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A comparison of the use of diesel and solar energy in threshing and milling of maize: A case study of Oyo state, Nigeria

Oluwabukonla Mercy Nana
International Environmental Sciences

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nanabukonla@gmail.com

Noragric
Department of International Environment and Development Studies
The Faculty of Landscape and Society
P.O. Box 5003
N-1432 Ås
Norway
Tel.: +47 67 23 00 00
Internet: https://www.nmbu.no/fakultet/landsam/institutt/noragric

Declarations

I, Oluwabukonla Mercy Nana, declare that this thesis is a result of my research investigations and findings. Sources of information other than my own have been acknowledged and a reference list has been added. This work has not been previously submitted to any other university for the award of any type of academic degree.

Signature..................................

Date………………………………

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ABSTRACT

The increasing demand for sustainable and efficient agricultural practices calls for the exploration of alternative energy sources in the agricultural mechanization value chain. This study aims to compare the utilization of diesel and solar energy in the threshing and milling operations of maize in Oyo state, Nigeria. Focusing on the potential to replace conventional energy sources, determining energy demand in threshing and milling, and examining how the adoption of solar energy can replace fossil energy in these operations. The research was conducted in the south-western Nigerian state of Oyo, with 90 maize farmers, 9 maize-mill operators, and 9 maize thresher operators participating in the study.

Through a comprehensive analysis of survey data and statistical calculations, the study reveals significant findings. It demonstrates that solar energy can replace conventional energy sources in threshing and milling. The research identifies barriers to the adoption of solar energy, including lack of government support, high installation costs, and the cost of electricity. However, the study also highlights the environmental benefits of solar energy, as emissions resulting from diesel-powered operations were found to be 195 kg (0.195 tons).

The analysis of energy demand demonstrated that the average energy consumption for threshing operations was 0.005 liters per kilogram (kg) of maize, while for milling operations, it was 0.014 liters per kg. The total fuel cost for running these operations using diesel was found to be 2,382,445 Naira. In contrast, the computation presented the aggregate expense of solar panel installation for the same operations, which amounted to 2,442,000 Naira (including the initial cost of solar panels and installation). Although the upfront cost for solar panels was slightly higher than the annual fuel cost, further evaluation highlighted the long-term advantages and cost savings associated with solar energy.
Furthermore, considering the prevailing diesel price in Nigeria (828 Naira per liter) and the electricity price from the national grid (70 Naira per kilowatt-hour), the study compared the annual costs of using diesel and solar energy. The analysis indicated that the cost of electricity from the national grid for the energy demand of the operations (calculated at 28770 kWh with a 20% energy loss) amounted to approximately 1,000,000 Naira. Electricity from the grid is also an environmentally friendly option as this energy is produced from hydroelectric power plants. It therefore seems interesting to use electricity from the grid rather than to use diesel to run the threshers and mills

The study recommends collaborative efforts between policymakers, renewable energy companies, and agricultural stakeholders to address the identified barriers. Financial support, such as subsidies and grants, should be provided to assist farmers and operators in the initial investment of solar panels and installation costs. Awareness programs should also be conducted to educate the agricultural community about the advantages of solar energy.
Additionally, future research should focus on technological advancements specific to solar energy in the agricultural sector, including improving the efficiency of solar-powered machinery, developing cost-effective storage solutions, and optimizing energy distribution.

Keywords: Solar energy, Renewable energy, Threshing, Milling

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CHAPTER ONE

INTRODUCTION

1.0 Introduction

Energy is the backbone of the modern world in terms of economic growth. Energy accessibility is essential for a nation's economic growth as well as development, quality of life, and wealth creation. The daily consumption of crude oil has climbed to 85 million barrels due to the sharp rise in global energy demands (National Master, 2010). Due to the ensuing rise in pollution levels, international environmental organizations have expressed grave concerns about the need to minimize the consumption of fossil fuels (Hyun Lee, 2015). Therefore, in order to ensure energy security, government authorities may stop relying on oil imports and start investing in renewable technologies such as solar, wind, and biofuels (Wang, 2008).

Agriculture utilizes a lot of energy for various agricultural activities. In the majority of the world, the agricultural mechanization value chain system is susceptible to a wide range of dangers and uncertainties because various agricultural machinery for crop production, harvesting, post harvesting, storage, processing, packing and distribution of food crops to a considerable degree are highly dependent on fossil fuel inputs. Also, given that the production and processing of food is strongly dependent on the use of fossil fuels and that the agri-food sector is responsible for over 20% of global greenhouse gas (GHG) emission, and in turn accelerate climate change (FAO, 2011); it is known that fuel wood, charcoal marking, burning crop and savannah residues in open fields, and burning diesel fuel all generate other local air pollutants such as black carbon, which has short-lived climate-altering effect. Therefore, a shift to a cleaner agricultural mechanization value chain is crucial.

The sun is the most abundant source of energy. Solar energy continues to be the best option when compared to other renewable sources because of its wide availability and high efficacy (Kim et al., 2010). This is because the sun emits a tremendous amount of energy every day. It radiates more energy per day than the entire planet uses in a year. The sun is also the source of numerous other types of energy in addition to providing a significant quantity of energy itself. We can harness other sources of energy by the use of the sun. For instance, the wind is created by solar energy, which enables us to employ wind turbines to convert kinetic energy into electricity; the process of photosynthesis in plants uses sun energy. The sun is where biomass may trace its energy origin. Even fossil fuels get their initial energy from the sun.

Renewable energy, especially solar, can address many concerns related to fossil energy use in the agricultural mechanization value chain. It produces little or no environmental emissions and does not rely on imported fuels. For instance, one of the most popular and practical uses of solar energy is drying grain and crops in the sun. Although the old-fashioned method of drying crops in vast, open fields is affordable and hassle-free, there are many drawbacks to it, including damage from dust, wind, rain, rodents, and birds. Different researchers have developed a variety of sophisticated designs of solar dryers for better finished goods (Abur et al., 2014). Compared to the traditional open-air method, these dryers reduce losses; produce a more uniform and quick drying process and safeguard fruit and grain from damage (Vidya Sagar Raju et al., 2013). Solar energy utilization in agriculture can increase self-sufficiency, cut costs, and lessen pollution. Solar energy lowers the cost of power by reducing consumption (Babatunde, et.al, 2019). The benefits of solar energy in agricultural applications amongst others include the following: Low cost of farm operations due to the removal of fossil fuels, low maintenance rate, effectiveness of farm activities, clean energy source that prevents gas emissions whilst ensuring environmental protection (Chel and Kaushik, 2011).

Purohit et al., (2006) on the basis of specific computed results and discussions performed a cost comparison of sun drying with open-air drying. Additionally, they unveiled that high cost solar powered drying systems were more financially viable for cash crops (such as coffee beans, cardamom, tea, etc) and expensive solar drying systems appeared more financially viable for perishable goods (such as fruits and vegetables). Hence, the adoption of solar as a renewable energy source to the agricultural mechanization value chain will create a milestone to the economy.

1.1 Problem statement

Mechanization is a component of agricultural productivity. Low yields compared to international standards, an inconsistent output supplies in terms of quantity and quality – particularly due to problems such as; lack of fossil fuels availability, diesel price, distance from gas stations to farm area, poor farm-to-market transportation and erratic electrical supply all result in higher investments, capital costs, running and operational costs of agricultural mechanization per unit output, which significantly lowers the profitability of most cash crops. Yet, present agricultural practices and mechanisms that strive to maximize yield are still extremely dependent on the use of fossil energy (Johansson et al., 2012). Also, the concern about climate change is proliferating and is regularly discussed among climate variability domains. The operations of significant sectors including agriculture and other industrial activities are held responsible for the growing climate change (Pardoe et al., 2018). Therefore, building resilience to the effects of climate change and controlling emissions of greenhouse gasses from agriculture is crucial. By using innovative and sustainable farming practices to ensure farm-level resilience against climatic changes, the agricultural sector can make a significant contribution to combating climate change.

Conversely, the adoption of renewable energy technologies in agricultural activities offers a promising potential in terms of addressing trade-offs and optimizing synergies between water, energy, food security and climate change for a sustainable agriculture (Babatunde, 2019).

Renewable energy is produced by utilizing naturally replenishable resources. The use of renewable energy technology does not increase emissions or the exploitation of natural resources. Potentially, renewable energy can offer solutions to the different issues in the agricultural component such as the agricultural mechanization value chain, making it both efficient and sustainable. Hence, the objective is to study to what extent can the use of solar energy as a renewable energy source in the agriculture mechanization value chain mitigate climate change, raise output and profitability, boost agricultural economy, and lower the worldwide proportion of GHG emissions and air pollution.

1.2 Objectives

The aim of this research is to evaluate how solar energy can be adopted in the agricultural mechanization value chain as a renewable energy source. Within this framework, I will also research the operating cost of using conventional energy sources in comparison to solar energy.

1.2.1 Specific Objectives

1. To evaluate how much of conventional energy supply can be replaced with solar energy.
2. To determine the energy demand in threshing and milling.
3. Assess constraints to adoption of solar energy in the post-harvest operations.

1.3 Research Questions

1. What is the energy demand in threshing and milling in maize production in Western Nigeria?
2. How much energy can be produced by solar cells for these operations, and at which cost?

3. Can solar energy replace fossil energy for threshing and milling: a socio-economic assessment
4. What are the constraints for replacing fossil fuel with solar energy in the cereal value chain?
5. What are the feasibility and long term sustainability implications of implementing solar energy solutions into agricultural mechanization value chain?

1.4 Theoretical Framework

Agricultural mechanization has a key role in the development process of sustainable production intensification as well as the value chain. The framework for this study will be drawn from FAO's sustainable agricultural mechanization framework for Africa. Specifically, this study will look at the mechanization processes involved in farm operations across the agricultural value chain and how solar energy can be used as a renewable energy source.

The concept of Agricultural mechanization can be defined as "…*the application of tools, implements and powered machinery and equipment to achieve agricultural production, comprising both crop and livestock production as well as aquaculture and apiculture"* (FAO, 2018). The value chain approach is an important framework for examining the different changes that occur along agricultural operations. It links the steps a product takes from the farmer to the consumer: With the inclusion of steps like inputs from suppliers, processors e.t.c (Olife et al., 2013)

In relation to the study crop, Agricultural value chain cuts across land preparation, sowing, weeding, pest control production, harvesting, post harvest handling (decortication, pounding, dehulling, parboiling, milling), storage, processing, packaging and transportation. For example, at production level, the key operational unit for increasing productivity of both land and labour is mechanization. Machinery efficiently prepares the land for planting as well as ensuring that other operations like seed sowing, weeding, fertilizer application and irrigation are effective (Breuer et al., 2015). At the processing stage, quality assurance is ensured using correct technology. Adequate machineries are required to process agricultural commodities: to grind, fry, bake, and extrude (Breuer et al., 2015).

