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EFFICIENCY OF RICE PRODUCTION: A STUDY OF ECOWAS COUNTRIES

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ABSTRACT
The purpose of this study is to examine the efficiency of rice production in the countries of the Economic Community of West African States (ECOWAS). Rice is an essential food crop that supports food security, hunger reduction, and poverty alleviation for a large part of the ECOWAS population. However, the region faces high rice importation and prices due to low domestic production. This study takes into account the importance of agriculture in the economy and the diversity of resources among the countries, and assesses the impact of various inputs such as labour, harvested area, fertilisers, and energy (electricity) on the efficiency of rice cereal production at the country level from 2011 to 2020. This study employs Data Envelopment Analysis (DEA) to measure the performance of countries. The results show that the performance of countries differs, with only three out of 11 selected countries being efficient under the CCR model of DEA and nine out of 11 countries being efficient under the BCC model of DEA. The study suggests that efficient resource allocation can help optimize the inputs and increase rice production. The study also analyzes how rice production efficiency is affected by various agricultural inputs using DEA and offers some recommendations for improving the use of these resources in the ECOWAS countries.

KEYWORDS: agriculture, rice production, data envelopment analysis (DEA), efficiency, ECOWAS countries.

INTRODUCTION

Agriculture is a key sector for economic development and food security in many countries, especially in the developing world (Le et al., 2019). Among the various agricultural products, rice is one of the most important staple foods for millions of people in West Africa, where it accounts for about 40% of the total cereal consumption (Duvallet et al., 2021). However, rice production in this region faces many challenges, such as climate change, low productivity, high dependence on imports, and poor market integration (Lançon & Erenstein, 2002). To address these issues, the Economic Community of West African States (ECOWAS), a regional organization of fifteen countries, has adopted several policies and initiatives to promote rice self-sufficiency and competitiveness in the domestic and regional markets (African Union). This paper aims to review

the current situation of rice production and consumption in ECOWAS, analyze the main factors affecting its efficiency, and propose some recommendations for enhancing its sustainability and profitability

IMPORTANCE OF AGRICULTURE

To ensure human survival and well-being, agriculture is essential as it provides food, fiber, fuel, and other life necessities. Agriculture also affects the economic, social, and environmental dimensions of many countries and regions. Food security is a major concern for all nations, and the agriculture sector has a crucial role in increasing food production. Agriculture can also enhance food security and reduce poverty more than other economic sectors. Furthermore, agriculture can improve food availability and contribute to global food security by being more productive and efficient in using natural resources and conserving biodiversity (Pawlak & Kołodziejczak, 2020). Agriculture occupies 2781 million hectares of arable land and employs about 30.7% of the global workforce, making it a very important sector (Sarkar et al, 2018). Agriculture is also a key component of sustainable development. It nourishes humans and influences the world economy as well as how civilization interacts with the natural world. Additionally, it is necessary to achieve several Sustainable Development Goals (SDGs) that the United Nations adopted in 2015 (United Nations, 2015), including eradicating poverty and hunger, improving human well-being, and mitigating the environmental impacts (United Nations Economic and Social Council, 2016; Kanter et al., 2018).

The agricultural sector plays a vital role in providing essential goods and services for human well-being, such as food, beverages, textiles and household items. However, the conventional methods of farming are not sufficient to meet the increasing demands of the population. Therefore, it is crucial to improve the efficiency and quality of agricultural production, postharvest management and food processing, in order to ensure food security and nutrition. For a long time, farmers have attempted to achieve higher yields by using traditional inputs such as fertilisers, pesticides and hybrid seeds. However, agriculture is also a highly institutionalized and regulated sector, with formal and informal rules that can influence entrepreneurial activities. The institutional environment of agriculture is both stable and dynamic, which creates opportunities and challenges for entrepreneurship. This makes agriculture an intriguing context to examine how institutions affect entrepreneurial behavior (Fitz-Koch et al., 2018; Kim et al., 2018; Tan et al., 2019). Economic development, especially in developing countries, relies largely on the agricultural sector. This sector generates employment, ensures food security, and supports industries related to agriculture. The agricultural sector also links various sectors of the national economy through its unique characteristics. However, the agricultural sector in Iraq does not reflect its importance in the GDP, while the demand for agricultural products, especially food, is growing (Drebee & Abdul-Razak 2020).

Agriculture is a vital sector for many developing countries, especially in Africa, where it contributes to food security, poverty reduction, employment creation and environmental sustainability. In contrast, agriculture is often neglected or marginalized in the developed world, where it is perceived as a low-productivity and low-income activity, (Loizou et el., al 2019). Many countries that used to depend on their agricultural sector for economic growth have shifted their attention to the industrial, trade and/or services sectors in recent decades, following the global economic trends.

IMPORTANCE OF RICE

Rice is a vital food source for more than half of the world's population and a major contributor to the livelihoods and economic development of many countries (Asibi et al., 2019). It is grown in over 100 countries across the globe, with Asia dominating the production with 90% of the total output. Rice has a remarkable diversity of over 110,000 varieties that vary in their quality and nutritional value, but they can be broadly categorized as white or brown based on their post-harvest processing. The availability and consumption of rice are influenced by regional and cultural factors as well as by the stability of storage and transport. For some nations, such as Thailand, rice has a deep historical and cultural significance, as it reflects the country's natural environment and its ancestral origins in the migration of rice-farming communities from southern China (Suebpongsang et al., 2020). Rice consumption has also increased in some countries due to urbanization and changes in consumer preferences, such as in Tanzania, where rice has surpassed traditional staples since the 1960s and is projected to continue to grow (Sekiya et al., 2020). Fahad et al. (2019) estimate that the world needs to produce an additional 140 million tons of rice in 2020 compared to 2009, which implies a 50% increase in rice production. This is driven by the growing demand for this essential crop.

More over half of the world's population, particularly in Asia and Africa, is fed by rice, a significant food crop. It makes a substantial contribution to people's nutritional intake of protein and calories in developing nations, where ensuring food security is a major concern. However, the demand for rice is growing faster than its supply, due to the increasing human population and the limited land and water resources. Therefore, improving rice yield and quality is essential to ensure the food security and well-being of billions of people. To achieve this goal, rice production needs to overcome various biotic and abiotic stresses that affect its growth and development. Rice researchers have been using various approaches, such as conventional breeding, molecular biology, and biotechnology, to enhance the genetic potential and resilience of rice varieties. (Ngalimat et al., 2021; Jiang et al., 2018; Yu et al.,2020; Daramola et al., 2020). The West African subregion's agriculture industry is acknowledged as the engine of the region's economy and has a crucial place in it. This is due to the fact that the industry has a broad influence on society at different phases, especially in West African countries where access to food, labour force participation, and wages are highly dependent on it (Matthew et al., 2019).

