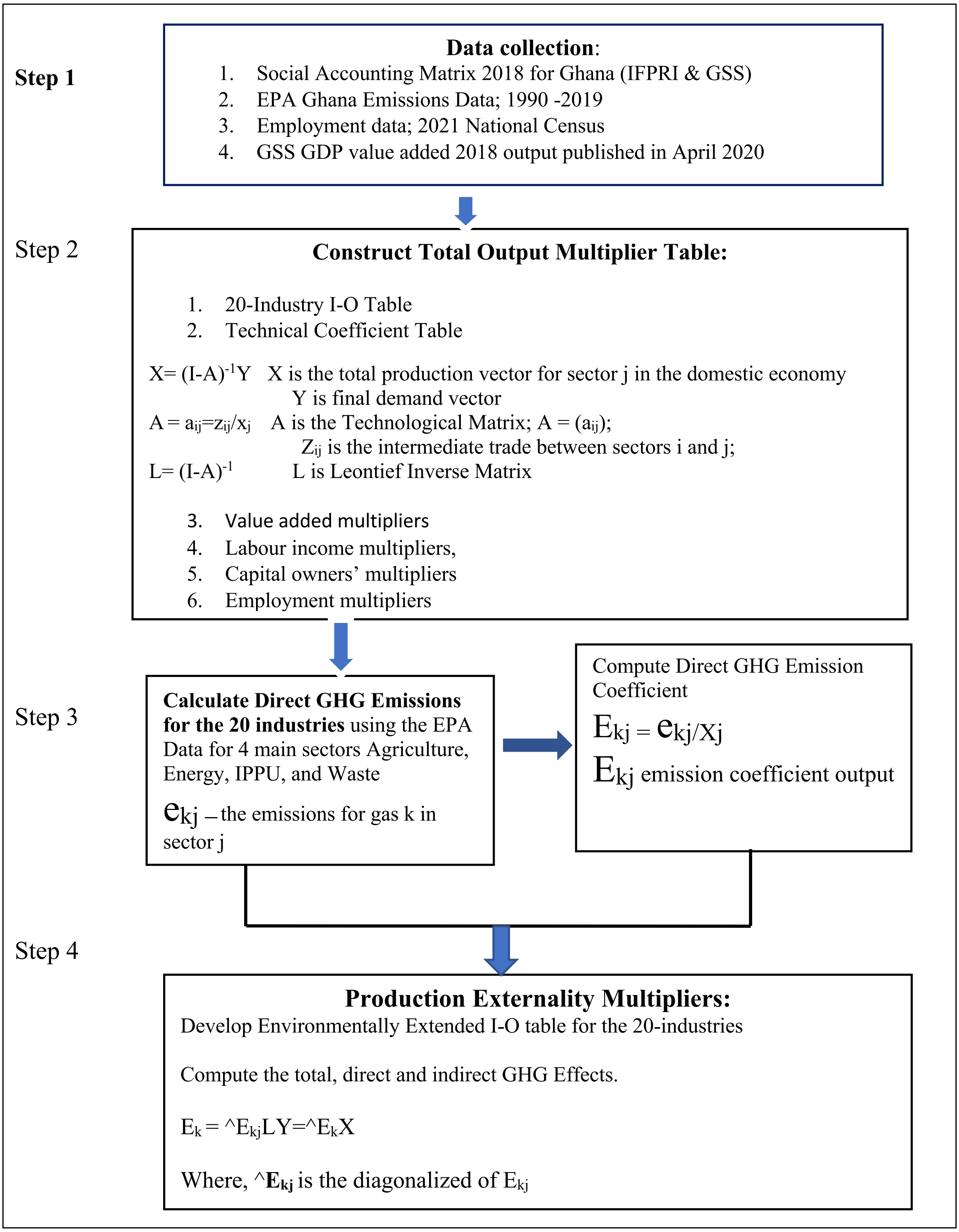


Figure 3. 5: Steps followed in estimating the multipliers used for the inter-industry analysis
Source: Author's construct (2022)

Every industry needs energy to run its activities. The energy-based GHG emissions were proportionally allocated to each industry based on its economic value of total output in relation to the total output of the 20 industries. The exceptions occurred for these eight industries: rice, agriculture, crude oil production, all other mining, electricity energy production, transport and storage, construction, chemicals; for these industries the Environmental Protection Authority (EPA) Ghana data gave the exact GHG emissions for these industries.

The industrial production-based GHG emissions (IP) were assigned directly to the industries as indicated by the EPA (2021). The IP is part of the industrial production and product use (IPPU) classification used by EPA Ghana. Waste was proportionally allocated to all the 20 industries based on their total production value in relation to the total value of output produced by the 20-producing quadrant of the economy.

Certain common elements like lubricant used in the economy (2.08 Giga grams) and refrigeration units used in the economy (613 Giga grams) were also allocated to all the 20 industries based on their shares of the total production value of the 20-industry producing quadrant of the economy. Lubricant use and refrigeration come under IPPU.

Agriculture and forestry sector was treated separately. Total GHG emissions accruing to cropland were also supplied by EPA. The share of rice cropland from total land cropped in 2019 was obtained from the Agricultural Facts and Figures Report 2020 produced by the Ministry of Food and Agriculture. It was assumed that in addition to its share of emissions coming from cultivated crop land, four percent of the total emissions from grasslands came from rice production reflecting the fact new lands devoted for the production of rice largely come from grasslands.

In a summary, EPA provides GHG emissions data for four main sectors: (1) agriculture, 2) energy, (3) IPPU, and (4) waste. The analyst assigns these emissions data to the 20 industries in the producing quadrant of the economy. Some of the data provided are directly linked to specific industries. For other industries, one has to use proportional representation for the allocation. The process is validated when the actual EPA total emissions are fully allocated to the 20 industries without any discrepancy.

3.6.2 Structure of the Ghana I-O table

Table 3 .2 depicts the national input-output table for Ghana for the year, 2018 showing industries in the producing quadrant of the economy. The intermediate or producing quadrant is one of the four components of the Ghanaian economy and represents the domestic component that produces goods and services in Ghana. This intermediate quadrant provides economic transactions among the firms in the domestic economy aggregated into 20 industries. The second quadrant is the payments quadrant. This quadrant represents the purchases made by industries in the intermediate quadrant of goods and services outside the local economy necessary to produce goods and services of the 20 industries in the local economy.

The third quadrant is the final demand quadrant which represents the final use of goods and services produced by the local economy (intermediate quadrant). The final demand quadrant is made of household consumption expenditures, government recurrent expenditures, investment expenditures by both government and private firms, change in stocks held by business firms and exports. Final demand changes drive firms and industries in the local economy to produce more goods and services to meet the change in demand. The fourth quadrant is the payments-to-final demand component; this quadrant represents the economic transactions that link the payment quadrant to final demand quadrant. Example of such transactions include the purchases of imported goods and services by householders in the local economy.

Table 3. 2: Illustration of Ghana 2018 Input-Output Table with 20 Industries

Industry	**(Outputs) Domestic Economy**				**Household consumption**	**Final Demand**	**Total**
	1	**2**	**3**	**……20**			
1. Rice Production 2. All other Agriculture 3. Crude Oil 4. All Other Mining 5. Manufacturing 6. Electricity, gas and steam 7. Water Supply and Sewage 8. Construction 9. Wholesale and Retail Trade 10. Transport and Storage 11. Hotels 12. Restaurant and Food Services 13. Information and Communication 14. Finance and Insurance 15. Real Estate Services 16. Business Services 17. Public Administration 18. Education 19. Health and Social Work 20. All Other Services	**PRODUCING QUADRANT** **(First Quadrant)**				**FINAL DEMAND QUADRANT** **(Third Quadrant)**		
P1. Wages and salaries of workers P2. Incomes of capital owners P3. Indirect taxes P4. Imported inputs	**PAYMENTS QUADRANT (Second Quadrant)**				**PAYMENTS-TO-FINAL DEMAND QUADRANT** **(Fourth Quadrant)**		
TOTAL OUTPUT							

Source: Author's adaptation from the 76-industry SAM developed by GSS&IFPRI (2020)

3.6.3 Data sources

The environmentally-extended input-output (EE I-O) built on the 2018 Social Accounting for Ghana, was constructed for this study using sectoral-level data on resource flows and usage, such as the GSS GDP value added 2018 output published in April 2020, EPA Ghana emissions to compute total greenhouse gas emissions, and employment data from the 2021 National Population and Housing Census, to calculate direct and indirect intensity in response to supply and demand stimuli. Shmelev and Brook (2021), and Ribeiro et al., (2018)) used the EE I-O approach to analyse the complexity of economic-environmental interactions.

3.6.4 Empirical method

The methodology of input-output analysis is well-established and is described in primary and intermediate texts (West, 1990; Anaman, 1994; Miller and Blair, 2009; Chen & Zhang, 2010; Ten Raa, 2017). Impact analysis arising from input-output analysis, sometimes called secondary impact analysis, deals with the changes in output, income and employment in the economy arising often from changes in one or more components of final demand. Assume that the transactions (tr) among industries in the economy are a system of equations denoted below:

$tr_{11} + tr_{12} + tr_{13} + tr_{14} + tr_{15} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots tr_{1n} + Y_1 = X_1$ Equation 3.12

$tr_{21} + tr_{22} + tr_{23} + tr_{24} + tr_{25} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad tr_{2n} + Y_2 = X_2$ Equation 3.13

$tr_{n1} + tr_{n2} + tr_{n3} + tr_{n4} + tr_{n5} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad tr_{nn} + Y_n = X_n$ Equation 3.14

where tr_{ij} is the output from industry i purchased by industry j; Y_j is the total demand for the output from industry i; X_i is the total output from industry i.

A matrix of direct coefficients (requirements) can be generated if the transactions tr_{ij} are divided by the respective output levels of j denoted as X_j. Calling the direct coefficients, $a_{ij}(tr_{ij}/X_j)$, a matrix of direct coefficients can be assembled as a system of equations, similar to the economic transactions table, as follows:

$a_{11}X_1 + a_{12}X_1 + a_{13}X_1 + a_{14}X_1 + a_{15}X_1 \dots\dots\dots\dots\dots\dots\dots\dots a_{1n} + Y_1 = X_1$ Equation 3.15

$a_{21}X_2 + a_{22}X_2 + a_{23}X_2 + a_{24}X_2 + a_{25}X_2 \dots\dots\dots\dots\dots\dots\dots\dots a_{2n} + Y_2 = X_2$ Equation 3.16

……………………………………………………………………………………………

$a_{n1}X_n + a_{n2}X_n + a_{n3}X_n + a_{n4}X_n + a_{n5}X_n \dots\dots\dots\dots\dots \dots\dots a_{nn} + Y_n = X_n$ Equation 3.17

Expressing the system of n equations in matrix format yields the equations denoted in Equations 3.15 to 3.17 as follows:

$AX + Y = X$ Equation 3.18

$X - AX = Y$ Equation 3.19

$[1 - A]X = Y$ Equation 3.20

$X = [1 - A]^{-1}Y$ Equation 3.21

where X represents $n \; x \; 1$ column vector of total production for each industry in the local or intermediate quadrant of the economy; A is $n \; x \; n$ matrix of direct coefficients which are inputs required from industry i for the production of one Ghana cedi worth of output by industry j; i is a $n \; x \; n$ identity matrix;

$L = [I - A] - 1$ where L is a $n \; x \; n$ Leontief inverse matrix; Y is a $n \; x \; 1$ column of final demand.

The value-added-output multipliers are computed by multiplying the value-added coefficient row vector "Ava, i" by the Leontief inverse "L_{ij}." Where "VA(j)" is the sector "j" value-added output multipliers.

$\text{Ava, i} = \frac{\text{Vai}}{\text{Xj}}$ Equation 3.22

$$VA(j) = \sum\nolimits_{i=1}^{n} (\text{Ava, i}).(L_{ij})$$ Equation 3.23

The value-added output multiplier measured the effect of an additional Ghana Cedi of final demand for sector $'j's$ output when all direct and indirect effects in the production process are converted into a Ghana Cedi estimate of new value-added generated.

The labour income multipliers are computed by multiplying the labour coefficient row vector "H_{li}" by the Leontief inverse "L_{ij}" Where "$Hl(j)$" is the sector "j" labour-income multiplier.

$$Hl, i = \frac{\text{hli}}{\text{Xj}}$$ Equation 3.24

$$Hl(j) = \sum\nolimits_{i=1}^{n} (\text{Hl, i}).(L_{ij})$$ Equation 3.25

The multiplier measured the effect of an additional Ghana Cedis of final demand for sector $'j'$ output when all direct and indirect effects in the production process are converted into an estimate of new labour income.

The capital owners' income multipliers are computed by multiplying the capital coefficient row vector "Ko_i" by the Leontief inverse "Lij." Where "Ko(j)" is the sector "j" capital owners'-income multiplier

$$Ko, i = \frac{\text{koi}}{\text{Xj}}$$ Equation 3.26

$$Ko(j) = \sum\nolimits_{i=1}^{n} (\text{Ko, i}).((L_{ij})$$ Equation 3.27

The multiplier measured the effect of an additional Ghana Cedis of final demand for sector 'j' output when all direct and indirect effects in the production process are converted into an estimate of new capital-owners' income.

The employment multipliers are computed by multiplying the employment-output ration row vector "a_{ei}" by the Leontief inverse "(L_{ij})" Where "$e(j)$" is the sector "j" number of jobs per million Ghana cedis output produced and X_j output for sector j.

$$\text{ae}\mathbf{i} = \frac{\text{ej}}{\text{Xj}} \qquad \text{Equation 3.28}$$

$$E = \sum_{i=1}^{n} (\text{ae}\mathbf{i}).((L_{ij}) \qquad \text{Equation 3.29}$$

3.7 Data Sources and Methodology for Analysing Farmers' Understanding of Climate Change Issues and Management Responses in Reducing GHG Emissions

3.7.1 The design of the researcher-managed survey

This micro-level study used a cross-sectional survey design. It was a quantitative research design that described trends, attitudes, or opinions of a population by studying a sample (Creswell, 2014:13). This study used a sampling approach and survey techniques to analyse the factors influencing rice farmers' use of GHG adaptation strategies (Creswell, 2009, 2013, 2014). This quantitative design was completed using key informant interviews with local rice farmers. Babbie (2015) and Sanderson & Keppel (1991) divide quantitative research design into two groups. Survey and experimental research. This study used "non-experimental design" or "cross-sectional survey design." By sampling a population, the survey explained its numerical description, pattern, behaviour, and views. Quantitative research surveys are useful for prediction. However, it cannot identify other influential variables, called extraneous or confounding variables. This limitation was partially overcome by using a cross-sectional survey from April to June 2022 (Feb. 2022 was pilot testing). The survey involved the researcher and one assistant. The pilot was undertaken with 20 farmers while the full survey involved 400 farmers.

3.7.2 The study area

The Volta region was purposefully chosen for the study because it is Ghana's leading rice producing region. The region accounts for 40 percent of the total national paddy production. The top three rice-producing districts (Districts of Ketu North, North Tongu, and South Tongu) were selected on purpose for the field survey. Figure 9 is the map of Volta Region, showing the study districts

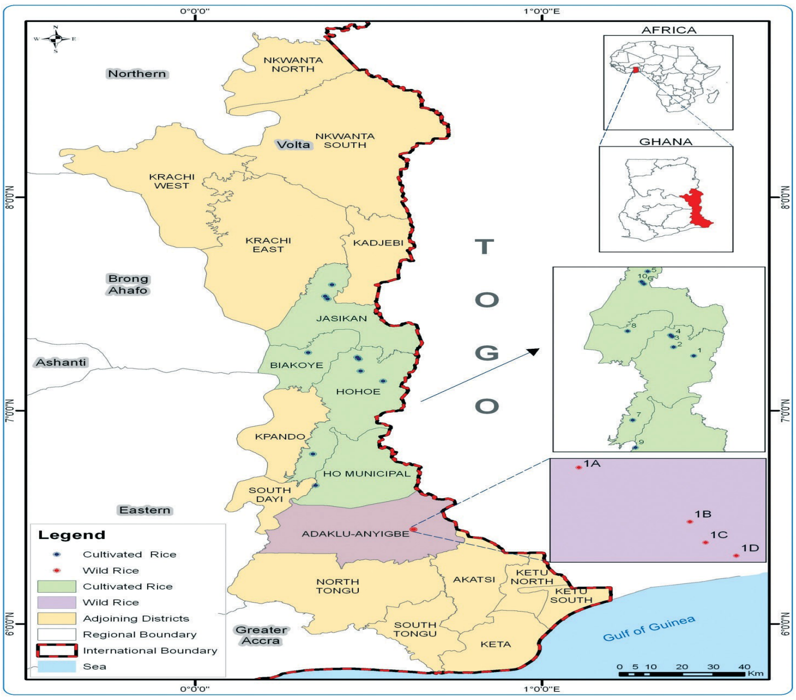


Figure 3. 6: Map showing the study districts of Volta Region

Source: Adomako (2018)

3.7.3 The sample design

A multi-stage cluster sampling was used, consistent with Creswell (2013, 2014), De Vaus (2016), Anaman (2014), and Babbie (2015). The farmers were clustered according to the existing farming systems; thus rainfed-upland, rainfed-lowland, and irrigation. The multi-stage cluster sampling recorded the target population's primary sampling units. Then, a sample of rice farmers was selected from the primary sampling units of the three districts in the Volta region. For a research study that used a multi-cluster sampling design, the list of rice farmers in the three districts of the Volta region was sent to the regional directorate of the Ministry of Food and Agriculture. From that list, the people who took part in the study were chosen. The sample design was chosen to ensure that every rice farmer in the survey areas had an equal chance of being chosen for the sample.

The number of farmers chosen for each district was proportional to the district's share of the total number of rice farmers in the three districts. In the North Tongu district, for instance, 200 farmers were interviewed as opposed to 100 farmers in each of the other two districts, as the North Tongu district accounted for 40% of the total number of registered rice farmers in all three districts.

A sample size of 400 rice farmers was established as the optimal number for this study. This optimal sample size of 400 was established using the statistical formula developed by Yamane (1973) and De Vaus (2014). The Yamane formula is indicated below.

$$n = \frac{\mathrm{N}}{(1+\mathrm{N}(\alpha^2))} \qquad \text{Equation 3.30}$$

where n is sample size, N is the population of rice farmers in the study and α is the sampling error, assumed to be 5% in the study referring to the proportion of rice farmers who have adopted GHG adaptation measures.

3.7.4 Random selection of farmers

For each district the farmers were randomly selected from the list based on the use of random numbers generated by a scientific calculator using the zero to one probability interval. The chosen probability level multiplied by the number of registered rice farmers in the district gives a number for the chosen farmer. This process was repeated till all the number of farmers assigned to the district had been chosen.

3.7.5 Empirical method of analysis of GHG adaption strategies

A multiple regression model analysis is used to ascertain the factors influencing the intensity of use of GHG adaptation strategies namely; (1) soil fertility management, (2) adoption of early-maturing varieties, (3) adoption of improved planting materials and seeds, (4) adoption of drought-tolerant rice varieties, (5) no till or zero tillage land preparation, (6) adoption of agro-ecological farming, and (7) conversion of rice husk to animal feed instead of burning them. The intensity of use of each of these seven strategies is scored on a Likert continuum scale of zero to 5, with zero denoting complete non-use of the strategy and 5 representing the maximum use of the strategy. The average score of use of the seven strategies (ADAPTATIONINTENSITY) is used as the dependent variable. The model specified is as follows:

$$\text{ADAPTATIONINTENSITY} = A_0 + A_1 AGE + A_2 AGESEQ + A_3\text{RICEEXPERIENCE} + A_4\text{FEDUCATION} + A_5\text{FBOMEMBER} + A_6\text{AFROTRADRELIGION} + A_7\text{EXTENSIONVISIT} + A_8\text{LACKINFOGHG} + A_9\text{EXTVISIT} * \text{AFROTRADRELIGION} + \text{U} \quad \text{Equation 3.31}$$

AGE is the age of the farmer in years.

$AGESQ$ is the squared of AGE.

$RICEEXP$ is the number of years of experience in rice farming**.**

$FEDUCATION$ is the number of formal years of education acquired by respondent.

FBO is a dummy variable with 1 representing membership of farmer-based organization (FBO) and zero for non-membership of FBO.

$AFROTRADRELIGION$ is a dummy variable with a value of 1 if the respondent is a follower or adherent of traditional African religions and zero otherwise.

$EXTVISIT$ is the average number of extension visits received by the respondent during the calendar years, 2020 and 2021.

$LACKINFOGHG$ is the indicated degree of lack of information regarding the phenomenon of climate change and its links to greenhouse gases. A value of 5 denotes the maximum value of lack of information and zero the minimum value of lack of information on the issue.

$EXTVISIT * AFROTRADRELIGION$ is the interaction term for $EXTVISIT$ and $AFROTRADRELIGION$. U is the equation error term.

3.7.6 Empirical method of analysis of GHG management constraints

A multiple regression model analysis is used to establish the overall level of constraints related to the management of GHG emissions in rice production by the responding farmers. The nine constraints were (1) poor soil fertility, (2) lack of understanding of effects of greenhouse emissions, (3) use of low yielding varieties, (4) high labour cost, (5) low level of extension officers' contacts, (6) high post-harvest losses, (7) poor agronomic practices, (8) excessive use of agro-chemicals and (9) tenure insecurity. The level of each of nine constraints is scored on a Likert continuum scale of zero to 5.

The overall level of constraint (CONSTRAINTSPOWER) was the average score for all nine constraints using the Likert scale. The model specified is as follows:

$$\text{CONSTRAINTSPOWER} = B_0 + B_1 AGE + B_2\text{RICEEXPERIENCE} + A_3\text{FEDUCATION} + A_4\text{RICEAREA} + A_5\text{FBOMEMBER} + A_6\text{AFROTRADRELIGION} + B_7 \text{ EXTVISIT} + Z \qquad \text{Equation 3.32}$$

Z is the equation error term.