CHAPTER TWO

LITERATURE REVIEW

2.0 Background

2.1 Environment and geography of Nigeria

Nigeria is a West African nation situated along the Atlantic coastline. The climates in Nigeria range from dry to humid equatorial, demonstrating the country's varied topography. While the temperature and humidity in the northern region experiences significant seasonal variations, the southern region exhibits a relatively stable pattern throughout the year. Throughout the year, the degrees range from 32 degrees (Max) to 22 degrees (Min). On a broader perspective, the northern regions exhibit relatively elevated mean maximum temperature (Ajayi et al., 2023).

According to Corral et al., (2017), agriculture serves as a primary catalyst for the economies of several Sub-Saharan African (SSA) nations. It fosters the growth of rural areas in a way that is sustainable and contributes to the improvement of the quality of life of indigenous populations. In the Nigerian context, the agricultural sector is a significant contributor to the country's gross domestic product (GDP), accounting for 26.80% of its growth. Additionally, the sector constitutes a significant proportion of the labor force, providing work for approximately 70% of the country’s labor force (Bello, 2020). This is noteworthy given that the primary source of revenue for the country is derived from the oil and gas industry.

2.2 Agricultural Mechanization in Nigeria

The concept of agricultural mechanization entails the utilization of various tools, implements, and powered machinery and equipment to attain agricultural production, encompassing both crop and livestock production, as well as aquaculture and apiculture (FAO, 2018). The diversity and extent of mechanization is a major contributing factor to the increased level of agricultural productivity seen across developed nations (Makanjuola, 1984). The renewed level of attention towards agricultural mechanization in Africa can be attributed to a combination of factors, including amplified global food prices, the advent of novel agricultural machinery and equipment in Asia, and concerns regarding sustainability in the context of environmental deterioration and climate change (FAO, 2018).

The potential contribution of mechanization to green food value chain development

Production	Post-harvest / storage	Processing	Marketing
Crop establishment	Drying	Chopping	Packaging
Weeding	Grading	Milling	Transport
Fertilization	Winnowing	Grinding	
Irrigation	Cleaning	Pressing	
Crop protection	Storage		
Harvesting			

Source: Breuer *et al.*, 2015 (adapted).

Figure 1: Potential contribution of mechanization to green food value chain (Breuer et al., 2015)

In Nigeria, agricultural mechanization is classified into three distinct levels, namely traditional agricultural mechanization, draught animal technology, and engine-powered machinery technology, as reported by Upahi (2018) and Bello (2020). Bello (2020) further reports that conventional agricultural mechanization relies on human labor as a power source and implements such as hoes and cutlasses. In contrast, the technology of draught animals relies predominantly on animal-driven implements as a primary source of energy. The agricultural sector in Nigeria has witnessed a significant increase in the number of farmers, with a reported figure of over 2 million farmers spread across 19 states of the country. In the realm of engine-powered technology, machines utilized for the production, harvesting, processing, and handling of diverse agricultural products are powered by engines and motors that rely on either fuel or electricity. These machines include threshers, mills, irrigation pumps, and grinders (Upahi, 2018).

It is crucial to keep in mind that the power source is frequently the most expensive component of any investment or input in agricultural mechanization, and finding an effective and sustainable power source is a difficulty (FAO, 2018). Although its methods and utilization have been gradual and lower than they should be under ideal conditions, mechanization has been recognized to be a part of the country's overall agriculture and food security program (Ibrahim et al., 2022).

2.2.1 Challenges to agricultural mechanization in Nigeria

Some of the challenges faced by the agricultural industries with regards to agricultural mechanization include; poor supporting agricultural infrastructure like railway construction for the transportation of these heavy machines, high prices of machines and spare parts, lack of funds towards mechanization research and development; unstable electricity supply, inflation and scarcity of fossil fuel etc (Ibrahim et al., 2022).

Regarding affordability, rural regions are often geographically secluded as a result of inadequate infrastructure and considerable distance. Furthermore, the perceived insufficiency of demand in these regions for equipment does not justify the establishment of a distribution network (Brian & Josef, 2016). Smallholder farmers, who are typically characterized by limited resources, encounter challenges in allocating funds towards physical assets, including agricultural machinery.

The persistent challenge of agricultural machinery availability remains a significant concern. The lack of development in the machinery manufacturing industry and substandard quality of domestically produced machinery are factors contributing to the limited accessibility of machineries.

To summarize, the diagram depicted in (Figure X) provides a comprehensive perspective on the correlation between the limited financial resources of farmers and the subsequent decrease in investment, leading to a reduced demand for agricultural inputs such as tools and machinery. Insufficient allocation of resources towards technological advancements leads to reduced productivity levels, thereby exacerbating the persistent issue of low income among farmers. Furthermore, the limited utilization of mechanization results in a reduced availability of mechanized resources such as tools, power sources, and equipment, which consequently contributes to elevated operational and maintenance expenses. This illustration demonstrates the interdependence between the demand and supply of agricultural mechanization.

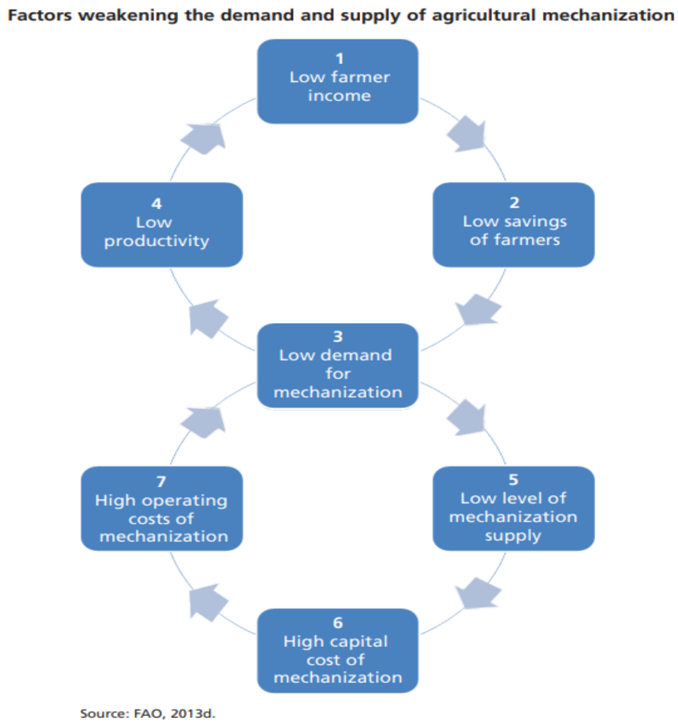


Figure 2: Factors weakening the demand and supply of agricultural mechanization (FAO, 2013d)

2.3 Nigeria's energy sector

Energy contributes immensely to present time civilization. It is considered to be a very vital ingredient for development and its input to economic needs is commendable (Ohunakin, 2010).

According to the US Energy Information Agency estimate, the total energy consumption in Nigeria in 2021 was about 1.9 quadrillion Btu (British Thermal Unit) (EIA, 2023). The former comprised 52% from crude oil and other petroleum liquids, 44% from natural gas and a much smaller percentage from renewables (4%) . The major driver behind increasing energy demand is the population growth, while the most important determinant is the level of economic activity, measured by the country's gross domestic product (GDP). Nigeria's population is projected to grow from 206 million (as of 2023) to 411 million by 2050 thereby making it the third most populous country in the world by 2050 (Sambo et al., 2006).

In addition, The Energy Commission of Nigeria (ECN) has developed models utilizing the Model for Analysis of Energy Demand (MAED) package to analyze Nigeria's energy sector from 2000 to 2030. It was proposed that the energy demand of Nigeria will increase by approximately 2.5, 3, 3.5, and 4.5 times between the years 2000 and 2015, and by approximately 8, 13, 17, and 22.5 times between the year 2000 and 2030. These projections were made using the Model for Analysis of Energy Demand (MAED) (Ohunakin, 2010). This prediction illustrates the predicted growth in energy consumption and underlines the need for effective energy planning and sustainable energy solutions to meet the increasing energy demand of the country's growing population. In addition, this projection highlights the need for effective energy planning and solutions to meet the increasing energy demand of the country.

Prior to 2005, the Nigerian energy sector's policy development, regulation, operation, and investment were under the responsibility of the Federal Government of Nigeria (FGN) with energy resources classified as conventional and renewable energy resources (Emodi, 2016).

2.3.1 Conventional energy sector

Nigeria possesses significant amounts of conventional energy resources in its reserves some of which are discussed briefly below.

- **Crude oil:** Crude oil has been a major source of revenue in Nigeria for the past three decades. It was first discovered in the Eastern Niger delta by Shell B in 1956. Petroleum production plays a major role in contributing to the country's GDP accounting for about 90% of her gross earnings (Odularu, 2008).
- **Natural gas:** Since its discovery, the amount of natural gas that is consumed in Nigeria has been steadily rising, and it reached its highest point in 2008, when there was a disruption in the country's gas supply. Nigeria's gas reserves are now estimated to be 182 TCF (trillion cubic feet) ranking 9th in the world (Worldometer), with a projected growth rate of over 70% by 2025 (Emodi, (2006); Charles, (2010)). According to Worldometer (Nigeria Natural Gas Reserves, Production and Consumption Statistics - Worldometer (worldometers.info), as of 2017, Nigeria's annual consumption of natural gas amounts to about 664,628 Million Cubic ft (MMcf) gas per year making it the 38th in the world.
- **Coal :** Coal was the first conventional energy to be discovered and used in Nigeria. It was discovered in the south-western region of Nigeria in 1909 with the railway corporation being the largest consumer of coal in the country. However, the discovery of oil in 1956 led to a decline in coal production. EIA (2023b) reports, Nigeria held about 379 million short tons in coal reserves in 2021. These reserves have not been

fully explored or even marginally developed despite the long history of the coal industry.

2.3.2 The renewable energy sector

Nigeria is blessed with so many renewables that we have not been able to fully explore, develop and properly use. The rural population's energy use constitutes about 90% of renewable energy, most of which is derived from non-fossil and non-nuclear sources in ways that can be replenished after harvesting and also its use has negative impacts on the ecosystem (Sambo, (2009); Ikuponisi,(2004)).

Today, the awareness on the need to consider renewable energy sources is increasing due to the need to diversify and also because the over reliance on fossil fuel is contributing greatly to climate change. It is interesting to note that the government plans to discourage increased use of fuel wood and other combustibles among rural dwellers in an attempt to preserve forest and natural ecosystems (Ohunakin, 2010).

The abundant reserve of renewables in Nigeria ranges from solar, hydro, wind to biomass.