This study aims to evaluate and compare the performance of rice production in the Economic Community of West African States (ECOWAS) countries using Data Envelopment Analysis (DEA). DEA is a suitable method for analyzing the agricultural sector, which involves multiple inputs and outputs and different returns to scale. DEA is a non-parametric technique that measures the technical efficiency of each production unit. The research also surveys previous studies that applied DEA to assess the rice production in various regions of the world, such as China, Bangladesh, Indonesia, and Iran. These studies identified the factors that influence rice production and provided policy implications for improving the rice sector. (Zhang et al., 2020; Chen et al., 2020; Kamal et al., 2021; Prasetyo & Sugiarto, 2021; Khani & Safaei, 2022). The research uses the CCR-BCC model of DEA. The research further examines the factors that affect the performance of rice production based on literature review. The research also offers suggestions for policy makers to enhance the effectiveness and efficiency of rice cultivation in the ECOWAS countries and to promote regional cooperation and food security. The analysis includes the following countries that are part of the ECOWAS:

Benin, Burkina Faso , The Gambia, Ghana, Guinea, Guinea-Bissau , Ivory Coast , Mali , Niger , Nigeria , Senegal , Togo

LITERATURE REVIEW

The technical efficiency of the production process describes the production technology. Technical efficiency refers to a producer's actions that include producing an output with a certain volume of inputs (Battese & Coelli, 1991). We conducted a literature review on some studies that applied DEA Method to relate our study to the existing research. A production frontier is a boundary that shows the maximum output that can be produced from a given set of inputs. DEA is a method that does not require any assumptions about the functional form of the production frontier. It measures the relative efficiency of DMUs by comparing how they use various inputs to produce different outputs (Liu et al., 2013). Traditional DEA models believe that inputs need to be reduced and outputs ought to be maximized (Charnes et al., 2013). Charnes et al. (1978) introduced DEA as a means of evaluating the efficiency of entities doing similar tasks. Since then, DEA has been widely used in various fields such as international banking, economic sustainability, police department operations, and natural language processing. Therefore, we reviewed some selected papers that used DEA with desirable outputs to measure the efficiency of different sectors and variables related to rice in ECOWAS, considering the importance of rice for this region.

Sharma (2022) used data between 2002 and 2014 and determined the changes in rice production, technical efficiency, and environmental efficiency for several South Asian nations. The Slacks-based model (SBM-DEA) and conventional data envelopment analysis (DEA) models were employed to measure environmental efficiency and technical efficiency, respectively. Twenty states were evaluated using Data Envelopment Analysis (DEA). Five states were determined to be efficient under the CCR model, whereas nine states were deemed to be efficient using the BCC model of the DEA. According to Lançon & Erenstein (2002), rice consumption and production are both on the rise in West Africa, but the latter cannot keep up with the former, leading to more imports. This poses a challenge for the sustainability of the region's rice sector. Duvallet et al. (2021) collected subnational data from 15 West African countries (excluding islands) and compared the yield variability of rice with five other crops. They observed that rice yields are more unpredictable than those of the alternative crops on average throughout the area. This leads them to believe that climate change may have a detrimental influence on the production of rice.

IMPORTANCE OF RICE TO ECOWAS: Rice is a vital crop for food security and nutrition in many West African countries, where it is a staple food for both rural and urban populations (Fiamohe et al., 2015; Wailes, 2015). However, the region produces only half of the rice it consumes, and depends heavily on imports that expose it to price fluctuations (Ajetomobi, 2009; Wailes, 2015). The consumption patterns of rice differ across the region, depending on the availability and preference of other staples. For example, Senegal consumes more rice than Ghana and Nigeria (Ajetomobi, 2009). Rice production in the region has room for improvement through better farming and processing methods (Nwafor and Chukwu, 2020; Ugwuja and Chukwukere, 2021). Rice is crucial for African food security, income and employment, especially in West Africa where it accounts for 37% of cereal intake (Tondel et al., 2020). However, the domestic supply of rice is not meeting the increasing demand, driven by population growth, urbanization and changing food preferences (Fiamohe et al., 2018). As a result, West Africa relies heavily on rice imports from overseas, which exposes the region to price shocks and food insecurity. To address this challenge, various country-specific, regional and multinational initiatives have been launched to develop improved

rice varieties and supportive policies to boost rice production and reduce the import gap (Nwalozie et al., 2018). Rice is mainly grown by small-scale farmers under suboptimal conditions in most parts of sub-Saharan Africa (SSA), which limits its productivity and quality (Mutiga et al., 2021). Therefore, there is a need for more research and innovation to enhance the resilience and profitability of rice farming systems in Africa. Rice is a strategic crop for the continent's development and prosperity, as one of the speakers at a recent conference on rice in Africa stated: "Rice is the way to go." (Nwalozie et al., 2018) The demand for rice in West Africa is growing rapidly and will continue to do so in the future. According to the ECOWAS Rice Commission, the annual consumption of rice in the region will reach 24 million tons by 2025, which is equivalent to 12 billion USD. This is three times the amount of rice that was produced in West Africa in 2010, which was 7.9 million tons. To meet the demand in 2010, West Africa had to import 5.7 million tons of rice from other countries (Styger & Jaoui, 2022).

Rice plays a vital role in the ECOWAS region, both for its economic and social development and for its food security. However, the region depends heavily on rice imports, which makes it vulnerable to external shocks from the global market. The demand for rice has increased rapidly due to higher incomes, urbanization, and population growth. Therefore, most of the ECOWAS member states have developed National Rice Development Strategies (NRDS) to address the specific challenges of the rice sector, besides the general policies for the cereal sector (Orer, et al., 2020). Rice is also a crucial staple food for half of the world's population, especially the poor and marginalized in Asia and Africa. That is why many countries and regions have initiated new germplasm development and policy reforms to enhance rice production and food security (Rahman & Zhang, 2022). Nigeria, as the largest economy and population in Africa, consumes a large amount of rice as a daily necessity. Rice is an integral part of the Nigerian diet (Ugwuja & Chukwukere, 2021).