CHAPTER FOUR

MACRO-LEVEL DETERMINANTS OF GREENHOUSE GAS EMISSIONS IN THE ECONOMY

RESULTS AND DISCUSSION

4.1 Introduction

This chapter is devoted to the findings of the 1990–2019 study that identified the macro-level contributors to total national GHG emissions, and the agriculture sector share of the total national GHG emission. The chapter, therefore presents results for objectives one and two of the study. Sequentially, the chapter is organized with graphical representations of the national greenhouse emissions trends, followed by the results of the regression analysis for determining the macro drivers of GHG emissions in the entire economy and the drivers of the agriculture sector's declining contribution to total GHG emissions.

4.2 National GHG Emission Trends by Sector from 1990 to 2019

A panel data from the EPA, Ghana shown in Table 4.1 was used to generate the emission trends by sector to understand growth pattern of the national GHG emissions from 1990 to 2019. As seen in Figure 4.1, the total national GHG emissions have been increasing steadily over the past three decades (1990–2019) with spikes in 2011 and 2017 attributed to increase in oil flaring that accompanied the production of new big oil fields. Figure 4.2 illustrates the energy sector total emissions trend. Again, the energy sector emission peaked between 2011 and 2017.

The agriculture sector total emissions trend is illustrated in Figure 4.3. The agricultural sector's emission pattern showed a sharp reduction in 2004 and 2014. In 2004 and 2014, Ghana experienced harsh weather conditions that may have had an influence on agricultural productivity, resulting in a decline in the agriculture sector emissions during both years. However, the share of the agriculture sector in terms of AFOLU contribution to the total national GHG emissions has shown a downward trend as illustrated in Figure 4.4. This downward trend could be attributed to the increase in the energy sector share of the total national GHG emissions.

Table 4. 1: The National Total Greenhouse Emissions Trends from 1990 to 2019

year	Energy	IPPU	Folu	Agriculture	Waste	Total
1990	2.864	1.964	14.308	4.687	1.130	24.953
1991	2.788	1.978	14.640	5.080	1.157	25.643
1992	4.602	2.031	14.700	4.982	1.121	27.435
1993	4.794	2.001	14.746	5.069	1.178	27.787
1994	5.009	1.648	14.802	5.249	1.214	27.921
1995	3.863	1.204	14.860	5.514	1.283	26.723
1996	3.798	1.197	14.919	5.670	1.332	26.916
1997	4.778	1.295	14.986	5.790	1.409	28.258
1998	6.390	0.496	14.983	5.940	1.472	29.281
1999	5.488	0.877	15.143	6.068	1.550	29.125
2000	4.073	0.904	13.308	6.218	1.648	26.151
2001	4.322	0.594	13.862	6.419	1.688	26.884
2002	5.625	0.345	14.079	6.604	1.732	28.385
2003	5.567	0.072	13.722	6.827	1.804	27.991
2004	4.700	0.054	13.182	6.198	1.830	25.965
2005	5.777	0.283	13.260	7.009	1.914	28.242
2006	7.184	0.484	13.446	7.266	2.007	30.386
2007	8.600	0.468	13.477	7.425	2.641	32.610
2008	6.400	0.674	13.519	7.671	2.756	31.020
2009	7.044	0.932	13.275	8.061	2.842	32.155
2010	12.793	0.940	13.569	8.389	2.893	38.583
2011	29.483	2.109	13.445	8.667	3.041	56.745
2012	14.903	2.005	13.565	9.034	3.105	42.613
2013	18.108	1.644	13.899	9.458	3.240	46.346
2014	19.793	1.810	13.770	9.492	3.547	48.412
2015	19.504	1.960	13.433	10.004	3.541	48.439
2016	22.353	1.679	13.403	10.324	3.632	51.390
2017	39.424	1.249	13.959	10.948	3.840	69.419
2018	27.938	1.326	12.527	11.121	4.037	56.948
2019	27.298	1.731	14.924	11.713	4.123	59.791

Source: Compiled from EPA (2021)

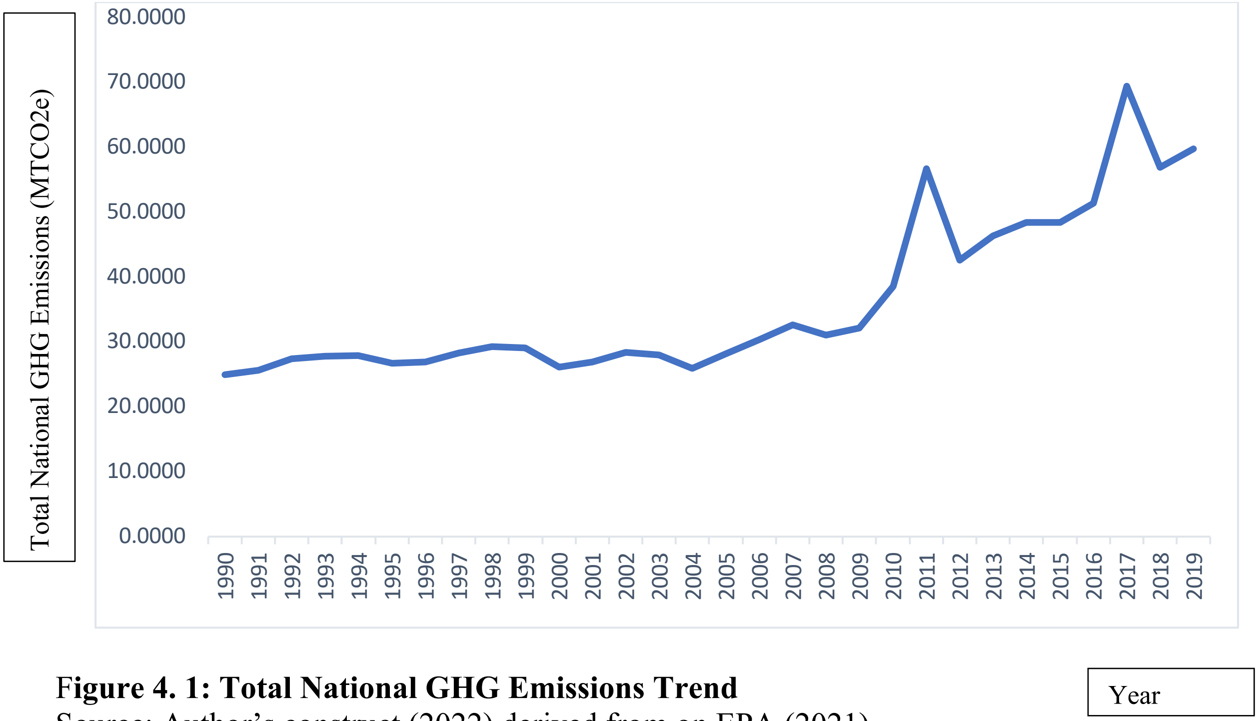


Figure 4. 1: Total National GHG Emissions Trend
Source: Author's construct (2022) derived from on EPA (2021)

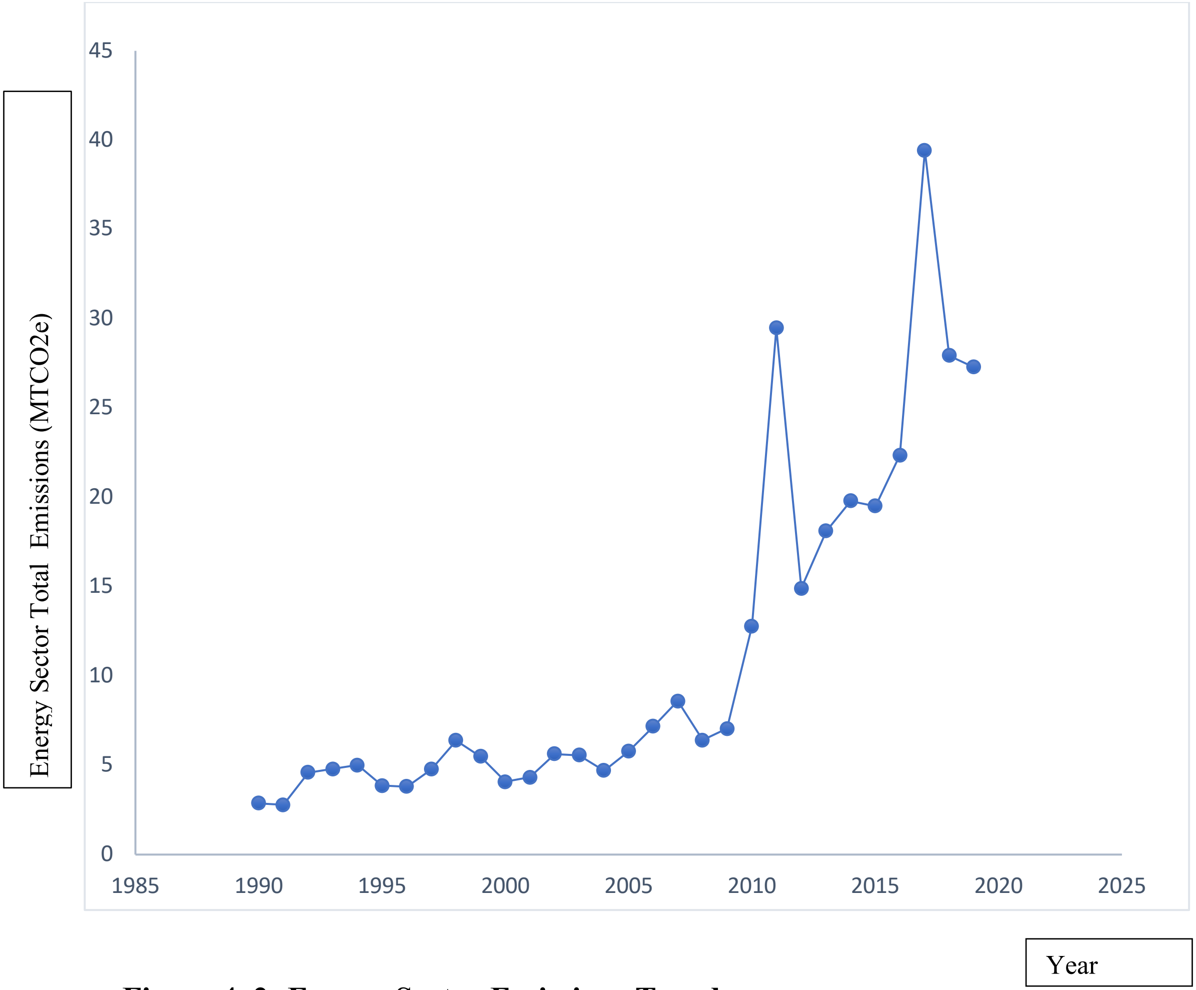


Figure 4. 2: Energy Sector Emissions Trend
Source: Author's construct (2022) derived from EPA (2021)

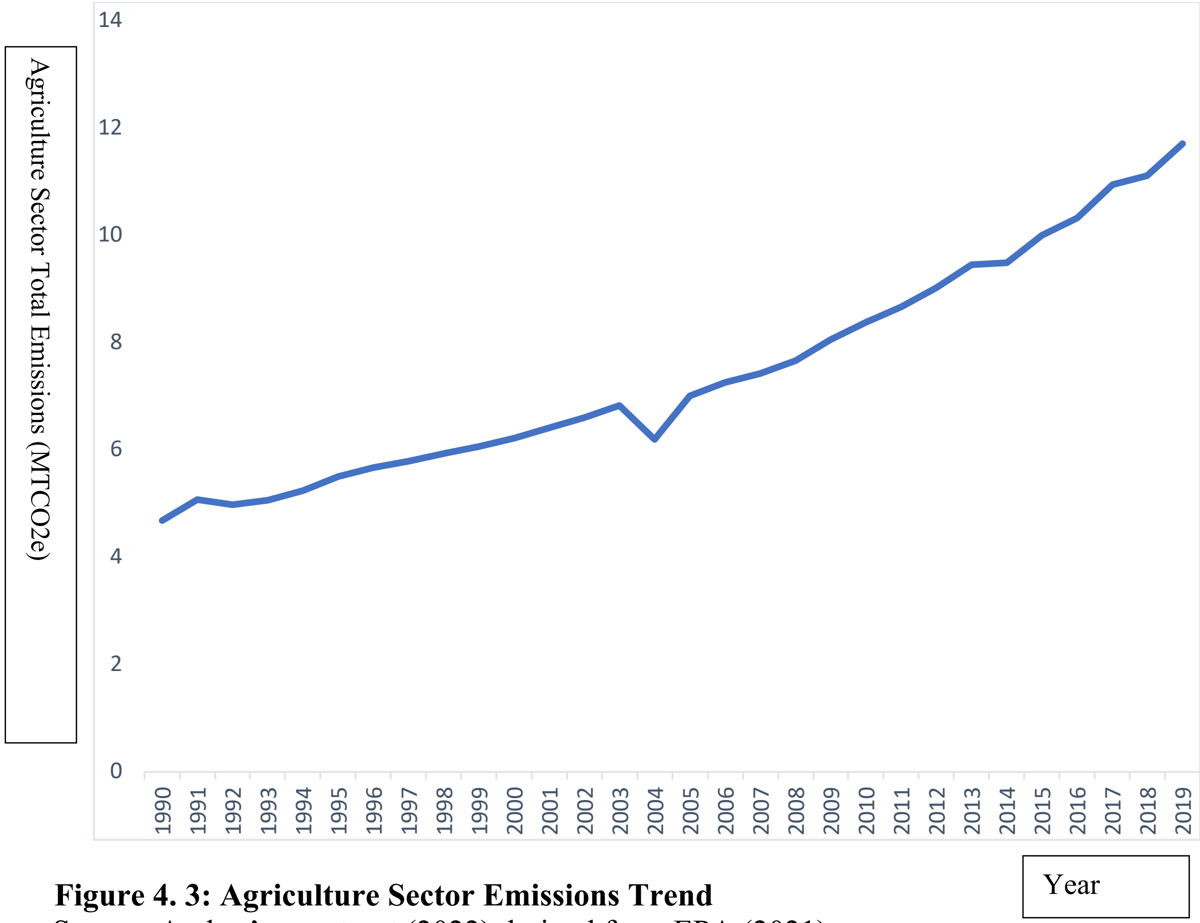


Figure 4. 3: Agriculture Sector Emissions Trend
Source: Author's construct (2022) derived from EPA (2021)

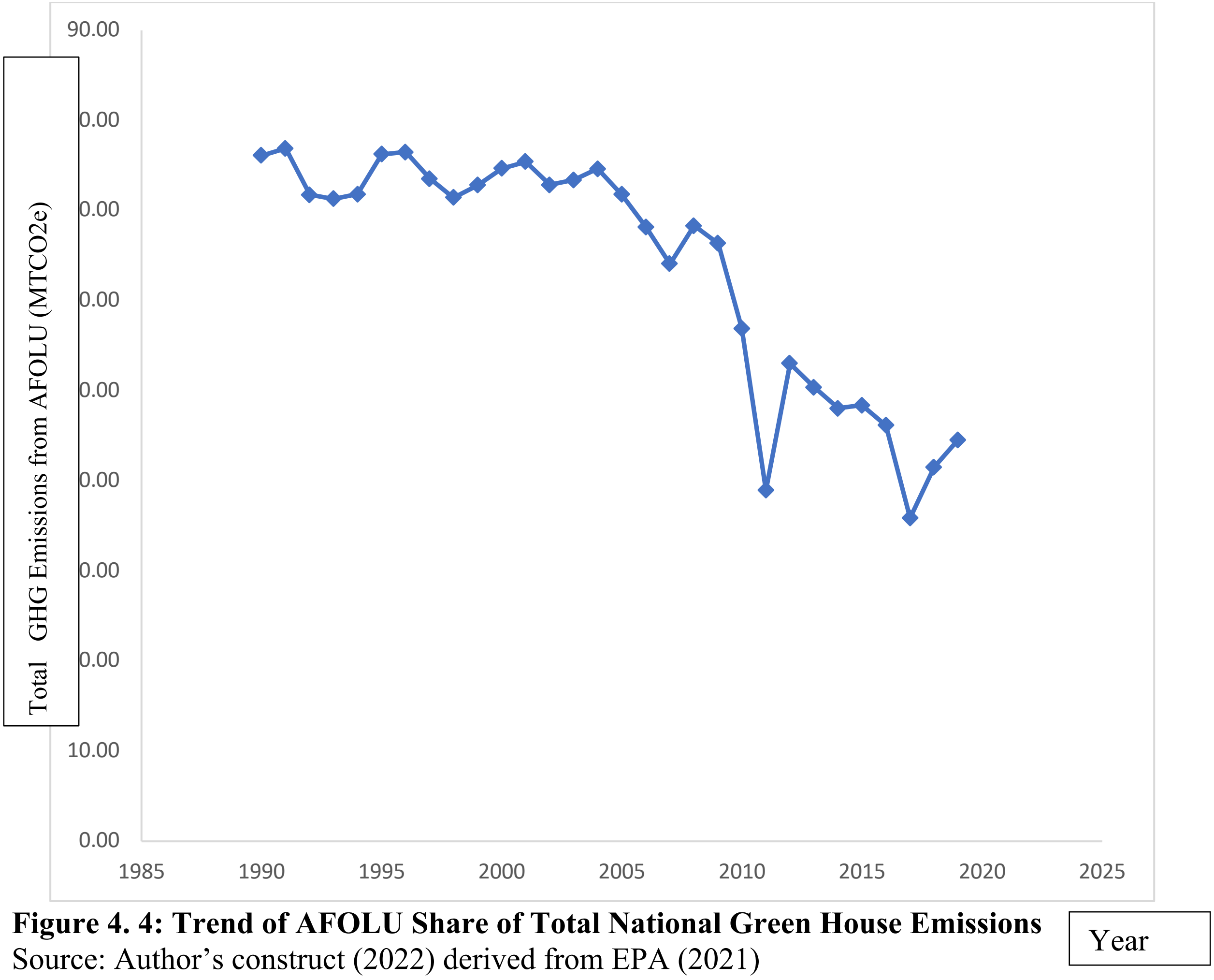


Figure 4. 4: Trend of AFOLU Share of Total National Green House Emissions
Source: Author's construct (2022) derived from EPA (2021)

4.3 Results of the Regression Analysis on Macro-level determinants of Total GHG Emissions in the Economy

Table 4.2 presents the results of the unit root tests of the variables used in the macroeconomic models. Based on ADF, PP, and Weighted Symmetric tests, the majority of the variables at the levels were non-stationary. Using the first differences, however, all variables were stationary according to either the ADF or PP test. As a result, these variables were integrated into the order I (1). The ARDL cointegration analysis, which uses a combination of stationary and non-stationary variables and different levels of integration, is the ideal tool for determining the long-run cointegration relationships between the dependent and independent variables (Pesaran et al., 2001).

Table 4. 2: Unit Root Tests of the Continuous Variables at the Levels and First Differences

Variable	ADF Statistic	P Value	PP Statistic	P Value	Weighted Symmetric Statistic	P Values
$LTGHG_t$	-1.4114	0.858	-7.5480	0.620	-1.5296	0.883
$LSAFOLU_t$	-1.8813	0.664	-10.3454	0.413	-1.7551	0.793
$LPCRGDP_t$	-1.6813	0.759	-3.3027	0.923	-0.5359	0.993
$GSHAREA_t$	-2.5677	0.295	-14.2987	0.211	-2.5913	0.240
$LRINTRATE_t$	-4.4897	0.001***	-14.9348	0.187	-2.6926	0.189*
$LEXPGDPR_t$	-2.5626	0.297	-7.2100	0.647	1.6436	0.843
$LIMPGDPR_t$	-1.9907	0.607	-5.4280	0.790	-1.1797	0.955
$LRICEAREA_t$	-1.7414	0.732	-11.3576	0.352	-2.0638	0.604
$\Delta LTOTALGHG_t$	-2.6257	0.268	-25.2617	0.024**	-3.2985	0.037**
$\Delta LSAFOLU_t$	-2.1417	0.523	-23.7380	0.033**	-3.4202	0.026**
$\Delta GSHAREA_t$	-3.8374	0.015**	-19.8881	0.072*	-4.2007	0.003***
$\Delta LPCRGDP_t$	-2.3655	0.398	-9.1115	0.499	-3.1920	0.050*
$\Delta LRINTRATE_t$	-2.5695	0.294	-16.9588	0.128	-3.8733	0.007**
$\Delta LEXPGDPR_t$	-2.7621	0.211	-27.5894	0.015**	-3.0452	0.075*
$\Delta LIMPGDPR_t$	-2.1102	0.5404	-22.1976	0.045*	-2.4640	0.316
$\Delta LRICEAREA_t$	-3.3648	0.056*	-22.8640	0.040**	-3.1793	0.052*

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

Notes

Δ denotes the first difference operator of a variable
*** denotes 1 percent statistical significance
** denotes 5 percent statistical significance
* denotes 10 percent statistical significance

The estimated optimal ARDL function is reported in Table 4.3. The bounds test confirmed that there was a valid cointegration relationship among the dependent variables; LTGHG and the independent variables; $LPCRGDP_t$, $LPCRGDPSQ_t$, $RINTRATE_t$, $LEXPGDPR_t$, $LIMPGDPR_t$, $LRICEAREA_t$, and $ENERGYS_t$.

The cointegration results reported in Table 4.3 shows that the bounds test F value was 12.192; this was much greater than the 95% critical upper bound value of 4.755. Similarly, the bounds test W value was 85.342; and this value was much greater than the 95% critical upper bound value of 33.285. One valid cointegration equation exists with the optimal lag length of two years using the Schwarz-Bayesian criterion. Based on the W and the F tests, the null hypothesis of no cointegration relationship among the variables was rejected at 5% level.

The econometric diagnostic tests generally indicated an excellent chosen cointegration equation. This equation was adequately specified (Ramsey Reset test computed probability value 0.188 is above 10%); the equation error term was normally distributed (Jarque-Bera test computed probability value of 0.218 is above 10%); there was no significant autocorrelation in the model (Breusch-Godfrey test of autocorrelation computed probability value 0.108 is above 10%); no significant heteroscedasticity in the model (Computed probability value of the LM test 0.245 is above 10%). The power of the ARDL model was also very high with R^2 of 0.994 and adjusted R^2 of 0.986.