Table 1: Renewable energy sources in Nigeria and their potential

Resource type	Reserves		Production	Domestic utilization (natural units)
	Natural units	Energy units (Btoe)		
Small Hydro-power	3500 MW	0.34 (over 40 years)	30 MW	30 MW
Large Hydro-power	11,250 MW	0.8 (over 40 years)	1938 MW	1938 MW
Wind	2–4 m/s at 10 m height (main land)	0.0003 (4 m/s @ 12 % probability, 70 m height, 20 m rotor, 0.1 % land area, 40 years	–	–
Solar Radiation	3.5–7.0 kWh/m^2/day (4.2 million MWh/day using 0.1 % land area)	5.2 (40 years and 0.1 % land area)	6 MWh/day	6 MWh/day
Biomass Fuel wood	11 million hectares of Forest and wood land Excess of 1.2 m ton/day	–	0.120 million ton/day	0.120 million ton/day
Animal waste	211 million assorted animals	–	0.781 million ton of waste/day	None
Energy crops and agricultural residue	28.2 million hectares of arable land (= 30 % of total land)	–	0.256 million ton of assorted crops/day	None

Source ECN (2009)

Adapted from Emodi (2016).

- **Biomass energy:** Biomass is considered as an indirect form of solar energy because it makes use of photosynthesis. It is an energy that is derived from organic material like crops, manure and some type of waste residue. Nigeria's biomass resources include forages, municipal solid waste, agricultural waste and crop residue, animal dung and have all been estimated at 88 × 102 MJ^2 (Sambo 2009). Fuelwood is the most widely used domestic renewable energy resource in rural Nigeria with about 80 million m^3 annual use (Sambo 2005). Sawdust and wood chips are other biomass energy resources of high potential in the country: According to Onyegegbu (2003), about 42 tonnes of sawdust is generated for every 100t of timber produced. This potential can be estimated at 1.8 million tonnes annually. Additionally, as Nigeria is an agricultural nation, her annual production of biomass will continue to be enormous.

- **Hydropower:** Nigeria is naturally endowed with large rivers and as such has a high hydropower potential. This share of energy is what supplies electricity in the country. In comparison to fossil fuel, hydropower is renewable and provides permanent and stable energy that is ever available. According to Ohunakin (2010), the gross exploitable hydro potential is approximately 14,750 MW. However, only 1,930 MW is currently being utilized (14%) at Kainji which represents 30% of the gross electricity generation capacity of the country.

- **Wind:** Akuru et al., (2016) defines wind energy as **"**the energy contained in the movement of air in the form of wind, which can be used to turn the blades of windmills or wind turbines, which in turn could drive electrical generators to produce electricity". In Nigeria, currently, no commercial wind power plants are connected to the national grid this is partly because the progress of harnessing the potential of wind energy is too slow and also because Nigeria falls into the poor/moderate wind regime with a weak wind speed except for coastal regions and offshore (Ohunakin, 2010). According to ECN (2005), the total exploitable wind energy reserve for different locations ranges from 8 MWh $year^{-1}$ to 97 MWh $year^{-1}$. The contribution of wind energy to the total energy consumption in the country is insignificant.

- **Solar:** Of all the highlighted renewable energy, solar energy is the most promising because of its limitless potential. Solar energy is a good alternative source of energy in the rural areas of Nigeria and could also contribute to an upscaling in development of small-scale industries and reduce rural-urban migration.

2.4 Background study of solar in Nigeria

Nigeria is a country in the western region of Africa with a latitude between 4˚N and 13˚N and a longitude between 3˚E and 15˚W with a lot of research going on on solar insolations and radiation potential in various parts of the country (Osueke et al., 2013). According to Nasir, (2001) for solar to be harnessed effectively, there is a need for available and appropriate technology. The earth receives a total amount of 1353 W/m2 in form of energy. Today, researchers are switching to approaches to gather this energy from sunlight. Nigeria has an annual average solar radiation of 5.25 kWh/m²/day. It also varies from 3.5 kWh/m²/day to 9.0 kWh/m²/day in the coastal region and northern region respectively (Oji et al., 2012). The annual average intensity is 6898.5 or 1934.5 kWh/m^2/ year depending on the region (Vincent & Yusuf 2014). Other reports have shown that as the average sunshine per day is 6.5 h, the solar energy available per annum is about 27 times of the country's total fossil fuel resources and over 115,000 times of electrical power generated (Augustine & Nnabuchi, 2009) This therefore means that only 3.7% of Nigeria's land mass is required to receive an amount equivalent to the country's conventional energy reserves.

Furthermore, the total energy demand of the nation could be met if only 0.1% of the total solar energy radiant on Nigeria's land mass is converted at an efficiency of 1% (Bugaje, 2006).

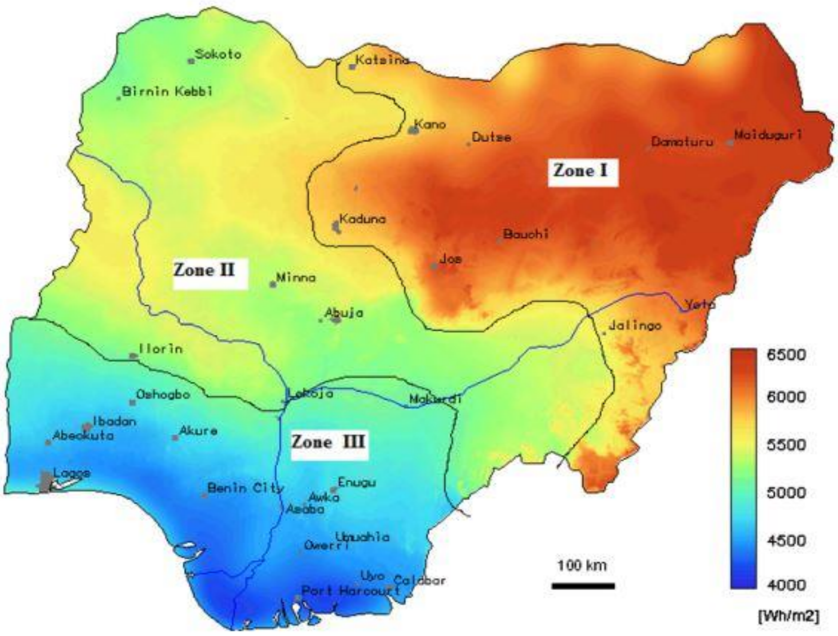


Figure 3. Solar radiation map of Nigeria (Ohunakin et., al 2013)

Table 2

Solar radiation zones (global horizontal irradiation)

Zones	kWh/m^2	h/d	$kWh/m^2/yr$
Zone I	5.7 - 6.5	6.0	2186
Zone II	5.0 - 5.7	5.5	2006
Zone III	< 5.0	5.0	1822

Several surveys and studies have been undertaken by the Sokoto Energy Research Center (SERC) and the National Center for Energy Research and Development (NCERD); some of which include putting in place PV-water pumping, electrification and solar-thermal installations. The thermal applications include solar crop drying, solar incubators, solar cooking e.t.c others include water pumping, rural clinic and schools power supply, village electrification and streetlights. (Oyedepo, 2013).

2.4.1 Solar Energy utilization in Nigeria agriculture

The rapid and persistent increase in petroleum-based products has resulted in the re-evaluating of present farming practices and search for alternatives for petroleum-based agriculture by farmers, government officials and scientists (Yohanna & Umogbai, 2010). Solar energy plays an important role in agriculture. It is cost effective, it is a cleaner and renewable source of energy unlike fossil fuel hence the production of greenhouse gas emissions is reduced, it reduces dependency on the grid and this is particularly beneficial for rural areas where access to the grid is unreliable, it extends operational hours and also beneficial to the environment. It provides energy without waste and reduces human labour on the farm by pumping water for consumption and irrigation.

The utilization of solar can either be direct or indirect using solar thermal/solar electric. Agricultural related application of solar energy in Nigeria includes drying, cooking, manure production e.t.c

1. CROP DRYING: Solar energy has been used in crop drying for ages through sun drying and solar crop drying. In a report by Arinze (1987), sun drying of harvested crops is prominent in most developing countries. where the crops are spread in the sun on a suitable surface or hung from trees. Although this requires little capital, it has many limitations and problems. Over 80% of harvested agricultural produce is sun dried in Nigeria.

   The solar crop drying also relies on the sun but differs from sun drying. It is a good alternative for sun drying and produces higher air temperatures. This sole advantage reduces the risk of spoilage during drying and storage.

   Different types of solar dryer have been developed by agencies like National Centre for Energy Research and Development (NCERD), Nsukka, Sokoto Energy Research Centre (SERC) (Awogbemi et al., 2015). The solar dryers in Nigeria are categorized into three types: concentrator/dryer, flat plate/dryer, and flat plate/dryer/storage unit (Igbeka, 1987).

2. POULTRY PRODUCTION: Solar energy has been used in various stages of poultry production. Some of which include egg incubation, chick brooding and chicken growing. Solar energy is managed in such a way that the required heat is provided for these different stages. In the case of egg incubation, a solar air heater glazed with a single thin PVC corrugated sheet is used so as to regulate the temperature while for chick brooding, solar energy is able to provide the required heat through water solar heaters (Yohanna & Umogbai, 2010). For the chicken growth, power is required to warm and circulate ventilation air of which the solar heaters can supply.

3. MANURE DRYING: Engineered solar dryers are used. This is a much safer way of dyeing manure as sun drying is said to be slow and hazardous by spreading bad odour and diseases. It also gives room for all round year usage compared to open sun drying.

4. SWINE AND DAIRY PRODUCTION: In swine production, solar radiation is used to heat the air in a forced circulation air heater that further feeds the baby pig house. Circulation pumps and fans are also powered by solar Photovoltaic generators. In dairy production, the solar energy derived power is used for ventilation, lighting, milking, milk cooling and waste disposal. Both productions use a solar photovoltaic generator (Yohanna & Umogbai, 2010).

5. IRRIGATION AND WATER PUMPING: The use of solar PV for pumping and irrigation has been demonstrated especially in the rural communities. These have contributed to increase in yield and income.

6. LIGHTING: A research carried out by the Sokoto Energy Research Center in 1998 reported that users were observed to save between 31NGN - 40NGN each month for not using kerosene in lighting their rooms at night (Yohanna & Umogbai, 2010).

In line with Awogbemi et al., (2015) and Ilenikhena & Ezemonye (2010), Other areas of utilization in agriculture include: refrigeration, lighting of agricultural houses, electric fences, pest control, fishing and aquaculture e.t.c. while non-agricultural areas include: water treatment, households, off-farm productive uses, social and community services (solar PV for health care, drinking water supply, schools and other public buildings), other productive activities (billboards/advertising).

2.4.2 Challenges confronting the adoption of solar use in Nigeria.

Despite the numerous advantages enjoyed from solar energy, Nigeria has not fully harnessed the opportunities available in solar energy. According to Chendo (2002), challenges faced in utilization of solar PV is due to the following factors:

I. Affordability: Though in the long run, solar PV may be cost beneficial. However, when compared to the price of diesel or solar generators, solar PV is still expensive and this majorly because the parts and accessories are imported.