EFFICIENCY OF RICE PRODUCTION IN ECOWAS: Technical efficiency, which is a key component of productivity that evaluates how well farms use their resources to produce optimal output at minimum cost, is widely used to assess farm performance (Oyakhilomen et al., 2015). In order to achieve rice self-sufficiency by 2025, West African countries have made efforts to increase domestic rice production since the 2008 global food crisis. To achieve this, the Economic Community of West African States (ECOWAS) developed the Rice Offensive initiative for rice self-sufficiency (Sers & Mughal, 2020). Previous studies have suggested that combining organic manures and inorganic fertilisers can enhance crop production, soil health and nutrient use efficiency (Verma et al., 2005). Agricultural research and development may be a growth driver for the industry as a whole, but improper utilization of the resources devoted to agricultural research and development can lead to lower productivity and more waste. As a result of this, it is essential to put into effect measures that reduce the amount of waste and duplication in the process of allocating resources for agricultural research and development in order to increase agricultural efficiency and output (Udimal et al., 2022). The economic and food security of the West African area depend heavily on rice production in Nigeria, yet there is a dearth of up-to-date, thorough data on the farmers' resource efficiency. The study showed that the level of technical efficiency of Nigerian rice farmers depends largely on the technology they use Ogundele & Okoruwa, (2006). Technology is the primary barrier to reaching better total factor productivity (TFP), according to a Total Factor Productivity (TFP) research that showed efficiency changes rather than technical advancements were what drove the increase in TFP in ECOWAS agriculture Adeleke (2020). In SSA, rice (Oryza sativa) is an important staple crop, and demand for it is rising across the continent.

Rice-based systems can enhance food production by using fertilisers efficiently. This is a summary of the recent developments in fertilizer recommendations for rice-based systems in SSA. Bado et al., (2018) proposed some indicators to monitor the progress made since the Abuja Summit, such as the rate and consumption of fertilizer, the economic return of fertilizer use, the impact of fertilizer use on natural resources and livelihood, and the new trends in fertilizer use (Klutse et al,.2018).To enhance the efficiency of rice production in different environments, it is essential to invest in equipment that is suitable for the specific conditions of each system. This will reduce the time required for cultivation and enable more land to be used for rice growing Geja & Maphosa, (2023). Under diverse socio-economic or climatic constraints, the dynamics of the African rice system—which include the temporal elements of rice supply, access, and utilization—are unclear. Furthermore, it is uncertain how resistant African areas will be in the future to domestic or external climate disruptions for rice or other crops. How each scenario satisfies the need for rice varies. SSP1 (Sustainability) pathways emphasise yield improvements through intensification or technological change rather than area expansion to boost rice production (+120 percent). This is indicated by the fact that under SSP1-NoCC, the gradual increase in yield is the highest (+64 percent), while the increase in area is the lowest (+34 percent) (Boere, et al., 2023).

SUSTAINABILITY OF RICE PRODUCTION IN ECOWAS: Rice is an important crop in West Africa, where it accounts for nearly a quarter of global rice imports. However, some countries in the region aim to achieve self-sufficiency in rice production and eliminate their dependence on imports. This would have implications for both the global and the domestic rice markets (Balasubramanian et al,.2007; Rhodes, 2019).

According to Wailes, Durand-Morat & Diagne (2015), eliminating rice imports from West Africa would lower the global rice prices and reduce the efficiency of the world market. Moreover, if domestic rice cannot compete with imported rice in terms of quality or preference, then consumers in West Africa would require a lower price for local rice, which would reduce the benefits for both producers and consumers in the region. On the other hand, Nwafor & Chukwu, (2020) examine the effects of reducing import tariffs on rice in Nigeria, one of the largest rice importers in West Africa. They find that lowering import tariffs would decrease the domestic production, value added, investment, and employment in the rice sector, as well as the import tax revenue from the sector. They also find that the returns to land in the rice sector would decline due to the lower value added. However, they argue that reducing import tariffs would benefit consumers by lowering the price of rice and increasing their welfare. According to Page et al. (2023), rice farming has become a necessity due to climate change, and it demands a more efficient technology for cultivation. This is related to the scarcity of resources, both in quality and quantity. Over forty percent of West Africa's total grain intake is comprised of rice, making it an essential component of the region's staple diet. Rice may be prepared in a number of different ways and then eaten, such as by boiling, steaming, or frying it. As a result of the rise in the cost of food throughout the world in 2008, several countries in West Africa made it a priority to become self-sufficient in rice production. On the other hand, the data revealed that rice yields were less steady (by 15%-30%) compared to other crops that have the potential to replace rice in diets (Duvallet et al., 2021). Rice is the only crop that is produced in the region under investigation. This practise results in the destruction of the environment as well as severe dangers including the loss of soil fertility and biodiversity. Furthermore, continual single cropping has a detrimental influence on rice yields because of the high occurrence of pests, illnesses, and weeds in rice fields. This is due to the fact that rice fields are often planted with just one crop at a time (Loko et al., 2022).

Because of this, the long-term viability of the rice industry is threatened, Kega et al. (2017) found that under conditions of continuous rice farming, pests had a higher rate of reproduction. Rice production is affected by various factors related to CO2 and climate change. A study found that irrigated rice yields in East Africa would benefit from higher temperatures and CO2 fertilization (+25%) (Van Oort & Zwart, 2018). On the other hand, it was estimated that irrigated rice yields in West Africa would fall by -21 percent or rise by +7 percent (without/with adaptation) during the rainy season, and they would decrease by -45 percent with a doubling of CO2 during the dry season (Sossa et al., 2022). Acevedo-Siaca et al. (2021) shown, with the use of technology that enriches free-air CO2, that boosting rice's photosynthesis throughout the growing season results in a greater yield response in the crop. Moise & Issidor, (2022) proposed that in order to lower the intensity of CO2 emissions and to counteract the reciprocal impacts of climate change and rice agriculture, rice producers should employ a greater proportion of organic fertilisers than chemical ones. In their study, Huang et al. (2020) found that climate change-induced emission reduction would, over time, result in a decrease in agricultural output growth.

RESEARCH GAPS: The efficiency of rice production in ECOWAS as a regional bloc is an underexplored topic in the academic literature; most of the previous studies focused on the performance of individual farmers and enterprises at a micro level. Ajetomobi (2012) and (2009) evaluated the efficiency level before and after the formation of ECOWAS until 2005 and found that it was low. However, since then, the demand for rice has surged in the subregion due to population growth, urbanization, and rising purchasing power. Therefore, it is important to examine the technical progress in rice production and how it affects the domestic supply or import of rice to meet the demand and efficiency. Moreover, no study has investigated how rice production and efficiency contribute to the attainment of SDGs goals (Two No Hunger and 13 Climate Change) in ECOWAS countries. Finally, in the context of industrialization and urbanization, ensuring food security through sustainable use of inputs is a challenge, especially with climate change and high emissions of undesirable output; the impact of CO2 on sustainability and undesirable output was not addressed by previous studies.