Table 4. 3: Results of the Estimated ARDL Cointegration Model of the production of GHG Emissions in Ghana, 1990 to 2019 based on the Optimal Lag Length of Two Years

Dependent variable is $LTGHG_t$ (natural logged total GHG emissions in Ghana in year t)

Explanatory variable	Unstandardized Parameter Estimate	Student t-statistic	P value
INTERCEPT	94.3072	3.7220	0.003
$LTGHG_{t-1}$	-0.6411	-4.8596	0.000***
$LTGHG_{t-2}$	-0.5174	-3.9022	0.002***
$LPCRGDP_t$	-133.3092	-4.6018	0.001***
$LPCRGDP_{t-1}$	110.8202	3.7692	0.003***
$LPCRGDPSQ_t$	8.2469	4.7482	0.000***
$LPCRGDPSQ_{t-1}$	-6.8257	-3.8663	0.002***
$RINTRATE_t$	-0.0869	-0.54582	0.595
$LEXPGDPR_t$	0.1739	1.1797	0.261
$LEXPGDPR_{t-1}$	-0.0770	-1.0729	0.304
$LEXPGDPR_{t-2}$	-0.2133	-3.1050	0.009**
$LIMPGDPR_t$	-0.3392	-2.5002	0.028**
$LRICEAREA_t$	0.0165	0.12802	0.900
$LRICEAREA_{t-1}$	0.3688	2.8562	0.014**
$LRICEAREA_{t-2}$	0.3782	4.9625	0.000***
$ENERGYS_t$	0.0471	1.7688	0.102*

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

Notes

Sample size	30
R^2	0.994***
Adjusted R^2	0.986***
F value	123.664***

* denotes 10 percent statistical significance
** denotes 5 percent statistical significance
*** denotes 1 percent statistical significance

The long-run function derived from the estimated ARDL cointegration model are reported in Table 4.4. The results showed that PCRGDP, PCRGDPSQ, IMPGDPR, RICEAREA and ENERGYS were all significant in determining the levels of total GHG emissions in the macroeconomy. As shown in Table 4.4, the long-run GHG emissions in Ghana on the one hand are influenced positively by per capita real GDP square (PCRGDPSQ), total land area devoted to rice production (RICEAREA), and energy shock (ENERGYS) related to the El-Nino weather phenomenon. On the other hand, the long-run GHG emissions are negatively related to per capital real GDP (PCRGDPR), and import-GDP ratio (IMGDPR).

The findings indicate that the correlation between total greenhouse gas emissions (LGHGt) and per capita real GDP (PCRGDP) does not conform to the conventional environmental Kuznets curve. The trajectory of the curve can be described as a parabolic U-shaped, with a minimum point of inflexion occurring in 1998, whereupon Ghana's national Gini coefficient, an indicator of rising inequality reached 40.1, up from the value of 35.0 in 1991. The value increased to 43.5 in 2017. The period spanning from 1990 to 2019 witnessed a transformation in the economy that exhibited decreasing inclusivity. Consequently, individuals belonging to the rural and marginalized segments of society could have been inclined to partake in illicit activities that abused the natural environment as a means of subsistence, disregarding the potential repercussions on environmental quality.

From the macro model, land area devoted for rice production is a long-term driver of total GHG emissions in the economy. It was found that one percent increase in the total land area devoted to rice production results in 0.354 percent rise in total GHG emissions in the economy. This was probably due to the methane (CH_4) and nitrous oxide (N_2O) produced from rice fields. Methane and nitrous oxide are known to stay in the atmosphere much longer and they also have relatively high Global Warming Potential (GWP) in comparison to CO_2. This finding is consistent with Fearnside (2019) that land use change through expansion and urbanisation lead to increased greenhouse gas (GHG) emissions.

Table 4. 4: Results of the Estimated Long Run Function Derived from the Optimal ARDL Cointegration Model of GHG Emissions in Ghana, 1990 to 2019

Dependent Variable is $LTGHG_t$ (log of total greenhouse gas emissions in year t)

Explanatory variable	Unstandardized Parameter Estimate	Student t-statistic	P value
INTERCEPT	43.6928	4.3841	0.001***
$LPCRGDP_t$	-10.4192	-4.2122	0.001***
$LPCRGDPSQ_t$	0.6584	4.2967	0.001***
$RINTRATE_t$	-0.0403	-0.5406	0.599
$LEXPGDPR_t$	-0.0539	-0.8090	0.434
$LIMPGDPR_t$	-0.1572	-2.5244	0.027**
$LRICEAREA_t$	0.3537	3.3169	0.006***
$ENERGYS_t$	0.0218	1.8007	0.097*

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

* denotes 10 percent statistical significance
** denotes 5 percent statistical significance
***denotes 1 percent statistical significance

The short-run error correction function is shown in Table 4.5. The short-run total GHG emissions in Ghana is positively influenced by short-run changes in the per capita real GDP square (highly significant at 1%), energy shock at first difference (significant at 10%), **e**xport-GDP ratio at second difference (significant at 5%), and total land area devoted to rice production (RICEAREA) is positive at first difference but not significant. However, at second difference, RICEAREA was negative and highly significant at 1%. Per capita real GDP at first difference is negative and highly significant at 1%. The error correction term is negative and highly significant at 1%.

Table 4. 5: Results of the Estimated Error Correction Function of the Production of Total GHG Emissions in Ghana over the period, 1990-2019

Dependent Variable is $\Delta LTOTALGHG_t$ (the first difference of the logged total GHG emissions in year t)

Explanatory variable	Unstandardized Parameter Estimate	Student t-statistic	P value
$\Delta LTOTALGHG_{t-1}$	0.51735	3.902	0.001***
$\Delta LPCRGDP_t$	-133.309	-4.602	0.000***
$\Delta LPCRGDPSQ_t$	8.247	4.748	0.000***
$\Delta RINTRATE_t$	-0.087	-0.546	0.593
$\Delta LEXPGDPR_t$	0.174	1.180	0.255
$\Delta LEXPGDPR_{t-1}$	0.213	3.105	0.007**
$\Delta LIMPGDPR_t$	-0.339	-2.500	0.024**
$\Delta LRICEAREA_t$	0.016	0.128	0.900
$\Delta LRICEAREA_{t-1}$	-0.378	-4.963	0.000**
$ENERGYS_t$	0.047	1.769	0.096*
V_{t-1} (Error Correction Term)	-2.158	-10.066	0.000***

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS**.**

Notes:

Sample size 30

R^2	0.962
Adjusted R^2	0 .915
F value	27.810

* denotes 10 percent statistical significance
** denotes 5 percent statistical significance
*** denotes 1 percent statistical significance

4.4 Drivers of the declining Agriculture Sector (AFOLU) share of the Total National GHG Emissions in the Economy

The cointegration analysis results reported in Table 4.6 shows that the bounds test computed F statistics value 8.1966 is greater than the 95% critical upper bound value of 5.5447; Similarly, the bounds test computed W statics value of 24.58883 is greater than the 95% critical upper bound critical value of 16.6332. There was one valid cointegration equation with the optimal lag length of three years using the Schwarz-Bayesian criterion. Based on the W and the F tests, the null hypothesis of no cointegration relationship among the variables was rejected at 5% level.

The econometric diagnostic tests generally indicated an excellent chosen cointegration equation. This equation was adequately specified. (Ramsey Reset test with null hypothesis of correct model specification of computed probability value of 0.482 is above 10%); the equation error term was normally distributed (Jarque-Bera test with a null hypothesis of normality, computed probability value of 0.367 is above 10%); there was no significant autocorrelation in the model (Breusch Godfrey test of autocorrelation with a null hypothesis of no autocorrelation has a computed probability value of 0.418 above the 10% critical level); and no significant heteroscedasticity in the model (Computed probability value of the LM test 0.535 is above 10%. The null hypothesis of no heteroscedasticity was accepted).

Table 4. 6: Results of the Estimated ARDL Cointegration Model of the Share of the Total GHG Emissions Attributed to the Agricultural Sector from 1990 to 2019 Based on the Optimal Lag Length of Three Years

Dependent Variable is $LSAFOLU_t$ (log of the share of total greenhouse gas emissions in year t attributed to the agricultural sector)

Explanatory variable	Unstandardized Parameter Estimate	Student t-statistic	P value
INTERCEPT	2.7737	5.5138	0.000***
$LSAFOLU_{t-1}$	0.57853	8.1932	0.000***
$GSHAREAG_t$	6.3706	4.9736	0.000***
$GSHAREAG_{t-1}$	-7.8825	5.5865	0.000***
$GSHAREAG_{t-2}$	5.0160	4.5207	0.000***
$LRICEAREA_t$	-0.20329	4.5483	0.000***
$FLAREDUM_t$	-0.27538	8.88861	0.000***

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

Notes:

Sample size	30
R^2	0.983***
Adjusted R^2	0 .982***
F value	232.981***

The results of the estimated long run cointegration function of the agriculture sector share (SAFOLU) of total greenhouse gas emissions in Ghana derived from the optimal ARDL cointegration model are reported in Table 4.7. The long-run agriculture sector share (SAFOLU) of the total greenhouse emissions in Ghana is influenced positively by the growth of agriculture share of GDP (significant at 5%). Conversely, the long-run AFOLU share of the total greenhouse emissions is negatively related to the total land area devoted to rice cultivation (RICEAREA), and oil flaring (Flaredum), which are highly significant at 1%.

A downward trend in growth of agriculture sector share of Ghana's Gross Domestic Product (GDP) could result in a significant decline of the agriculture sector share of Ghana's total GHG emissions in the long term. The energy sector's contribution to the overall national greenhouse gas (GHG) emissions is on the rise due to increased flaring in the crude oil production industry resulting from the commencement of production in new oil fields thereby causing a significant downward trend in the agriculture sector share of the total national GHG emissions.

Moreover, a negative correlation is observed between the total area designated for rice cultivation, denoted as RICEAREA, and the proportion of total greenhouse gas (GHG) emissions contributed by the agriculture sector at the national level. Over a prolonged period, the cultivation of rice offers the potential to significantly mitigate the proportion of total national greenhouse gas emissions originating from the agricultural sector, so contributing to the overall reduction of total national greenhouse gas emissions in the economy. The aforementioned finding is a major outcome derived from the study. It is evident that rice growers are implementing some agronomic or management strategies that are contributing to the reduction of the agriculture sector's proportionate contribution to the overall national greenhouse gas (GHG) emissions in the economy. Therefore, the question is: to what extent does the local rice production contribute to the overall national greenhouse gas emissions in the economy as a driver of greenhouse gas emissions? Furthermore, how can rice farmers manage emissions to help Ghana reach its NDC target of a 15 percent reduction in the growth of the country's overall GHG emissions by 2030, while also ensuring that the self-sufficiency policy is achieved by 2025?

Table 4. 7: Results of the Estimated Long Run Function derived from the Optimal ARDL Cointegration Model of the share of Total GHG Attributed to the Agricultural Sector from 1990 to 2019

Dependent Variable is $LSAFOLU_t$ (log of the share of total greenhouse gas emissions in year t attributed to the agricultural sector)

Explanatory variable	Unstandardized Parameter estimates	Student t-statistic	P value
INTERCEPT	6.5810	27.1197	0.000***
$GSHAREAG_t$	8.3143	2.3266	0.031**
$LRICEAREA_t$	-0.48233	9.7908	0.000***
$FLAREDUM_t$	-0.65338	4.6765	0.000***

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

* denotes 10 percent statistical significance
** denotes 5 percent statistical significance
*** denotes 1 percent statistical significance

Table 4.8 presents the outcomes of the estimated error correction function. In the immediate term, the contribution of the agriculture sector (AFOLU) to overall greenhouse gas emissions within the economy is influenced in a positive way by short-term fluctuations in the growth of agriculture's share of the Gross Domestic Product (GDP), which exhibits a high level of statistical significance at 1%. Contrarily, oil flaring (FLAREDUM) fluctuations have a significant statistical impact at the 1% level on the contribution of the Agriculture, Forestry, and Other Land Use (AFOLU) sector to the economy's overall greenhouse gas emissions. Additionally, the proportion of total land area (RICEAREA) dedicated to rice production also exerts a negative influence on AFOLU's share of total national greenhouse gas emissions but is not significant.

Table 4. 8: Results of the Estimated Error Correction Function of the share of the Total GHG Attributed to the Agricultural Sector over the Period, 1990-2019

Dependent Variable is $\Delta LSAFOLU_t$ (the first difference of the logged share of the total greenhouse gas emissions attributed to the agricultural sector in year t)

Explanatory variable	Unstandardized Parameter estimate	Student t-statistic	P value
$\Delta GSHAREAG_t$	6.3706	4.9736	0.000***
$\Delta GSHAREAG_{t-1}$	-5.0160	4.5207	0.000***
$\Delta LRICEAREA_t$	-0.23033	4.5483	0.856
$\Delta FLAREDUM_t$	-0.2754	8.8861	0.000***
ECT_{t-1} (Error Correction Term)	-0.42147	5.9689	0.000***

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

Notes

Sample size	30
R^2	0.948
Adjusted R^2	0.931
F value	68.935***

* denotes 10 percent statistical significance
** denotes 5 percent statistical significance
*** denotes 1 percent statistical significance

CHAPTER FIVE

INPUT-OUTPUT ANALYSIS OF GREENHOUSE GAS EMISSIONS IN THE ECONOMY OF GHANA

RESULTS AND DISCUSSION

5.1 Introduction

This chapter presents the results for the objective three of the thesis. The objective three of the thesis seeks to respond to how the government of Ghana's rice self-sufficiency policy, directly and indirectly affect the total GHG emissions based on the linkages between the rice industry and all other industries in the economy. The chapter therefore presents the findings of the input-output analysis of the direct and indirect contributions of the 20 industries, including rice production, to Ghana's total GHG emissions involving the use of the 2018 IO Table.

The chapter is organized into five sections. Following the introductory section, the results on the GHG emissions of the 20 industries in the domestic economy and their share of the total GHG emissions are reported in Table 5.1. The third section provides information on the production externalities (total GHG emissions multipliers) in the domestic economy based on one unit change in final demand for both backward and forward linkages, reported in Tables 5.2 and 5.3. As shown in Tables 5.4 and 5.5, the fourth section presents the findings about the relative performance of the 20 industries with respect to their production externalities and value-added output multipliers based on a one unit change in final demand for both backward and forward linkages. The fifth section of the chapter presents information about the relative performance of the 20 industries in terms of their production of GHG emissions and employment multipliers. The analysis is based on the effect of a one unit change in final demand, including both backward and forward linkages. The results are reported in Tables 17 and 18, which give information on

GHG emissions, and employment multipliers, respectively. The final section is devoted to the chapter summary of the study.

5.2 GHG Emissions of the 20 Industries in the Domestic Economy

The total domestic output in 2018 was 244541.976 million Ghana Cedis with a corresponding total national GHG emissions of 43.434 million tonnes of carbon dioxide equivalent (CO2e). All other agriculture industries (excluding rice) recorded an output of 75899.601 million and produced 14.179 million tonnes of CO2e of GHG emission, accounting for 32.65 percent share of total national GHG emissions in 2018 and it ranked 1st in the domestic economy. The rice production industry, the subject of this study, recorded an output of 1289.802 million Ghana Cedis with a corresponding GHG emissions of 0.867 million tonnes of CO2e, accounted for about 2.00 percent of total national GHG emissions and ranked 6th among the 20 industries. Total emissions from the whole agricultural sector therefore accounted for 34.65 percent (32.65 + 2.00). Transportation and storage industry holds the second biggest share accounting for 22.64 percent of the total national GHG emissions. The next top three emitting industries, with their percentage shares in brackets, were crude oil production (17.50), electricity, gas and steam (17.14), and manufacturing (5.02). As reported in Table 5.1, these six industries (including rice production) accounted for a total of 96.95 percent of total GHG emissions in 2018; the remaining 14 industries accounted for only 3.05 percent of total GHG emissions. In order for Ghana to achieve its Nationally Determined Contribution (NDC) goal of a 15 percent reduction in emissions growth by 2030 compared to the business-as-usual scenario, it is essential for policymakers to prioritize efforts aimed at decreasing the proportion of the top six industries in the country's domestic economy.

Table 5. 1: GHG Emissions of the 20 industries in the Domestic Economy and their share of the Total GHG Emission in 2018

No.	Industry	Industry Output (Millions of Ghana cedis	Total GHG Emissions (million kg)	Share of GHG Emissions (%)	Ranking in terms contribution to Total GHG Emissions
1	Rice production	1289.802	868.806	2.000	6th
2	All other agricultural industries	75899.601	14178.779	32.645	1st
3	Crude oil	26262.881	7602.768	17.504	3rd
4	All other mining	32515.393	154.457	0.356	
5	Manufacturing	128416.727	2178.289	5.015	5th
6	Electricity, gas and steam	14099.987	7445.762	17.143	4th
7	Water supply and sewage	2549.863	20.370	0.047	
8	Construction	45210.884	361.177	0.832	
9	Wholesale and retail trade	57100.372	269.442	0.620	
10	Transport and storage	26925.476	9831.764	22.636	2nd
11	Hotels	5814.664	28.314	0.065	
12	Restaurants and food services	14260.047	68.228	0.157	
13	Information and communication	13791.973	62.794	0.145	
14	Finance and Insurance	19909.268	90.645	0.209	
15	Real Estate Services	6249.185	28.452	0.066	
16	Business Services	7413.787	33.754	0.078	
17	Public Administration	12326.930	56.123	0.129	
18	Education	14863.854	67.674	0.156	
19	Health and Social Work	11617.379	52.955	0.122	
20	All Other Services	6508.295	33.095	0.076	
	TOTAL	244541.976	43434		

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

5.3 Production Externalities in the Domestic Economy Based on a Unit Change in Final Demand

The magnitudes of the direct, indirect and total GHG emission multipliers arising from unit change in final demand for all the 20 industries in the domestic economy for both backward and forward linkages are presented in Tables 5.2 and 5.3 respectively.

The backward linkage production externalities (GHG emission multipliers) are presented in Table 5.2. Backward linkage refers to the connection between an industry and the industries from which it purchases inputs. It measures the extent to which an industry that purchases inputs from other industries generates GHG emissions for each unit change in final demand. For instance, a one-cedi change in the final demand for rice results in total GHG emissions of 0.699 kg, comprised of direct emissions of 0.673 kg and indirect emissions of 0.026 kg. The backward linkage effect is measured in terms of power of dispersion (POD) index. This metric measures the inter-industry and effect-induced effects of final demand. The average POD index for the entire domestic economy is estimated to be 0.707, so any industry with a POD index greater than 0.707 is regarded as a relatively high emitter of greenhouse gases. The top five GHG-emitting industries based on one cedi change in final demand, according to results presented in Table 5.2, are: electricity, gas, and steam; rice production; crude oil; transport and storage; and all other agricultural industries.

Conversely, forward linkage measures the how connected one industry is to the industries to which it sells outputs. It measures the extent to which an industry that sells inputs to other industries generates GHG emissions for each unit change in final demand. The forward linkage effect is measured in terms of sensitivity of dispersion (SOD) index. Table 5.3 reports on the forward linkage production externalities (GHG emission multipliers) and SOD index of the 20 industries in the domestic economy. The SOD index for the entire domestic economy is estimated to be 0.697, so any industry with a SOD index greater than 0.697 is regarded as a relatively high emitter of greenhouse gases. The top five GHG-emitting industries be on one cedi change in final demand, according to results presented in Table 5.3, are: electricity, gas, and steam; rice production; transport and storage; crude oil; and all other agricultural industries.

Table 5. 2: Backward Linkage Production Externalities based on One Ghana Cedi Change in Final Demand for 20 Industries in the Domestic Economy for 2018

No.	Industry	Direct GHG Multiplier (kg per cedi)	Indirect GHG Multiplier (kg per cedi)	Total GHG Multiplier (kg per cedi)	Power of Dispersion (POD)	Ranking
1	Rice production	0.674	0.026	0.699	3.021	2nd
2	All other agricultural industries	0.187	0.014	0.201	0.868	5th
3	Crude oil	0.289	0.100	0.390	1.683	3rd
4	All other mining	0.005	0.010	0.014	0.063	
5	Manufacturing	0.017	0.067	0.084	0.361	
6	Electricity, gas and steam	0.528	0.293	0.821	3.546	1st
7	Water supply and sewage	0.008	0.122	0.130	0.561	
8	Construction	0.008	0.037	0.045	0.193	
9	Wholesale and retail trade	0.005	0.064	0.069	0.296	
10	Transport and storage	0.365	0.017	0.382	1.652	4th
11	Hotels	0.005	0.043	0.048	0.208	
12	Restaurants and food services	0.005	0.062	0.067	0.289	
13	Information and communication	0.005	0.021	0.025	0.109	
14	Finance and Insurance	0.005	0.021	0.025	0.109	
15	Real Estate Services	0.005	0.005	0.009	0.040	
16	Business Services	0.005	0.043	0.048	0.206	
17	Public Administration	0.005	0.029	0.033	0.144	
18	Education	0.005	0.032	0.036	0.157	
19	Health and Social Work	0.005	0.058	0.063	0.272	
20	All Other Services	0.005	0.079	0.084	0.365	

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

Note: The average power of dispersion index for the overall domestic economy is 0.707

Table 5. 3: Forward Linkage Production Externalities based on One Ghana Cedi Change in Final Demand for 20 Industries in the Domestic Economy for 2018

No.	Industry	Direct GHG Multiplier (kg per cedi)	Indirect GHG Multiplier (kg per cedi)	Total GHG Multiplier (kg per cedi)	Sensitivity of Dispersion (SOD)	Ranking
1	Rice production	0.674	0.027	0.700	3.025	2nd
2	All other agricultural industries	0.187	0.166	0.352	1.322	5th
3	Crude oil	0.289	0.100	0.390	1.685	4th
4	All other mining	0.005	0.002	0.006	0.028	
5	Manufacturing	0.017	0.083	0.099	0.430	
6	Electricity, gas and steam	0.528	0.426	0.954	4.121	1st
7	Water supply and sewage	0.008	0.001	0.009	0.037	
8	Construction	0.008	0.001	0.009	0.039	
9	Wholesale and retail trade	0.005	0.002	0.006	0.027	
10	Transport and storage	0.365	0.318	0.683	2.952	3rd
11	Hotels	0.005	0.000	0.005	0.022	
12	Restaurants and food services	0.005	0.001	0.005	0.023	
13	Information and communication	0.005	0.002	0.007	0.030	
14	Finance and Insurance	0.005	0.010	0.014	0.061	
15	Real Estate Services	0.005	0.001	0.005	0.023	
16	Business Services	0.005	0.003	0.007	0.031	
17	Public Administration	0.005	0.000	0.005	0.020	
18	Education	0.005	0.001	0.005	0.023	
19	Health and Social Work	0.005	0.000	0.005	0.020	
20	All Other Services	0.005	0.000	0.005	0.022	

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

Note: The average sensitivity of dispersion index for the overall domestic economy is 0.697

5.4 Comparative Performance of the 20 industries' Production Externalities and Value-Added Income Multipliers based on Unit Change in Final Demand

Information about the GHG emissions (pollution) and the backward and forward linkages comparative value-added multiplier effects from one unit change in final demand for all 20 industries is presented in Tables 5.4 and 5.5. The value-added multipliers are decomposed into labour income multipliers and capital owners' income multipliers. This decomposition is to allow for the analysis of the economic benefits going to workers and capital owners separately, given the reported fast rise in national income inequality in Ghana as measured by the Gini coefficient over the last 30 years.