II. Technological barrier: Despite the development of technologies geared towards the improvement of harnessing solar energy, most components still have to be imported which further pushes the investment costs higher. A lot still needs to be done to equip Nigerian engineers and technologists with the required knowledge on the technology.

III. Financial constraint: This poses a significant barrier to the adoption of solar technology. The high upfront cost like installation cost, investment cost, operation and maintenance cost associated with solar energy systems makes it challenging for individuals and businesses to afford setup and installation. Additionally, the lack of supportive initiatives from government and financial institutions further contributes to this.

IV. Low level of public awareness: Low public awareness contributes to the barrier to solar energy adoption in Nigeria. Lack of awareness about solar energy, as well as misconceptions and misinformation, contribute to uncertainty and resistance to its implementation. Ohunakin et al., (2013) also reported that the different political and administrative levels in Nigeria has a low level awareness about the socio-economics and environmental benefits obtainable from solar energy.

V. Political barriers: The lack of long term policies and political will to diversify into clean energy serve as a barrier to future planning for solar and other renewable energy. Additionally. Policies instituted by the government have not supported the profitable exploitation of renewable energy resources (particularly solar energy) (Ohunakin et al., 2013).

VI. Other factors that affect adoption of solar energy include: absence of effective energy policy, grid unreliability, variability and intermittency of radiation, ineffective quality of control of products, insecurity of solar plant infrastructure, competition with land uses, market distortion issues (Ohunakin et al., 2013; Abdullahi et al., 2017)

CHAPTER THREE

METHODOLOGY

This chapter explains the research methods utilized to collect data in accordance with the research questions and objectives of the study. Thus, this section describes the research design and methodology, including the population sample, sample size, research instruments, and data analysis strategy.

3.1 Study area and crop

The research was conducted in the south-western Nigerian state of Oyo. The state is situated between latitudes 7 0 3' and 9 0 12' north of the equator and longitudes 2 0 47' and 4 0 23' east of the Meridian, and has a total land area of approximately 27, 249 square kilometers. Overall, the farming system of Oyo is diverse, with a combination of crop cultivation and livestock farming. There are three agro-ecological zones in the state: the rainforest, the savannah, and the derived savannah. The high relative humidity of the rainforest allows for the development of tree crops such as citrus, oil palm, and cocoa, as well as arable crops such as cassava, maize, and yam. The vegetation of the savannah zone is mostly conducive to the growth of sorghum, maize, cowpea, and yam, whereas the derived savannah combines the distinctive traits of the first two. They utilize improved seed varieties, employ mechanization, irrigation systems e.t.c Livestock farming is another integral component of the farming system in Oyo state. Cattles, goats, sheep, and poultry are raised for meat and other livestock products. The sector employs various techniques and management practices.Despite its strengths, the farming system in Oyo state faces challenges such as inadequate access to capital, climate variability, weather related risks and credit impacts the sector's growth.

The study crop which is maize, is the most abundantly produced cereal in the world (Danilo, 2003). Its domestication was in Mexico, around 1500 BC. Nigeria, being the African largest producer of maize, produces over 33 million tons (IITA, 2021). All parts of the crop can be used for food and non-food products. In addition, 60% of Nigeria's maize production is utilized by the industrial sector. Some of the farm operations practiced in maize production include land clearing and soil preparation, planting, management practices, harvesting, just to mention a few.

3.2 The Study Population

The population of the study comprises 108 respondents. 90 maize farmers, 9 maize-mill operators and 9 maize thresher operators all belong to three Local Government Areas in Oyo state. Namely; Orelope, Olorunsogo and Irelope. Maize farmers, maize millers and maize threshers in the three L.G.As make up the target population.

3.3 Sample technique and sample size

Selection of the respondents was done using a multi-stage sampling technique. The first stage involved was the purposive selection of Oyo state out of the six states in the South-Western Nigeria. Purposive sampling is a more strategic way of sampling that allows a good deal of variety in the resulting sample (Bryman 2016, pg. 410) and also because of its relevance to the research question. The second stage was proportionate to size sampling of Local Government Areas in the state. Three LGAs (Irepo, Orelope and Olorunsogo) were proportionally selected from nine maize producing Local Government Areas spread across the west of Oyo state. The third stage involved simple random selection from the selected communities on the sampling frame to give a total of 108 respondents. A total of 108 questionnaires were administered which were satisfactorily filled. Every responder in the population has an equal chance of being selected for the study thanks to a simple random process (Bryman, 2016).

3.4 Research design

Research design determines how the study material will be gathered (Huberman and Miles, 2002). This research uses a mixed-method approach. This design will allow me to answer my research question effectively, as each needs a different approach. Moreover, with the mixed method, the qualitative part gives a high platform for exploring the problem being researched as it offers rich and in-depth knowledge about the phenomena under study (Thomas et al., 2010, Bryman, 2016). It is the best tool for researching and accessing information (Creswell and Poth, 2016).

This involved employing a questionnaire to collect information in order to respond to the study's research questions. There were 74 open and close ended questionnaires for investigating this study. The questionnaire was categorized into four sections. Section A was a general question for all 108 respondents, section B was questionnaire for maize farmers only, section C was for maize thresher operator operators only and section D was for maize mill operators only. This study used a descriptive sample of statistics because it enables a more in-depth interpretation of experiences, phenomena, and meaning. It also enables the asking of questions that are challenging to answer quantitatively and helps us better comprehend human experience (Tamachi Giles et al., 2018). According to Bryman (2016), descriptive analysis helps the researchers to provide a deeper grasp of the research topic by providing answers to the questions raised in the study.

As part of the data analysis, SPSS (Statistical Package for Social Science) was used in analyzing and interpreting the primary data obtained from the field.

3.5 Activities and methods

Two weeks were allocated to do data collection for this study. Data collection started on 2nd February,2023 to 16th February, 2023. A pilot study was conducted prior to these dates. According to Bryman (2016, Pg. 85), a pilot study helps to determine how well a research instrument works. The data for this work was obtained in the selected three LGAs (Irepo, Orelope, Olorunsogo).

3.6 Data collection and analysis procedure

Three research assistants from each of the LGAs were recruited. Following a mini training, they collected the data using a questionnaire that was created on google form. It was a self-administered questionnaire. According to Bryman (2016, pg.) this type of questionnaire uses predominantly close-ended questions to ask respondents about specific situations that are relevant to the research interest.

An analysis of the data obtained from the questionnaire was analyzed. Results were inputted into the Statistical Package for Social Science (SPSS) software and the results were in the form of graphs, tables and charts.

3.7 Ethical consideration

To carry out the study, I considered ethical principles by providing full disclosure of the nature of the research and purpose of the interviews through consent forms in addition to full orientation before the interviews. According to Bryman (2016), the process of informed consent means that “prospective research participants should be given as much information as might be needed to make an informed decision on whether or not they wish to participate in the study" (pg. 129).

3.8 Challenges and limitations during and after fieldwork

When conducting fieldwork, it is typical to face difficulties. This summary focuses on some of the constraints encountered during the study process. One of the most significant limitations discovered was the difficulty in locating and securing a research assistant. The lack of a research assistant hampered the study's efficiency and pace, as administering a questionnaire necessitated additional assistance because I could not travel for field work owing to financial constraints, which was the second issue encountered. Another key obstacle was the lack of time. Time is an important aspect in any research effort, and the lack of timely assistance may have resulted in missed deadlines, hasty data collecting, and analysis.

A further challenge is that the study sample is not representative. Obtaining a properly representative sample can be difficult, especially when working with a specialized demographic and limited resources. It is critical to recognize that the research findings may have limited generalizability beyond the unique sample used, thus affecting the study's external validity.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter reports on the main findings of the research, including presentation of relevant statistical data. Information from the interviews and close ended questionnaires were analyzed and the results presented.

4.1 Socio-Economic characteristics of respondents

The socio-economic characteristics of respondents considered here were age, gender, education level, maize farm size and maize production output per year.

4.1.1 Distribution of maize farmers according to other socio-economic characteristics

Out of the 90 questionnaires administered. 71% of the respondents were males and 28.9% were females (Table 3). There was a better representation of male in this study. This finding may have impacts on farming activities.

The result shows that 45.6% of the respondents fell within the age range of 35 - 49 years, while 36.7% were between 50 years and above years, and 15.6% were between 26 - 34 years(Table 3). Also, 2.2% were between 18 - 25 years. This implies that the young participated less in farming activities in comparison to the aged who are still in their active years, agile and vibrant to engage in farming activities.

Furthermore, 42.2% of the respondents had completed their secondary education while 37.8% had their primary education completed, and 13% had tertiary education while 5% had no formal education. This shows that the farming community is relatively well educated. Education plays a significant role in empowering individuals with knowledge and skills thereby increasing their level of reasoning and understanding (Ajala et al., 2013).

The result further revealed that about half (52.2%) of the respondents have access to medium farms while 38.9% had small farms. Only 8.9% had large farms. This shows that the majority of maize farmers in the study area are medium scale farmers (i.e 2 - 10 hectares). The categorization of farm size used is according to Badmus (2019), small farms are farms less than 2 hectares, medium farms are between 2 - 10 hectares while large farms are greater than 10 hectares.

Table 3: Distribution of maize farmers according to other socio-economic characteristics (n= 90)

Variables		**Frequency**	**Percentage (%)**
Gender	Female		28.9
	Male		71.1
Age	18-25 years	2	2.2
	26-34 years	14	15.6
	35-49 years	41	45.6
	50 years and above	33	36.7
Education status	None	5	5.8
	Primary level	34	37.8
	Secondary level	38	42.2
	University	13	14.4
Farm Size	Small farms	35	38.9
	Medium farms	47	52.2
	Large farms	8	8.9

4.1.2 Maize production per year

The maize production in the study area is both commercial and subsistence level oriented. The minimum production per farm was 188 kg while the maximum was 110,000kg. Those who produce on a small scale do so for personal consumption. Few farmers produce above 20 tons and about 37% of the farmers produced less than 5 tons (Figure 4).