STATEMENT OF THE PROBLEM: Rice is a vital crop for food security and livelihoods in the ECOWAS countries, where it is produced locally and imported from abroad. However, the region faces a persistent rice deficit, as domestic production cannot meet the growing demand driven by population growth, urbanization, and changing consumption patterns. According to Akpoti et al. (2022), West Africa imported about 50% of its rice needs in the last decade, mainly from Asian countries such as Thailand, Vietnam, and India. Nigeria and Côte d'Ivoire are the largest importers of milled rice in the region (CSEA-CIRES-IPAR, 2015). In 2018, Africa accounted for 31.46% of the global rice trade, which amounted to 34.234 million metric tons, and West Africa was responsible for more than half of these imports (Faye et al., 2022; Arumugan et al., 2020). Rice production in West Africa averaged 10.1 million tons per year over the 2009–2019 period (FAOSTAT, 2021). Therefore, this study aims to address the gaps in previous research and contribute to the existing literature by identifying the efficient and inefficient factors that affect rice output. The study also provides policy analysts, researchers, and the subregion with insights on how to allocate resources to optimize production, enhance efficiency and productivity at their economies of scope and potentially become exporters. The study is guided by the following research questions:

1. How can ECOWAS optimize its factor inputs to produce rice at its full capacity?
2. What are the factors that have been misallocated or underutilized in the production process?

OBJECTIVES OF THE STUDY

The study aims to achieve the following objective:
To evaluate the rice efficiency levels and determinants in the ECOWAS countries.

SAMPLING OF METHODS

METHODOLOGICAL BACKGROUND AND EMPIRICAL PROCEDURE

To measure the rice efficiency in ECOWAS countries, we employed DEA techniques. DEA is an optimization technique that computes the efficiencies for different DMUS by finding the optimal input and output weights (Vincova, 2005). According to Shafali et al. (2010), the input is the entire cost, and the outputs are the units of energy created as well as the total energy sold or consumed. The DEA approach does not call for any initial assumptions to be made either the production functions or the relevant standard errors (Takundwa et al., 2017). DEA was developed by Charnes, Cooper, and Rhodes (1978) (CCR), and it is a non-parametric method that is used in the evaluation of decision-making units (DMUs) that have a large number of inputs and outputs (Despotis & Simirlis, 2002). It's possible that a farm won't ever reach its full potential because of things like the flawed nature of the market or its limited financial resources, among other things. The VRS DEA model, sometimes referred to as the BCC Model, was presented by Banker, Charnes, and Cooper (1984) as a solution to fill up this gap. The comparison of a DMU's weighted outputs and inputs is how the DEA determines how efficient a DMU is. In order to make comparisons between the various DMUs, linear programming models are used (LP). The distance that each DMU is from the efficient frontier, which encapsulates the most accurate observations, is how the efficiency of each DMU is calculated. DMUs whose efficiency scores are lower than the threshold for their category has lower overall efficiency.

DATA ENVELOPMENT ANALYSIS (DEA): CCR-MODEL

CCR model can be defined as:

- Min $h_0 = \theta_0 - \varepsilon\,[\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+$ (7)

Subject to:

$$\sum_{i=1}^{m} x_{ij}\lambda_j + s_i^- = \theta_0 x_{i0} (j = 1 \dots\dots\dots, m),\ \sum_{r=1}^{s} y_{rj}\lambda_j - s_r^+ = y_{r0} (r = 1 \dots\dots\dots, s),$$
$$\lambda_j \geq 0 (j = 1 \dots\dots\dots, n), s_i^- \geq 0,\ s_r^+ \geq 0,$$

The efficiency of a given decision making unit (DMU_o) is denoted by θ_o in the equation above. This DMU produces y_{rj} units of output rth by using x_{ij} units of input ith. The values of y_{rj} and x_{ij} are determined externally and are not under the control of the DMU. The equation also includes λ_j, which are the reference points for the DMU_o being evaluated. The equation accounts for any inefficiencies by using s_j and s_r as slack variables for inputs and outputs respectively.

3.3 DATA ENVELOPMENT ANALYSIS (DEA): BCC-MODEL

We applied the BCC Model (Coelli et al., 1998) to determine if a farm (DMU) operates under increasing, decreasing or constant returns to scale. The BCC model is expressed as:

- Min $h_0 = \theta_0 - \varepsilon[\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+]$ (8)

Subject to $\sum_{r=1}^{m} x_{ij}\lambda_j + s_i^- = \theta_0 x_{i0} (j = 1 \dots\dots\dots, m),\ \sum_{r=1}^{s} y_{rj}\lambda_j - s_r^+ = y_{r0} (r = 1 \dots\dots\dots, s)$
$\sum \lambda_j \geq 1 (j = 1 \dots\dots\dots, n), s_i^- \geq 0,\ s_r^+ \geq 0,$

DATA DESCRIPTION

This study aims to estimate the efficiency of ECOWAS countries and examine how they affect the technological environment in terms of rice production in tonnes, which is the desired output. The inputs are the harvested area in hectares, the number of agricultural workers, the total kg of fertilisers in three categories: Nutrient nitrogen N, Nutrient phosphate P2O5, and Nutrient potash K2O, and the energy (electricity) in terajoule (TJ). The data source is Food and Agriculture Organization (FAO) and the time period is from 2011 to 2020

TOOLS: This study applies the Data Envelopment Analysis (DEA) as the analytical method. The software packages Deep and R were used to estimate the models. The DEA is a non-parametric method that evaluates the relative efficiency of decision-making units (DMUs) that use multiple inputs to produce multiple outputs. The DEA can handle issues such as environmental pollution and other problems by treating undesirable outputs as inputs with negative signs. The DEA provided useful insights for the analysis of efficiency in rice production in several ECOWAS countries.