For the backward linkage comparative value-added multiplier effects reported in Table 5.4, rice production is the second biggest unit emitter in terms of GHG multipliers, but it is ranked 15th in terms of value-added multipliers; the rice industry is ranked 6th in terms of the size of the labour income multiplier and 16th in terms of capital owners' income multiplier. In terms of GHG multipliers, real estate services industry is the lowest-ranked industry in the domestic economy; however, this industry has the highest value-added multiplier. But virtually all the value-added multipliers are accounted for by capital owners. The discussion now shifts to the three biggest polluters other than rice production. The biggest GHG emitter is the electric generation industry, with a value-added multiplier of 0.801. However, its labour income component is relatively small, and most of the economic benefits from value-added income go to capital owners. The transport industry is the third biggest GHG unit emitter. Much of its relatively large value-added multiplier (0.928) is earned by capital owners.

In the case of forward linkage comparative value-added effects presented in Table 5.5, rice production is the second biggest unit emitter in terms of GHG multipliers but it is ranked 9th in terms of value-added multiplier; rice industry is ranked 11th in terms of the size of the labour income multiplier and 15th in terms of capital owners' income multiplier. In terms of GHG multipliers real estate services is the lowest ranked industry; however, this industry has the 6th highest value-added multiplier (1.093). But virtually all the value-added multiplier (1.077) is accounted for by capital owners. Comparing the three biggest polluters other than rice production, the biggest GHG emitter is the electricity generation industry with a value-added multiplier of 0.527. However, its labour income component is relatively very small (0.055), most of the economic benefits through value added income go to capital owners (0.473). The transport industry is the third biggest GHG unit emitter. Much of its relatively large value-added multiplier (1.449) is earned by capital owners (0.957).

In the context of both backward and forward linkage analyses, it is seen that the value-added multiplier pertaining to rice production, the industry of interest, is equitably allocated across labour and capital owners.

Table 5. 4: Backward Linkage GHG Emissions and Value-Added Income Multipliers Based on One Cedi Change in Final Demand for 20 Industries in the Domestic Economy

No.	Industry	GHG Emissions Multiplier (kg per cedi)	Total value-added multiplier (Ghana cedi)	Labour income multiplier (Ghana cedi)	Capital owners' income multiplier (Ghana cedi)
1	Rice production	0.699	0.829	0.477	0.352
2	All other agricultural industries	0.201	0.767	0.253	0.513
3	Crude oil	0.390	0.858	0.236	0.622
4	All other mining	0.014	0.907	0.242	0.665
5	Manufacturing	0.084	0.542	0.181	0.361
6	Electricity, gas and steam	0.821	0.801	0.172	0.629
7	Water supply and sewage	0.130	0.870	0.633	0.237
8	Construction	0.045	0.803	0.167	0.636
9	Wholesale and retail trade	0.069	0.963	0.486	0.476
10	Transport and storage	0.382	0.928	0.321	0.607
11	Hotels	0.048	0.815	0.274	0.542
12	Restaurants and food services	0.067	0.850	0.220	0.629
13	Information and communication	0.025	0.964	0.287	0.676
14	Finance and Insurance	0.025	0.970	0.352	0.618
15	Real Estate Services	0.009	0.990	0.028	0.963
16	Business Services	0.048	0.935	0.372	0.563
17	Public Administration	0.033	0.973	0.555	0.418
18	Education	0.036	0.920	0.720	0.201
19	Health and Social Work	0.063	0.835	0.566	0.269
20	All Other Services	0.084	0.893	0.374	0.519

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

Table 5. 5: Forward Linkage GHG Emissions and Value-Added Income Multipliers Based on One Cedi Change in Final Demand for 20 Industries in the Domestic Economy

No.	Industry	GHG Emissions Multiplier (kg per cedi)	Total value-added multiplier (Ghana cedi)	Total labour income multiplier (Ghana cedi)	Total capital owners' income multiplier (Ghana cedi
1	Rice production	0.700	0.769	0.463	0.306
2	All other agricultural industries	0.352	1.328	0.437	0.891
3	Crude oil	0.390	0.567	0.122	0.444
4	All other mining	0.006	1.124	0.288	0.836
5	Manufacturing	0.099	1.436	0.497	0.940
6	Electricity, gas and steam	0.954	0.527	0.055	0.473
7	Water supply and sewage	0.009	0.648	0.598	0.050
8	Construction	0.009	0.487	0.061	0.426
9	Wholesale and retail trade	0.006	0.983	0.543	0.439
10	Transport and storage	0.683	1.449	0.492	0.957
11	Hotels	0.005	0.468	0.152	0.316
12	Restaurants and food services	0.005	0.626	0.135	0.491
13	Information and communication	0.007	0.755	0.181	0.574
14	Finance and Insurance	0.014	1.906	0.701	1.205
15	Real Estate Services	0.005	1.093	0.015	1.077
16	Business Services	0.007	0.848	0.367	0.481
17	Public Administration	0.005	0.747	0.469	0.279
18	Education	0.005	0.730	0.685	0.045
19	Health and Social Work	0.005	0.482	0.435	0.047
20	All Other Service	0.005	0.442	0.222	0.220

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

5.5 Comparative Performance of the 20 industries' Production Externalities and Total Employment Multipliers Based on Unit Change of Final Demand

The backward and forward linkages effects on Total employment multipliers, reported in Tables 5.6 and 5.7 are measured in terms of the additional physical employment generated by the direct and indirect effects of a one million Ghana cedi increase in domestic final demand on production. In terms of backward linkage GHG emissions multipliers measured in tonnes per million Ghana Cedis of output in the domestic economy as presented in Table 5.6, rice production is the second biggest emitter (699.145 tonnes per million Ghana Cedis of output). However, among the top five emitting industries in the domestic economy, the rice production recorded the highest total employment multiplier measured in number of workers per million Ghana cedis of output (54.195) based on the 2018 national I-O Table.

The discussion now shifts to the four biggest emitting industries other than rice production. The electricity generation industry is the biggest emitter (820.635) among the top five but it is ranked 3rd in terms of total employment multiplier (32.055 workers per million Ghana cedis of output). The crude oil industry being the third emitter is ranked 5th in terms of employment multiplier (17.380 workers per million Ghana cedis of output). All-other agriculture industry has the second highest total employment multiplier but lowest unit emitter of GHG emissions among the top five emitting industries. Among the 20 industries, real estate is the lowest emitter (9.308) but has the lowest employment multiplier (2.721).

In Table 5.7 it was observed that the top five emitting industries based on the forward linkage GHG emissions multipliers were consistent with that of the backward linkage analysis in Table 5.6. However, the forward linkage emissions were much higher than that of the backward linkage. The top five emitting industries in terms of forward linkage are in the following order: (1). Electricity, gas and steam; (2). Rice production; (3). Transport and storage; (4). Crude oil;

and (5). All other agriculture. However, in terms of total employment multipliers, all-other agriculture is ranked highest (91.282), followed by rice production (50.297), while transport and storage (39.888), and electricity generation (18.286) are ranked 3rd and 4th respectively. It was also found that crude oil offered the lowest total employment multiplier (4.141) among the top five emitting industries.

Table 5. 6: Backward Linkage GHG Emissions Multipliers and the Number of Workers Employed Based on Unit Change in Final Demand for 20 Industries in the Domestic Economy

No.	Industry	Backward Linkage GHG Emissions Multipliers (Tonnes Per Million Ghana Cedis of Output)	Initial Employment (Number of Workers Per Million Ghana Cedis of Output)	Total Employment (Number of Workers Per Million Ghana Cedis of Output)
1	Rice production	699.145	48.387	54.195
2	All other agricultural industries	200.987	48.393	51.744
3	Crude oil	389.601	3.074	17.380
4	All other mining	14.484	3.010	7.816
5	Manufacturing	83.577	18.322	33.577
6	Electricity, gas and steam	820.635	10.123	32.055
7	Water supply and sewage	129.803	5.680	18.819
8	Construction	44.758	25.995	40.776
9	Wholesale and retail trade	68.577	39.128	46.979
10	Transport and storage	382.294	21.316	28.724
11	Hotels	48.226	68.960	87.815
12	Restaurants and food services	66.778	70.146	87.950
13	Information and communication	25.175	2.929	20.250
14	Finance and Insurance	25.279	11.025	22.698
15	Real Estate Services	9.308	1.146	2.721
16	Business Services	47.773	48.518	63.636
17	Public Administration	33.282	11.683	21.518
18	Education	36.385	51.802	70.180
19	Health and Social Work	62.848	34.606	54.090
20	All Other Services	84.373	349.305	367.140

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS

Table 5. 7: Forward Linkage GHG Emissions Multipliers and the Number of Workers Employed Based on Unit Change in Final Demand for 20 Industries in the Domestic Economy

No.	Industry	Forward Linkage GHG Emissions Multipliers (Tonnes Per Million Ghana Cedis of Output)	Initial Employment (Number of Workers Per Million Ghana Cedis of Output)	Total Employment (Number of Workers Per Million Ghana Cedis of Output)
1	Rice production	700.190	48.387	50.297
2	All other agricultural industries	352.370	48.393	91.282
3	Crude oil	389.957	3.074	4.141
4	All other mining	6.448	3.010	4.086
5	Manufacturing	99.466	18.322	107.436
6	Electricity, gas and steam	953.898	10.123	18.286
7	Water supply and sewage	8.606	5.680	6.119
8	Construction	8.935	25.995	29.073
9	Wholesale and retail trade	6.277	39.128	52.053
10	Transport and storage	683.299	21.316	39.888
11	Hotels	5.149	68.960	72.916
12	Restaurants and food services	5.336	70.146	78.228
13	Information and communication	6.981	2.929	4.492
14	Finance and Insurance	14.205	11.025	34.398
15	Real Estate Services	5.237	1.146	1.318
16	Business Services	7.283	48.518	77.607
17	Public Administration	4.649	11.683	11.931
18	Education	5.284	51.802	60.117
19	Health and Social Work	4.601	34.606	34.934
20	All Other Services	5.116	349.305	351.461

Source: Derived from secondary data from various sources such as the EPA (2021) and GSS.

5.6 Chapter Summary

Rice production, the industry of interest, was found to be the second largest unit emitter of GHG emissions based on one cedi change in final demand among the 20 industries analysed for both forward and backward linkages. Nevertheless, its share of the total national GHG emissions in 2018 was relatively low, estimated at about two percent among the top unit-emitting industries in the domestic economy. In addition, the incomes of labour and capital owners are distributed equitably in terms of value-added output. Despite being the second-largest emitter among the 20 industries in the domestic economy, the rice industry has relatively high total employment multipliers for both backward and forward linkages.

CHAPTER SIX

FARMERS' UNDERSTANDING OF CLIMATE CHANGE ISSUES AND THEIR MANAGEMENT RESPONSES IN REDUCING GREENHOUSE GAS EMISSIONS

RESULTS AND DISCUSSION

6.1 Introduction

This chapter presents the results for the objective four of the thesis. The objective four of the thesis seeks to assess how local rice producers manage their production systems to deal with GHG emissions in a just and sustainable way. The chapter is therefore devoted for the findings of the field survey undertaken in three selected rice growing districts in the Volta region of Ghana. The chapter is organized into six sections. Following the introduction is the section two that presents the results on the socio-economic characteristics of the 400 rice farmers interviewed. The third section reports on the characteristics and management of farms of respondents. Farmers perception of the causes of Climate Change is reported in section four. The fifth section is devoted for the management responses to reduce GHG emissions. The sixth section reports on the constraints affecting the management of GHG emissions.

6.2 Socio-economic Characteristics of the Respondents

The results of the socioeconomic and farm-level characteristics of the selected rice farmers are shown in Tables 6.1 and 6.2. The vast majority of respondents (over 97%) were Ewes, the dominant tribe in the Volta Region where the study was conducted. Additionally, the majority of respondents were Christians (61.6%). Notable is the fact that a substantial proportion of respondents practice traditional African religions. This finding is important because religious beliefs influence people's opinions and perceptions of scientific issues such as climate change.

More than seventy percent of respondents were male, indicating that rice production in the study area is dominated by men.

The majority of respondents are between 30 and 59 years old, with an average age of 47 years. The cultivation of rice is physically taxing and labor-intensive. This may explain why the industry is dominated by men in their productive years. Regarding education, the majority of respondents (approximately 60 percent) were formally educated, in some cases even to the postgraduate level. A little more than 40 percent had completed formal education through the secondary level. These respondents are a relatively educated farming population. It is anticipated that formal education will shape attitudes and perceptions regarding climate change and influence adaptation strategies. Respondents had on average about 16 years of rice farming experience, which is quite remarkable. With an average age of 47, the majority of farmers entered rice farming at a young age, indicating that rice farming is appealing to young people in the study area.

The majority of respondents were small-scale farmers with an average farm size of 2.5 acres. The average monthly non-farm income received during the 2021 farming season was approximately 87 Ghana Cedis, or 1,044 Ghana Cedis annually, which is slightly higher than the average credit received (844 Ghana Cedis) during the same time period. It is essential to note that the average credit requested and received were almost identical, which speaks volumes about the creditworthiness of rice farmers in the study area. Agricultural extension officers simply visited rice farmers who had an excess crop. Educated farmers typically require little or no technical assistance from extension agents, as evidenced by the infrequency of extension officer visits. The average annual revenue from rice sales ranges between 11,062 and

11,470 Ghana Cedis, which is significantly greater than the average credit received and non-farm income combined. However, this is insufficient to make an accurate assessment of the respondents' financial circumstances.

Table 6. 1: Summary of Socio-Economic Characteristics of Rice Farmers Based on Frequency Analysis Using Percentages

Characteristics of Farmer	Percent
Sex	
Male	76.0
Female	24.0
Age group of farmers	
19 and below	0.5
20 to 29	6.0
30 to 39	25.5
40 to 49	24.8
50 to 59	24.2
60 to 69	15.0
70 to 79	3.8
80 and above	0.2
Marital status	
Currently Married	66.1
Single	12.5
Divorced	8.3
Widowed	6.0
Engaged	0.8
Separated	5.0
Consensual	1.3
Religious affiliation	
African Traditional Religions Only	30.8
African traditional religion and Christianity	7.0
African traditional religion and Muslim	0.3
Christian only	61.6
Muslim only	0.0
Other religions	0.3
Level of education	
No Schooling	25.3
Incomplete primary	6.5
Complete primary	7.2
Junior high	22.8
Senior high	24.3
Technical institute	5.8
College of education	4.5
Bachelor's degree	2.8
Postgraduate degree	1.0
Ethnic group and tribes of farmers	
Akan-Agona	0.3
Akan-Ahanta	0.2
Akan-Akuapem	0.3
Akan-Akyem	0.2
Akan-Asante	0.3
Akan-Fante	0.2
Dangme	0.3
Ewe	97.7
Guan	0.2
Dagomba	0.3

Source: Derived from survey data, April 2022 to June 2022.

Table 6. 2: Summary of Socio-Economic Characteristics of Rice Farmers Based on Average, Standard Deviation and Range Figures

Characteristics of Farmer	Average	Standard Deviation	Range
Age of Farmer	47.29	12.32	22 to 74
Household size	4.08	1.73	1 to 9
Farmers level of education	7.62	5.35	0.00 to 18.00
Average monthly non-farm income 2020	182.30	2531.14	0.00 to 50400.00
Average monthly non-farm income 2021	182.49	2534.36	0.00 to 50400.00

Source: Derived from survey data, April 2022 to June 2022.

6.3 Characteristics and Management of Farms of Respondents

Results regarding farm management practices can be found in Tables 6.3 to 6.7. The farm management and agronomic practices provide a good idea of the nature and extent of adaptation strategies. As shown Table 6.3, four out of ten respondents owned the land that they farm on. Thirty-six percent rented land for farm production. Approximately 75 percent of them adopted the dry land preparation method. The most common method of rice planting was broadcasting. Agra and X-Baika were the most common rice varieties cultivated by farmers in the study area. These agronomic practices have not changed since last harvest season. Importantly, the use of improved rice varieties and water management practices are among the most common adaptation strategies for reducing rice fields' greenhouse gas emissions. It is advantageous for adaptation that the majority of respondents have adopted improved rice cultivars and dry land preparation.

As shown by Table 6.4, rice farmers used on average 110 kilograms of NPK fertilizer and 80 kilograms of Urea-based fertilizer. The quantity of NPK fertilizer was larger than that of urea, which is cause for concern because excessive use of NPK results in the leaching of nitrite oxides into the soil, which is one of the primary sources of nitrous oxide emission, one of the most significant greenhouse gases from rice fields. The majority of respondents said their primary farm tools were cutlasses and hoes as shown in Table 6.5. This demonstrates that the majority are smallholders who use rudimentary farm tools.

The level of mechanization was low. In terms of production costs as depicted in Table 6.6, land preparation and harvesting were the most expensive. Due to the low level of mechanization, land preparation and harvesting cost farmers a great deal of money. Mechanization has the potential to reduce production costs and increase labor output. From Table 6.7, the majority of respondents were able to manage risks associated with harvesting activities, followed by those associated with fertilizer application, marketing, land preparation, and weeding. Climate change is a weather-related risk, and adaptation to climate change is linked to farmers' risk perceptions and attitudes.

Table 6. 3: Frequency Analysis on Production and Input Use on Rice Production

Item	Percent in 2020	Percent in 2021
Method of acquisition of land		
Inherited	17.5	18.0
Rented	36.3	36.8
Owned plot	40.0	39.0
Owned and rented	5.5	5.0
Owned and inherited	0.2	0.8
Inherited and rented	0.5	0.4
Method of land preparation		
Dry land preparation	76.5	76.3
Wet land preparation	23.3	23.5
Both	0.2	0.2
Method of planting of rice		
Broadcasting	79.5	80.0
Transplanting	20.5	19.8
Both	0.0	0.2
Variety of rice produced		
Agra	43.0	41.5
X-Baika	43.0	44.5
Jasmine 85	10.0	10.0
Togo marshall	4.0	4.0
The form the rice was sold		
Paddy rice	90.2	90.2
Milled	8.6	8.6
Seed rice	1.2	1.2
Change in the method of land preparation compared to previous year		
No change	97.8	94.7
Change	2.2	5.3
Change in the method of planting rice compared to previous year		
No change	99.0	96.0
Change	1.0	4.0
Change in the variety of rice produced from the previous year		
No change	100.0	96.5
Change	0.0	3.5

Source: Derived from survey data, April 2022 to June 2022.

Table 6. 4: Characteristics of Inputs Used in Rice Production, their Average Quantity and Average Prices in Years 2020 and 2021

Capital inputs	2020		2021	
	Quantity	Price	Quantity	Price
Glyphosate (L)	5.08	101.53	5.11	104.19
Selective Herbicides (L)	0.63	117.79	0.63	119.76
Insecticide (L)	1.08	70.88	1.05	73.01
Fungicide (L)	0.55	103.49	0.56	116.53
NPK Fertilizer	108.54	180.52	108.81	220.17
Urea 46% Fertilizer	80.08	129.21	81.19	156.08
Ammonia fertilizer	5.85	77.00	5.38	119.23
Other types of fertilizer	0.14	93.75	0.14	98.75
Catapult	0.96	21.93	0.96	21.93
Rodenticide	0.03	26.50	0.03	26.50
Fuel	0.01	101.67	0.01	101.67
Net	0.3	705.00	0.3	705.00

Source: Derived from survey data, April 2022 to June 2022**.**

Table 6. 5: The Major Moveable Agricultural Assets Used in the 2021 Production Year

Agricultural assets	Percent of farmers who used their own assets	Average number	Current Market value
Tractor	1.8	0.2	25000
Combined harvester	0.3	0.0	20000
Rotovator	0.5	0.1	13500
Power tiller	3.3	0.4	18230.77
Thresher	0.8	0.1	1750.00
Knapsack sprayer	58.3	0.62	190.17
Cutlass and hoe	96.3	1.99	71.75
Tarpaulin	21.3	0.69	1202.86
Others	0.3	1.00	30.00

Source: Derived from survey data, April 2022 to June 2022.

Table 6. 6: Average Amount of Money Spent per Acre for Farm Operations in 2020 and 2021

Production activity	2020	2021
Land preparation	280.05	290.91
Chemical spraying	87.80	101.77
Planting	77.05	77.66
Fertilizer application	74.19	86.17
Hand weeding	145.95	151.08
Bund dressing	14.90	16.45
Bird scaring	169.74	172.97
Harvesting	391.24	391.83
Carting	83.17	91.07

Source: Derived from survey data, April 2022 to June 2022.