Table 4: Respondent's annual maize production (in kg)

	N	Minimum	Maximum	Mean
MP/YEAR	90	188	110,000	10105.42

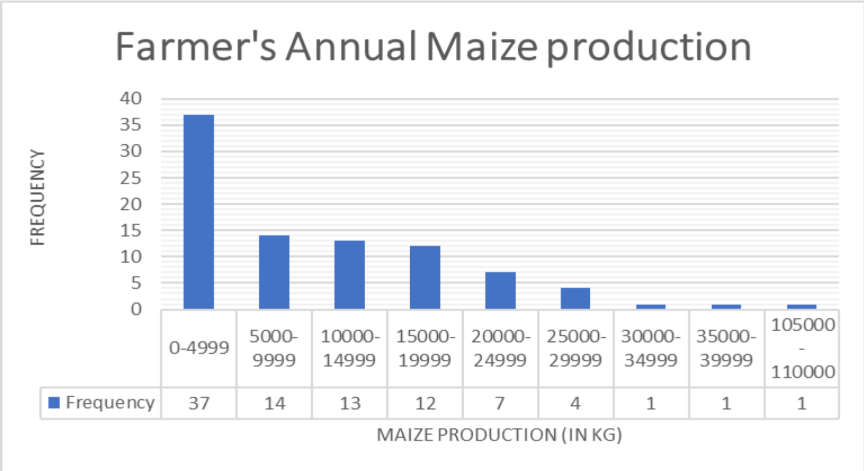
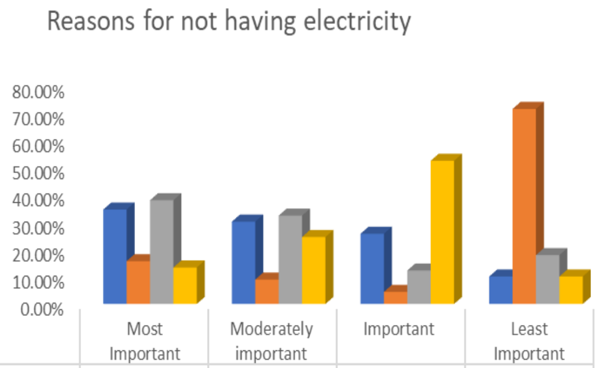


Figure 4: Maize production of respondents per year

4.2 Assessing the constraints for adopting solar energy source and replacing fossil fuel with solar energy in the cereal value chain

There is a clear limit to how much power that can be supplied by human muscle power. During a typical workday of ten hours, the human body is only capable of producing roughly 75 watts (W) of continuous energy output. As a result, the standard of living that can typically be achieved through human labor alone is at the subsistence level. It is necessary to have additional energy sources in order to advance beyond the level of merely subsisting (Fluck, 2012).

Results from the survey showed that none of the maize farmers respondents have electricity on their farms. This finding corroborates with Oke et al., (2019) who had earlier reported that farmers in rural areas are faced with the challenge of electricity power supply.



	Most Important	Moderately important	Important	Least Important
Cost of electricity	34.40%	30%	25.60%	10%
Lack of access	15.60%	8.90%	4.40%	71.10%
Lack of Government support	37.80%	32.20%	12.20%	17.80%
Installation cost	13.30%	24.40%	52.20%	10%

Figure 5: Distribution of respondents according to electricity use

37.80% of the respondents considered lack of government support as the most important factor as to why they have no electricity on the farm. This is followed by cost of electricity (34.40%), lack of access (15.60%) and installation cost (13.30%). On the other hand, lack of access (71.10%) was considered as the least important factor as to why they do not have electricity on their farm, 17.80% also responded that lack of government support was the least important factor while installation cost and cost of electricity had 10% respondents each.

One of the most important factors restricting farmers from having electricity is the cost of electricity. As of June 2022, the price of electricity used in households in Nigeria amounted to approximately 70 - 75 Nigerian naira per kilowatt hour, equivalent to about 0.25 U.S dollar. On the other hand, industrial electrical energy was priced at approximately 150 NGN per kilowatt hour. This is considered a relatively high cost due to the standard of living in Nigeria.

4.2.1 Solar Use:

The solar use in the study area was relatively low as only 20% used solar energy while 80% did not use solar energy in their houses or on the farm. Despite the abundance of solar energy in Nigeria, its application and utilization is majorly limited to small scale and isolated application although for decades solar thermal has been highly utilized by rural dwellers for agricultural processing in purposes like drying of crops, hide and skins, and drying of manure (Ohunakin et al., 2013). In addition to this result, respondents reported they use solar mainly for lighting, charging, refrigeration and pumping.

4.2.1.1 Distribution of respondents according to solar energy use

Some of the benefits enjoyed from the use of solar as highlighted by the respondents (20% of the respondents that had access and utilize solar energy) include its simplicity to use, reliability, environmentally friendly, and its cost-effectiveness.

The figure below shows the responses from 80% of the respondents who do not use solar energy.

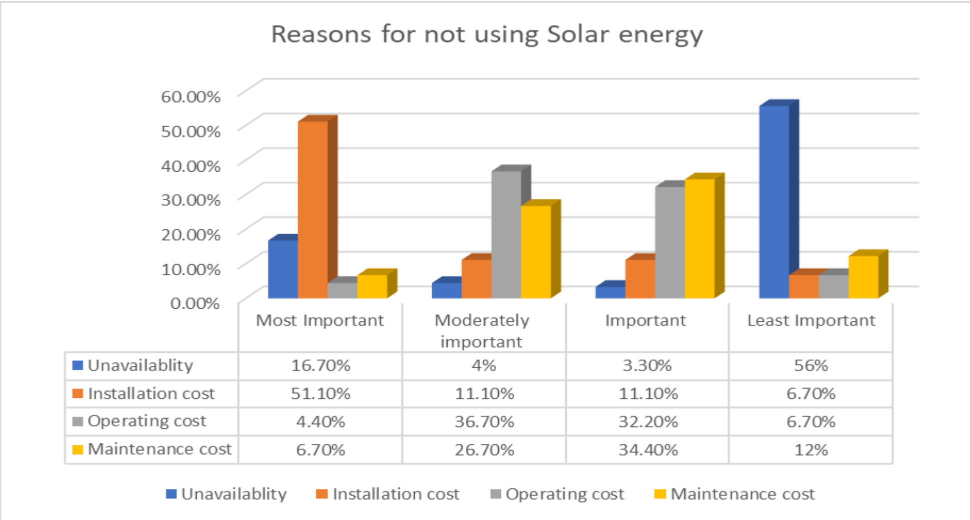


Figure 6:Distribution of respondents according to why they don't use solar energy

The respondents (maize farmers) ranked their reasons for not using solar as their source of energy either at home or on the farm. 51.10% of the respondents responded that installation cost is the most important factor as to why they do not use solar energy. It was furthermore shown that 36.70% responded that operating cost is the moderately important reason, followed by 34.40% responding that maintenance cost is important for them in considering solar use while 56% responded that unavailability is the least important factor. In general, financial constraint poses as a significant barrier to the adoption of solar technology. Some of the financial barriers to the implementation of solar energy in Nigeria are lack of capital, credit to consumers and financial instrument (Abdullahi et al., 2017).

4.3 The energy demand in farm operations in the cereal value chain in Western Nigeria

Threshing and Milling were the two postharvest operations chosen for the purpose of this research. The survey was carried out among nine maize thresher operators and ine maize miller operators. In addition, data was also analyzed from the response of the ninety farmers earlier.

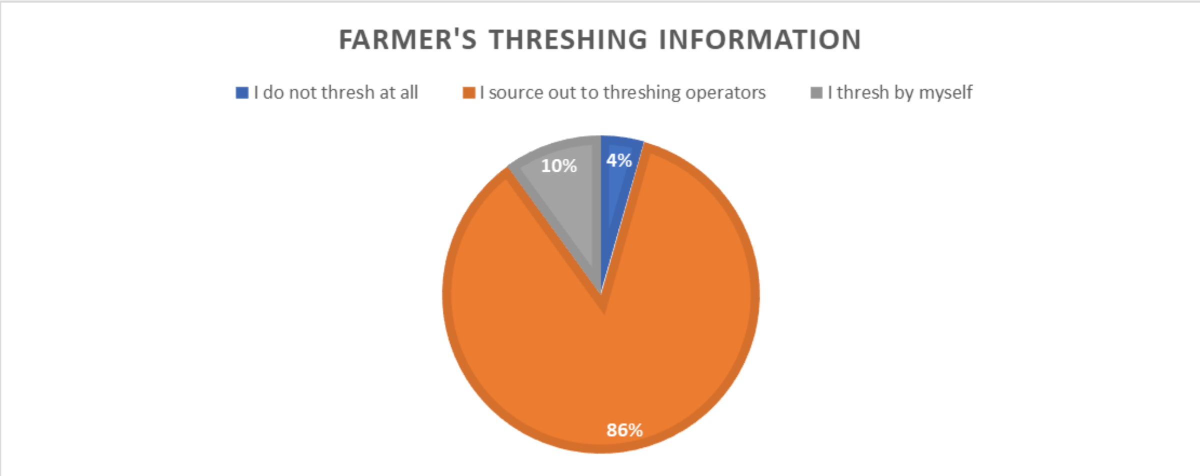


Figure 7: Distribution of respondent according to threshing activity

According to the result of this survey, about 86% of the maize farmers source out threshing to an operator, 10% of the farmers carry out threshing themselves and this is done manually with sticks and sacks while 4% do not thresh at all. This high level of outsourcing is as a result of low level of ownership of threshers which is most likely due to the high cost of a threshing machine.

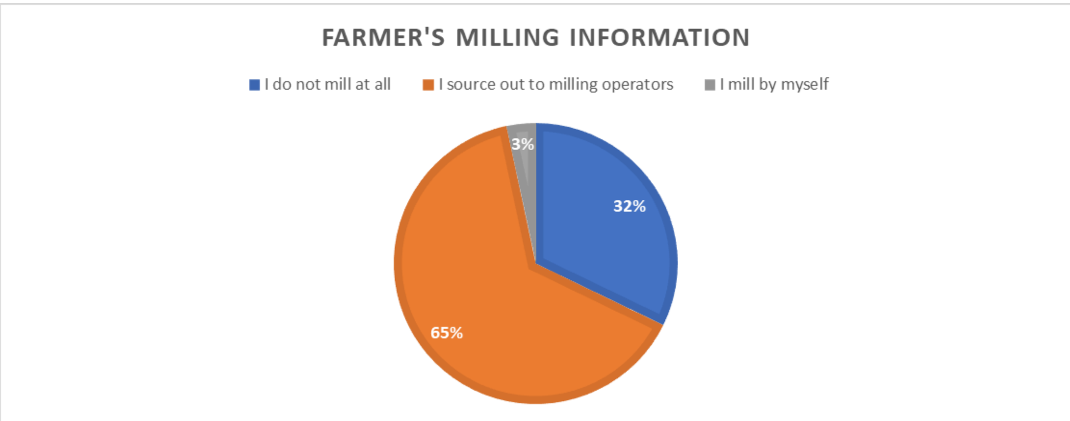


Figure 8: Distribution of farmers according to milling activity

Regarding the milling process, 65% of respondents reported that they source out their milling to maize mill operators, while 3% responded that they carry out milling by themselves by using either portable electric blenders or self-owned grinding machines. This category of respondent mills for their family consumption alone.