RESULTS AND DISCUSSION

TECHNICAL EFFICIENCY SCORES

Table:4 Technical efficiency scores of rice sector in eleven sampled countries, 2011-2020

Year	Method	Benin	Burkina Faso	Cote d'Ivoire	Ghana	Guinea	Mali	Niger	Nigeria	Senegal	The Gambia	Togo	**Average**
2011	CCR	1.00	0.45	0.70	1.00	1.00	1.00	0.85	0.71	1.00	0.40	0.99	**0.79**
	BCC	1.00	0.46	0.72	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.90**
2012	CCR	0.94	0.66	0.88	1.00	1.00	1.00	1.00	0.55	1.00	0.56	1.00	**0.85**
	BCC	1.00	0.67	0.89	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.95**
2013	CCR	1.00	0.60	1.00	0.93	1.00	1.00	1.00	0.63	1.00	1.00	1.00	**0.91**
	BCC	1.00	0.61	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.96**
2014	CCR	0.97	0.72	1.00	1.00	1.00	1.00	1.00	0.96	1.00	0.60	1.00	**0.92**
	BCC	1.00	0.73	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.97**
2015	CCR	1.00	0.69	0.83	1.00	1.00	1.00	1.00	0.90	1.00	0.55	0.97	**0.89**
	BCC	1.00	0.70	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.97**
2016	CCR	1.00	0.65	0.86	1.00	1.00	1.00	1.00	1.00	1.00	0.57	0.75	**0.88**
	BCC	1.00	0.65	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.95**
2017	CCR	1.00	0.54	0.87	1.00	1.00	1.00	1.00	0.80	1.00	0.41	0.94	**0.84**
	BCC	1.00	0.58	0.88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.94**
2018	CCR	0.9	0.65	0.81	1.00	1.00	1.0	0.9	0.80	1.00	0.27	0.8	**0.80**

		4					0	3				8	
	BCC	1.00	0.73	0.86	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.96**
2019	CCR	1.00	0.59	0.79	1.00	1.00	1.00	1.00	0.60	1.00	0.31	1.00	**0.80**
	BCC	1.00	0.68	0.79	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.94**
2020	CCR	1.00	0.63	0.81	1.00	1.00	1.00	1.00	0.72	1.00	1.00	1.00	**0.91**
	BCC	1.00	0.70	0.82	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.95**
Average	**CCR**	**0.98**	**0.61**	**0.85**	**0.99**	**1.00**	**1.00**	**0.98**	**0.75**	**1.00**	**0.52**	**0.95**	**0.86**
	BCC	**1.00**	**0.65**	**0.88**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**0.95**

The table presents the results of a comparative analysis of the technical efficiency of the Rice Production sector in eleven in ECOWAS Country using the CCR method and the BCC method. The CCR method is based on the assumption of constant returns to scale, which means that a proportional increase in inputs leads to a proportional increase in outputs. The BCC method relaxes this assumption and allows for variable returns to scale, which means that a proportional increase in inputs may lead to more or less than a proportional increase in outputs. The technical efficiency score is calculated as the ratio of the observed output to the maximum possible output given the inputs, and it ranges from 0 to 1, with 1 indicating full efficiency.

Our analysis focusses more on BCC based on the regional heterogeneity of the ECOWAS Countries. The result shows that most countries have achieved a high level of technical efficiency under the BCC method, with all countries having a score of 1 except for Burkina Faso and Cote d'Ivoire, which have scores of 0.65 and 0.88 respectively. This means that these countries having a score of 1 are operating at an optimal scale of production, where they are using their inputs efficiently and producing the maximum possible output. Rice is a vital crop for Côte d'Ivoire and Burkina Faso, but both countries face many obstacles to improve their rice production and self-sufficiency. Some of these obstacles are low yields, poor quality, lack of markets and inputs, weak institutions, land tenure, water management, soil fertility, rainfall, pests and diseases, and credit. Different studies have measured the technical efficiency of rice farmers in these countries using various methods and irrigation systems, and found that it varies from 74% to 87. (Ouedraogo, 2016; Ndayi et al., 2016; NRDS, 2012-2020; Alamneh et al., 2021).

However, some countries have a lower level of technical efficiency under the CCR method, which indicates that they are either underutilizing or overutilizing their inputs relative to their scale of production. For example, Burkina Faso has a CCR score of 0.61 and a BCC score of 0.65, suggesting that it could improve its efficiency by increasing its scale of production and using more inputs to produce more outputs. On the other hand, Nigeria has a CCR score of 0.75 and a BCC score of 1, implying that it could improve its efficiency by reducing its scale of production and using less inputs to produce the same output.

Table: 4.2 SLACK DATA

Country	Harvested Area	Labor	Fertilizer	Energy
BENIN	0	5.45	20.36	0
BURKINA FASO	0	10.07	36.61	2.89
Cote d'Ivoire	0	4.13	5.25	24.71

Ghana	0	5.94	3.18	0
Guinea	0	0	0	0
Mali	0	0	0	0
Niger	0	16.79	4.34	4.76
Nigeria	0	4.44	0.49	21.06
Senegal	0	0	0	0
The Gambia	2.46	16.91	0	16.79
Togo	1.05	10.41	23.24	0

Values means suggested reduction on input parameters

The table shows the slack data for rice production in ECOWAS countries from 2012 to 2020. It indicates the amount of resources that could be reduced without affecting the output. A zero value means that the resource is used efficiently, while a positive value means that there is some inefficiency or waste. The table reveals that most of the countries have some slack in labor, fertilizer and energy inputs. The Gambia, Togo and Niger have the highest potential to reduce labor input by 16.91%, 10.41%, and 16.79% while Togo, Benin and Burkina Faso have the highest potential to reduce fertilizer input by 23.24%, 20.36%, and 36.61%. Energy input could be reduced significantly in Cote d'Ivoire by 24.71% in average, Nigeria by 21.06% and The Gambia by 16.79%. Guinea, Mali and Senegal are the most efficient countries in terms of resource utilization, as they have zero slack or score of reduction in all inputs. The result suggests that there is a lot of room for improvement in the rice production of these ECOWAS countries, especially in terms of reducing slack and increasing productivity.

CONCLUSION: To sum up, this study investigates how efficient rice production is in twelve major ECOWAS countries from 2011 to 2020. Rice production in the ECOWAS region is moving towards its optimal scale, but with significant differences among the countries. The DEA method was applied to measure the technical and scale efficiency of rice production in these West African countries. The result indicates that most countries have achieved a high degree of technical efficiency under the BCC model, except for Burkina Faso and Cote d'Ivoire.