Table 6. 7: Farmers' Perceived Ability to Handle the Risks Associated with Various Components of Rice Production

Influencing factors	No.	Average score	Standard deviation of score	Ranking
Harvesting	400	3.86	0.718	1
Fertilizer application	400	3.76	0.826	2
Marketing	400	3.72	0.760	3
Planting	400	3.71	0.775	4
Land preparation	400	3.61	0.754	5
Weeding and other agronomic practices	400	3.57	0.893	6

Source: Derived from survey data, April 2022 to June 2022.

6.4 Respondents' Perceived Causes of Climate Change

Knowledge of the causes of climate change is the initial step in the process of climate adaptation, as it serves as a proxy for awareness of climate change issues. The majority of respondents cited pollution from nearby factories as a potential cause of greenhouse gas emissions, as shown in Tables 6.8 and 6.9. This followed by automobile pollution, thermal power generation, deforestation, land clearing, and improper waste disposal, in order of importance. For specific activities related to farming which directly contribute to climate change, land preparation techniques, particularly slash-and-burn methods for clearing land, the burning of rice straw, and the application of fertilizer, were assessed as important contributing factors. The climate change contributing factors emanating from farming activities were ranked lower in comparison to non-agricultural activities.

The respondents' specific cause of GHG production arising from rice farming is presented in Table 6.9. The most important source of GHG production in rice farming was attributed to land clearing, including the use of slash and burn method. This was followed in order of importance by burning of rice straw, fertilizer application, irrigation and water control, rice milling, harvesting and threshing, processing, weed control, planting, and waste disposal of rice husk respectively.

Table 6. 8: Ranking of Respondents' Perceptions of the Causes of Climate Change Through Greenhouse Gas Emissions

Influencing factors	No.	Average score	Standard deviation of score	Ranking
Pollution from factories	400	4.81	0.530	1
Pollution from cars	399	4.72	0.586	2
Electricity energy generation through thermal power plants	400	4.00	0.776	3
Deforestation and large-scale destruction of forests	400	3.96	0.709	4
Land clearing and burning of biomass	400	3.46	0.819	5
Livestock production	399	2.85	0.915	6
Improper waste disposal both in agriculture and non-agriculture activities	399	2.56	0.781	7

Source: Derived from survey data, April 2022 to June 2022.

Table 6. 9: Ranking of the Respondents' Declared Factors Contributing to the Climate Change Specifically from Greenhouse Gases Released from Rice Production

Influencing factors	No.	Average score	Standard deviation of score	Ranking
Land clearing including slash and burn method	398	3.94	0.656	1
Burning of rice straws	396	3.73	0.556	2
Fertilizer application	398	3.06	0.921	3
Irrigation and water control	398	2.88	1.090	4
Rice milling	395	2.75	0.649	5
Harvesting/threshing	397	2.75	0.700	6
Processing	398	2.63	0.711	7
Weed control	398	2.46	0.701	8
Planting	398	2.29	0.842	9
Waste disposal of rice husks	395	2.22	0.748	10

Source: Derived from survey data, April 2022 to June 2022**.**

6.5 Farmers' Responses in the Management and Reduction of GHG Emissions

The results of the analysis of the adaptation strategies used by rice farmers to manage and reduce greenhouse gas emissions are shown in Tables 6.10 and 6.11. As indicated in Table 6.10, soil fertility management was the most important adaptation strategy used by the respondents in managing GHG emissions on their rice fields. This is followed in order of importance, by adoption of early-maturing varieties, adoption of improved planting materials and seeds, adoption of drought-tolerant rice varieties, no till land preparation, adoption of agro-ecological farming and conversion of rice husks to animal feed instead of burning them, respectively.

Table 6. 10: Ranking of the Adaptation Measures to Reduce Greenhouse Gas Emissions Emanating from Rice Production Used by Responding Farmers

Influencing factors	No.	Average score	Standard deviation of score	Ranking
Soil fertility management	400	4.40	0.645	1
Adoption of early-maturing varieties	400	4.17	0.610	2
Adoption of improved planting materials and seeds	400	4.08	0.695	3
Adoption of drought-tolerant rice varieties	399	4.03	0.729	4
No till land preparation (zero tillage)	400	3.12	0.956	5
Adoption of agro-ecological farming	400	3.11	0.899	6
Conversion of rice husk to animal feed instead of burning them	400	2.39	1.066	7

Source: Derived from survey data, April 2022 to June 2022.

The results of the regression analysis of the factors which influenced the use of adaptation strategies to manage and reduce the release of greenhouse gases in rice production are summarized in Table 6.11. The power of the estimated model, as measured by R^2 was 0.232. This power could be described as modest given the cross-sectional nature of the data. The model was adequately specified based on the Ramsey Reset of model specification. The equation error term was deemed normal based on the Shapiro-Wilk and the Kolmogorov-Smirnov tests of normality. Further, the model had no significant heteroscedasticity as indicated by the Glejser test. Multicollinearity was generally absent from the model due to the low figures of the variance inflation factors (VIF) of the independent variables which were below the critical value of 10 suggested by Akbar (2011) for the lack of presence of this econometric problem. The relatively higher VIF values for age and the square of age variables were due to the close relationship of the variables. Nevertheless, there was no binding multicollinearity problem as the parameter estimates of both variables were significant.

Given the good nature of the estimated model, it could be used for interpretative discussion. The intensity of adaptation strategies to deal with GHG production was directly and positively related to experience in rice farming, the number of extension visits received by farmers and the number of years of formal education received by the farmer. Inadequate information on greenhouse gas emissions and their effects contributed to lower level of adaptation intensity. Further, adherents of traditional African religions had lower levels of adaptation intensities than adherents of other religions. The age of the farmer had a curvilinear (quadratic relationship) with the intensity of adaptation strategies. Older farmers tended to have higher levels of adaptation strategies compared to younger farmers.

Table 6. 11: Results of the Regression Analysis of Factors Influencing the Intensity of use of Adaptation Strategies by Respondents to combat the Release of GHGs in Rice Production

The Dependent Variable is ADAPTATION INTENSITY (The average Likert scale intensity score of all the adaptation measures used by rice farmers)

Explanatory Variable	Parameter Estimate	Standardised Estimate	Student t Test Value	Significance Probability	VIF
INTERCEPT	4.205	0.000	19.955	0.000***	0.000
AGE	-0.009	-0.446	-2.093	0.037**	22.533
AGESQ	0.000016	0.325	1.700	0.090*	18.083
RICEEXPERIENCE	0.010	0.190	2.325	0.021**	3.325
FEDUCATION	0.015	0.161	2.630	0.009***	1.847
FBOMEMBER	0.060	0.058	1.281	0.201	1.016
AFROTRADRELIGION	-0.129	-0.116	-2.035	0.043**	1.619
EXTENSIONVISIT	0.054	0.136	2.607	0.009***	1.352
LACKINFOGHGCC	-0.124	-0.206	-4.056	0.000***	1.278
EXTVISIT*AFROTRADRELIGION	0.047	0.056	1.012	0.312	1.512

Source: Derived from survey data, April 2022 to June 2022.

Notes:

R^2	0.233
Adjusted R^2	0.213
Significance level of Ramsey Reset test of correct model specification	0.828
Significance level of Glejser test of heteroscedasticity	0.146
Significance level of Shapiro-Wilk test of normality of equation error term.	0.895
Significance level of Kolmogorov-Smirnov test of normality of equation error term	0.200

*** 1% level statistical significance
** 5% level statistical significance
* 10% level statistical significance

6.6 Constraints Affecting Farmers' Management of GHG emissions

Climate change adaptation presents challenges in a resource-limited context. It is critical to understand the factors that limit the extent of adaptation at the farm level. Table 6.12 shows the major constraints farmers face when attempting to manage greenhouse gases in their rice fields. Poor soil fertility came in first place. Soil management was named by the majority of rice farmers as the most important strategy for reducing greenhouse gas emissions from rice fields. Low soil fertility and extensive use of soil amendments, particularly inorganic fertilizers, characterize upland rice production. Over time, intensive use of inorganic fertilizers may increase both the nitrogen content of soil biomass and the rate of greenhouse gas emissions. Soil management is critical because reductions in fertilizer application will have a significant impact on output and income levels, affecting the extent of adaptation. The promotion of organic soil amendments, such as biochar fertilizer, for upland rice production has the potential to increase productivity while preserving soil health.

The second most common problem was a lack of understanding about the effects of greenhouse gas emissions. This was not surprising given the respondents' indicated infrequent extension visits. Extension agents educate farmers on good agronomic practices, among other things. The first stage of adaptation by the farmer is for him/her to become aware. Awareness is increased when farmers are taught about the potential causes and effects of greenhouse gas emissions through field schools and other extension methods. Other constraints to GHG management indicated in order of importance were the use of low yielding rice varieties, high labour costs, low levels of contacts with extension officers, high post-harvest losses, poor agronomic practices, excessive use of agrochemicals and insecurity of land tenure, respectively.

Table 6. 12: Ranking of Constraints to Management of Greenhouse Gas Emissions Arising from Rice Production Declared by Responding Farmers

Influencing factors	No.	Average score	Standard deviation of score	Ranking
Poor soil fertility	399	4.45	0.655	1
Lack of understanding of effects of greenhouse gas emission	399	4.21	0.846	2
Low yielding varieties	399	4.16	0.667	3
High labour cost	399	3.77	0.761	4
Low level of extension officers' contact	399	3.47	0.937	5
High post-harvest losses	399	3.33	0.709	6
Poor agronomic practices	399	3.08	0.756	7
Excessive use of agro-chemicals	399	2.87	0.782	8
Land insecurity	399	2.25	1.525	9

Source: Derived from survey data, April 2022 to June 2022**.**

The results of the regression analysis of factors influencing the constraints in the management of GHG emissions in rice production are summarized in Table 6.13. The power of the model, as measured by R^2, was relatively low at only 0.073. Nevertheless, the econometric diagnostic tests suggested that the model was good. The model was correctly specified based on the Ramsey Reset computed p value of 0.618 being much greater than the critical p value of 0.10 used in this study. Further, the model had no significant heteroscedasticity problem using the Glejser test. The Shapiro-Wilk and Kolmogorov-Smirnov tests both confirmed that the equation error term was normally distributed with their computed p values greater than 0.10. The variance inflation factors of all the independent variables were very low, all below 2.0; this result suggested the absence of significant multicollinearity.

The results from Table 6.13 show that the extent of constraint was largely influenced by farming experience, farm size and extension contacts. Farm experience had negative effect on the extent of constraint. The implication is that experienced farmers are less constrained in terms of managing GHG emissions in rice production. Farmers with more experience may have a better grasp of climate change and how to mitigate its effects. The size of the farm positively affected the level of constraint. Larger farms are more likely to have higher levels of constraints than smaller farms given that production costs are proportional to the size of a farm. For example, the cost of improving soil management through the use of alternative soil amendments may be greater for larger farms than for smaller ones. Smallholders in the study area may be able to increase climate change adaptation through mechanization, a proxy for labour productivity. Cock et al. (2022) suggests that unless labour productivity increases, farmers would remain poor and food supply would decline.

The provision and utilization of extension services reduce the level of constraint. The aforementioned phenomenon can be ascribed to the expectation placed upon extension agents to advocate for the adoption of environmentally friendly agronomic practices, which includes the integration of techniques aimed at adapting to climate change. In essence, the study area necessitates the incorporation of extension education as a crucial component for facilitating climate change adaptation.

The Dependent Variable is CONSTRAINTSPOWER (The average Likert scale score of all the constraints affecting the management of GHG reduction by rice farmers)

Explanatory Variable	Parameter Estimate	Standardised Estimate	Student t Test Value	Significance Probability	VIF
INTERCEPT	3.605	0.000	50.762	0.000***	0.000
AGE	-0.001	-0.069	-1.246	0.214	1.265
RICEEXPERIENCE	-0.006	-0.172	-2.865	0.004***	1.497
FEDUCATION	0.004	0.065	1.047	0.296	1.574
RICEAREA	0.022	0.102	2.040	0.042**	1.045
FBOMEMBER	-0.040	-0.053	-1.078	0.282	1.013
AFROTRADRELIGION	0.047	0.059	1.049	0.295	1.288
EXTENSIONVISIT	-0.027	-0.095	-1.843	0.066*	1.090

Source: Derived from survey data, April 2022 to June 2022.

Notes

R^2	0.073
Adjusted R^2	0.056
Significance level of Ramsey Reset test of correct model specification	0.618
Significance level of Glejser test of heteroscedasticity	0.514
Significance level of Shapiro-Wilk test of normality of equation error	0.132
Significance level of Kolmogorov-Smirnov test of normality of equation error	0.187

*** denotes 1% level statistical significance
** denotes 5% level statistical significance
* denotes 10% level statistical significance

6.7 Chapter Summary

Smallholders typically have a modest understanding of climate change and implement some agronomic practices to reduce GHG emissions arising from their rice production. These practices include; soil fertility management, and use of improved rice seeds of superior varieties. However, adaptation to GHG emissions is hampered by a number of factors, including the low fertility status of cultivated soils, climate-resilient rice varieties, and inadequate understanding of the effects of GHG emissions on rice yields. Access to extension services, and the number of years of rice farming experience significantly influence the degree to which a rice farmer adopts measures to reduce GHG emissions in rice production. This was a relatively educated farming population, and increasing farmers' access to well-trained extension agents has the potential to increase smallholders' climate change adaptation intensity. The study showed that GHG emission adaptation management intensity is influence by biological, human, and social capital of rice farmers in the study area.

The results support the research conducted by Pata and Caglar (2021), which demonstrated the significance of human capital in mitigating environmental degradation in China. Moreover, the results substantiate Theodore Schultz's (1961) human capital hypothesis of economic growth. The capacity of rice farmers in the designated study region to address greenhouse gas (GHG) emissions through adaptation strategies is reliant on their human capital, encompassing elements such as education, training, and experience in rice farming.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter concludes the thesis report and is made up of six components. The first component provides a summary of the entire study with regards to the problem statement, objectives and methods used for the study. The second component deals with the statistical and econometric models used for the analysis of effects of increasing local rice production on greenhouse gas emissions in Ghana. The results and conclusions of the study are presented in the third component. The fourth component provides a summary of the key policy recommendations arising from the study. The fifth component is devoted to the limitations of the study and suggestions for further research. The final component is about the contribution to knowledge made by this study.

7.2 Summary of the Study

This study, which is in the area of resource and environmental economics, was motivated by the government's initiative to increase local rice production in order to achieve self-sufficiency by 2025, in accordance with the country's commitment to meet its NDC of a 15% reduction in the growth of total national GHG emissions by 2030 relative to a BAU scenario. Rice production emits methane and nitrous oxide, which have a higher potential to contribute to global warming than carbon dioxide. Increasing local rice production to achieve self-sufficiency may increase GHG emissions, rendering unattainable Ghana's NDC commitment to reduce CO_2, CH4, and N_2O. The government policy of increasing local rice production therefore brings about conflicting policy goals, thus meeting the Sustainable Development Goals and national climate change contributions outlined in the United Nations Framework Convention on Climate Change while simultaneously feeding a growing population and reducing greenhouse gas emissions. A conflict analysis becomes necessary in the context of policymaking when conflicts occur between policies. In order to make evidence-based decisions, policymakers rely on robust empirical evidence to determine the most effective mix of policy instruments. Nevertheless, the issue of greenhouse gas (GHG) emissions stemming from the cultivation of paddy rice has been extensively examined in many studies conducted in sub-Saharan Africa, including Ghana. However, these studies have mostly focused on rice intensification as a means to alleviate food insecurity and poverty, with minimal attention given to the associated environmental consequences.

This study was guided by four objectives as outlined in the problem description. The first objective was to identify the overarching factors that influenced the overall greenhouse gas (GHG) emissions at the national level between the years 1990 and 2019. The second objective of this study was to identify the factors that are attributed to the downward trend in the share agricultural sector GHG emissions of the total national greenhouse gas (GHG) emissions in Ghana between the years 1990 and 2019. Time series data analysis was employed to ascertain the macro factors influencing the overall economy's total national greenhouse gas (GHG) emissions and the diminishing proportion of the agriculture sector's contribution to these emissions, as outlined in objectives one and two respectively. The third objective was to examine the direct and indirect GHG emissions arising from rice production based on the linkages between the rice industry and all other industries in the economy using the environmental extended input-output analysis. The fourth objective was to assess how local rice farmers manage their production systems to deal with GHG emissions. This was accomplished through a cross-sectional random survey of farmers as well as qualitative research methods such as focus groups and in-depth interviews with industry elite managers.

Greenhouse gas (GHG) emissions were examined utilizing a three-tier methodology consisting of macro, meso, and micro levels. Time series, panel, and survey data were employed to study these emissions at each respective level. The sample for this study consisted of 400 rice farmers located in the Volta region of Ghana in the year 2022. The remaining two sets of data consist of secondary data obtained from various sources, including the Ghana Environmental Protection Agency (EPA) (2021), Ghana Statistical Service, Bank of Ghana, Ghana Metrological Agency, Agricultural Facts and Figures (MOFA-SRID 2019), Agriculture Census (2019), World Bank's 2019 Ghana World Development Indicators, and GSS & IFPRI/2018 Social Accounting Matrix for Ghana.

7.2.1 Objective one: macro-level drivers of total GHG emissions in the economy

The autoregressive distributive lag (ARDL) cointegration analysis was used to derive the long-run cointegration relationships among macro-economic variables that drive total national GHG emissions in the economy from 1990 to 2019. The findings indicate that, in contrast to the conventional application of the environmental Kuznets curve, the correlation between total greenhouse gas emissions and per capita real gross domestic product (PCRGDP) takes the form of a parabolic U-shaped curve with a minimum point of inflexion occurring in the year 1998. It is in 1998 when Ghana's Gini coefficient, which is a measure of rising inequality, reached a value of 40.1. This marked the onset of a significant shift in the prevailing circumstances. The period spanning from 1990 to 2019 witnessed a significant transformation in economic growth, which was notably characterized by a lack of inclusion. Consequently, individuals residing in economically impoverished rural and peri urban areas, as well as socially marginalized groups, may exhibit a higher propensity to partake in illicit practices that abuse the natural environment for their sustenance, without adequately considering the potential adverse ramifications on the quality of the environment.

Based on the conducted macro-analysis, it can be inferred that the cultivation of rice makes a substantial contribution to the economy's overall greenhouse gas (GHG) emissions. A significant association exists between the aggregate land area allocated for rice cultivation and the overall greenhouse gas (GHG) emissions of the economy; 1 percent expansion in the land area allocated to rice cultivation is associated with a proportional increase of 0.3537 percent in greenhouse gas (GHG) emissions. The phenomenon in question is most likely attributed to the emission of methane (CH4) and nitrous oxide (N2O) from rice fields. Upon comparing the atmospheric characteristics of carbon dioxide (CO2) with those of methane and nitrous oxide, it becomes apparent that the latter two gases have a longer duration of stay in the atmosphere and possess a greater capacity to contribute to global warming.

From the aforementioned results, the major macro drivers of the total national GHG emissions in the overall economy from 1990 to 2019 are; per capita real gross domestic product (PCRGDP), total import gross domestic product ratio (IMGDPR), land area devoted to rice production (RICEAREA), and energy shock related to the occurrence of severe El Nino events (ENERGYS).

7.2.2 Objective two: drivers of the observed declining AFOLU share of the total national GHG emissions

The drivers of the declining AFOLU (agriculture sector) share of the total national GHG emissions were estimated using time series analysis. Among the major findings are: the declining AFOLU share of the total national GHG emissions is positively influenced by the growth of agriculture share of GDP (GSHAREAG); and negatively influenced by total area devoted to rice cultivation (RICEAREA), and oil flaring in the long term. In the short-run, the declining AFOLU share of the total national GHG emissions is still significantly influenced by the growth of agriculture share of GDP (GSHAREAG); and oil flaring (FLAREDUM).

7.2.3 Objective three: determination of the rice industry share of total GHG emissions and its performance in comparison to other industries in the economy.

The results were based on an I-O table for 20 domestic industries, derived from IFPRI's 2018 Social Accounting Matrix (SAM) of Ghana, which is based on 76 industries, including rice production. Rice production was on the 20-industry I-O table. All other agricultural industries (29 in total), crude oil production, other mining and quarrying, electricity generation, water and sewage production, construction, and 13 service industries make up the remaining 19 industries.

Among the 20 industries examined for both forward and backward linkages, rice production was found to be the second largest unit emitter of GHG emissions. Nevertheless, with 2% of the country's total GHG emissions, it had one of the lowest shares in 2018. In addition, the distribution of labor and capital owners' incomes is equitable in terms of output value added. The rice industry was found to have one of the relatively highest total employment multipliers, despite the fact that it ranks as the second-largest unit emitter in the domestic economy in terms of both backward and forward linkages.

7.2.4 Objective four: farmers' response in reducing GHG emissions

From the cross-sectional survey, rice farmers are aware of climate change and employ agronomic practices to reduce rice-related greenhouse gas emissions. These include the management of soil fertility and the use of improved rice seeds. Adaptation to GHG emissions is hindered, however, by low soil fertility, a lack of climate-resilient rice varieties, and a lack of understanding of how GHG emissions affect rice yields. Rice farmers' efforts to reduce greenhouse gas emissions are contingent on their access to extension services and their level of experience. This was a relatively educated farming population, and access to well-trained extension agents could increase the degree to which smallholder rice farmers adapt to climate change. To adapt, rice farmers require state-run climate change awareness programs.

7.3 Conclusions of the Study

Three main findings are drawn from the macro-analysis of the variables affecting the economy's overall GHG emissions as well as the share of emissions attributed to the agriculture sector:

1. There exists a non-linear relationship between per capita real GDP (PCRGDP) and total greenhouse gas (GHG) emissions. The relationship between total greenhouse gas (GHG) emissions and per capita real gross domestic product (PCRGDP) follows a parabolic U-shaped curve, with a low point of inflection. The observed trend exhibits a notable divergence from the standard environmental Kuznets curve. The period spanning from 1990 to 2019 had a significant economic growth in Ghana, which was

accompanied with noteworthy environmental consequences, namely in relation to air pollution, such as the emission of greenhouse gases.

2. A major long-term macroeconomic driver of total GHG emissions is increased land area used for rice cultivation; in the short term, however, this is not the case. This phenomenon can be attributed to the emission of methane (CH4) and nitrous oxide (N2O), both of which possess a significantly longer atmospheric lifetime compared to carbon dioxide (CO2). This outcome is consistent with the findings reported in other studies (Boateng et al., 2017; Gupta et al., 2021).
3. A significant driver for the declining agriculture sector share of the total GHG emissions in the economy is growth of agriculture share of GDP (GSHAREAG).

In the analysis conducted at the meso-level, the focus was on the environmental extended input-output framework derived from the 2018 social accounting matrix (SAM). The study yielded four significant conclusions:

1. In relation to the effects of greenhouse gas (GHG) emissions on backward linkages, the industries that have the greatest impact on the domestic economy in Ghana, based on the change in final demand per unit of Ghana cedi, are ordered according to their dispersion power. These industries include electricity generation, rice production, crude oil, transportation, and other agricultural activities. One significant consequence of crude oil extraction is the emission of greenhouse gases, with flaring being a prominent contributor;
2. With regards to the forward linkage effects, the industries within the domestic economy that have the greatest impact on greenhouse gas emissions, as measured by the change in final demand per unit of Ghana Cedi, and ranked based on the sensitivity of

dispersion, include electricity generation, rice production, transport, crude oil, and other agricultural activities;

3. Though rice production is a significant emitter of GHG emissions per unit Ghana cedi change in final demand, its share of total national GHG emissions is about two percent;
4. The input-output study reveals that rice production, though among the top six GHG-impacting industries in the local economy, has significant economic welfare implications. Specifically, the rice production industry leads to a more equitable distribution of income among labour and capital owners, as well as more job prospects. The disaggregated value-added and employment multipliers of the rice sector demonstrate these phenomena.

The findings of the micro level analysis of the field survey on rice farmers management practices in dealing with GHG emissions are:

1. The farmers residing in the study area have a limited comprehension of climate change and employ some agronomic techniques to mitigate greenhouse gas emissions resulting from their rice cultivation endeavors. GHG emissions are effectively managed by the implementation of several methods, such as soil fertility management, the use of early maturing varieties, the adoption of enhanced planting materials and seeds, the cultivation of drought-tolerant rice varieties, and zero-tillage land preparation.
2. The management of greenhouse gas (GHG) emission adaptation is contingent upon various elements, including the biological, social, and human capital of farmers. The study uncovered that the degree of adaptability among farmers in terms of biological capital, which is influenced by age and age squared, exhibiting a parabolic connection with a minimum age threshold of 28 years. Rice farmers who are older than 28 years

exhibit a higher level of adaptation intensity. In relation to social capital, rice farmers adhering to traditional African religion have relatively lower levels of greenhouse gas (GHG) adaption intensity compared to their counterparts in the rice farming community. The degree of greenhouse gas (GHG) adaption intensity is favorably and significantly influenced by the enhanced human capital of rice farmers, which encompasses their level of expertise in rice farming, formal education attainment, and access to extension services. The finding aligns with the proposition made by T.W. Schultz (1961) in his human capital theory. Schultz posits that farmers exhibit efficiency in their agricultural practices, although have limitations in terms of available resources. Consequently, the transformation of their farming system could be achieved through the enhancement of their human capital.

The comparison of the results derived from the macro, meso, and micro analyses shows that rice cultivation makes a substantial contribution to the production of greenhouse gases in Ghana. This finding confirms Lucas's critique, a generally acknowledged assertion that well-conducted research often produces consistent outcomes at both macro and micro levels. The increase in domestic rice production will subsequently have a significant effect on the economy's GHG emissions. However, the development of the human capital of rice farmers has the potential to enhance their efficiency in the improved management of GHG emissions in their farming operations.

7.4 Policy Recommendations

The study's findings and conclusions offer valuable evidence-based insights for formulating policies aimed at tackling market failure issues that result in suboptimal allocation of resources.

This study examined the policy conflict arising from the government of Ghana's initiative to enhance domestic rice production for achieving self-sufficiency by 2025, with the aim of promoting economic well-being, including food security, employment, and income generation for the country's expanding population. Simultaneously, the study considered the challenge of aligning this policy with Ghana's 2030 NDC target for GHG emissions. It is imperative to fully understand the causes and effects of greenhouse gas emissions associated with rice production, since it is critical to strike a harmonious equilibrium between Ghana's food security goals and its obligations to global climate agreements. The government must immediately embark on an integrated, sustainable, and climate-resilient rice intensification programme in order to achieve its dual goals of reaching its NDC target by 2030 and attaining rice self-sufficiency by 2025.

For the aforementioned reason, the following policy recommendations are presented for possible adoption:

1. There exists a necessity for augmenting investments from both the public and private sectors in order to enhance the accessibility of rice farmers to information through extension services. Ghana's extension strategy exhibits a pluralist approach, necessitating the Ministry of Food and Agriculture to assume a leading role in mobilizing both public and private resources. This endeavor aims to enhance coverage by combining traditional in-person extension delivery services with digital extension technologies. Enhancing the human capital of farmers will have a substantial impact on the adoption of effective agronomic methods, leading to increased production and greater resilience of farmers in the face of climate shocks and stresses.

2. It is imperative for the government to allocate resources towards research initiatives aimed at enhancing rice cultivars. These efforts should focus on the development of genetically superior varieties that possess desirable traits such as shortened maturity period, resilience to drought and diseases, and increased yield potential. Furthermore, it is imperative for the research to prioritize the investigation of novel strategies pertaining to soil fertility and water management that exhibit efficacy in mitigating GHG emissions within rice fields. Specifically, the focus should be directed towards addressing the emissions of methane and nitrous oxide, as they possess a considerably higher global warming potential than carbon dioxide and serve as significant contributors to climate change.

3. Despite the widely known GHG emissions associated with rice production, this staple crop holds significant potential to address food security concerns, create employment opportunities, and stimulate economic growth. Therefore, it is essential for the government to proactively promote the production of rice within the country, employing the assets and expertise of the Ministry of Food and Agriculture, the Ministry of Trade and Industry, and the Ministry of Local Government, Rural Development, and Decentralization. To meet its GHG NDC international commitment, the government must prioritize the mitigation of GHG emissions originating from other prominent sectors within the economy. The reduction of GHG emissions in specific industries can be accomplished by the utilization of appropriate fiscal policy instruments, such as the introduction of a Pigouvian tax consistent with the suggestion made by Lauer et al. (2023). Nevertheless, it is widely acknowledged that the implementation of such a tax may not necessarily result in an optimal allocation of

resources over an extended period of time. The imposition of a per-unit tax has the unpleasant consequence of increasing a firm's average cost curve. Consequently, in the long run, the firm aims to minimize its average cost curve at the same level of output as observed prior to the implementation of the tax. The output level that achieves societal optimality in the presence of externalities differs from the output level that minimizes the average production cost of the firm. Additional research will be necessary to ascertain the most effective Pigouvian taxing approach for addressing environmental emissions in Ghana.

7.5 Limitations of the Study and Suggestions for Further Research

The study was limited in its focus to the examination of greenhouse gas (GHG) emissions specifically arising from rice cultivation. The Volta region was selected as the primary area of interest due to its status as the major rice-producing region in Ghana. As a result of limitations in financial resources and time availability, a subset of three districts out of the total thirteen districts within the Volta region were selected for investigation. Subsequent investigations could potentially focus on the entirety of the nation's rice-producing regions. In addition, it is imperative to gather empirical data in order to guide the government's future fiscal policy aimed at reducing the impact of greenhouse gas-emitting sectors on the overall national greenhouse gas emissions within the economy, with the ultimate objective of attaining Ghana's NDC target for the year 2030.

7.6 Contribution to Knowledge

Using a three-tiered approach—macro, meso, and micro—this study examined the policy conflict between attaining Ghana's 2030 Intended National Determined Contribution of GHG emissions target and achieving rice self-sufficiency by 2025 through increased local rice production. The majority of scholarly investigations primarily focus on a single approach among the three. The primary contribution of this study involves the expansion of Ghana's input-output (I-O) model to incorporate environmental factors, with a specific focus on GHG emissions. This contribution holds significant importance due to its emphasis on incorporating evidence-based information into the formulation and execution of environmental and food security policies. The previously mentioned approach exhibits a broad range of applicability to various policy questions within the nation, necessitating a comprehensive understanding of the necessary adjustments to the national input-output model in order to effectively capture sector-specific impacts.

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APPENDICES

APPENDIX 1: TECHNICAL (DIRECT) COEFFICIENTS OF THE GHANAIAN ECONOMY, 2018

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.0126810	0.000000	0.00000	0.00000	0.00370	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00411	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.0545105	0.016269	0.00000	0.00002	0.09950	0.00000	0.00024	0.00040	0.00635	0.00041	0.00067	0.17970	0.00035	0.00037	0.00002	0.00020	0.00001	0.00034	0.00052	0.00141
3	0.0000000	0.000000	0.00000	0.00000	0.03634	0.07417	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	0.0000000	0.000345	0.00795	0.00038	0.02461	0.00190	0.01417	0.16143	0.00006	0.00000	0.00000	0.00168	0.00000	0.00002	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
5	0.0685185	0.050770	0.08202	0.04375	0.22987	0.28009	0.22233	0.39594	0.04051	0.15169	0.38597	0.22937	0.02959	0.02993	0.01731	0.09870	0.02293	0.12482	0.32172	0.17843
6	0.0000000	0.001777	0.00182	0.00311	0.00607	0.27194	0.12249	0.00007	0.00540	0.00060	0.00059	0.00007	0.00256	0.00361	0.00235	0.01887	0.01025	0.00847	0.01401	0.04570
7	0.0000000	0.000727	0.00002	0.00002	0.00057	0.00780	0.00050	0.00048	0.00317	0.00009	0.00030	0.00720	0.00095	0.00184	0.00097	0.00153	0.00534	0.00437	0.00854	0.01459
8	0.0000000	0.000994	0.00011	0.00001	0.00028	0.00007	0.00000	0.00223	0.00177	0.00051	0.00222	0.00034	0.01601	0.00438	0.00113	0.01002	0.01542	0.01019	0.01759	0.00513
9	0.0000000	0.003420	0.00000	0.00761	0.00008	0.00483	0.00064	0.00001	0.01293	0.02030	0.01838	0.00118	0.00547	0.01319	0.00151	0.03643	0.04663	0.02045	0.02802	0.01837
10	0.0000000	0.012075	0.22613	0.00227	0.01182	0.03881	0.00277	0.00264	0.13608	0.00280	0.01267	0.00662	0.00169	0.01188	0.00093	0.02109	0.02481	0.01110	0.03300	0.04221
11	0.0000000	0.000000	0.00002	0.00000	0.00000	0.00254	0.00065	0.00000	0.00008	0.00004	0.00096	0.00001	0.00344	0.00627	0.00000	0.00097	0.00242	0.01455	0.00430	0.00073
12	0.0000000	0.000000	0.00000	0.00000	0.00003	0.00508	0.00130	0.00000	0.00017	0.00008	0.00192	0.00000	0.00689	0.01264	0.00000	0.00196	0.00472	0.02923	0.00860	0.00147
13	0.0000000	0.000052	0.13341	0.00042	0.00187	0.00062	0.01018	0.00069	0.00658	0.00157	0.01857	0.00004	0.00509	0.03610	0.00130	0.02663	0.03702	0.01729	0.02479	0.05008
14	0.0000000	0.001495	0.01921	0.00227	0.01626	0.01201	0.00854	0.00031	0.02950	0.03153	0.07881	0.00524	0.31715	0.24178	0.01936	0.19049	0.05375	0.00039	0.00128	0.14903
15	0.0000000	0.001295	0.00055	0.00029	0.00110	0.00755	0.00025	0.00006	0.00746	0.00153	0.00393	0.00134	0.00807	0.00412	0.00074	0.01135	0.00856	0.01777	0.01359	0.02040
16	0.0000000	0.000253	0.02815	0.04300	0.00451	0.00061	0.01467	0.00006	0.00773	0.00333	0.03283	0.00073	0.11031	0.02305	0.00452	0.05157	0.01161	0.02553	0.00645	0.03040
17	0.0000000	0.000000	0.00000	0.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.01131	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
18	0.0000000	0.000000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00000	0.00005	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02198	0.08436	0.03966	0.00003
19	0.0000000	0.002357	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00269	0.00173	0.00026	0.00000
20	0.0000000	0.000001	0.00000	0.00004	0.00028	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00015	0.00062	0.00042	0.00317

1.Rice production; 2. All other agricultural industries; 3. Crude oil; 4. All other Mining; 5. Manufacturing; 6. Electricity, gas and steam; 7. Water supply and sewage; 8. Construction; 9. Wholesale and retail trade; 10. Transport and storage; 11. Hotels; 12. Restaurants and food services; 13. Information and communication; 14. Finance and Insurance; 15. Real Estate Services;16. Business Services; 17. Public Administration; 18. Education; 19. Health and Social Work; 20. All Other Service

APPENDIX 2: Total GHG Emission Multiplier Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.68249193	0.00018922	0.00045862	0.00017635	0.00336311	0.00141701	0.00094393	0.00136546	0.00024073	0.00053149	0.00136428	0.00362587	0.00029712	0.00026332	7.2598E-05	0.00048626	0.00021203	0.00066411	0.00123417	0.00079199
2	0.01231401	0.19132616	0.00352098	0.00134573	0.02522781	0.01075228	0.0071687	0.01032345	0.00306193	0.00410705	0.01045242	0.04032414	0.00253247	0.00233434	0.00055925	0.00384999	0.00176468	0.00551967	0.00954489	0.00634004
3	0.00103751	0.00086055	0.29151592	0.00086573	0.01426535	0.03547057	0.00760942	0.00581493	0.00120035	0.00227984	0.0058044	0.00351656	0.00131526	0.0010925	0.00038311	0.00263533	0.00118155	0.00275283	0.00558693	0.00476787
4	1.1648E-05	1.1515E-05	6.1896E-05	0.00476091	0.00015867	8.3507E-05	0.00011412	0.00083342	1.3746E-05	2.5847E-05	6.6805E-05	4.7925E-05	2.795E-05	1.6203E-05	4.538E-06	3.2527E-05	2.2968E-05	3.7137E-05	7.2295E-05	4.459E-05
5	0.0016364	0.00126833	0.00303124	0.00117698	0.02257065	0.00936609	0.00628559	0.00916249	0.00159677	0.00355209	0.00908451	0.0054987	0.00174412	0.00143585	0.00047952	0.00314664	0.00128833	0.00384376	0.00808513	0.00521322
6	0.00055858	0.00182004	0.0036625	0.00334076	0.00660092	0.7295054	0.0912789	0.00326887	0.0051679	0.00189495	0.00419919	0.00262156	0.00574669	0.00496966	0.00210867	0.01682155	0.00940977	0.00907906	0.01409272	0.03775003
7	9.8569E-07	6.9239E-06	5.6192E-06	2.1042E-06	8.6949E-06	9.1131E-05	0.00800668	7.714E-06	2.8268E-05	4.0988E-06	9.4822E-06	6.1129E-05	1.891E-05	2.35E-05	8.7704E-06	2.2356E-05	4.9219E-05	4.4469E-05	7.6709E-05	0.00012906
8	1.0778E-06	9.2391E-06	2.9127E-05	5.2611E-06	8.1803E-06	9.0803E-06	6.7171E-06	0.00801086	1.988E-05	9.754E-06	3.2508E-05	6.8505E-06	0.00015959	5.8376E-05	1.1046E-05	0.00010301	0.00013807	9.8174E-05	0.00015364	6.4155E-05
9	1.9165E-06	1.9345E-05	4.4335E-05	4.684E-05	1.2226E-05	4.951E-05	1.7691E-05	1.2893E-05	0.00480141	0.00010633	0.00011074	1.3541E-05	8.2381E-05	9.7563E-05	1.0682E-05	0.00021142	0.00024189	0.00012114	0.00015224	0.00012329
10	0.0010667	0.00542094	0.08583426	0.00244428	0.01105792	0.03337282	0.00799232	0.00577647	0.05203664	0.36940949	0.0111825	0.00614405	0.00569155	0.00823949	0.0009353	0.01395423	0.01343834	0.00850347	0.01855427	0.02224399
11	1.3122E-07	2.9707E-07	6.3022E-06	9.2246E-07	1.6545E-06	1.9246E-05	6.8281E-06	8.5725E-07	2.5381E-06	2.1721E-06	0.00487937	7.7459E-07	3.2293E-05	4.2648E-05	1.0244E-06	1.5215E-05	1.7757E-05	7.9218E-05	2.6125E-05	1.3479E-05
12	2.7101E-07	5.9579E-07	1.2316E-05	1.8338E-06	3.4311E-06	3.7952E-05	1.3487E-05	1.7599E-06	5.0288E-06	4.3096E-06	1.9541E-05	0.00478608	6.3751E-05	8.4405E-05	2.0297E-06	3.0141E-05	3.4399E-05	0.00015639	5.1443E-05	2.6709E-05
13	3.719E-06	4.3405E-06	0.00064381	1.3511E-05	5.0136E-05	9.6136E-05	7.5695E-05	2.5514E-05	4.628E-05	2.6293E-05	0.00013231	1.4688E-05	0.00467479	0.00023368	1.2748E-05	0.0001884	0.00019681	0.00010664	0.00014339	0.00029249
14	1.3814E-05	2.4201E-05	0.00051088	8.3828E-05	0.00017979	0.00024675	0.00016692	8.916E-05	0.00025306	0.00024113	0.00064883	8.252E-05	0.00212944	0.00617175	0.00013298	0.00134173	0.0004595	0.00013403	0.00015982	0.0011352
15	1.1046E-06	7.1585E-06	1.5853E-05	5.2104E-06	1.0222E-05	5.4611E-05	1.2084E-05	5.2861E-06	3.8641E-05	1.1212E-05	2.8507E-05	1.016E-05	5.5277E-05	3.1402E-05	0.00455764	6.6425E-05	4.8969E-05	9.5374E-05	7.354E-05	0.00010856
16	4.0243E-06	5.467E-06	0.00023456	0.00021298	5.3639E-05	5.7095E-05	0.00010133	5.6661E-05	5.542E-05	3.3529E-05	0.00020804	1.9267E-05	0.00060199	0.00018321	2.7674E-05	0.00486509	9.9898E-05	0.00016244	7.7114E-05	0.00022319
17	1.5072E-07	7.6711E-07	1.211E-05	3.7928E-07	1.5615E-06	4.7091E-06	1.1285E-06	8.211E-07	7.3468E-06	5.2117E-05	1.5784E-06	8.6764E-07	8.0329E-07	1.1627E-06	1.3201E-07	1.9692E-06	0.00455481	1.2001E-06	2.6185E-06	3.1387E-06
18	3.7773E-08	4.9824E-07	3.0949E-07	1.7446E-08	1.4791E-07	1.624E-07	5.9038E-08	6.5186E-08	4.4469E-07	1.2802E-06	8.8837E-08	1.3339E-07	3.3695E-08	4.2042E-08	6.1407E-09	7.4898E-08	0.00010987	0.00497279	0.00019736	2.7009E-07
19	7.0916E-07	1.1008E-05	2.3643E-07	7.8756E-08	1.4613E-06	6.3381E-07	4.1708E-07	5.9845E-07	1.9707E-07	3.7966E-07	6.0793E-07	2.3233E-06	1.4833E-07	1.3784E-07	3.2655E-08	2.2768E-07	1.2554E-05	8.926E-06	0.00456029	3.7492E-07
20	1.3819E-07	1.1522E-07	2.5902E-07	2.8943E-07	1.8996E-06	7.8977E-07	5.3195E-07	8.0197E-07	1.361E-07	3.0889E-07	7.6489E-07	4.6473E-07	1.4758E-07	1.2133E-07	4.0424E-08	2.656E-07	9.7741E-07	3.7653E-06	2.952E-06	0.00510169

APPENDIX 3: Total Value Added Multiplier Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.74952672	0.00020781	0.00050367	0.00019367	0.00369344	0.00155619	0.00103664	0.00149958	0.00026438	0.00058369	0.00149828	0.00398201	0.0003263	0.00028919	7.9728E-05	0.00053402	0.00023285	0.00072934	0.00135539	0.00086978
2	0.04641064	0.72109491	0.01327032	0.00507195	0.09508185	0.04052459	0.02701832	0.03890834	0.01154018	0.01547917	0.03939444	0.15197884	0.0095447	0.00879795	0.00210776	0.01451035	0.00665095	0.02080325	0.03597401	0.02389518
3	0.00150751	0.00125039	0.42357749	0.00125792	0.02072779	0.05153933	0.01105661	0.0084492	0.00174413	0.00331265	0.0084339	0.00510961	0.0019111	0.00158742	0.00055666	0.00382918	0.00171681	0.0039999	0.0081179	0.00692779
4	0.00202966	0.00200662	0.01078575	0.82962133	0.02765007	0.01455163	0.01988631	0.14522895	0.00239537	0.00450399	0.01164126	0.00835117	0.00487045	0.00282355	0.00079077	0.00566804	0.00400226	0.00647131	0.01259788	0.00777009
5	0.02363057	0.01831555	0.04377306	0.01699638	0.32593435	0.13525225	0.09076792	0.13231205	0.02305837	0.05129439	0.13118601	0.07940469	0.02518621	0.02073457	0.00692453	0.04543944	0.01860424	0.05550627	0.11675437	0.07528211
6	0.00030883	0.00100626	0.00202492	0.00184704	0.00364952	0.40332948	0.05046634	0.0018073	0.00285723	0.00104768	0.00232165	0.00144941	0.00317724	0.00274763	0.00116585	0.00930031	0.00520248	0.00501964	0.0077916	0.02087126
7	7.4189E-05	0.00052114	0.00042294	0.00015837	0.00065444	0.00685915	0.60263638	0.00058061	0.00212766	0.0003085	0.00071369	0.004601	0.00142329	0.0017688	0.00066012	0.00168266	0.00370454	0.00334702	0.00577365	0.00971414
8	5.8777E-05	0.00050385	0.00158844	0.00028691	0.00044611	0.00049519	0.00036631	0.43686768	0.00108414	0.00053193	0.00177281	0.00037359	0.00870341	0.0031835	0.00060237	0.00561761	0.00752974	0.00535387	0.00837874	0.00349866
9	0.00029998	0.00302792	0.0069394	0.00733161	0.00191368	0.00774942	0.00276904	0.00201803	0.75153211	0.01664365	0.0173336	0.0021195	0.01289457	0.01527085	0.00167197	0.03309207	0.03786156	0.01896055	0.02382976	0.01929726
10	0.00226168	0.01149381	0.18199111	0.0051825	0.02344568	0.07075912	0.01694581	0.01224763	0.11033129	0.78324479	0.02370983	0.01302698	0.01206757	0.01746987	0.00198309	0.02958663	0.02849279	0.01802957	0.03933991	0.04716307
11	1.1915E-05	2.6975E-05	0.00057227	8.3763E-05	0.00015023	0.0017476	0.00062002	7.7842E-05	0.00023047	0.00019724	0.44306645	7.0336E-05	0.00293235	0.00387265	9.3019E-05	0.00138161	0.00161239	0.00719334	0.00237221	0.00122396
12	3.1811E-05	6.9935E-05	0.00144567	0.00021525	0.00040274	0.0044548	0.00158314	0.00020658	0.00059028	0.00050586	0.00229377	0.56179627	0.0074832	0.00990761	0.00023825	0.00353803	0.00403785	0.01835736	0.00603842	0.00313515
13	0.00040225	0.00046947	0.06963364	0.00146138	0.00542269	0.01039804	0.00818707	0.00275959	0.00500565	0.0028438	0.01431057	0.00158859	0.50562121	0.0252751	0.00137876	0.02037672	0.02128721	0.0115338	0.01550877	0.03163581
14	0.00185326	0.00324682	0.06854102	0.01124653	0.02412159	0.03310478	0.02239422	0.01196196	0.03395132	0.03235108	0.08704811	0.01107102	0.28569046	0.82801682	0.01784038	0.18000947	0.06164768	0.01798153	0.02144153	0.15230152
15	0.00023045	0.00149347	0.00330731	0.00108705	0.00213251	0.01139336	0.00252103	0.00110284	0.00806164	0.00233908	0.00594744	0.00211969	0.0115323	0.00655139	0.95085751	0.0138582	0.0102164	0.01989776	0.01534254	0.02264882
16	0.00046862	0.00063661	0.02731429	0.02480092	0.00624608	0.00664862	0.01180015	0.00659808	0.00645354	0.00390433	0.02422541	0.00224362	0.07010017	0.02133386	0.00322261	0.56652737	0.01163291	0.01891602	0.00897968	0.02599031
17	2.4223E-05	0.00012328	0.00194626	6.0955E-05	0.00025096	0.00075681	0.00018136	0.00013196	0.00118072	0.00837591	0.00025366	0.00013944	0.0001291	0.00018686	2.1215E-05	0.00031648	0.73201643	0.00019288	0.00042082	0.00050444
18	5.2168E-06	6.8812E-05	4.2744E-05	2.4095E-06	2.0427E-05	2.2429E-05	8.1538E-06	9.0029E-06	6.1416E-05	0.00017681	1.2269E-05	1.8423E-05	4.6537E-06	5.8064E-06	8.4809E-07	1.0344E-05	0.01517469	0.68679049	0.02725725	3.7302E-05
19	7.4249E-05	0.00115252	2.4755E-05	8.2458E-06	0.000153	6.636E-05	4.3668E-05	6.2658E-05	2.0634E-05	3.9751E-05	6.3651E-05	0.00024325	1.553E-05	1.4432E-05	3.4191E-06	2.3838E-05	0.00131445	0.00093456	0.47746573	3.9254E-05
20	1.1926E-05	9.9434E-06	2.2354E-05	2.4979E-05	0.00016394	6.8159E-05	4.5908E-05	6.9212E-05	1.1746E-05	2.6658E-05	6.6012E-05	4.0107E-05	1.2736E-05	1.0471E-05	3.4887E-06	2.2922E-05	8.4353E-05	0.00032495	0.00025476	0.4402877

APPENDIX 4: Total Labour Income Multiplier Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.451036	0.000125	0.000303	0.000116	0.002222	0.0009364	0.0006238	0.0009023	0.0001590	0.0003512	0.0009016	0.0023962	0.0001963	0.0001740	4.7977E-05	0.0003213	0.0001401	0.0004388	0.0008156	0.0005234
2	0.015257	0.237058	0.004362	0.001667	0.031257	0.0133223	0.0088822	0.0127910	0.0037938	0.0050887	0.0129508	0.0499627	0.0031378	0.0028923	0.0006929	0.0047702	0.0021864	0.0068390	0.0118263	0.0078555
3	0.000325	0.000269	0.091323	0.000271	0.004468	0.0111119	0.0023838	0.0018216	0.0003760	0.0007142	0.0018183	0.0011016	0.0004120	0.0003422	0.0001200	0.0008255	0.00037015	0.00086238	0.00175023	0.0014936
4	0.000520	0.000514	0.002763	0.212587	0.007085	0.0037288	0.0050957	0.0372143	0.0006138	0.0011541	0.0029830	0.0021399	0.00124803	0.00072352	0.00020263	0.00145241	0.00102556	0.00165825	0.00322816	0.0019910
5	0.008173	0.006334	0.015139	0.005878	0.112730	0.0467795	0.0313938	0.045762	0.0079751	0.0177411	0.0453731	0.0274636	0.00871113	0.00717145	0.00239498	0.0157161	0.00643463	0.0191979	0.04038172	0.0260377
6	3.2055E-05	0.000104	0.000210	0.000191	0.000378	0.0418635	0.0052381	0.0001875	0.0002965	0.0001087	0.0002409	0.0001504	0.00032978	0.00028519	0.00012101	0.00096532	0.00053999	0.00052101	0.00080873	0.0021663
7	6.8477E-05	0.000481	0.000390	0.00014	0.000604	0.0063309	0.5562310	0.0005359	0.0019638	0.0002847	0.0006587	0.0042467	0.0013136	0.0016325	0.0006092	0.0015530	0.003419	0.0030892	0.0053290	0.0089661
8	7.3283E-06	6.2819E-05	0.00019	3.5772E-05	5.562E-05	6.174E-05	4.5671E-05	0.0544683	0.0001351	6.6321E-05	0.0002210	4.6579E-05	0.0010851	0.0003969	7.5103E-05	0.0007004	0.0009388	0.0006675	0.0010446	0.0004362
9	0.000165	0.001674	0.003838	0.00405	0.001058	0.0042861	0.0015315	0.001116	0.415663	0.0092054	0.009587	0.0011722	0.0071318	0.0084461	0.0009247	0.0183028	0.0209407	0.0104868	0.0131799	0.0106730
10	0.000768	0.003904	0.061824	0.00176	0.007964	0.0240376	0.0057566	0.0041606	0.0374808	0.2660773	0.0080545	0.0044254	0.0040994	0.0059347	0.0006736	0.0100509	0.0096793	0.0061248	0.0133642	0.0160218
11	3.8722E-06	8.7662E-06	0.0001859	2.7221E-05	4.8822E-05	0.00056792	0.00020149	2.5297E-05	7.4896E-05	6.4097E-05	0.14398451	2.2857E-05	0.0009529	0.0012585	3.0229E-05	0.00044899	0.0005239	0.0023376	0.0007709	0.0003977
12	6.8751E-06	1.5115E-05	0.000312	4.6521E-05	8.7042E-05	0.0009627	0.0003421	4.4647E-05	0.0001275	0.0001093	0.0004957	0.121417	0.0016173	0.0021412	5.1492E-05	0.000764	0.0008726	0.0039674	0.0013050	0.000677
13	9.6685E-05	0.000112	0.016737	0.000351	0.001303	0.0024993	0.0019678	0.0006633	0.0012031	0.0006835	0.0034397	0.000381	0.1215327	0.0060752	0.0003314	0.0048978	0.0051166	0.0027723	0.0037277	0.0076040
14	0.000681	0.001194	0.025216	0.004137	0.008874	0.0121793	0.0082388	0.0044008	0.0124907	0.0119020	0.0320251	0.004073	0.1051061	0.3046291	0.0065635	0.0662258	0.0226803	0.0066154	0.0078883	0.0560320
15	3.2419E-06	2.101E-05	4.6526E-05	1.5292E-05	2.9999E-05	0.0001602	3.5465E-05	1.5514E-05	0.0001134	3.2905E-05	8.3666E-05	2.9819E-05	0.0001622	9.2162E-05	0.0133763	0.0001949	0.0001437	0.0002799	0.0002158	0.0003186
16	0.000202	0.000275	0.011813	0.010726	0.002701	0.0028755	0.0051035	0.0028536	0.0027911	0.0016886	0.0104775	0.000970	0.0303183	0.0092269	0.0013937	0.2450236	0.0050312	0.0081812	0.0038837	0.0112408
17	1.5193E-05	7.7325E-05	0.001220	3.8232E-05	0.000157	0.0004746	0.0001137	8.2768E-05	0.000740	0.0052534	0.0001591	8.7458E-05	8.0972E-05	0.0001172	1.3306E-05	0.0001985	0.4591267	0.0001209	0.0002639	0.0003163
18	4.8963E-06	6.4584E-05	4.0118E-05	2.2615E-06	1.9172E-05	2.1051E-05	7.6528E-06	8.4498E-06	5.7642E-05	0.00016595	1.1515E-05	1.7291E-05	4.3678E-06	5.4497E-06	7.9599E-07	9.7086E-06	0.0142424	0.6445967	0.0255826	3.5011E-05
19	6.7023E-05	0.0010403	2.2346E-05	7.4433E-06	0.0001381	5.9902E-05	3.9419E-05	5.656E-05	1.8625E-05	3.5882E-05	5.7456E-05	0.0002195	1.4019E-05	1.3027E-05	3.0863E-06	2.1518E-05	0.0011865	0.0008436	0.4309980	3.5434E-05
20	5.9829E-06	4.9883E-06	1.1214E-05	1.2531E-05	8.2243E-05	3.4193E-05	2.3031E-05	3.4721E-05	5.8925E-06	1.3373E-05	3.3116E-05	2.012E-05	6.3893E-06	5.2528E-06	1.7502E-06	1.1499E-05	4.2317E-05	0.0001630	0.0001278	0.2208770

APPENDIX 5: Total Capital Owners' Income Multiplier Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.29849035	8.2757E-05	0.00020058	7.7125E-05	0.00147087	0.00061973	0.00041283	0.00059719	0.00010528	0.00023245	0.00059667	0.00158579	0.00012994	0.00011517	3.1751E-05	0.00021267	9.273E-05	0.00029045	0.00053977	0.00034638
2	0.03115323	0.48403627	0.00890773	0.00340455	0.06382386	0.0272022	0.0181361	0.0261173	0.00774637	0.01039042	0.02644359	0.10201608	0.0064069	0.00590564	0.00141484	0.0097401	0.00446446	0.01396422	0.02414762	0.01603968
3	0.00118249	0.00098081	0.33225388	0.00098671	0.01625886	0.04042741	0.0086728	0.00662754	0.00136809	0.00259844	0.00661554	0.00400798	0.00149907	0.00124517	0.00043665	0.00300361	0.00134667	0.00313752	0.00636768	0.00543415
4	0.00150957	0.00149243	0.00802195	0.61703414	0.02056485	0.01082284	0.01479052	0.1080146	0.00178157	0.00334986	0.00865823	0.00621122	0.00362242	0.00210003	0.00058814	0.00421563	0.0029767	0.00481307	0.00936972	0.00577904
5	0.01545749	0.01198077	0.02863331	0.01111786	0.21320375	0.08847268	0.05937411	0.0865494	0.01508319	0.03355325	0.08581283	0.05194106	0.01647508	0.01356312	0.00452955	0.02972334	0.01216961	0.03630837	0.07637265	0.04924436
6	0.00027677	0.00090182	0.00181475	0.00165533	0.00327072	0.36146595	0.0452282	0.00161971	0.00256067	0.00093894	0.00208068	0.00129897	0.00284746	0.00246244	0.00104484	0.00833499	0.00466249	0.00449862	0.00698287	0.01870493
7	5.7129E-06	4.013E-05	3.2568E-05	1.2195E-05	5.0394E-05	0.00052818	0.04640534	4.4709E-05	0.00016384	2.3756E-05	5.4957E-05	0.0003543	0.0001096	0.0001362	5.0832E-05	0.00012957	0.00028526	0.00025773	0.00044459	0.00074803
8	5.1449E-05	0.00044103	0.0013904	0.00025114	0.00039049	0.00043345	0.00032064	0.38239937	0.00094897	0.00046561	0.00155178	0.00032701	0.00761827	0.00278658	0.00052726	0.00491721	0.00659094	0.00468635	0.00733408	0.00306245
9	0.00013406	0.00135321	0.00310131	0.00327658	0.00085525	0.00346331	0.00123752	0.00090188	0.33586899	0.00743825	0.0077466	0.00094723	0.00576274	0.00682473	0.00074722	0.01478925	0.0169208	0.0084737	0.01064981	0.00862419
10	0.00149336	0.00758923	0.12016663	0.00342195	0.01548091	0.04672143	0.01118912	0.00808697	0.07285048	0.51716749	0.01565532	0.00860157	0.00796808	0.01153515	0.00130941	0.01953571	0.01881346	0.01190472	0.02597569	0.03114123
11	8.0432E-06	1.8209E-05	0.0003863	5.6542E-05	0.00010141	0.00117968	0.00041853	5.2545E-05	0.00015557	0.00013314	0.29908194	4.7478E-05	0.00197941	0.00261415	6.279E-05	0.00093263	0.00108841	0.0048557	0.00160131	0.00082621
12	2.4936E-05	5.482E-05	0.00113323	0.00016873	0.0003157	0.00349201	0.00124098	0.00016193	0.00046271	0.00039653	0.00179803	0.44037898	0.00586591	0.00776634	0.00018676	0.00277338	0.00316518	0.01438991	0.00473338	0.00245757
13	0.00030556	0.00035663	0.05289628	0.00111012	0.00411928	0.00789873	0.0062192	0.00209629	0.00380248	0.00216025	0.01087083	0.00120675	0.38408847	0.0191999	0.00104736	0.01547891	0.01617054	0.0087615	0.01178103	0.02403173
14	0.00117144	0.00205231	0.04332463	0.00710891	0.01524721	0.02092546	0.01415534	0.00756113	0.02146056	0.02044905	0.05502293	0.00699797	0.18058433	0.52338767	0.01127686	0.1137836	0.03896737	0.01136609	0.01355314	0.09626947
15	0.00022721	0.00147246	0.00326078	0.00107175	0.00210251	0.01123308	0.00248556	0.00108733	0.00794823	0.00230618	0.00586377	0.00208987	0.01137007	0.00645923	0.93748121	0.01366325	0.01007268	0.01961784	0.01512671	0.0223302
16	0.00026594	0.00036128	0.01550084	0.0140745	0.00354464	0.00377309	0.00669658	0.0037444	0.00366238	0.00221571	0.0137479	0.00127325	0.03978178	0.01210695	0.00182883	0.32150377	0.00660167	0.01073482	0.00509596	0.01474948
17	9.03E-06	4.5959E-05	0.00072555	2.2724E-05	9.3554E-05	0.00028213	6.7611E-05	4.9194E-05	0.00044016	0.00312247	9.4564E-05	5.1982E-05	4.8127E-05	6.966E-05	7.9087E-06	0.00011798	0.27288964	7.1904E-05	0.00015688	0.00018805
18	3.205E-07	4.2275E-06	2.626E-06	1.4803E-07	1.255E-06	1.378E-06	5.0094E-07	5.531E-07	3.7731E-06	1.0863E-05	7.5378E-07	1.1318E-06	2.859E-07	3.5672E-07	5.2104E-08	6.355E-07	0.00093227	0.04219377	0.00167458	2.2917E-06
19	7.226E-06	0.00011216	2.4092E-06	8.0249E-07	1.489E-05	6.4582E-06	4.2499E-06	6.098E-06	2.0081E-06	3.8686E-06	6.1946E-06	2.3674E-05	1.5114E-06	1.4045E-06	3.3275E-07	2.32E-06	0.00012792	9.0953E-05	0.04646772	3.8203E-06
20	5.9432E-06	4.9551E-06	1.114E-05	1.2448E-05	8.1697E-05	3.3966E-05	2.2878E-05	3.4491E-05	5.8534E-06	1.3284E-05	3.2896E-05	1.9987E-05	6.3469E-06	5.218E-06	1.7385E-06	1.1423E-05	4.2036E-05	0.00016194	0.00012696	0.2194106

APPENDIX 6: Total Employment Multiplier Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	36.9152384	0.0092747	0.02254797	0.00830742	0.1653695	0.06968824	0.04641377	0.06708294	0.01141499	0.02611807	0.06272174	0.18278689	0.01463201	0.01297986	0.00356967	0.02390499	0.01041848	0.03271705	0.0606231	0.03485709
2	2.3691054	37.2883298	0.62518921	0.22884237	4.47262222	1.90772529	1.27212197	1.83002248	0.54483838	0.72954149	1.7356115	7.37964906	0.45316318	0.41870535	0.09933657	0.68485676	0.31441857	0.98548513	1.69395019	1.01161193
3	0.00749404	0.00623697	2.3145093	0.00607282	0.10302378	0.27749035	0.05757039	0.04196914	0.00848884	0.01647578	0.03922046	0.02419038	0.00961192	0.00797127	0.00282279	0.01946879	0.00876219	0.02001901	0.04060603	0.03175169
4	0.00650405	0.00654728	0.03677952	2.9206971	0.08851152	0.0475441	0.06755007	0.50777064	0.00752626	0.01445391	0.03498105	0.02592623	0.01642721	0.00932892	0.00259476	0.01869627	0.01355428	0.02118806	0.04110459	0.02264013
5	1.28273749	0.99113245	2.37443258	0.8838069	17.6951422	7.33892517	4.92597326	7.17697144	1.20654056	2.78256957	6.65662662	4.10145799	1.36063978	1.11699439	0.37564844	2.46213958	1.00437502	2.99763652	6.32492273	3.6549278
6	0.01007801	0.03487663	0.07010508	0.06211295	0.11747292	14.290348	1.78532635	0.05879185	0.09683312	0.03516993	0.07237444	0.04609965	0.11155947	0.09646795	0.04105866	0.32778523	0.18347759	0.17558364	0.27138335	0.65954749
7	0.00047269	0.00349843	0.00280396	0.00100335	0.00402797	0.04632906	4.08680087	0.00376291	0.01388395	0.00201444	0.00435451	0.02959378	0.00958981	0.01192979	0.00446622	0.01132126	0.02506063	0.02255716	0.03892649	0.05886031
8	0.00227364	0.02040749	0.06459882	0.01112668	0.01652673	0.0194773	0.01446602	17.8356268	0.04256195	0.02140833	0.06699607	0.01410795	0.35514264	0.12978208	0.02455275	0.22903096	0.30722054	0.21814958	0.34099501	0.12745172
9	0.0099309	0.10444383	0.23988403	0.24364204	0.06000832	0.26616296	0.09413174	0.06574149	26.0929862	0.57665443	0.56019227	0.06845641	0.44686546	0.52938056	0.05790249	1.14790127	1.31398272	0.65640016	0.82379787	0.59822523
10	0.04429055	0.23848025	3.82595329	0.10156852	0.44848086	1.470445	0.34388998	0.23870116	2.23752262	16.4868283	0.44802441	0.25026457	0.24885427	0.36287179	0.04061028	0.61299541	0.59309223	0.36894156	0.80844664	0.87767496
11	0.00134666	0.00322	0.0704147	0.00981713	0.016843	0.21505788	0.07606994	0.00884776	0.02732157	0.02405483	54.7059614	0.00786356	0.36190938	0.47803057	0.01144657	0.17030583	0.19893051	0.88784051	0.29190755	0.1348867
12	0.00282971	0.00656617	0.14002137	0.01985491	0.03555106	0.43153444	0.15287531	0.01847762	0.05508296	0.0485481	0.20708442	54.618562	0.72712722	0.96284857	0.02307959	0.34333854	0.3922007	1.78383258	0.58494299	0.27199152
13	0.00183901	0.00220713	0.3493887	0.00690051	0.02474338	0.05116076	0.04041207	0.01279821	0.02406969	0.01386491	0.06623748	0.00701066	2.53928697	0.12672305	0.00686891	0.10194037	0.10670657	0.05738459	0.07684781	0.14166927
14	0.02554898	0.04692977	1.03022036	0.16091679	0.33081349	0.48546789	0.32858436	0.16589665	0.49205279	0.48270087	1.21597448	0.15125559	4.31087839	12.5012183	0.26865006	2.7126885	0.92773915	0.26360041	0.31023464	2.05106296
15	0.00018801	0.00128638	0.00285454	0.00089649	0.00168581	0.00984886	0.0021462	0.00088419	0.00675939	0.0020042	0.00477319	0.00171591	0.01002461	0.00568634	0.82827503	0.01203512	0.00887462	0.01728744	0.01327621	0.01761607
16	0.03023771	0.04266457	1.93720689	1.68934004	0.40176911	0.45451899	0.8265927	0.44032704	0.43984729	0.27062938	1.59529702	0.1418297	4.98421682	1.51404118	0.22835872	40.3112351	0.82392205	1.33620243	0.62153744	1.64592956
17	0.00027375	0.00147622	0.02361212	0.00069128	0.0027702	0.00907594	0.00212392	0.00148452	0.01381855	0.10174595	0.00276608	0.00154591	0.00153634	0.00223985	0.00025071	0.00378391	8.89981316	0.00227768	0.00499059	0.00541725
18	0.00043373	0.00586096	0.00363678	0.0001879	0.00158713	0.00185091	0.00065213	0.0007035	0.00506133	0.01511257	0.00091711	0.00145951	0.00038133	0.00048122	6.873E-05	0.00085438	1.29995746	58.8359133	2.33228702	0.00282154
19	0.00451543	0.071007	0.00140885	0.0004437	0.00857498	0.00372865	0.00245083	0.00351161	0.00116761	0.00231617	0.00334251	0.01407184	0.00087939	0.00081969	0.00019214	0.00134309	0.08122385	0.05761069	29.5252351	0.00198387
20	0.00671824	0.00562274	0.01259476	0.01436894	0.09233353	0.03837294	0.02585474	0.03902992	0.00638385	0.01505042	0.03474983	0.02149944	0.00714037	0.00585358	0.00196361	0.0128877	0.05170839	0.19969274	0.15432999	272.811083

APPENDIX 7: SURVEY QUESTIONNAIRE

STRICTLY CONFIDENTIAL

DEPARTMENT OF AGRICULTURAL ECONOMICS AND AGRIBUSINESS

UNIVERSITY OF GHANA, LEGON, ACCRA, GHANA

SURVEY QUESTIONNAIRE FOR THE STUDY OF THE MANAGEMENT OF GREENHOUSE GASES BY RICE PRODUCERS

INVESTIGATOR'S INTRODUCTION AND STATEMENT OF INFORMED CONSENT

My name is **Mr. Forster Kwame Boateng,** PhD candidate of the Department of Agricultural Economics and Agribusiness, University of Ghana, Legon, Accra. My phone number is 0540116738
Email address: orleansboateng@gmail.com

The objective of this study is to analyse the management of greenhouse gases by producers in Ghana. The Ghanaian government has enacted a food self-sufficiency programme which aims to make Ghana self-sufficient in rice production by 2025. Production of rice leads to an expanded production of greenhouse gases which contribute to global warming and climate change. The government's local rice production intensification programme conflicts with the country's Intended National Determined Contribution towards global reduction of greenhouse gases. Ghana plans to reduce its emissions by 15% in 2030 based on 2016 business-as-usual conditions. Hence the effective management of greenhouse gases by rice producers will help to reduce emissions and meet the goal of the country. This questionnaire is eliciting information on greenhouse gases from local rice producers especially with regards to their management of emissions.

May I begin the interview now? **1.** Respondent **agrees** to be interviewed**...........** **2.** Respondent does not **agree** to be interviewed**................**

DISTRICT/CONSTITUENCY:

ADDRESS OF RESPONDENT (NAME NOT REQUIRED):

TELEPHONE NUMBER:

DATE OF SURVEY:

TIME OF STARTING THE INTERVIEW:

SURVEY QUESTIONNAIRE NUMBER:

SECTION A: INFORMATION CONCERNING RICE PRODUCTION AND LIVELIHOOD OF RESPONDENT

For how many years have been living in this village? [ ]

Were you born in this village? [ ] 1 = Yes 0 = No

If yes, then go to Question 6

If no, please indicate the reasons for moving to this village

……………………………………………………………………….

Where did you live before coming here? [ ]

1 = Another village in this district 2 = Another district in this region

3 = Outside this region 4 = Outside Ghana

Please specify the place if possible……………………….

How many plots of rice farm do you have? [ ]

How often do you cultivate rice?

Every year	Every other year	Most years	Some years

Why did you venture in rice farming? **(open-ended question to derive answers from farmers)**

SECTION B. PRODUCTION AND INPUT USE INFORMATION

Please indicate this information about your rice production during the previous two production years?

Production Year	2020	2021
Number of acres		
Method of Acquisition of Land		
Method of Land Preparation		
Method of Planting of Rice		
Variety of Rice Produced		
Quantity of Seed Used		
How does the farmer sell his/her produce?		

Indicate the reason for change in method of planting, variety of rice produced (if any). **No change is a logical answer**.

Production	2020	2021
Change in the Method of Land Preparation Compared to the Previous Year		
Change in the Method of Planting Rice Compared to the Previous Year		
Change in Variety of Rice Produced from the Previous Year		

Use of selected inputs in rice production over the previous two years

Production	**2020**		**2021**	
	Quantity	**Price (GHC)**	**Quantity**	**Price (GHC)**
Glyphosate (L)				
Selective Herbicide (L)				
Insecticide (L)				
Fungicide (L)				

Please specify the amount and price per acre of each of the following fertilizers used for the previous two years.

Production Year	**2020**		**2021**	
	Quantity	**Price (GHS)**	**Quantity**	**Price (GHS)**
N P K Fertilizer				
Urea 46% Fertilizer				
Ammonia Fertilizer				
Other Types of Fertilizer				
Other Blends of Fertilizer				

Did you use any other inputs which are not indicated above? Please specify and indicate the quantity used and the per unit price. (e.g. catapult, rodenticide, nets etc.)

……………………………………………………………………………………………

For each production activity, please indicate the amount spent per acre for the years indicated in GHS.

	Land Prep	Chemical Spraying	Planting	Fertilizer App	Hand Weeding	Bund Dressing	Bird Scaring	Harvesting	Carting
Year									
2020									
2021									

SECTION C: YIELD AND PRICE INFORMATION

What was your total yield in kilograms for the acreage cultivated for the year below?

Production Year	2020	2021
Yield (bags or kilograms)		

Whom did you sell your produce to during the last two production years?

Year 2020: 1 = GADCO Ltd 2 = Market Women 3=Creditors 4. Others (please specify)

Year 2021: 1 = GADCO Ltd 2 = Market Women 3=Creditors 4. Others (please specify)

How much of your produce did you sell during the 2020 and 2021?

Year 2020: 1 = All 2 = All except what was kept for consumption at home 3 = None was sold.

Year 2021: 1 = All 2 = All except what was kept for consumption at home 3 = None was sold.

What price did you receive per kilogram for paddy rice in the years named below.

Production Year	2020	2021
Price/kg		

What price did you receive per kilogram for paddy rice in the year below.

Production	2020	2021
Price/kg		

SECTION D: FARMER AND FARM CHARACTERISTICS

Is rice farming your only occupation? [ ] 1 = Yes 0 = No (Enumerator: If Yes go to question 4)

If No, what other work(s) do you do apart from rice farming?

…………………………………………………………………………………….

For how many years have you been in rice farming? ………………. Years

What is current rice farm size (acres)? [ ]

Do you have access to improved rice varieties (early maturing or drought resistant)? [ ]1 = Yes 0 = No

Do you have easy access to farm inputs? [ ] 1 = Yes 0 = No

Do you have easy access to credit? [ ] 1 = Yes 0 = No **(If no, go to question 9)**

How much credit did you request for and how much did you actually receive for the following years?

Production Year	2020		2021	
Amount (GHS)	Requested	Received	Requested	Received

Do you have access to extension services? [ ] 1 = Yes 0 = No **(If no, to question 11)**

How many extension visits did you receive during the following production years?

Production	2020	2021
Number of Extension Visits		

Are you a member of an FBO? [ ] 1 = Yes 0 = N

Please provide information on major moveable agricultural assets used during the 2021 production year

Agricultural Asset	**Owned? 1 = Yes 0 = No**	**Number**	**Current Market value (GHS)**
Tractor			
Combine Harvester			
Rotovator			
Power Tiller			
Thresher			
Knapsack Sprayer			
Cutlass and Hoe			

Tarpaulin			
Others			

Did you use mechanization for any production activities during the 2021 production year ? 1 = Yes 0 = No

If no then go to Question 15

If Yes, tick the activities you used mechanization for during the 2021 production year .

Land Preparation	
Planting	
Fertilizer Application	
Agrochemical Spraying	
Weed Control	
Bird Scaring	
Harvesting	
Others	

How would you rate your ability as a manager to deal with the risks involved with the following components of rice production?

Please tick the appropriate answer.

15A LAND PREPARATION

Very high ability	High ability	Moderate ability	Low ability	Very low ability	No ability at all
5	4	3	2	1	0

15B PLANTING

Very high ability	High ability	Moderate ability	Low ability	Very low ability	No ability at all
5	4	3	2	1	0

15C FERTILIZER APPLICATION

Very high ability	High ability	Moderate ability	Low ability	Very low ability	No ability at all
5	4	3	2	1	0

15D WEEDING AND OTHER AGRONOMIC PRACTICES

Very high ability	High ability	Moderate ability	Low ability	Very low ability	No ability at all
5	4	3	2	1	0

15E HARVESTING

Very high ability	High ability	Moderate ability	Low ability	Very low ability	No ability at all
5	4	3	2	1	0

15F MARKETING

Very high ability	High ability	Moderate ability	Low ability	Very low ability	No ability at all
5	4	3	2	1	0

SECTION E: KNOWLEDGE OF GREENHOUSE GAS EMISSIONS AND THEIR IMPACTS

Scientists around the world indicate the earth is warming and this can be observed by increasing temperatures and variability of rainfall and increasing numbers of weather-related extreme events. Do you agree that the earth is warming? Yes No Does not know

If Yes, on a scale of **0 to 5, 0** (not considered as a factor at all), **1** (least important), **2** (less important), **3** (moderately important), **4** (important) and **5** (extremely important), please rate your knowledge on greenhouse gas emissions and their effects on the economy and society

(please circle the most appropriate number in each case).

No	Influencing Factors	Rating Scale					
1	Deforestation and large scale destruction of forests	0	1	2	3	4	5
2	Land clearing and burning of biomass	0	1	2	3	4	5
3	Pollution from cars	0	1	2	3	4	5
4	Improper waste disposal	0	1	2	3	4	5
5	Livestock production	0	1	2	3	4	5
6	Electricity energy generation through thermal power plants	0	1	2	3	4	5
7	Pollution from factories	0	1	2	3	4	5
8							
9							

SECTION F: EMISSIONS OF GREENHOUSE GASES FROM RICE PRODUCTION

On a scale of **0 to 5, 0** (not considered as a factor at all), **1** (least important), **2** (less important), **3** (moderately important), **4** (important) and **5** (extremely important), please rate the importance of the following factors in contributing to the problem of climate change and global warming through the release of greenhouse gases from rice production? *(please circle the most appropriate number in each case).*

No	Influencing Factors	Rating Scale					
1	Land clearing including slash and burn method	0	1	2	3	4	5
2	Land preparation	0	1	2	3	4	5
3	Planting	0	1	2	3	4	5
4	Irrigation and water control	0	1	2	3	4	5
5	Weed control	0	1	2	3	4	5
6	Fertilizer application	0	1	2	3	4	5
7	Harvesting/threshing	0	1	2	3	4	5
8	Processing	0	1	2	3	4	5
9	Waste disposal of rice husks						
10	Rice milling						

11	**Burning of rice straws**						

SECTION G: ADAPTATION MEASURES AND STRATEGIES TO REDU

GREENHOUSE GAS EMISSIONS

On a scale of **0 to 5, 0** (not considered as a factor at all), **1** (least important), **2** (less important), **3** (moderately important), **4** (important) and **5** (extremely important), please rate the importance you attach to undertaking the following adaptation measures to reduce greenhouse gas emissions *(please circle the most appropriate number in each case).*

No	**Influencing Factors**	**Rating Scale**					
1	**Adoption of improved planting materials and seeds** **How does this method help to reduce GHG emissions?**	**0**	**1**	**2**	**3**	**4**	**5**
2	**Soil fertility management** **How does this method help to reduce GHG emissions?**	**0**	**1**	**2**	**3**	**4**	**5**
3	**No till land preparation (zero tillage)** **How does this method help to reduce GHG emissions?**	**0**	**1**	**2**	**3**	**4**	**5**
4	**Conversion of rice husk to animal feed instead of burning them** **How does this method help to reduce GHG emissions?**	**0**	**1**	**2**	**3**	**4**	**5**

5	**Adoption of drought-tolerant rice varieties** **How does this method help to reduce GHG emissions?**	**0**	**1**	**2**	**3**	**4**	**5**
6	**Adoption of early-maturing varieties** **How does this method help to reduce GHG emissions?**	**0**	**1**	**2**	**3**	**4**	**5**
7	**Adoption of agro-ecological farming** **How does this method help to reduce GHG emissions?**	**0**	**1**	**2**	**3**	**4**	**5**
8.							
9							
10							
11							
12							

13							
14							
15							

SECTION G:

CONSTRAINTS TO MANAGEMENT OF GREENHOUSE GASES BY BUSINESS

On a scale of **0 to 5, 0** (not considered as a factor at all), **1** (least important), **2** (less important), **3** (moderately important), **4** (important) and **5** (extremely important), please rate the importance you attach to how the following factors have constrained your adaptation strategies in the management of greenhouse gases *(please circle the most appropriate number in each case).*

No	**Influencing Factors**	**Rating Scale**					
1	**Lack of understanding of effects of greenhouse gas emissions**	**0**	**1**	**2**	**3**	**4**	**5**
2	**Low level of extension officers' contacts**	**0**	**1**	**2**	**3**	**4**	**5**
3	**High labour costs**	**0**	**1**	**2**	**3**	**4**	**5**
4	**Land insecurity**	**0**	**1**	**2**	**3**	**4**	**5**
5	**Low yielding varieties**	**0**	**1**	**2**	**3**	**4**	**5**
6	**Poor soil fertility**	**0**	**1**	**2**	**3**	**4**	**5**
7	**Poor agronomic practices**	**0**	**1**	**2**	**3**	**4**	**5**

8	**Excessive use of agro-chemicals**	**0**	**1**	**2**	**3**	**4**	**5**
9	**High post-harvest losses**	**0**	**1**	**2**	**3**	**4**	**5**
10							
11							

<u>SECTION H: SOCIO-ECONOMIC INFORMATION OF RESPONDENTS</u>

1. Sex: Male [ ] Female [ ]

2. Age: ....

3. Marital Status: Married [ ] Single [ ] Divorced [ ] Widowed [ ] Engaged [ ] Separated [ ] Consensus [ ]

4. Household size

5. Please indicate your religious affiliation (please tick noting possible mixed religious preferences)

African Traditional Religions Only [ ]

African Traditional Religions and Christianity [ ] **Mixed religious preferences**

African Traditional Religions and Muslim [ ] **Mixed religious preferences**

Christian Only [ ]

Muslim Only [ ]

Other Religions (Please specify)…………………………………………

6. Level of Education (current level of education)

Level of Education	Length(Years)	Level of Education	Length(Years)
No Schooling		Technical Institute	
Incomplete Primary		College of Education	

Complete Primary		Bachelor's Degree	
Junior High		Postgraduate Degree	
Senior High		Others	

7. What is the estimated average monthly non-farm income for the following years ended:

December 2020: GHS……………. December 2021: GHS…………….

Use this tabular form as a guide and the interviewer should insert the code at the appropriate places.

0. Zero (0) GH₵ 0.0		16. GH₵1501-GH₵1600	
1. Less than GH₵100	☐	17. GH1601-GH₵1700	☐
2. GH₵100-GH₵200	☐	18.GH₵₵1701- GH₵1800	☐
3. GH₵201- GH₵300	☐	19GH ₵1801-GH₵1900	☐
4. GH₵301-GH₵400	☐	20.GH₵1901-GH₵2000	☐
5. GH₵401-GH₵500	☐	21.GH₵2001-GH₵2100	☐
6.GH₵501-GH₵600	☐	22 GH₵2101-GH₵2200	☐
7. GH₵601- GH₵700	☐	23.GH₵2201- GH₵2300	☐
8. GH₵701-GH₵800	☐	24.GH ₵2301-GH₵2400	☐
9. GH₵801-GH₵900	☐	25.GH₵2401-GH₵2500	☐
10. GH₵901-GH₵1000	☐	26.GH ₵C 2501-GHC2600	☐
11. GH₵1001-GH₵1100	☐	27. GH₵2601-GHC2700	☐
12. GH₵1101-GHC1200	☐	28.GH₵ 2701-GHC 2800	☐
13. GH₵ 1201-GHC1300	☐	29GH₵ 2801-GHC 2900	☐
14. GH₵1301-GHC1400	☐	30.GH₵ 2901-GHC3000	☐
15. GH₵1401-GHC1500	☐	31. GH₵3000- GH₵4000	☐
	☐	32. Over GHC 4000	☐

8. Which tribe or ethnic group do you belong? (refer to Appendix for guidance)

SECTION I: SOCIO-ECONOMIC INFORMATION OF SPOUSE OF RESPONDENTS

1. Sex: Male [ ] Female [ ]

2. Age: ....

3. Marital Status: Married [ ] Single [ ] Divorced [ ] Widowed [ ] Engaged [ ] Separated [ ] Consensus [ ]

4. Household size

5. Please indicate your religious affiliation (please tick noting possible mixed religious preferences)

African Traditional Religions Only [ ]

African Traditional Religions and Christianity [ ] **Mixed religious preferences**

African Traditional Religions and Muslim [ ] **Mixed religious preferences**

Christian Only [ ]

Muslim Only [ ]

6. Level of Education (current level of education)

Level of Education	Length(Years)	Level of Education	Length(Years)
No Schooling		Technical Institute	
Incomplete Primary		College of Education	
Complete Primary		Bachelor's Degree	
Junior High		Postgraduate Degree	
Senior High		Others	

7. What is the estimated average monthly non-farm income for the following years ended:

December 2020: GHS……………. December 2021: GHS…………….

Use this tabular form as a guide

0. Zero (0) GHȻ 0.0
1. Less than GHȻ100
2. GHȻ100-GHȻ200
3. GHȻ201- GHȻ300
4. GHȻ301-GHȻ400
5. GHȻ401-GHȻ500
6. GHȻ501-GHȻ600
7. GHȻ601- GHȻ700

16. GHȻ1501-GHȻ1600
17. GH1601-GHȻ1700
18.GHȻȻ1701- GHȻ1800
19GH Ȼ1801-GHȻ1900
20.GHȻ1901-GHȻ2000
21.GHȻ2001-GHȻ2100
22 GHȻ2101-GHȻ2200
23.GHȻ2201- GHȻ2300

8. GH₵701-GH₵800
9. GH₵801-GH₵900
10. GH₵901-GH₵1000
11. GH₵1001-GH₵1100
12. GH₵1101-GHC1200
13. GH₵ 1201-GHC1300
14. GH₵1301-GHC1400
15. GH₵1401-GHC1500

24.GH ₵2301-GH₵2400
25.GH₵2401-GH₵2500
26.GH ₵C 2501-GHC2600
27. GH₵2601-GHC2700
28.GH₵ 2701-GHC 2800
29GH₵ 2801-GHC 2900
30.GH₵ 2901-GHC3000
31. GH₵3000- GH₵4000
32. Over GHC 4000

8. Which tribe or ethnic group do you belong? (refer to Appendix for guidance)

ETHNICITY CLASSIFICATION

AKAN	GA/ DANGBE	EWE	GUAN	GRUMA	MOLE-DABANI	GRUSI	MANDE	All Others
Agona	Ga		Akpafu, Lolobi, Likpe, Bowiri, Buem, Santrokofi, Akposo	Bimoba	Builsa (Kangyaga or Kanjaga)	Kasena (Paga)	Busanga	
Ahafo	Dangbe		Avatime, Nyongbo, Tafi, Logba	Kokomba	Dagarte (Dagaba), Lobi , Wali (Wala)	Mo	Wangara	
Ahanta	Other Ga-Dangbe		Awutu, Efutu, Senya, Breku	Basare(Kyamba)	Dagomba	Sissala	Others	
Akuapem			Cherepong, Larteh, Anum-Boso	Pilapila	Kusasi	Vagala		
Akwamu			Gonja	Salfalba (Sabulaba)	Mamprusi	Other Grusi (e.g. Lela, Templensi, Birifor, Yangala, Miwo)		
Akyem			Nkonya	Kotokoli	Namnam (Nabdom)			
Aowin			Yeji, Nchumuru, Krachi, Nawuri, Bassa Achode Nkomi, Wiase, Dwan	Chamba (Kyamba)	Nankansi, Talensi & Gurense (Frafra)			
Asante			Other Guan	Other Gurma	Nanumba			
Asen (Assin)					Mosi			
Bono (Banda)					Other Mole-Dagbani			
Bawle								
Chokosi (Anufor)								

Denkyira								
Twifo								
Evalue								
Fante								
Kwahu								
Nzema								
Sefwi								
Wasa								
Other Akan								

APPENDIX 8: EXPECT INTERVIEW

Rice production is a source of GHG (notably N2O and CH4) emissions. A study was conducted in the Volta Region to assess how smallholders were managing emissions in their rice fields. The Research Team (led by Forster Kwame Boateng, PhD Candidate, University of Ghana, Legon Accra) would like to clarify a few things from an extension perspective. The interview will be recorded for academic purposes only and last between 10-15 mins. With your permission, I will proceed with the questions.

(Q1) Does MoFA train Public Extension Agents specifically on how farmers should manage GHG emissions in Rice fields?

Response: NO

(Q2a) If yes to (Q1) what are some of the adaptation measures promoted among Rice Farmers for the past 3years? (Emphasize on Volta Regional Extension Director).

(Q2b) If NO to (Q1), please are there any plans in the pipeline to educate Public Extension Agents on how farmers should manage GHG emissions in rice fields? If yes please explain briefly.

Response:

a) **Yes. The Ministry of Food and Agriculture is collaborating closely with the Ministry of Environment Science, Technology, and Innovation to implement Alternate Wet and Drying (AWD) Technology to maximize water use and reduce greenhouse gas emissions. Sensitization has occurred;**

b) Also, the department of Agricultural Extension Services in collaboration with UNDP has met rice farmers in irrigated fields in Volta Region and Central Region to discuss the AWD Technology in line with GHG emissions. Extension Officer has been selected for training. The training is set to commence soon for Extension Officers and some lead farmers.

(Q3) What are some of the complaints Extension Agents received from Rice Farmers (if any) concerning challenges in managing GHG emissions in rice fields?

Response: Rice farmers complain of yellowing of rice leaves and lodging.

Thank you for your participation.