On the other hand, 32% of the farmers responded that they do not mill their maize. The primary reason for this is that the majority of farmers tend to sell the maize immediately after harvest to industries and consumers. This is due to the fact that maize can be processed into such a wide variety of end products as well as the fact that the farmers lack the resources necessary to produce these end products.

In addition, a total of nine operators who threshed maize and nine operators who milled maize were included in the survey, making the total number of operators who participated in the study eighteen. Most of these operators provide their services to between 40 and 50 farms. All of these operators use diesel as their primary source of power for the machines that they use for their many different tasks.

The figures below show the variation in the amount of maize that is threshed and milled daily by these operators and the corresponding liters of fuel consumed daily.

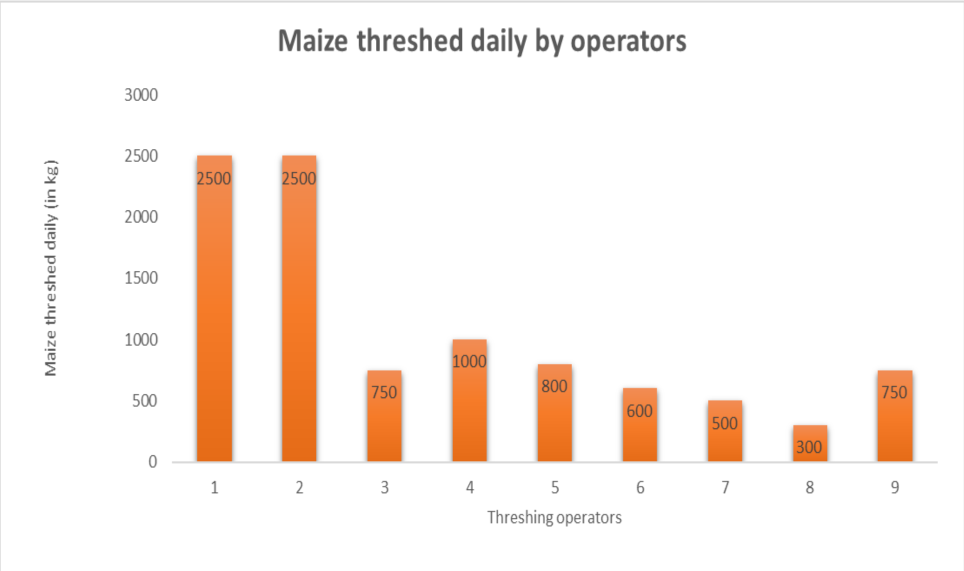


Figure 9: Quantity of maize threshed daily by the nine different operators

Average Mean: 1077
Standard Deviation: 829.9
Confidence interval at 95%: 1077 ± 637.95

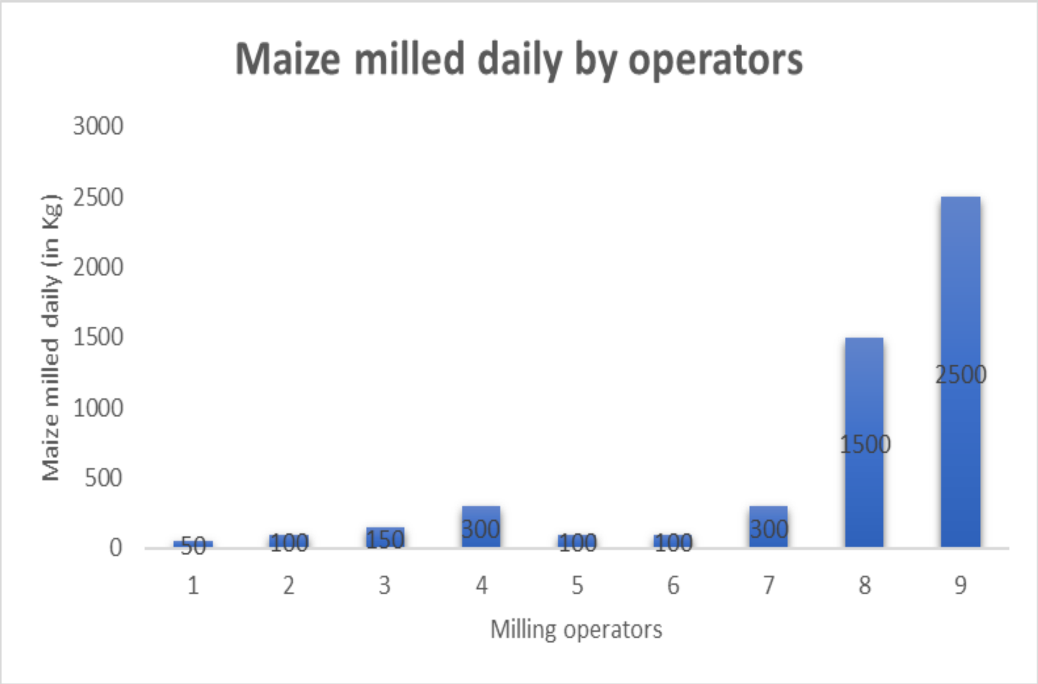


Figure 10: Quantity of maize milled daily by nine different operators

Average Mean: 566
Standard Deviation: 854.766
Confidence interval at 95%: 566 ± 657.03

4.3.1 ENERGY DEMAND

This section aims to explore the calculation of energy demand, a pivotal facet in comprehending and efficiently managing energy resources. The analysis will heavily rely on daily fuel consumption data, serving as a fundamental parameter in the estimation process. Figure 11 presents the daily fuel consumption for various operations, with diesel being the primary energy source for the machinery. The data depicted in the figure indicates that milling exhibits a higher fuel consumption compared to threshing, highlighting contrasting energy utilization patterns between the two operations.

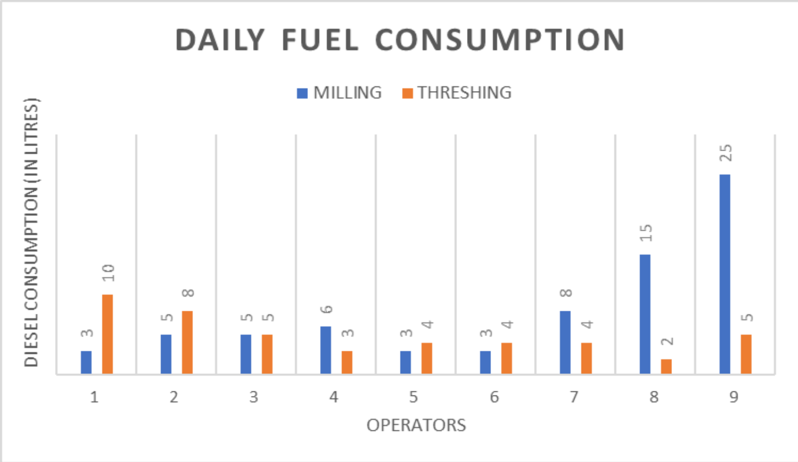


Figure 11: Daily diesel consumption of different operators (in Litres)

4.3.1.1 Energy demand for threshing

The energy demand for both operations was calculated by dividing the average kg of maize by the liters of fuel used. Therefore, the energy demand for threshing operation is 0.005L/kg. This means that 5 litres diesel is consumed per ton threshed.

Table 5: Distribution of maize threshed daily by operators and average energy demand

Threshing Operators	Kg/day	Liters	Energy Demand (L/kg)
1	2500	10	0.004
2	2500	8	0.0032
3	750	5	0.006667
4	1000	3	0.003
5	800	4	0.005
6	600	4	0.006667
7	500	4	0.008
8	300	2	0.006667
9	750	5	0.006667

TOTAL	**9700**	**45**	**0.005**
AVERAGE	**1077KG**	**5**	**0.005**

4.3.1.2 Calculating equivalent solar energy needed for threshing:

It has been determined that the energy content level of one litre of diesel fuel is approximately 38MJ – which is equivalent to 10 kilowatt-hours (kWh) (Team, 2022). Table 5 illustrates that the average amount of maize threshed per day is 1077 kg, utilizing a daily volume of 5 liters. Utilizing this data, the estimated energy content for this quantity amounts to 50 kWh (i.e., 5 liters multiplied by 10 kWh). However, a diesel generator normally operates in its specified operating range at about 40% efficiency, with a maximum load capacity of up to 80%. Only 40% of the total energy input, or 40 units, are produced for every 100 units of energy intake due to the system's efficiency. Energy is lost due to heat and frictional effects, just like in other mechanical systems (Diesel Generator vs. Gas Generator: Which is More Efficient? - General Power Limited (genpowerusa.com)). This implies that if 50kWh is the given intake energy, then the total energy input produced with an efficiency of 40% is 20kWh (that is 50*0.4).
A Nigerian solar operator contacted during the course of this research reported that a pair of a 350 watt solar panel will produce 2.5kWh per day. Therefore 8 pairs of this solar panel will be needed to cover the daily needs. (202.5 = 8). However, there is also a loss in electric engines that can be assessed to a 20% loss. About 9 pairs will give the same energy as 5 liters of diesel. A pair of 350 watt solar panels cost about 174,000 Naira in Nigeria. Hence, the total cost of the 9 pairs will be **1,566,000 Naira** equivalent to **3396.65 USD.** Apart from the initial cost of the solar panel, an estimated amount of 180,000NGN is required for the complete installation, which includes maintenance and necessary accessories. However, it is noteworthy that certain solar companies in Nigeria provide complimentary maintenance services for the first six months following installation.

4.3.1.3 Energy demand for milling

The energy demand for milling operation is 0.014L/kg. This means that the average litre diesel consumed per kilo milled is 0.014L. This is presented in the table below

Table 6: Distribution of maize milled daily by operators and average energy demand

Milling operators	Kg/day	Liters	Average Energy demand(L/kg)
1.	50	3	0.06
2	100	5	0.05
3	150	5	0.033333
4	300	6	0.02
5	100	3	0.03
6	100	3	0.03
7	300	8	0.026667
8	1500	15	0.01
9	2500	25	0.01
TOTAL:	**5100KG**	**73**	**0.014**
AVERAGE	**566KG**	**8**	**0.014**

4.3.1.4 Calculating Equivalent solar energy needed for milling:

Similarly, when assessing the energy content for milling operations, the energy level of one liter of diesel fuel is 10kWh. According to table 6, an average of 566kg of maize is milled using 8 liters of diesel fuel daily, resulting in an equivalent energy content level of 80kWh (i.e, 8 litres multiplied by 10kWh).