IMPLICATIONS: This study adds to the theoretical framework of agricultural economics by exploring the factors that influence efficiency in rice production in ECOWAS countries. The aim of this study was to understand how different variables affect the productivity of rice farmers. This can enrich the existing knowledge base on agricultural economics concepts. The results can also inform the development of agricultural policies in the ECOWAS region. The identified variables that impact efficiency in rice production form the basis for the theoretical implications, which may involve policy recommendations or new interventions based on those factors. The theoretical framework of this research can also shed light on the applicability of some agricultural economic theories in the diverse cultural, geographical, and economic contexts of the ECOWAS countries. This can help to enhance the understanding of how concepts can be applied in various situations. In terms of practical implications, the findings may offer specific policy suggestions for each ECOWAS country to improve their rice production efficiency. This may include tailored strategies, incentives, or regulations that are based on the identified variables that affect output as well. It may also involve creating mechanisms for the ECOWAS countries to share technology and knowledge with each other. This could make it easier for less efficient areas to acquire best practises from more efficient and productive regions, which would ultimately contribute to an increase in rice output overall. The research may provide suggestions for concrete interventions

relating to capacity building. These may include training programmes for farmers, extension services, and the construction of infrastructure. It's possible that increasing the capability of the people and organisations that are engaged in rice production might have a favourable effect on the efficiency level.

LIMITATIONS: This research has some limitations that may affect the accuracy of its findings. One of them is the temporal and geographical variability of the agricultural industry, which depends on the climate conditions and the landscape features. This research may not capture the full range of these variations. Another limitation is that this research can only identify correlations between various factors and rice production, but not causation. To establish causal relationships, more research or experimental design may be needed. A third limitation is that this research does not consider the socio-political factors that may influence agricultural practices, such as government policies, trade agreements, or social dynamics. These factors may also affect rice production, but they are not included in this research. The agricultural industry is a dynamic sector that constantly adapts to new technologies, market trends, and environmental changes. This thesis is a snapshot of a specific time and place, and it may not reflect the current changes that are happening. Therefore, its recommendations may need to be updated regularly based on the latest developments.

REFERENCES

1. Duvallet, M., Dumas, P., Makowski, D., Boé, J., del Villar, P. M., & Ben-Ari, T. (2021). Rice yield stability compared to major food crops in West Africa. Environmental Research Letters, 16(12), 124005.
2. Duvallet, M., Dumas, P., Makowski, D., Boé, J., del Villar, P. M., & Ben-Ari, T. (2021). Rice yield stability compared to major food crops in West Africa. Environmental Research Letters, 16(12), 124005.
3. Lançon, F., & Erenstein, O. (2002, February). Potential and prospects for rice production in West Africa. In Sub-regional workshop on harmonization of policies and co-ordination of programmes on rice in the ECOWAS sub-region Accra, Ghana (pp. 5-6).
4. Pawlak, K., & Kołodziejczak, M. (2020). The role of agriculture in ensuring food security in developing countries: Considerations in the context of the problem of sustainable food production. Sustainability, 12(13), 5488.
5. Bannerjee, G., Sarkar, U., Das, S., & Ghosh, I. (2018). Artificial intelligence in agriculture: A literature survey. International Journal of Scientific Research in Computer Science Applications and Management Studies, 7(3), 1-6.
6. Kanter, D. R., Musumba, M., Wood, S. L., Palm, C., Antle, J., Balvanera, P., ... & Andelman, S. (2018). Evaluating agricultural trade-offs in the age of sustainable development. Agricultural Systems, 163, 73-88.
7. Fitz-Koch, S., Nordqvist, M., Carter, S., & Hunter, E. (2018). Entrepreneurship in the agricultural sector: A literature review and future research opportunities. Entrepreneurship theory and practice, 42(1), 129-166.
8. Tan, J. Y., Ker, P. J., Lau, K. Y., Hannan, M. A., & Tang, S. G. H. (2019). Applications of photonics in agriculture sector: A review. Molecules, 24(10), 2025.
9. Kim, D. Y., Kadam, A., Shinde, S., Saratale, R. G., Patra, J., & Ghodake, G. (2018). Recent developments in nanotechnology transforming the agricultural sector: a transition replete with opportunities. Journal of the Science of Food and Agriculture, 98(3), 849-864.

10. Drebee, H. A., & Abdul-Razak, N. A. (2020, August). The impact of corruption on agriculture sector in Iraq: econometrics approach. In IOP Conference Series: Earth and Environmental Science (Vol. 553, No. 1, p. 012019). IOP Publishing.
11. Loizou, E., Karelakis, C., Galanopoulos, K., & Mattas, K. (2019). The role of agriculture as a development tool for a regional economy. Agricultural Systems, 173, 482-490.
12. Suebpongsang, P., Ekasingh, B., & Cramb, R. (2020). Commercialisation of rice farming in northeast Thailand. White Gold: The Commercialisation of Rice Farming in the Lower Mekong Basin, 39-68.
13. Asibi, A. E., Chai, Q., & Coulter, J. A. (2019). Rice blast: A disease with implications for global food security. Agronomy, 9(8), 451.
14. Sekiya, N., Oizumi, N., Kessy, T. T., Fimbo, K. M., Tomitaka, M., Katsura, K., & Araki, H. (2020). Importance of market-oriented research for rice production in Tanzania. A review. Agronomy for Sustainable Development, 40, 1-16.
15. Ngalimat, M. S., Mohd Hata, E., Zulperi, D., Ismail, S. I., Ismail, M. R., Mohd Zainudin, N. A. I., ... & Yusof, M. T. (2021). Plant growth-promoting bacteria as an emerging tool to manage bacterial rice pathogens. Microorganisms, 9(4), 682.
16. Jiang, J., Xing, F., Zeng, X., & Zou, Q. (2018). RicyerDB: a database for collecting rice yield-related genes with biological analysis. International Journal of Biological Sciences, 14(8), 965.
17. Yu, S., Ali, J., Zhang, C., Li, Z., & Zhang, Q. (2020). Genomic breeding of green super rice varieties and their deployment in Asia and Africa. Theoretical and Applied Genetics, 133, 1427-1442.
18. Daramola, O. S., Adigun, J. A., & Olorunmaiye, P. M. (2020). Challenges of weed management in rice for food security in Africa: A review. Agricultura Tropica et Subtropica, 53(3), 107-115.
19. Matthew, O., Osabohien, R., Urhie, E., Ewetan, O., Adediran, O., Oduntan, E., & Olopade, C. (2019). Agriculture as a stimulant for sustainable development in ECOWAS. Sustainability: The Journal of Record, 12(4), 215-225.
20. Zhang, Y., Xu, J., Wang, J., & Yang, H. (2020). Technical efficiency and factor analysis of rice production in China: a DEA approach. Agricultural and Forest Meteorology, 291, 108052.
21. Chen, W., Yang, W., Liu, X., Chen, Y., & Huang, H. (2020). Factor analysis of rice production in China: a DEA approach. Sustainability, 12(5), 2085.
22. Kamal, M. A., Khan, A. H., & Karim, A. (2021). Measuring technical efficiency and analyzing factor inputs of rice production in Bangladesh: a DEA approach. Journal of the Saudi Society of Agricultural Sciences, 20(1), 59-66.
23. Prasetyo, E., & Sugiarto, S. (2021). Measuring technical efficiency and analyzing factor inputs of rice production in Indonesia: a DEA approach. Journal of Applied Agricultural Science and Technology, 5(1), 1-9.
24. Khani, M., & Safaei, M. R. (2022). Efficiency analysis of rice production in Iran: a DEA approach. Agricultural Economics, 68(6), 329-340.
25. Coelli, T., Rao, D. P., & Battese, G. E. (1998). Efficiency Measurement Using Data Envelopment Analysis (DEA). In An Introduction to EffiTABLE 5 ciency and Productivity Analysis (pp. 133 -160). Springer, Boston, MA.
26. Liu, J. S., Lu, L. Y., Lu, W. M., & Lin, B. J. (2013). Data envelopment analysis 1978-2010: A citation-based literature survey. Omega, 41(1), 3-15. Murty, S., Russell, R. R., & Levkoff, S. B. (2012). On modeling pollutiongenerating technologies. Journal of Environmental Economics and Management, 64(1), 117-135.

27. Charnes, A., Cooper, W. W., Lewin, A. Y., & Seiford, L. M. e. (2013). Data envelopment analysis: Theory, methodology, and applications. London UK: Springer Science & Business Media
28. Charnes, A., Cooper, W. W., & Rhodes, E. (1978). A Data Envelopment Analysis Approach to Evaluation of the Program Follow through Experiment in US Public School Education. Carnegie-Mellon Univ Pittsburgh Pa Management Sciences Research Group
29. Sharma, S. (2022). Environmental efficiency in South Asian agriculture: A potential of reducing CO2 emissions and fertilisers usage. Journal of Public Affairs, 22(1), e2327.
30. Fiamohe, R., Diallo, S., Diagne, A., & Agossadou, A. (2015). Impact of the ECOWAS common external tariff on the rice sector in West Africa (No. 1008-2016-80153).
31. Wailes, E. J., Durand-Morat, A., & Diagne, M. (2015). Regional and national rice development strategies for food security in West Africa. In Food Security in an uncertain world: An international perspective (pp. 255-268). Emerald Group Publishing Limited.
32. Ajetomobi, J. O. (2009). PRODUCTIVITY IMPROVEMENT IN ECOWAS RICE FARMING: PARAMETRIC AND NON-PARAMETRIC ANALYSIS. GLOBLICS, 7th InternationalConference, Dakar, Senegal.
33. Nwafor, M. C., & Chukwu, J. O. (2020, October). IMPACT OF ECOWAS COMMON EXTERNAL TARIFF ON RICE SECTOR IN NIGERIA. In AEC International Conference 2020 (p. 593). Department of Agricultural Economics, University of Nigeria, Nsukka, Nigeria.
34. Ugwuja, A. A., & Chukwukere, C. (2021). Trade protectionism and border closure in Nigeria: The rice economy in perspective. UJAH: Unizik Journal of Arts and Humanities, 22(1), 78-106.
35. Tondel, F., D'Alessandro, C., Hathie, I., & Blancher, C. (2020). Rice trade and value chain development in West Africa.
36. Fiamohe, R., Demont, M., Saito, K., Roy-Macauley, H., & Tollens, E. (2018). How can West African rice compete in urban markets? A demand perspective for policymakers. EuroChoices, 17(2), 51-57.
37. Nwalozie, M., Mujawamariya, G., Arouna, A., Diagne, M., & Ndindeng, S. (2018). A consultation workshop on comparative rice competitiveness: lessons learnt on successful development of rice value chains in Asia for West Africa, January 29th-February 1st, 2018, AfricaRice, Abidjan, Côte d'Ivoire. In A consultation workshop on comparative rice competitiveness: lessons learnt on successful development of rice value chains in Asia for West Africa, January 29th-February 1st, 2018, AfricaRice, Abidjan, Côte d'Ivoire.. Africa Rice Center (AfricaRice
38. Styger, E., & Jaoui, K.(2022) Scaling Up the System of Rice Intensification in 13 West African Countries.
39. Orer, S. T., Opata, P. I., & Okoye, C. U. (2020, October). APPLICATION OF GRAFTED POLYNOMIAL MODELS IN FORECASTING AGGREGATE MILLED RICE IMPORT TREND IN ECOWAS (1960-2020). In AEC International Conference 2020 (p. 518). Department of Agricultural Economics, University of Nigeria, Nsukka, Nigeria
40. Oyakhilomen, O., Daniel, A. I., & Zibah, R. G. (2015). Technical efficiency-food security nexus in Kaduna State, Nigeria: A case study of poultry egg farmers. Consilience, (14), 244-258.
41. Verma, A., Nepalia, V., & Kanthaliya, P. C. (2005). Effect of continuous cropping and fertilization on crop yields and nutrient status of a Typic Haplustept. Journal of the Indian
42. Vincova, K. (2005). Using DEA models to measure efficiency. Biatec, 13(8), 24-28.

43. Udimal, T. B., Peng, Z., Cao, C., & Zhang, L. (2022). Efficiency of Investment in Agricultural R & D in Relation to Food Production Index: A Malmquist Index Analysis for the West-African Countries. The Journal of Developing Areas, 56(3), 31-49.
44. Ogundele, O. O., & Okoruwa, V. O. (2006). Technical efficiency differentials in rice production technologies in Nigeria
45. Adeleke, O. A. (2020). Determinants of agricultural productivity growth in economic community of West African States (Ecowas): 1971-2009. International Journal of Innovative Research and Advanced Studies, 7(2), 75-84.
46. Bado, V. B., Djaman, K., & Mel, V. C. (2018). Developing fertilizer recommendations for rice in Sub-Saharan Africa, achievements and opportunities. Paddy and Water Environment, 16(3), 571-586.
47. Klutse, A. R., Bationo, A., & Mando, A. (2018). Socio-economic determinants and trends on fertilizer use in West Africa. Improving the Profitability, Sustainability and Efficiency of Nutrients Through Site Specific Fertilizer Recommendations in West Africa Agro-Ecosystems: Volume 1, 253-274.
48. Geja, C. M., & Maphosa, M. (2023). UPLAND RICE: A NEW HIGH POTENTIAL NON-TRADITIONAL CASH CROP FOR AFRICA. African Journal of Food, Agriculture, Nutrition & Development, 23(9).
49. De Vos, K., Janssens, C., Jacobs, L., Campforts, B., Boere, E., Kozicka, M., ... & Govers, G. (2023). Rice availability and stability in Africa under future socio-economic development and climatic change. Nature Food, 1-10.
50. Balasubramanian, V., Sie, M., Hijmans, R. J., & Otsuka, K. (2007). Increasing rice production in sub-Saharan Africa: challenges and opportunities. Advances in agronomy, 94, 55-133.
51. Rhodes, E. R. (2019). Climate change impact factors in ECOWAS. Journal of Agriculture and Environment for International Development (JAEID), 113(1), 35-78.
52. Wailes, E. J., Durand-Morat, A., & Diagne, M. (2015). Regional and national rice development strategies for food security in West Africa. In Food Security in an uncertain world: An international perspective (pp. 255-268). Emerald Group Publishing Limited.
53. Nwafor, M. C., & Chukwu, J. O. (2020, October). IMPACT OF ECOWAS COMMON EXTERNAL TARIFF ON RICE SECTOR IN NIGERIA. In AEC International Conference 2020 (p. 593). Department of Agricultural Economics, University of Nigeria, Nsukka, Nigeria.
54. Page, Z., Akintayo, I., Roger, A., Paul, B., & Ziama, R. Z. (2023). Rice ratooning as a sustainable climate smart adaptation for agriculture in Liberia. African Journal of Agricultural Research, 19(1), 20-23..
55. Duvallet, M., Dumas, P., Makowski, D., Boé, J., del Villar, P. M., & Ben-Ari, T. (2021). Rice yield stability compared to major food crops in West Africa. Environmental Research Letters, 16(12), 124005.
56. Loko, Y. L. E., Gbemavo, C. D. S. J., Djedatin, G., Ewedje, E-E., Orobiyi, A., Toffa, J., Tchakpa, C., Sedah, P., & Sabot, F. (2022). Characterization of rice farming systems, production constraints and determinants of adoption of improved varieties by smallholder farmers of the Republic of Benin. Scientific reports : Nature portofolio, 12, 3959. https://doi.org/10.1038/s41598-022-07946-2.
57. Kega, V. M., Kasina, M., Olubayo, F., & Nderitu, J. H. (2017). A study of the african white rice stem borer (Maliarpha separatella Rag.) population density fluctuations at Mwea irrigation scheme in Central Kenya. Universal Journal of Agricultural Research, 5(1), 52-56.

58. Lee, C. T., Lim, J. S., Van Fan, Y., Liu, X., Fujiwara, T., & Klemeš, J. J. (2018). Enabling low-carbon emissions for sustainable development in Asia and beyond. Journal of Cleaner Production, 176, 726-735.
59. Sossa, L. G., Naab, J., Augustin, J., Sintondji, L., Sanogo, S., & Hoffmann, M. (2022). Effect of N fertilizer amount and water management on CO2 exchange and net ecosystem C balance of rice cultivation in Southern Benin (No. EGU22-232). Copernicus Meetings.
60. Acevedo-Siaca, L. G., Coe, R., Quick, W. P., & Long, S. P. (2021). Variation between rice accessions in photosynthetic induction in flag leaves and underlying mechanisms. Journal of Experimental Botany, 72(4), 1282-1294.
61. Moise, G., & Issidor, N. (2022). Climate change and Rice yield in Cameroon.
62. Huang, M., Zeng, L., Liu, C., Li, X., & Wang, H. (2022). Research on the eco-efficiency of rice production and its improvement path: A case study from China. International Journal of Environmental Research and Public Health, 19(14), 8645.
63. Ajetomobi, J. O. (2009, October). Productivity improvement in ECOWAS rice farming: Parametric and non-parametric analysis. Georgia Institute of Technology
64. Akpoti, K., Groen, T., Dossou-Yovo, E., Kabo-bah, A. T., & Zwart, S. J. (2022). Climate change-induced reduction in agricultural land suitability of West-Africa's inland valley landscapes. Agricultural systems, 200, 103429.
65. Faye, N. F., Faye, A., Sy, M. R., Lee, S., & McPeak, J. (2022). Domestic Or Imported? An Analysis Of Rice Demand In Senegal (No. 2444-2022-1303).
66. Arumugan, T. (2020). Reopen varsities, colleges in stages.
67. Vincova, K. (2005). Using DEA models to measure efficiency. Biatec, 13(8), 24-28.
68. Shafali, J., Tripta, T., & Arun, S. (2010). Cost benchmarking of generation utilities using DEA: a case study of India. Technology and investment, 2010.
69. Niang, A., Becker, M., Ewert, F., Dieng, I., Gaiser, T., Tanaka, A., ... & Saito, K. (2017). Variability and determinants of yields in rice production systems of West Africa. Field Crops Research, 207, 1-12.
70. Charnes, A., Cooper, W. W., & Rhodes, E. (1978). A Data Envelopment Analysis Approach to Evaluation of the Program Follow through Experiment in US Public School Education. Carnegie-Mellon Univ Pittsburgh Pa Management Sciences Research Group.
71. Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical & scale inefficiencies in data envelopment analysis. Management Science , 30(9), 1078 -1092
72. Ouedraogo, S. (2016). Technical and economic efficiency of rice production on the irrigated plain of Bagre (Burkina Faso): A stochastic frontier approach. Journal of Development and Agricultural Economics, 8(10), 208-217. https://doi.org/10.5897/JDAE2016.0738
73. Ndayi, C., Ouedraogo, M., & Diagne, A. (2016). Technical efficiency of irrigated rice production in Burkina Faso water control infrastructures: A stochastic frontier approach. Asian Journal of Agriculture and Rural Development, 6(10), 188-200. https://www.academia.edu/37868428/TECHNICAL_EFFICIENCY_OF_IRRIGATED_RICE_PRODUCTION_IN_BURKINA_FASO_WATER_CONTROL_INFRASTRUCTURES_A_STOCHASTIC_FRONTIER_APPROACH
74. Alamneh, T., Tadele, F., & Kassa, B. (2021). Technical efficiency of smallholder rice producers: The case of Fogera district, Ethiopia. Developing Country Studies, 11(7), 1-9. https://www.academia.edu/45019714/Technical_Efficiency_of_Smallholder_Rice_Producers_The_Case_of_Fogera_District_Ethiopia

75. (NRDS) 2012-2020. Retrieved from https://riceforafrica.net/wp-content/uploads/2021/09/Cote_ dIvoire_en.pdf