Applying the same efficiency considerations for the diesel generator as mentioned earlier, where only 40% of the total energy input is converted into usable energy, the total energy input produced with an efficiency of 40% for the given intake energy of 80 kWh amounts to 32kWh (i.e 80 kWh multiplied by 0.4). Also based on the information from the key informant from a Nigerian solar firm, a pair of 350-watt solar panels could generate 2.5kWh per day. Therefore, approximately 12 pairs of solar panels would be required to meet the daily energy needs (i.e

322.5 = 12.8). However, considering a 20% loss in electric engines, the required number of solar panel pairs would be about 14.
Considering the cost of a pair of 350-watt solar panels at 174,000 Naira, the total cost of acquiring 14 pairs would amount to **2,262,000 Naira** equivalent to **4906.28 USD.**

4.4 Farmer's CO_2 emission

In the context of agricultural practices, the assessment of carbon dioxide (CO_2) emissions from farmers has emerged as a critical area of study, aimed at understanding and mitigating the environmental impact of agricultural activities. This section of the result analyzes the average CO_2 that is emitted by a household based on the data collected for this research. 76 families source out threshing to operators while 57 families source out milling to operation; Table 7 and 8 shows the Kg produced per household and the equivalent energy demand and CO_2 emission that can be attributed to them. This calculation was done by using the energy demand for the different operations respectively and further calculating the CO^2 emission by multiplying the energy demand with the standard CO_2 emission factor. According to the National Inventory Report (2021), the standard CO_2 emission factor for diesel is 2.66 kg/liter.

Table 7

Farmer's energy demand and equivalent CO_2 emission for threshing per year

Farmers	Frequency	Kg threshed/year	Energy demand (0.005L/kg)	CO_2 emission (2.66)
1	1	200	1	2.66
2	1	300	1.5	3.99
3	1	500	2.5	6.65
4	2	625	3.125	8.3125
5	3	1000	5	13.3
6	1	1200	6	15.96

7	2	1500	7.5	19.95
8	1	1800	9	23.94
9	4	2000	10	26.6
10	1	2250	11.25	29.925
11	3	2500	12.5	33.25
12	3	3000	15	39.9
13	3	3500	17.5	46.55
14	1	3750	18.75	49.875
15	4	4000	20	53.2
16	7	5000	25	66.5
17	1	5620	28.1	74.746
18	1	6500	32.5	86.45
19	3	7000	35	93.1
20	4	7500	37.5	99.75
21	2	8000	40	106.4
22	1	8750	43.75	116.375
23	11	10000	50	133
24	2	12000	60	159.6
25	1	12500	62.5	166.25
26	2	13500	67.5	179.55
27	7	15000	75	199.5
28	1	18000	90	239.4

29	2	20000	100	266
30	1	22000	110	292.6
TOTAL			**997.475**	**2653.284**
AVR. TOTAL			**33.25**	**88.44**

From this table, the average energy demand by a farmer per year is **33.25L/kg** while the average CO_2 emission contribution is **88.44kg**

Table 8

Farmer's energy demand and equivalent CO_2 emission for milling per year

Farmers	Frequency	Kg milled/year	Energy demand (0.014)	CO_2 emission (2.66)
1	2	20	0.28	0.7448
2	1	24	0.336	0.89376
3	1	30	0.42	1.1172
4	1	35	0.49	1.3034
5	1	50	0.7	1.862
6	1	66	0.924	2.45784
7	2	100	1.4	3.724
8	2	125	1.75	4.655
9	1	180	2.52	6.7032
10	4	200	2.8	7.448
11	2	250	3.5	9.31

12	1	290	4.06	10.7996
13	3	300	4.2	11.172
14	1	325	4.55	12.103
15	1	400	5.6	14.896
16	2	450	6.3	16.758
17	7	500	7	18.62
18	2	600	8.4	22.344
19	1	625	8.75	23.275
20	1	924	12.936	34.40976
21	8	1000	14	37.24
22	1	1200	16.8	44.688
23	2	1500	21	55.86
24	3	2000	28	74.48
25	1	6000	84	223.44
26	1	6250	87.5	232.75
27	1	10000	140	372.4
28	1	13500	189	502.74
29	1	36500	511	1359.26
TOTAL			**1168.216**	**3107.4546**
AVR.T			**40.28331**	**107.15**

From this table, the average energy demand by a farmer per year is **40.28L/kg** while the average CO_2 emission contribution is **107kg.**

Based on the data provided by Worldometer, it can be inferred that the per capita CO_2 emissions in Nigeria were approximately 400kg (0.44 tons per person) in the year 2016 while the World Bank (2020) recorded a per capita CO_2 emission of 0.64 tons, considering the country's population of 185,960,241. The recorded figure falls significantly below the worldwide mean of 7 metric tons and is comparatively lower than the corresponding values observed in India (2.7 metric tons), Mexico (5.5 metric tons), and Indonesia (9.2 metric tons) (CBF, 2023).

However, the sum of emission from the two operations studied in this research is 195 kg (threshing: 88 kg and milling: 107kg) approximately. This simply implies that the emission from these operations present almost 50% of emission of the average Nigerian. The amount threshed and milled is however far more than what is needed in a household.

4.5 ECONOMIC ANALYSIS

It is essential for farmers and other stakeholders to conduct agricultural economic assessments in order to gain an understanding of the profitability and sustainability of farming operations. These analyses can also assist in informing decision-making in order to maximize yields, reduce costs, and enhance overall economic outcomes.

For this study, the major fixed costs for threshing and milling are connected to depreciation of the machines while major variable cost is connected to fuel costs and repair cost per year (i.e Fuel cost + Repair cost). These costs are considered variable because they are dependent on the level of the usage of the machines and output. The repair and fuel cost were obtained from the survey, depreciation was calculated using machine prices.

NOTE: Straight Line Method of Depreciation is used in calculating depreciation. Where cost is the price of the machine, salvage value is 10% of cost and estimated useful life of the machine was set at 10 years.

Formula for Calculating Annual Depreciation amount

$$= \frac{\textbf{Cost} - \textbf{Salvage Value}}{\textbf{Estimated useful life of the machine}}$$

Table 9: Variable and fixed cost for threshing operation per year (1 USD = 500 NAIRA)

OPERATORS	Fuel cost/year	Repair cost/year	**VARIABLE COST**	Machine cost	Depreciation cost (Machine)	**FIXED COST**
1	1,280,000	21000	1,301,000	23,000	2,070	2,070
2	650,000	20000	670,000	97,000	8,730	8,730
3	1,300,000	25000	1,325,000	97,000	8,730	8,730
4	547,000	30000	577,000	25,000	2,250	2,250
5	1,250,000	20000	1,270,000	35,000	3,150	3,150
6	1,000,000	20000	1,020,000	80,000	7,200	7,200
7	1,200,000	24000	1,224,000	20,000	1,800	1,800
8	815,000	16000	831,000	10,000	900	900
9	1,315,000	25000	1,340,000	7,000	630	630
TOTAL	9,357,000	201,000	9,558,000	394,000	35,460	35,460
AVERAGE TOTAL	**1,039,667**	**40200**	**1,079,867**	**43,778**	**3,940**	**3,940**

On an average, the variable cost for threshing based on these nine operators is **1,079,867 Naira** While that of fixed cost is **3,940 Naira.** Therefore, the total cost of production would be 1,083,807NGN.

Table 10: Variable and fixed cost for milling operation per year (1 USD = 500 NAIRA)

OPERATORS	Fuel cost/year	Repair cost/year	**VARIABLE COST**	Machine cost	Depreciation cost (Machine)	**FIXED COST**
1	800,000	40000	840,000	30,000	2,700	2,700
2	1,250,000	15000	1,265,000	70,000	6,300	6,300
3	1,300,000	20000	1,320,000	25,000	2,250	2,250
4	730,000	25000	755,000	66,000	5,940	5,940
5	1,095,000	16000	1,111,000	8,000	720	720
6	1,700,000	25000	1,725,000	25,000	2,250	2,250
7	2,790,000	25000	2,815,000	60,000	5,400	5,400
8	1,200,000	25000	1,225,000	70,000	6,300	6,300
9	1,220,000	50000	1,270,000	180,000	16,200	16,200
TOTAL	12,085,000	241,000	12,326,000	534,000	48,060	48,060
AVERAGE TOTAL	**1,342,778**	**26,777.78**	**1,369,556**	**59,333**	**5,340**	**5,340**

On an average, the variable cost for milling based on these nine operators is **1,369,556 Naira** While that of fixed cost is **5,340 Naira.** Therefore, the average total cost of production would be 1,374,896NGN.

Following Table 9 and 10, both operations have a relatively low fixed cost. However, the variable cost which is the summation of fuel and repair cost is relatively high. According to the National Bureau of Statistics (2023), The average price that customers paid for Automotive Gas Oil (Diesel) at retail establishments in January 2023 was N828.82 per litre. This is an increase of 187.69% when compared to the price of N288.09 per litre that was recorded for the same month the previous year (2022).

It is not uncommon to come across individuals who invest the equivalent of one thousand dollars in petroleum products monthly in order to generate electricity for their own individual consumption at home (Adesiji, 2009). In addition to the unpredictability of fuel prices, the persistent rise in prices can have an impact on the productivity and profitability of farmers in rural areas.

4.5.1 Further discussion on the economic feasibility of adopting solar energy.

The total fuel cost for running threshing and milling operations are 2 382 445 Naira. The total cost for installation of 14 pairs of solar panels would be 2 262 000 + 180,000 NGN = 2,442 000 NGN. Based on this, the total cost of installing 14 pairs of solar panels is approximately 2.5% higher than the annual fuel cost for threshing and milling operations. The upfront investment required for solar panel installation is only slightly higher than the cost of purchasing diesel fuel for one year. However, this conclusion should be evaluated in the context of long-term benefits and sustainability. While the initial cost of solar panel installation may appear higher, it is important to consider the long-term cost savings and environmental advantages that solar energy offers. Solar panels provide a renewable and clean source of energy, reducing reliance on fossil fuels and mitigating carbon emissions. Over time, the operational expenses associated with diesel fuel, such as fuel purchases, maintenance, and fluctuating fuel prices, will add up significantly, surpassing the initial investment in solar panels. Additionally, solar panels offer the potential for energy independence and resilience, particularly in rural areas where access to reliable electricity from the national grid may be limited. By harnessing solar energy, farmers and operators can reduce their dependence on external energy sources and ensure a more stable and sustainable energy supply for their agricultural mechanization activities. It is essential to take a comprehensive view of the economic viability of solar panel installation, considering not only the initial cost but also the long-term financial benefits and positive environmental impacts

Another option would be to use electricity from the grid for providing energy for threshing and milling. Given that 1 liter of diesel in Nigeria costs 828 Naira which is equivalent to 10 kWh, it follows that the price of 10 kWh from diesel would be 828 Naira. Conversely, electricity from the national grid is priced at 70 Naira per kWh, making 10 kWh equivalent to 700 Naira. Electricity from the grid is also an environmentally friendly option as this energy is produced from hydroelectric power plants. It therefore seems interesting to use electricity from the grid rather than to use diesel to run the threshers and mills.

Multiplying the 2,877 liters of diesel by 10 kWh gives a total energy demand of 28,770 kWh. This corresponds to a fuel cost for a year of about 2 382 445 Naira. Accounting for an energy loss of 0.4, the actual energy demand would be (28,770 kWh multiplied by 0.4), resulting in 11,508 kWh. With the price of electricity per kWh at 70 Naira, the cost of electricity for this demand would be 805,560 NGN. However, considering an estimated 20% energy loss in electric engines, the cost would be adjusted to approximately 1,000,000 NGN. These calculations suggest that it would be more cost-effective for farmers to install electricity from the national grid, as it is cheaper than relying on diesel engines.

Nevertheless, it is crucial to acknowledge the potential constraints associated with depending on the national grid in Nigeria, such as unstable electricity supply. The inconsistent and unreliable nature of the grid can hinder operational efficiency and productivity in the agricultural mechanization value chain. Therefore, while electricity from the national grid may offer cost advantages, the reliability and stability of the supply should be taken into account when making decisions regarding energy sources.

In conclusion, the findings highlight the economic feasibility of implementing solar energy solutions in the agricultural mechanization value chain, particularly for threshing and milling operations. Solar panels present a cost-effective alternative to diesel fuel, offering potential cost savings and long-term sustainability benefits. However, a careful assessment of the reliability and stability of the national grid is necessary when considering electricity as an alternative. Policymakers, government agencies, and renewable energy companies should collaborate to address barriers, provide financial support, and promote the adoption of solar energy in the agricultural sector, ensuring a sustainable and efficient future for agricultural mechanization.

CHAPTER FIVE

CONCLUSION

In conclusion, this study aimed to assess the utilization of solar energy in the agricultural mechanization value chain, with the main objectives of evaluating the potential to replace conventional energy sources with solar energy, determining the energy demand across various value chain components, and understanding how the adoption of solar energy can increase the capacity of the entire agricultural mechanization value chain system. The research was conducted in the south-western Nigerian state of Oyo, involving 90 maize farmers, 9 maize-mill operators, and 9 maize thresher operators across three Local Government Areas (LGAs).

The findings of this study have shed light on several key aspects related to the utilization of solar energy in agricultural mechanization. Firstly, the results revealed that there is a substantial opportunity to replace conventional energy sources with solar energy in the value chain. The energy demand for threshing and milling operations was calculated, demonstrating the feasibility and efficiency of using solar power in these processes. The emissions resulting from the studied operations were found to be 195 kg (0.195 tons). The study also indicate that electricity from the grid is cheaper than to use diesel as a fuel.

However, the research also identified various barriers to the widespread adoption of solar energy in the agricultural sector. Lack of government support, high installation costs were significant factors hindering the utilization of solar energy among farmers and operators. Addressing these challenges will require collaborative efforts from policymakers, renewable energy companies, and agricultural stakeholders. It is recommended that the government and cooperatives provide financial support, such as subsidies, grants, or loans, to assist farmers and operators in the initial investment of solar panels and installation costs. And also support to installing electricity from the grid. Moreover, awareness programs should be conducted to educate the agricultural community about the advantages of solar energy, promoting its adoption as a sustainable and cost-effective solution.

To facilitate the integration of solar energy into the agricultural mechanization value chain, collaboration between various stakeholders is crucial. Government agencies, renewable energy companies, and agricultural associations should work together to develop policy frameworks that incentivize and regulate the use of solar energy in agricultural practices. These policies can include tax incentives, feed-in tariffs, and regulations to encourage the installation of solar panels and the development of solar-powered machinery.

Furthermore, it is recommended that future research focuses on technological advancements specific to solar energy in the agricultural sector. This research should aim to improve the efficiency and performance of solar-powered machinery, develop cost-effective storage solutions to address the intermittent nature of solar power, and optimize energy distribution across the value chain. By exploring these areas, the agricultural sector can maximize the potential benefits of solar energy in terms of increased productivity, reduced operational costs, and enhanced sustainability.

In conclusion, the findings of this study highlight the significant potential of solar energy in revolutionizing the agricultural mechanization value chain. By overcoming barriers such as lack of support and high costs, and by promoting awareness and collaboration, solar energy can play a pivotal role in enhancing agricultural practices, reducing environmental impact, and contributing to a more sustainable future. Embracing solar energy in the agricultural sector will require collective efforts and the development of supportive policies, but the potential rewards are well worth the investment.

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APPENDIX

QUESTIONNAIRE

Norwegian University of Life Sciences

QUESTIONNAIRE

A COMPARISON OF THE USE OF DIESEL AND SOLAR ENERGY IN THRESHING AND MILLING OF MAIZE: A CASE STUDY OF OYO STATE, NIGERIA

Dear Respondent,

I am Oluwabukonla Mercy Nana, a final-year student pursuing a master's degree in International Environmental Studies at the Norwegian University of Life Sciences (NMBU). I am conducting research on the topic "***A comparison of the use of diesel and solar energy in threshing and milling of maize: a case study of Oyo state, Nigeria***". Be assured of confidentiality on all personal information you give as information obtained from this questionnaire will be used for the purpose of this research only.

Statement of Consent

Dear respondent(s),

Participation in this study is voluntary. Please, put a tick [√] if you are willing and give consent to participate in this survey.

I agree to participate in this study. Agree [ ] Disagree [ ].

PART ONE: SOCIO-DEMOGRAPHIC QUESTIONS

1. Gender: Male ( ) Female ( )
2. Age: 18-25 years ( ) 26-34 years ( ) 35-49 years ( ) 50 years and above ( )
3. Highest Education level: None ( ) Primary level ( ) Secondary level ( ) University ( )
4. Farm location …………………… (lga)
5. Farm size ……………… (in hectares)
6. Total maize production per year …………….. (kg)

PART TWO: ENERGY SOURCE QUESTIONS

1. Do you have electricity on the farm ? Yes ( ) No ( )

If yes, kindly answer the following;

a. How much energy do you use in a month ………. (in kW/hr)

b. How much electricity bill do you pay per month and year? ……………….

c. For what purpose do you use electricity ?

Lighting ( ) Cooking ( ) Charging ( ) Pumping ( ) Refrigeration ( )

If no, Why? Please rank the following: (1 = Most Important, 4 = Least Important)

- Lack of access ( )
- High initial cost of electricity ( )
- Lack of tenure to authorize instalment of electricity ( )
- High operating cost ( )
- Others (Specify): ………………….

2. Do you use Solar at home or on your farm ? Yes ( ) No ( )

If you answered yes, please answer the question in section A

If you answered No, please answer the questions in section B

SECTION A

a. **check the box next to the opportunities you enjoy for using solar.**

Reliable	Environmentally friendly	Cost effective	Affordable	Easy to use	Others? Please specify

b. For which purpose do you use solar? Lighting ( ) Cooking ( ) Charging ( ) Pumping( ) Refrigeration ( )

c. Do you intend to use it for farming operations in the future? Yes ( ) No ( )

d. How many solar panels do you have ?................

e. What is the capacity/energy output ? .... (kW)

SECTION B

Please rank the following reasons why you do not have solar for farmers who do not use solar. (1 = Most Important, 4 = Least Important)

- Unavailability
- High installation cost.
- Lack of tenure to authorize installment.
- High operating cost.
- High maintenance cost
- Not accessible
- Others (Specify): ………………………………….

PART THREE: POST HARVEST OPERATION QUESTIONS

1. Do you normally thresh your maize by yourself ? Yes ( ) No ( )

a. If YES,

i. How many Kg do you thresh per day on average ? ………

ii. How many hours does this take you on average ? …………..

iii. What equipment do you use ? ………………………

iv. What is the average kg you thresh by yourself per day?.......................

v. What is the average kg you give to the thresher operator to thresh ? …………

vi. What is the average kg of maize you thresh yearly ? …………….

b. If NO,

i. What's the cost of threshing a kilo of Maize by a thresher operator ? ………..

ii. What is the average kg you give to the thresher operator to thresh daily ? ………..

iii. What is the average kg you thresh yearly ? …………………

2. Do you mill/grind your maize by yourself ? Yes ( ) No ( )

a. If YES,

i. How many Kg do you mill per day on average ? ………

ii. How many hours does this take you on average ? ……………

iii. What equipment do you use ? ………………………

iv. What is the average kg you mill/grind by yourself per day?.......................

v. What is the average kg you give a milling operator ? ………….

vi. What is the average kg of maize you mill yearly ? …………….

b. If NO,

i. What's the cost of milling/grinding your maize per Kilo?...............

ii. What is the average kg you give to the mill operator daily ? ………..

iii. What is the average kg you mill yearly ? …………………

Norwegian University of Life Sciences

A COMPARISON OF THE USE OF DIESEL AND SOLAR ENERGY IN THRESHING AND MILLING OF MAIZE: A CASE STUDY OF OYO STATE, NIGERIA

Dear Respondent,

I am Oluwabukonla Mercy Nana, a final-year student pursuing a master's degree in International Environmental Studies at the Norwegian University of Life Sciences (NMBU). I am conducting research on the topic "***A comparison of the use of diesel and solar energy in threshing and milling of maize: a case study of Oyo state, Nigeria***". Be assured of confidentiality on all personal information you give as information obtained from this questionnaire will be used for the purpose of this research only.

1. Gender: Male [ ] Female [ ]
2. Age: 18-25 years [ ] 26-34 years [ ] 35-49 years [ ] 50 years and above [ ]
3. Location ……………… (LGA)
4. How long have you been practicing this ? ……..
5. How long have you had your machine ? ……….
6. What is the horsepower of the machine ? ………
7. What is the price at purchase ? ……………….
8. How many times do you make repairs per year ? ………..
9. What is the average cost you spend on repairs yearly ? …..
10. Source of energy for the machine? Fuel ( ), Electricity ( ), Others, Please specify………….
11. How many litres of fuel or kWh is used daily ? ………….(litres) …………kWh
12. What is the cost of the fuel or electricity per day and per year ? ……………..
13. How many farmers are your customers? ………..
14. How much do you charge per kg of threshed grains ? ………..
15. What is the maximum Kg you produce per day ? ………..
16. How many Kg do you thresh in average per year ? ……………
17. What is your interest rate monthly and yearly ? ……….
18. Do you have any plans to change to another power source like electricity or solar ? ……

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11. How many litres of fuel or kWh is used daily ? ………….
12. What is the cost of the fuel or electricity per day and per year ? ……………..
13. How many farmers are your customers? ………..
14. How much do you charge per kg of milled grains ? ………..
15. What is the maximum Kg you produce per day ? ………..
16. How many Kg do you mill on average per year ? ……………
17. What is your interest rate monthly and yearly ? ……….
18. Do you have any plans to change to another power source like electricity or solar ? ……

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway