Comparative Economic and Environmental Analysis of Open Field (Rainfed and Irrigated) and Environmental Agriculture (Screenhouse) Leafy and Pulpy Vegetables Production Systems in North West Nigeria.

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Abstract

Screenhouse farming demonstrates remarkable water-use efficiency, requiring only 7.00 liters per kg for cabbage, 3.58 liters/kg for lettuce, and 2.38 liters/kg for spinach, a significant contrast to rainfed cabbage at 10,625 liters/kg and rainfed pumpkin at 17,628 liters/kg. This means screenhouse farming uses just 0.066% of the water consumed by rainfed cabbage and 0.014% of the water used by rainfed pumpkin. While screenhouse farming involves higher investment costs at ₦5,342,973 per hectare, making it 764% more expensive than rainfed farming, it offers superior yield efficiency. In contrast, rainfed farming has a lower cost of ₦698,972 per hectare but suffers from reduced productivity and inefficient resource utilization. Greenhouse gas (GHG) emissions are significantly lower in screenhouse farming, with lettuce producing only 3.24 kg CO_2-eq/kg, just 2.74% of the emissions generated by rainfed lettuce, which releases 118.25 kg CO_2-eq/kg. Similarly, screenhouse farming is more energy-efficient, with spinach requiring only 0.09 MJ/kg, amounting to 3.4% of the energy demand of irrigated pumpkin, which stands at 2.62 MJ/kg. These findings highlight the advantages of screenhouse farming in reducing water consumption, emissions, and energy demand, while irrigated farming ensures stable moisture levels but requires substantial water resources. Rainfed farming minimizes irrigation dependency but lacks productivity efficiency, underscoring the need for sustainable irrigation strategies such as drip irrigation, fertigation, and rainwater harvesting to enhance long-term resource conservation in vegetable production..

Key words: Comparative Analysis, Economic Efficiency, Environmental Impact, Rainfed Farming, Irrigated Farming , Screenhouse Farming, Leafy Vegetables, Pulpy Vegetables, Water Use Efficiency, Greenhouse Gas Emissions, Energy Demand, North West Nigeria.

1. Introduction

Vegetables and fruits are a fundamental part of global food systems, yet they contribute significantly to food miles, accounting for nearly one-fifth of total food transportation and over one-third of transport-related emissions (Carbon Brief, 2022). Their high water content and reliance on energy-intensive refrigeration throughout the supply chain make them environmentally demanding.

Among these, leafy vegetables such as cabbage (*Brassica oleracea var. capitata*), lettuce (*Lactuca sativa*), and spinach (*Spinacia oleracea*) are known for their delicate texture, high moisture content, and rich nutritional profile, including essential vitamins A, C, K, and folate (Bhatti *et al.,* 2024). These vegetables flourish in cooler climates and require frequent irrigation for maximum yield (USDA, 2021). While they are widely consumed fresh or cooked (HSPH, 2021; FAO, 2023), their short shelf life accelerates spoilage, potentially increasing food waste.

Conversely, pulpy vegetables, including eggplant (*Solanum melongena*), cucumber (*Cucumis sativus*), and pumpkin (*Cucurbita pepo*), are characterized by firmer, fleshy pulp and moderate to high water content (Bhatti *et al.,* 2024). These vegetables provide essential fiber, antioxidants, and minerals, adapting well to warmer climates. Their longer shelf life enhances transport resilience and market stability, making them integral to global food systems.

From an environmental perspective, leafy vegetables require more frequent irrigation and space-efficient farming methods, while pulpy vegetables often demand more land but are typically drought-resistant, making them a sustainable alternative in arid regions (FAO, 2020).

The global vegetable market is expanding rapidly, driven by rising demand for fresh and processed vegetables. By 2025, global vegetable revenue is projected to reach $1.16 trillion, with an annual growth rate of 6.59% (CAGR 2025-2030) (Statista, 2025). In comparison, Nigeria's vegetable market revenue is estimated at $31.52

billion, growing at a faster rate of 11.33% annually (CAGR 2025-2030) (Statista, 2025). China remains the largest producer, generating $171 billion in revenue, highlighting its dominance in global vegetable consumption. On a per capita basis, global vegetable revenue is expected to be $147.84 per person, whereas Nigeria's per capita revenue is projected at $132.71 in 2025 (Global Market Statistics, 2025).

From a volume standpoint, global vegetable production is expected to reach 686.44 billion kg by 2030, with a 4.3% growth in 2026, while Nigeria's vegetable market volume is projected to reach 10.54 billion kg by 2030, showing 5.5% growth in 2026—reflecting strong domestic demand (Global Market Statistics, 2025).

The yield and efficiency of leafy and pulpy vegetable farming are largely influenced by soil fertility, management practices, and irrigation techniques. Traditional open-field farming, whether rainfed or irrigated, has remained the dominant cultivation method for centuries. Rainfed agriculture, which depends on the use of open pollinated varieties (OPV) and natural precipitation, is particularly susceptible to climate variability (Fadeyi & Ayodeji, 2023). Conversely, irrigated farming enhances yield stability by supplementing rainfall with artificial watering systems, though it leads to higher water consumption (Wudil *et al.,* 2022).

This raises an important question—can local vegetable production serve as a sustainable solution by improving economic stability while simultaneously lowering the carbon footprint associated with production and long-distance transportation (Tilman *et al.,* 2002)? Addressing this concern, studies examining irrigation efficiency and soil amendments in cabbage cultivation demonstrate that hydrogel, NPK fertilizer, and biochar significantly enhance marketable yields, offering viable strategies to optimize productivity (Enguwa *et al.,* 2024). Drip irrigation at 0.8 Crop Evapotranspiration (ETc) with 100% Randomized Fertigation (RDF) is economically viable, while lower irrigation levels (0.4 ETc) optimize water-use efficiency (Jadhav *et al.,* 2020a; Jadhav *et al.,* 2020b). Advanced techniques like Deficit Irrigation (DI) and Partial Root Drying (PRD) have shown success in water conservation without compromising crop yield (Demir *et al.,* 2024).

For leafy vegetables, research has explored nutritional bioavailability and how processing techniques impact phytonutrient retention in spinach (Sarma & Bhavya, 2024). Socioeconomic analyses in Nigeria show that organic fertilizers, such as compost, improve yield sustainability, making them preferable to inorganic fertilizers (Obebe *et al.,* 2020).

Modern farming techniques enable cabbage yields ranging from 15 to 20 tons per hectare, generating high profits, particularly for export markets (FAO, 2023). Although a broader study on genetic diversity in vegetable crops discusses breeding strategies for resilience and yield improvement, including crops like lettuce, spinach, cucumber, and eggplant (Bhatti *et al.,* 2024). However, Nigeria's agricultural sector remains food-import dependent, with agricultural imports totaling 3.35 trillion Naira from 2019 to 2023, significantly outpacing exports (Nwanojuo *et al.,* 2025). This trade imbalance underscores the need for alternative solutions to improve domestic vegetable production sustainability.

Controlled Environmental Agriculture (CEA) optimizes temperature, humidity, and light to enhance vegetable production efficiency. Technologies like hydroponics, aeroponics, and aquaponics reduce water usage and minimize pest exposure. While CEA systems require higher initial investments, they boost productivity and sustainability. Research on spinach and lettuce production in NFT hydroponic systems demonstrated that greenhouse cultivation enhances yield and nutritional quality compared to open-field farming in Leh, India (Kumarac *et al.,* 2023).

CEA techniques significantly impact the yield potential of leafy vegetables (lettuce & spinach) and pulpy vegetables (cucumber, eggplant & pumpkin). Hydroponic systems significantly improve leafy vegetable yields, with lettuce yielding an average of 27.5 tons per hectare and spinach averaging 19 tons per hectare, sometimes doubling productivity compared to traditional open-field farming. Trellising and greenhouse farming enhance cucumber yield to an average of 30 tons per hectare and eggplant to 28 tons per hectare, leading to higher fruit quality and better disease resistance. Pumpkin, which requires more space due to sprawling growth, yields an average of 22.5 tons per hectare under optimized conditions (Plant calculators, 2025; Acharya *et al.,* 2021).

The GLASE (2024) study evaluates the environmental performance of greenhouse and indoor farming, revealing that Controlled Environment Agriculture (CEA) enhances crop yields by up to 446%, particularly benefiting leafy vegetables such as lettuce. While CEA significantly reduces water usage (by 60–77%), it demands five times more energy than traditional open-field farming, resulting in higher greenhouse gas (GHG) emissions. The study underscores the importance of optimizing energy efficiency and integrating renewable energy sources to improve the sustainability of greenhouse and vertical farming systems (Ogbonna *et al.*, 2023).

Although CEA can lower GHG emissions associated with transportation (IRENA, 2019), its energy-intensive operations pose economic and logistical challenges (Nicholson et al., 2023). Therefore, directed research and policy interventions are necessary to assess its feasibility in Nigeria, ensuring economic sustainability and efficiency within urban agriculture. A comparative economic analysis of various farming systems evaluates production costs, market value, and profitability.

Among leafy vegetables, cabbage remains a staple crop, maintaining year-round market demand, much like potatoes (Kiran *et al.,* 2024). Meanwhile, its pulpy counterpart, cucumber, is widely recognized in Nigeria as the Farmers' Automated Teller Machine (ATM) due to its fast-growing cycle and profitability, allowing farmers to earn substantial income within a short time frame (Veggie Concept, 2022). However, there is limited data on their environmental impact, particularly regarding water consumption, carbon footprint, and land efficiency. As a result, further research is needed to explore sustainability factors, including climate resilience, resource conservation, and long-term viability.

This study examines the comparative economic and environmental implications of Open Field farming (rainfed and irrigated) versus Screenhouse leafy and pulpy vegetable production systems. Utilizing Life Cycle Analysis (LCA), the research evaluates production cost, yield, cumulative energy demand (CED), global warming potential (GWP), and water usage (WU), offering insights into the sustainability and efficiency of these agricultural systems in the Kudan Local Government Area (LGA) of Kaduna State, Nigeria. The findings will provide valuable guidance for policymakers, farmers, and investors, ensuring optimal resource allocation and sustainable farming practices for Nigeria's vegetable production.

2. Materials and method

Environmental sustainability data for Likoro remains scarce, necessitating an in-depth analysis of three distinct vegetable production systems: rainfed open-field farming, irrigated field-based cultivation ("Fadama"/"Lam-bu"), and screenhouse farming. To ensure comparability, the study defines its functional unit as one kilogram of saleable, unprocessed vegetable produce, encompassing both leafy vegetables—cabbage (*Brassica oleracea var. capitata*), lettuce (*Lactuca sativa*), and spinach (*Spinacia oleracea*)—and pulpy vegetables, including eggplant (*Solanum melongena*), cucumber (*Cucumis sativus*), and pumpkin (*Cucurbita pepo*). This approach aims to bridge critical knowledge gaps and evaluate the environmental implications of each farming system.

Kudan Local Government Area (LGA) in Kaduna State is positioned at latitude 11°16'23"N and longitude 7°47'56"E, covering an area of 400 square kilometers with an average temperature of 27°C (Weather Spark, 2024). Excessive heat can lead to flower abortion in vegetables, significantly reducing yield. The region experiences two distinct seasons—the dry season and the rainy season—which begins in early April and ends in October, shaping local agricultural practices. Approximately 98% of vegetable farmers in Nigeria cultivate in the open field using rainfed and irrigated production methods. During the dry season, which spans October to April, irrigated farming becomes crucial for sustaining vegetable production. Among irrigation methods, flood irrigation using wells—typically shared at a ratio of one well per 10 farmers—is the most widely practiced technique, employed by over 95% of producers (Table 1A).

Drip irrigation, which is predominantly used in screenhouse, is widely recommended as a superior alternative for boosting vegetable yields. By enabling daily fertigation, this system can increase productivity by up to 200% while supporting continuous, year-round cultivation. Allowing multiple cultivation cycles per year, significantly increasing productivity compared to rainfed and irrigated systems, which typically support only 1–2 cycles annually. In line with survey results and available research, cabbage can be cultivated 4–6 times per year, depending on variety and environmental conditions. Lettuce, benefiting from rapid growth and controlled climate, can be grown 6–8 times annually, making it one of the most frequently cultivated leafy vegetables in screenhouse systems. Spinach follows closely with 5–7 cycles per year, supported by optimized fertigation and nutrient delivery that accelerate its growing cycle.

Among pulpy vegetables, cucumber can be produced 4–6 times per year, with precision irrigation and nutrient management enhancing its yield potential. Eggplant requires longer maturation periods, limiting cultivation to 3–5 cycles annually. Pumpkin, due to its extended growing period and larger space requirements, typically achieves only 2–4 cultivation cycles per year in controlled environments (Table 1A). These estimates align with findings from crop rotation studies and Controlled Environment Agriculture guidelines, which emphasize the advantages of year-round production, optimized resource utilization, and climate control in CEA systems (Fadeyi & Ayodeji, 2023; Kumarac et al., 2023).

However, vegetable farmers in this area frequently grow open-pollinated varieties due to their affordability, though these seeds often result in lower yields and reduced resistance to pests and diseases compared to hybrid alternatives (Afri-Agri Products, 2025; Nigerian Seed Portal Initiative, 2025; SME Guide, 2025; Ugoo, 2024; Das et al., 2023; Veggie Concept, 2022; Alam & Salimullah, 2021; Rakha et al., 2021). Land preparation in this region is less labor-intensive and more cost-effective than in the rainforest belt, primarily due to the minimal presence of trees. Ox-drawn implements are commonly used for tillage, ploughing, and harrowing, though some farmers opt for tractors where available. Pulpy vegetables thrive in sandy loamy soil with a pH range of 5.5–6.7, enriched with organic matter to promote high yields (Table 1A).

In open-field vegetable cultivation, pesticide application is crucial since plants lack protective coverings against pests. Soil amendments, such as nematicides, improve fertility and pest control, while applying 1–6 tonnes of chicken manure per hectare enhances soil health before planting. These amendments also improve water retention and nutrient availability, optimizing crop growth.

Applying base fertilizers following chicken manure application further enhances soil nutrition. Phosphatic fertilizers support early growth, while nitrogen-based fertilizers facilitate leaf development for higher yields. During flowering and fruiting, potassium and calcium fertilizers improve fruit quality and stress resistance. Drip irrigation fertigation, commonly used in screenhouse, boosts nutrient efficiency, while calcium remains essential for plant resilience and fruit longevity, though often overlooked by farmers.

Although nursery cultivation is common in vegetable farming, direct sowing is preferred for cucumber production in Nigeria, as cucumber seedlings are highly susceptible to transplant shock. Instead of transplanting, farmers can plant seeds directly into small holes, cover them with soil, and allow natural germination, promoting stronger plant establishment and higher yields.

Spacing recommendations for leafy and pulpy vegetables ensure optimal air circulation and nutrient absorption. Cabbage is typically planted at 45–60 cm between plants and 60–75 cm between rows, allowing for a plant population of 22,222–29,630 plants per hectare. Lettuce requires 20–30 cm between plants and 30–40 cm between rows, supporting a density of 83,333–166,667 plants per hectare, making it one of the highest-density crops. Spinach thrives in closer arrangements, spaced at 10–15 cm between plants and 30–40 cm between rows, leading to a density of 166,667–333,333 plants per hectare (Plant Calculators, 2025; Gardening Tips, 2025; Gardening Know How, 2023).

Among pulpy vegetables, cucumbers—if trellised—are planted 30–50 cm apart within rows and 100–150 cm between rows, resulting in a plant population of 13,333–33,333 plants per hectare. Eggplants follow cabbage-like spacing, requiring 45–60 cm between plants and 60–75 cm between rows, leading to a density of 22,222–29,630 plants per hectare. Pumpkin, a sprawling crop, requires 100–150 cm between plants and 200–300 cm between rows, yielding a lower plant population of 2,222–5,000 plants per hectare (Plant Calculators, 2025; Gardening Tips, 2025; Gardening Know How, 2023). These spacing recommendations are crucial for determining plant populations per hectare, ensuring proper growth, nutrient access, and yield efficiency.

Cucumber yields in Nigeria range from 5,000 kg to 99,000 kg per hectare, depending on agronomic practices. A hectare of cucumber can yield between 99 and 247 bags (Veggie Concept, 2022). Non-production areas for parking and loading account for approximately 56% of total land use in agricultural setups (Eaves & Eaves, 2018; Nicholson et al., 2020). In field production, an estimated 50% of Fresh Fruits and Vegetables (FFVs) are lost due to poor handling, processing, and preservation practices in Nigeria (FAO, 2024; Gain Health, 2022; Balana et al., 2022; de Brauw & Bulte, 2021), resulting in significant yield losses (Table 2A).

Unlike leafy vegetables, staking is crucial for open-field pulpy vegetable farming, particularly for cucumber, eggplant, and pumpkin (Table 1A). However, some farmers overlook this essential practice, leading to lower yields. When pulpy vegetables spread along the soil, they become highly vulnerable to infections, fruit deterioration, and rotting. Implementing staking techniques—using bamboo, planks, binding wires, ropes, or staking nets—enhances plant health, improves fruit quality, and boosts productivity (Veggie Concept, 2022).

Leafy and pulpy vegetables thrive under screenhouse, with hybrid varieties dominating cultivation (Afri-Agri Products, 2025; Nigerian Seed Portal Initiative, 2025; SME Guide, 2025; Ugoo, 2024; Das et al., 2023; Veggie Concept, 2022; Alam & Salimullah, 2021; Rakha et al., 2021). screenhouse farming employs non-automated NAERLS freestanding screenhouse, measuring 79' × 20' (147 m^2 or approximately 0.02 hectares), similar to structures featured in Amoako et al. (2022) and Olabisi & Nofiu (2022), as well as the hoop-style houses described by Wang et al. (2017).

These screenhouse incorporate insect-proof netting, creating a regulated microclimate that optimizes temperature, humidity, light penetration, and airflow, ensuring ideal conditions for vegetable growth. The netted enclosure serves as a pest barrier, significantly reducing reliance on chemical pesticides while promoting healthier, more resilient crops.

Beyond pest management, screenhouse systems extend the harvesting period, supporting intensive vegetable production with higher fertilizer application and input use per plant. Its high-density planting approach further amplifies crop yields, positioning it as an efficient and productive cultivation method (Table 2A).

Despite their numerous benefits, Controlled Environment Agriculture (CEA) methods, including screenhouse, poly-tunnels, and greenhouse farming, remain uncommon in Nigeria due to substantial initial investment costs required for construction and irrigation system installations. Additionally, technical expertise for implementation and management poses a significant barrier to widespread adoption.

2.1 Assessment of Economic and Environmental Metrics

2.2 Production Costs

Analyzing the production costs of leafy vegetables (cabbage, lettuce, and spinach) and pulpy vegetables (cucumber, eggplant, and pumpkin) across three farming systems—screenhouse, rainfed farming, and irrigated farming—provides insights into financial investments and yield efficiency (Tables 3A and 4A). Data was compiled to assess fixed and variable costs per hectare, comparing key inputs and their influence on overall production efficiency.

Fixed Costs

Fixed costs include expenses that remain unchanged across production cycles, such as land rental prices, which vary across screenhouse, rainfed, and irrigated conditions. Infrastructure investments encompass drip irrigation systems, flood irrigation systems, and well construction, which are particularly relevant to irrigated farming. Additional fixed expenditures involve essential equipment such as farm tools, pumping machines, and overhead tanks for effective water management. Screenhouse structures, unique to CEA production, represent a higher initial investment due to the requirements of protected cultivation (Tables 3A and 4A).

Variable Costs

Variable costs cover recurring production expenses, including seeds, fertilizers (NPK, Calcium Magnesium, and Potassium Humate), chicken manure, and pesticides. Labor costs account for both hired and family labor, ensuring operational efficiency. Irrigation-related expenses, such as electricity for pumps and diesel fuel, are calculated based on seasonal usage. Data is recorded on a per-hectare basis to facilitate standardized comparison between different production systems (Tables 3A and 4A).

Yield and Saleable Product

Yield data for each vegetable type is recorded in kilograms per hectare per year, reflecting productivity across farming systems. Saleable product values represent the portion of total yield deemed market-ready, allowing for an effective cost analysis per unit output. This comparative framework evaluates financial investment in leafy and pulpy vegetable cultivation while accounting for profitability and yield efficiency (Tables 3A and 4A).

This methodology establishes a comprehensive assessment of production costs, highlighting investment requirements, operational expenses, and yield optimization strategies across different agricultural practices.

2.3 Cumulative Energy Demand

Evaluating the energy consumption of diesel and electric pumps in vegetable production provides insights into efficiency across two distinct farming systems: Screenhouse and irrigated farming. Rainfed production excludes the use of diesel fuel, resulting in lower direct emissions from energy consumption.

The analysis focuses on energy usage, assessing fuel consumption per hectare, plant population density, and yield productivity. Screenhouse farming, which relies on precision irrigation, operates within a 0.0147-hectare area, whereas irrigated farming spans 1 hectare (Table 5A).

Plant population densities differ depending on vegetable type and production system. Leafy vegetables, such as cabbage, lettuce, and spinach, exhibit higher densities, with irrigated farming accommodating up to 250,000 plants per hectare, while screenhouse production supports fewer plants, ranging from 381 to 3,675 per 0.0147 hectares. Conversely, pulpy vegetables, including cucumber and eggplant, maintain lower densities, with irrigated farming housing 23,333 to 25,926 plants per hectare, while screenhouse production holds 343 to 381 per 0.0147 hectares (Table 5A).

Diesel consumption per hectare is recorded and compared with secondary sources (Energypedia, 2022; Energypedia, 2021; Energypedia, 2020). Energy equivalent values are calculated using the standard diesel energy content of 35.8 megajoules per liter (MJ/L). Energy efficiency assessments include total diesel usage per season, daily consumption rates, energy usage per plant per day, and yield efficiency (MJ/kg) across different vegetable types and farming systems (Table 5A).

A comparative analysis of diesel and electric pump energy consumption across screenhouse, rainfed, and irrigated farming assesses irrigation system efficiency. Diesel pump energy usage is calculated per hectare, while electric pump energy demand is measured in kilowatt-hours (kWh) per hectare, using a conversion factor of 1 kWh = 3.6 MJ (Table 6A).

For diesel-powered irrigation, fuel consumption is analyzed across leafy vegetables (cabbage, lettuce, spinach) and pulpy vegetables (cucumber, eggplant, pumpkin). Screenhouse farming operates within 0.0147 hectares, while rainfed and irrigated farming span 1 hectare, enabling direct comparisons of fuel efficiency. Key variables examined include plant population per hectare, total seasonal fuel usage, daily energy consumption per plant, and yield intensity per kilogram (MJ/kg).

In contrast, electric pump irrigation is evaluated based on kilowatt-hour usage per hectare, seasonal electricity consumption, and energy equivalents for each vegetable type. The estimated energy usage of 250 to 350 kilowatt-hours (kWh) per season for an electric pump makes it a practical choice for many farmers. On average, electric pumps might consume around 0.5 to 1.5 kWh per hour of operation. As of November 2024, the average cost for households is approximately ₦23.59 per kWh, while for businesses, it is around ₦38.53 per kWh (Nigerian Price, 2024). Rainfed farming, which requires lower irrigation dependency, is included in the analysis (Table 6A), demonstrating its reduced energy demand compared to irrigated farming. By assessing energy factors across production methods, the findings offer valuable insights into the sustainability and efficiency of diesel versus electric irrigation systems.

2.4 Global Warming Potential (GWP)

Assessing the Global Warming Potential (GWP) associated with nitrogen inputs in vegetable production provides insights into greenhouse gas emissions from irrigated, rainfed, and screenhouse systems (Table 7A). Using Tier 1 default methods and emission factors from the 2006 IPCC Guidelines, greenhouse gas (GHG) emissions from nitrogen fertilizer applications in managed soils were estimated (IPCC, 2007). Nitrous oxide (N_2O) emissions were quantified based on direct emissions from nitrogen inputs and indirect emissions from manure management systems (MMS), which contribute through ammonia volatilization and nitrate leaching (Eaves & Eaves, 2018).

The assessment examines synthetic fertilizers, including NPK formulations (15-15-15, 20-10-10, and 12-12-17), alongside organic manure applications (Table 7A). Emission factors for synthetic fertilizers are standardized at 4%, meaning 4 kg of N_2O emissions occur per 50 kg of fertilizer applied (Nicholson, Harbick, Gómez, Mattson, 2020). Chicken manure applications exhibit a significantly higher emission factor of 20%, resulting in 20 kg of N_2O emissions per 100 kg of chicken manure used (IPCC, 2014). To quantify the climate impact of nitrogen emissions, Global Warming Potential (GWP) conversion values were applied: 298 CO_2-equivalents per kg of N_2O (IPCC, 2014), 0.014 CO_2-equivalents per kg of NH_3 (Ritchie, Max, and Rosado, 2020), and 0.001 CO_2-equivalents per kg of NO_3 (Omorogbe, 2021).

Nigeria's carbon dioxide emissions per gigawatt-hour (GWh) of energy generation are reported to be 400 tCO_2, according to data from the International Renewable Energy Agency (IRENA, 2024). The carbon emissions per kilowatt-hour (kWh) provide a basis for evaluating Nigeria's energy-related environmental impact. Diesel consumption of 375.6 liters in irrigated systems and 7.51 liters in screenhouse vegetable production contributes to greenhouse gas emissions, with estimated carbon dioxide, methane, and nitrous oxide emissions of 2.68%, 0.0003%, and 0.00002%, respectively (Jun, Franca & Iwuozor, 2023; Dirisu, Oyedepo, Airhihen, Adelekan, Efemwenkiekie & Khan, 2024).

Nitrogen input quantities were recorded per vegetable type and production system, while direct and indirect emissions were calculated based on nitrogen application rates. GWP values were used to convert emissions into CO_2-equivalents for a 100-year time horizon (Table 7A). The findings provide comparative insights into nitrogen management efficiency across irrigated, rainfed, and screenhouse vegetable farming methods, contributing to a broader understanding of sustainable fertilizer application strategies. This approach supports the identification of optimal nitrogen management practices that minimize emissions and mitigate climate change effects while maintaining agricultural productivity.

2.5 Water Use (WU)

Water consumption in leafy and pulpy vegetable production varies significantly depending on the production system—irrigated, rainfed, or screenhouse. Effective water management plays a vital role in sustaining plant health, optimizing yield efficiency, and minimizing resource waste across these systems (Sangare, Compaore, Buerkert et al., 2012; Eaves & Eaves, 2018).

Irrigated farming operates on a 1-hectare scale, where water availability is regulated through surface methods to maintain stable moisture levels. Rainfed production, also on a 1-hectare scale, relies entirely on natural precipitation, resulting in seasonal fluctuations in water supply and crop yield outcomes. In contrast, screenhouse farming takes place within a smaller 0.0147-hectare controlled environment, utilizing precise fertigation techniques (drip irrigation) to ensure efficient water distribution, optimal soil moisture, and nutrient uptake (Table 9A).

Water consumption varies based on vegetable type, production method, and environmental conditions. Leafy vegetables have shorter growing periods ranging from 30 to 95 days, requiring moderate water intake, whereas pulpy vegetables demand longer maturation periods (45–140 days), increasing their overall water requirements (Table 9A). On average, irrigated crops require between 45,000–80,000 liters/ha/day, while rainfed crops rely on rainfall, consuming 30,000–65,000 liters/ha/day (Table 9A). The screenhouse production systems, using precision irrigation, demand higher water intake ranging from 50,000–90,000 liters/ha/day, particularly for pumpkin and eggplant, which require greater moisture retention (Sangare, Compaore, Buerkert et al., 2012; Eaves & Eaves, 2018).

Optimizing irrigation efficiency is essential for maximizing yield while reducing excess water usage. Irrigated farming balances resource availability with external irrigation inputs, ensuring consistent productivity. Rainfed farming has the lowest irrigation demand, but its strong dependence on seasonal rainfall limits reliability. Screenhouse farming, despite its higher water usage, ensures controlled irrigation efficiency, enabling year-round vegetable cultivation with precise nutrient management.

Assessing daily water requirements per hectare allows for better resource allocation, improved yield efficiency, and enhanced sustainability, particularly in water-scarce regions that include Kudan Local Government Area.

3 Results and Discussion

3.1 Results

A comparison of the production costs for leafy vegetables (Table 3A) and pulpy vegetables (Table 4A) reveals notable differences in investment, yield, and profitability across screenhouse, rainfed farming, and irrigated systems.

Fixed costs remain relatively consistent between both vegetable categories. Land rental expenses, irrigation systems, screenhouse structures, and essential farm tools are identical across Tables 3A and 4A. The investment required for screenhouse production is significant (₦4,702,326), while rainfed and irrigated farming maintain lower fixed costs (₦145,250 and ₦942,750, respectively).

Variable costs show similarities, with both vegetable types requiring seeds, fertilizers, labor, and irrigation inputs. However, fertilizer and insecticide costs differ slightly, as pulpy vegetables such as cucumber, eggplant, and pumpkin require varied quantities and pricing. Additionally, insecticide and fungicide expenses range between ₦9,750–₦20,000 for pulpy vegetables, compared to ₦10,800 for leafy vegetables. Despite these discrepancies, both groups maintain similar total variable costs per hectare, averaging ₦640,646.68 in screenhouse, ₦553,722.33 in rainfed farming, and ₦1,091,395.01 in irrigated systems.

When evaluating total production costs, both vegetable categories exhibit similar figures across farming systems, with screenhouse costing ₦5,342,973, rainfed farming at ₦698,972, and irrigated farming at ₦2,034,145.

Yield Differences

Screenhouse production achieves higher yield efficiency due to its ability to support multiple cropping cycles per year, compared to rainfed and irrigated systems, which are limited to only one cycle per year. The integration of hybrid seed varieties, precision irrigation, and controlled environmental conditions enhances productivity, reduces resource waste, and improves profitability.

Screenhouse farming incurs higher initial costs, with ₦5,342,973/ha required for cabbage, lettuce, spinach, cucumber, eggplant, and pumpkin production, compared to ₦2,034,145/ha in irrigated farming and ₦698,972/ha in rainfed farming. However, this investment translates into significantly higher yields, with screenhouse cabbage producing 17,500 kg/ha per year, lettuce 24,000 kg/ha per year, spinach 26,600 kg/ha per year, cucumber 21,000 kg/ha per year, eggplant 15,200 kg/ha per year, and pumpkin 11,700 kg/ha per year. In contrast, rainfed systems produce only 700–750 kg/ha per year for leafy vegetables and 800–850 kg/ha for pulpy vegetables, while irrigated farming yields 2,000–2,300 kg/ha per year.

A breakdown of cost per yield reveals screenhouse's economic advantage. Screenhouse cabbage costs ₦611/kg, whereas rainfed cabbage costs ₦1,997/kg and irrigated cabbage ₦2,034/kg, proving screenhouse's superior efficiency in production cost per unit of saleable product. Similar trends appear in lettuce and spinach, where screenhouse farming lowers unit costs, making it the most profitable system. Among pulpy vegetables, screenhouse cucumber costs ₦509/kg, eggplant ₦703/kg, and pumpkin ₦913/kg, compared to ₦1,747/kg for rainfed cucumber, ₦1,645/kg for rainfed eggplant, and ₦1,792/kg for rainfed pumpkin. Irrigated production remains more costly, with ₦1,849/kg for cucumber, ₦1,769/kg for eggplant, and ₦1,808/kg for pumpkin.

Screenhouse supports higher-frequency cropping cycles, ranging from 4–6 cycles per year for cabbage, 6–8 cycles for lettuce, 5–7 cycles for spinach, 4–6 cycles for cucumber, 3–5 cycles for eggplant, and 2–4 cycles for pumpkin. This ability to produce multiple harvests annually ensures consistent market supply, optimized land use, and higher economic returns, far exceeding the limited annual yield potential of rainfed and irrigated systems.

The use of hybrid seed varieties enhances yield stability and crop resilience. Hybrid varieties, such as Tycoon F1 cabbage, Tropicana F1 lettuce, Greengo F1 cucumber, Black Beauty F1 eggplant, and Jacqueline F1 pumpkin, are bred for higher germination rates, disease resistance, and adaptability to controlled environments, ensuring optimal productivity in screenhouse farming. In contrast, open-pollinated varieties (OPVs) used in rainfed and irrigated farming suffer from inconsistent growth rates, lower resilience to pests, and longer maturation periods, contributing to yield instability and lower overall output.

Additionally, screenhouse precision irrigation and fertigation techniques ensure continuous nutrient delivery, reducing water waste and maximizing plant health. In contrast, rainfed systems rely solely on natural precipitation, leading to moisture inconsistencies and crop stress, while irrigated farming provides controlled water access but lacks optimized nutrient absorption, limiting overall yield potential.

From an economic and sustainability standpoint, screenhouse farming offers superior cost efficiency per kilogram, strengthens market competitiveness, and maximizes returns per hectare, making it the preferred model for long-term vegetable farming. While rainfed systems are cheaper, they suffer from high unit costs due to limited yield potential, making them less viable for large-scale commercial production. Irrigated farming, though ensuring stable moisture, remains water-dependent, increasing long-term resource consumption risks.

Key Takeaway

screenhouse farming outperforms rainfed and irrigated systems by optimizing higher-frequency cropping cycles, hybrid seed advantages, and resource-efficient irrigation techniques, ensuring higher yield efficiency, reduced production costs per kilogram, and greater profitability in vegetable farming.

Cumulative Energy Demand (CED)

The cumulative energy demand (CED) analysis for leafy and pulpy vegetables reveals significant differences in energy consumption across different production systems, including irrigated, rainfed, and screenhouse. The results indicate that irrigated farming exhibits the highest energy equivalent values due to its increased dependency on irrigation systems. In contrast, rainfed farming demonstrates the lowest energy consumption, as crops rely solely on natural rainfall, eliminating the need for fuel-powered or electric irrigation systems. Screenhouse farming, despite its smaller operational area of 0.0147 hectares, shows intermediate energy usage due to specialized irrigation techniques, climate control, and precision farming technologies (Table 1).

Leafy Vegetables

Leafy vegetables, including cabbage, lettuce, and spinach, tend to be more energy-efficient across all farming methods. Rainfed cabbage, lettuce, and spinach require only 0.57 MJ/kg, 0.48 MJ/kg, and 0.41 MJ/kg, respectively, indicating minimal energy dependence due to natural precipitation. However, irrigated cabbage, lettuce, and spinach demand significantly higher total energy equivalents per hectare, ranging from 6,807 MJ for cabbage to 4,228 MJ for spinach, mainly due to pumping costs and irrigation energy inputs.

In screenhouse farming, energy consumption per kilogram of produce is notably lower, with cabbage requiring 0.22 MJ/kg, lettuce 0.12 MJ/kg, and spinach 0.09 MJ/kg (Table 1). This reduction stems from efficient water management systems, climate regulation, and optimized growing conditions, which minimize waste and maximize output despite the smaller cultivated area.

Pulpy Vegetables

Pulpy vegetables, such as cucumber, eggplant, and pumpkin, follow similar trends in CED and energy efficiency across production systems. Rainfed cucumber, eggplant, and pumpkin require only 0.63 MJ/kg, 0.52 MJ/kg, and 0.72 MJ/kg, respectively, demonstrating low-energy dependence compared to irrigated production, which demands 7,524 MJ for cucumber, 6,879 MJ for eggplant, and 10,568 MJ for pumpkin.

Energy consumption per kilogram in screenhouse production remains comparatively low, with cucumber requiring 0.20 MJ/kg, eggplant 0.25 MJ/kg, and pumpkin 0.50 MJ/kg (Table 1). These reductions are attributed to precise irrigation applications, controlled environment conditions, and reduced energy-intensive processes, making screenhouse a more sustainable alternative despite requiring specialized infrastructure.

Table 1: Cumulative Energy Demand (CED) Analysis for Leafy and Pulpy Vegetables

Vegetable Type	Crop	Production System	Area (ha)	Plant Population	Energy Equivalent (MJ)	CED (MJ/kg)
Leafy	Cabbage	Irrigated	1	25,926	6,807	1.90
	Cabbage	Rainfed	1	25,926	720	0.57
	Cabbage	Screenhouse	0.0147	381	100.24	0.22
	Lettuce	Irrigated	1	125,000	5,088	1.35
	Lettuce	Rainfed	1	125,000	648	0.48
	Lettuce	Screenhouse	0.0147	1,837	74.99	0.12
	Spinach	Irrigated	1	250,000	4,228	1.21

	Spinach	Rainfed	1	250,000	504	0.41
	Spinach	Screenhouse	0.0147	3,675	62.49	0.09
Pulpy	Cucumber	Irrigated	1	23,333	7,524	1.91
	Cucumber	Rainfed	1	23,333	900	0.63
	Cucumber	Screenhouse	0.0147	343	110.75	0.20
	Eggplant	Irrigated	1	25,926	6,879	1.67
	Eggplant	Rainfed	1	25,926	792	0.52
	Eggplant	Screenhouse	0.0147	381	101.29	0.25
	Pumpkin	Irrigated	1	3,611	10,568	2.62
	Pumpkin	Rainfed	1	3,611	1008	0.72
	Pumpkin	Screenhouse	0.0147	53	155.30	0.50

Note: Data Source: Authors' calculations

Screenhouse production demonstrates greater energy efficiency compared to irrigated farming, offering a sustainable alternative that balances resource optimization with climate control. While irrigated systems demand significant energy inputs due to water pumping and infrastructure reliance, rainfed farming remains the most energy-efficient but suffers from lower yields and unpredictable environmental conditions.

Screenhouse, although requiring moderate energy investment per hectare, maintains a balance between efficient resource utilization and continuous production cycles, optimizing energy use per kilogram of harvested produce. This makes screenhouse a feasible solution for mitigating agricultural energy demand while maintaining high productivity.

Global Warming Potential (GWP)

GWP varies across leafy and pulpy vegetable production systems due to differences in plant population density, nitrogen inputs, and farming methods. Screenhouse farming consistently exhibits the lowest GWP per kilogram of produce, reflecting higher yield efficiency, while rainfed farming maintains the lowest total emissions per hectare, reinforcing its environmental sustainability.

Leafy Vegetables

Leafy vegetables in irrigated systems generate moderate emissions, with cabbage, lettuce, and spinach producing between 51,940.78 and 52,566.58 kg CO_2-eq per hectare annually. Rainfed systems reduce total emissions, ranging from 44,343.30 to 44,969.10 kg CO_2-eq per hectare, maintaining a lower overall impact. However, Screenhouse production significantly improves yield-based efficiency, reducing emissions per kilogram of harvested produce. Screenhouse cabbage records 5.88 kg CO_2-eq/kg, lettuce 3.24 kg CO_2-eq/kg, and spinach 2.93 kg CO_2-eq/kg, making them the most efficient in terms of GWP per unit of harvested product (Table 8A).

Despite higher total emissions in irrigated and rainfed systems, GWP per kilogram of produce is significantly higher in rainfed farming, with rainfed cabbage at 128.48 kg CO_2-eq/kg, rainfed spinach at 130.42 kg CO_2-eq/kg, and rainfed lettuce at 118.25 kg CO_2-eq/kg, underscoring the trade-off between emissions and productivity(Table 2).

Pulpy Vegetables

Pulpy vegetables show similar trends. Irrigated cucumber, eggplant, and pumpkin generate total GWP values of approximately 52,566.58 kg CO_2-eq per hectare, while rainfed systems reduce emissions to 44,969.10 kg CO_2-eq per hectare. However, screenhouse farming significantly reduces per-kilogram emissions, with cucumber recording 3.77 kg CO_2-eq/kg, eggplant 5.20 kg CO_2-eq/kg, and pumpkin 6.76 kg CO_2-eq/kg (Table 2).

By contrast, rainfed cucumber reaches 112.42 kg CO_2-eq/kg, rainfed eggplant 105.81 kg CO_2-eq/kg, and rainfed pumpkin 115.31 kg CO_2-eq/kg, demonstrating higher emission intensities due to lower productivity. Irrigated systems, though falling between screenhouse and rainfed methods, still exhibit relatively high overall emissions, with cucumber at 47.79 kg CO_2-eq/kg, eggplant at 45.71 kg CO_2-eq/kg, and pumpkin at 46.20 kg CO_2-eq/kg (Table 8A).

Implications

Screenhouse farming offers the lowest GWP per kilogram of harvested produce, making it the most efficient production method in terms of greenhouse gas intensity relative to output. While rainfed systems generate fewer total emissions per hectare, they suffer from high GWP per kilogram due to lower productivity, reinforcing the need for improved nitrogen and irrigation management.

Overall, these findings emphasize the trade-offs between total emissions, per-hectare greenhouse gas intensity, and per-kilogram efficiency across different farming systems. Screenhouse reduces emissions per kilogram while maintaining high yields, whereas rainfed farming minimizes total emissions but increases GWP per kilogram due to lower productivity. Irrigated farming falls between these systems but remains relatively energy-intensive.

Table 2: Global Warming Potential (GWP) Per Unit Product for Rainfed, Irrigated and Screenhouse Leafy and Pulpy Vegetable Production

Vegetable Type	Vegetable	Production System	Total GWP (kg CO_2-eq)	Saleable Product (kg/ha/year)	GWP/kg Product
Leafy	Cabbage	Irrigated	52566.58	1000	52.57
	Cabbage	Rainfed	44969.10	350	128.48
	Cabbage	Screenhouse	51456.91	8750	5.88
	Lettuce	Irrigated	51940.78	1050	49.47
	Lettuce	Rainfed	44343.30	375	118.25
	Lettuce	Screenhouse	38911.08	12000	3.24
	Spinach	Irrigated	51940.78	975	53.27
	Spinach	Rainfed	44343.30	340	130.42
	Spinach	Screenhouse	38911.08	13300	2.93
Pulpy	Cucumber	Irrigated	52566.58	1100	47.79
	Cucumber	Rainfed	44969.10	400	112.42
	Cucumber	Screenhouse	39536.88	10500	3.77
	Eggplant	Irrigated	52566.58	1150	45.71
	Eggplant	Rainfed	44969.10	425	105.81
	Eggplant	Screenhouse	39536.88	7600	5.20
	Pumpkin	Irrigated	51970.58	1125	46.20
	Pumpkin	Rainfed	44969.10	390	115.31
	Pumpkin	Screenhouse	39536.88	5850	6.76

Note: Data Source: Authors' calculations

Water Use (WU)

Water consumption varies significantly across irrigated, rainfed, and screenhouse systems, influencing crop productivity, resource efficiency, and sustainability. Screenhouse farming consistently demonstrates the highest water-use efficiency, significantly reducing total consumption while supporting intensive vegetable production through precision irrigation.

Water Use Across Production Systems

Irrigated farming demands higher water inputs to sustain adequate moisture levels, with cabbage requiring 4.33 million liters per season, lettuce 2.49 million liters, and spinach 1.91 million liters per hectare (Sangare, Compaore, Buerkert et al., 2012; Eaves & Eaves, 2018). Pulpy vegetables consume even greater amounts, with cucumber requiring 3.02 million liters per hectare, eggplant 5.9 million liters, and pumpkin 8.05 million liters per season (Nicholson et al., 2020; Ritchie, Max, and Rosado, 2020).

Rainfed farming, though lower in total water consumption, faces seasonal fluctuations impacting crop productivity. Rainfed cabbage consumes 3.71 million liters per hectare, lettuce 2.15 million liters, and spinach 1.71 million liters, demonstrating reduced water availability compared to irrigated farming (Sangare, Compaore, Buerkert et al., 2012; Omorogbe, 2021). Pulpy vegetables such as rainfed cucumber and eggplant require 2.65 million and 5.11 million liters per hectare per season, while pumpkin reaches 6.88 million liters, reinforcing its high-resource nature (Gain Health, 2022; de Brauw & Bulte, 2021).

Screenhouse farming leverages precision fertigation techniques via drip irrigation, ensuring efficient water utilization. Despite higher daily water requirements per hectare, total seasonal consumption remains significantly lower due to small-scale production models. Screenhouse cabbage consumes only 61,280 liters per season, lettuce 42,942 liters, and spinach 31,696 liters, while screenhouse cucumber requires 48,234 liters, eggplant 89,302 liters, and pumpkin 123,480 liters (Amoako et al., 2022; Olabisi & Nofiu, 2022; Wang et al., 2017).

Water Use Per Kilogram of Produce

Analyzing water consumption per kilogram of harvested product highlights efficiency differences among vegetable types and production systems. Screenhouse consistently achieves the lowest water use per unit yield, with cabbage requiring just 7.00 liters/kg, lettuce 3.58 liters/kg, and spinach only 2.38 liters/kg, demonstrating optimized water utilization through precise irrigation and fertigation.

Rainfed farming remains the least water-efficient, with rainfed cabbage requiring 10,625 liters/kg, lettuce 5,750 liters/kg, and spinach 5,029 liters/kg, reinforcing yield limitations from reliance on natural precipitation. Irrigated farming, while more efficient than rainfed systems, still consumes significantly higher water per kilogram, with irrigated cabbage at 4,331 liters/kg, irrigated lettuce at 2,375 liters/kg, and irrigated spinach at 1,961 liters/kg.

Pulpy vegetables display higher overall water-use intensity, with rainfed cucumber demanding 6,640 liters/kg, eggplant 12,014 liters/kg, and pumpkin 17,628 liters/kg, underscoring their water-intensive nature. Screenhouse production improves efficiency, reducing water consumption per kilogram, with cucumber at 4.59 liters/kg, eggplant at 11.75 liters/kg, and pumpkin at 21.11 liters/kg.

Comparative Analysis and Sustainability Insights

Comparing these findings with existing research reinforces screenhouse's superior water-use efficiency. A study in Ethiopia found irrigation users achieved 90% technical efficiency compared to 74% for rainfed farmers, supporting the benefits of irrigation in maintaining consistent yields, despite higher water consumption (Ketema, 2021; Sangare, Compaore, Buerkert et al., 2012; Eaves & Eaves, 2018). Additional studies confirm that drip irrigation and poly-mulching improve water efficiency, aligning with screenhouse's controlled water distribution methods (Bwire, Watanabe, Suzuki & Suzuki, 2024; Nicholson et al., 2020; Ritchie, Max, and Rosado, 2020).

While irrigated farming ensures steady moisture levels, it remains resource-intensive, requiring substantial water inputs per season. Rainfed farming minimizes irrigation dependency but suffers from inefficiency due to limited yield potential, reinforcing the need for improved agronomic practices. Screenhouse production stands out as the most efficient system, reducing total consumption while optimizing water use per kilogram of produce through precision irrigation and fertigation.

Table 3: Water Use (WU) Per Unit Product for Rainfed, Irrigated and Screenhouse Leafy and Pulpy Vegetable Production

Vegetable Type	Vegetable	Production System	Area (ha)	Average Growing Period (Days)	Total Average Water Requirement per season(liter/season)	Saleable Product (kg/ha/yr)	Water Use (liter)/kg Product
Leafy	Cabbage	Irrigated	1	82.5	4331250	1000	4331.25
	Cabbage	Rainfed	1	87.5	3718750	350	10625.00
	Cabbage	Screenhouse	0.0147	72.5	61280.625	8750	7.00
	Lettuce	Irrigated	1	52.5	2493750	1050	2375.00
	Lettuce	Rainfed	1	57.5	2156250	375	5750.00
	Lettuce	Screenhouse	0.0147	47.5	42942.375	12000	3.58
	Spinach	Irrigated	1	42.5	1912500	975	1961.54
	Spinach	Rainfed	1	47.5	1710000	340	5029.41
	Spinach	Screenhouse	0.0147	37.5	31696.875	13300	2.38
Pulpy	Cucumber	Irrigated	1	57.5	3018750	1100	2744.32
	Cucumber	Rainfed	1	62.5	2656250	400	6640.63
	Cucumber	Screenhouse	0.0147	52.5	48234.375	10500	4.59
	Eggplant	Irrigated	1	100	5900000	1150	5130.43
	Eggplant	Rainfed	1	107.5	5106250	425	12014.71
	Eggplant	Screenhouse	0.0147	90	89302.5	7600	11.75
	Pumpkin	Irrigated	1	115	8050000	1125	7155.56
	Pumpkin	Rainfed	1	125	6875000	390	17628.21
	Pumpkin	Screenhouse	0.0147	105	123480	5850	21.11

Note: Data Source: Authors' calculations

3.2 Discussion

Screenhouse production demonstrates significant advantages in yield efficiency, cost-effectiveness, and sustainability over traditional rainfed and irrigated systems. Supporting multiple cropping cycles per year, this system enhances annual productivity while ensuring consistent market supply and profitability. Hybrid seed varieties, precision fertigation, and controlled environmental conditions further optimize vegetable production, making screenhouse a viable solution despite higher initial costs.

Economic and Yield Comparisons

Cost per saleable product analysis highlights the efficiency of screenhouse in reducing production costs per kilogram of yield. Screenhouse cabbage costs ₦611/kg, compared to ₦1,997/kg in rainfed farming and ₦2,034/kg in irrigated farming. Lettuce follows a similar trend, costing ₦445/kg in screenhouse, significantly lower than ₦1,864/kg in rainfed farming and ₦1,937/kg in irrigated farming. Spinach is even more efficient, with screenhouse farming costing ₦402/kg, while rainfed and irrigated systems cost ₦2,056/kg and ₦2,086/kg, respectively (Ayinde, Nicholson & Ahmed, 2024).

Higher cropping frequencies in screenhouse further enhance its economic advantage. With cabbage undergoing 4–6 cycles per year, lettuce 6–8 cycles, and spinach 5–7 cycles, total annual yields far exceed those of rainfed and irrigated systems, which are limited to one cycle per year. Annual production in screenhouse reaches up to 17,500 kg/ha for cabbage, 24,000 kg/ha for lettuce, and 26,600 kg/ha for spinach, surpassing the 700–750 kg/ha in rainfed farming and 2,000–2,100 kg/ha in irrigated production.

Pulpy vegetables, including cucumber, eggplant, and pumpkin, follow similar trends. Economic analysis shows screenhouse cucumber costs ₦509/kg, eggplant ₦703/kg, and pumpkin ₦913/kg, compared to ₦1,747/kg for rainfed cucumber, ₦1,645/kg for rainfed eggplant, and ₦1,792/kg for rainfed pumpkin. Irrigated production remains less competitive than screenhouse, with ₦1,849/kg for cucumber, ₦1,769/kg for eggplant, and ₦1,808/kg for pumpkin. Annual production in screenhouse reaches 21,000 kg/ha for cucumber, 15,200 kg/ha for eggplant, and 11,700 kg/ha for pumpkin, exceeding the 800–850 kg/ha in rainfed systems and 2,200–2,300 kg/ha in irrigated production (Ketema, 2021).

Sustainability and Resource Efficiency

Hybrid seed varieties play a crucial role in yield optimization and production stability. Varieties such as Greengo F1 cucumber, Black Beauty F1 eggplant, and Jacqueline F1 pumpkin are engineered for resilience, improved fruit size, and adaptability to controlled conditions, ensuring optimal nutrient absorption and consistent yields. In contrast, rainfed and irrigated production rely on open-pollinated varieties (OPVs), which experience slower growth, inconsistent harvest cycles, and greater vulnerability to pests, leading to lower economic efficiency.

Precision irrigation and fertigation further support yield optimization, delivering nutrients and water efficiently, reducing production losses (Bwire, Watanabe, Suzuki & Suzuki, 2024). Rainfed systems, dependent on natural precipitation, experience moisture inconsistencies and crop stress, while irrigated farming provides stable moisture but lacks precision nutrient absorption, limiting its overall efficiency.

Water Use and Efficiency Comparisons

Water use per kilogram of product strongly favors screenhousefarming in terms of efficiency. Screenhouse cabbage requires only 7.00 liters per kg, while irrigated cabbage demands 4,331 liters per kg and rainfed cabbage an overwhelming 10,625 liters per kg. Pulpy vegetables such as cucumber, eggplant, and pumpkin require significantly more water per kg in rainfed production, with rainfed pumpkin needing 17,628 liters per kg, compared to screenhouse pumpkin at just 21.11 liters per kg.

These differences align with global research on water management efficiency, where precision irrigation in screenhouse systems reduces unnecessary water loss while maximizing output (Ketema, 2021). Studies on West African agriculture indicate that excessive water application in conventional farming often surpasses crop requirements by up to 40%, leading to wasteful resource consumption (Bwire, Watanabe, Suzuki & Suzuki, 2024).

Key Takeaways

Screenhouse farming delivers superior yield performance, cost efficiency, and sustainability, making it the preferred model for large-scale vegetable production. By optimizing energy use, minimizing water consumption, and improving greenhouse gas efficiency, screenhouse production stands out as the best approach for maximizing agricultural profitability while reducing environmental impact. Future strategies should integrate precision irrigation techniques and hybrid seed innovations to further enhance production efficiency.

3.3 Conclusion

Screenhouse consistently demonstrates superior performance in yield efficiency, cost-effectiveness, and environmental sustainability compared to traditional irrigated and rainfed farming systems. Screenhouse production achieves significantly higher yields, with cabbage producing 17,500 kg/ha per year, lettuce 24,000 kg/ha, and spinach 26,600 kg/ha, compared to only 700–750 kg/ha in rainfed systems and 2,000–2,100 kg/ha in irrigated systems. Pulpy vegetables follow similar trends, with screenhouse cucumber yielding 21,000 kg/ha, eggplant 15,200 kg/ha, and pumpkin 11,700 kg/ha, significantly surpassing rainfed and irrigated production outputs.

Economic analysis highlights screenhouse's profitability, with cost per kilogram of saleable product proving far lower than conventional systems. Screenhouse cabbage costs ₦611/kg, lettuce ₦445/kg, spinach ₦402/kg, cucumber ₦509/kg, eggplant ₦703/kg, and pumpkin ₦913/kg, compared to rainfed cabbage at ₦1,997/kg, rainfed lettuce at ₦1,864/kg, and rainfed spinach at ₦2,056/kg. Irrigated production falls between the two, though screenhouse remains the most cost-efficient, reinforcing its suitability for large-scale commercial vegetable production.

Environmental assessments further validate screenhouse's advantages in energy efficiency, carbon emissions, and water use. Screenhouse cabbage consumes only 7.00 liters/kg, lettuce 3.58 liters/kg, and spinach 2.38 liters/kg, significantly lower than rainfed cabbage at 10,625 liters/kg, rainfed lettuce at 5,750 liters/kg, and rainfed spinach at 5,029 liters/kg. Similarly, screenhouse cucumber requires just 4.59 liters/kg, eggplant 11.75 liters/kg, and pumpkin 21.11 liters/kg, making screenhouse the most sustainable system for resource optimization.

Greenhouse gas emissions per kilogram of harvested product further emphasize screenhouse's superior carbon efficiency, with cabbage emitting 5.88 kg CO_2-eq/kg, lettuce 3.24 kg CO_2-eq/kg, spinach 2.93 kg CO_2-eq/kg, cucumber 3.77 kg CO_2-eq/kg, eggplant 5.20 kg CO_2-eq/kg, and pumpkin 6.76 kg CO_2-eq/kg, compared to significantly higher emissions in rainfed and irrigated systems.

Final Takeaway

Screenhouse farming proves the most viable solution for future agricultural development, reducing production costs, minimizing environmental impact, and maximizing yield output. Investments in screenhouse infrastructure, hybrid seed innovations, and precision irrigation techniques will further enhance profitability, improve sustainability, and ensure long-term food security.

3.4 Limitations in Vegetable Production Systems

Several challenges affect the efficiency and sustainability of rainfed, irrigated, and screenhouse production systems, impacting yield stability, environmental footprint, and economic feasibility. Key limitations include:

1. Open-Pollinated Varieties (OPVs) in Open-Field Cultivation

Inconsistent Growth and Yield Fluctuations: OPVs often exhibit variability in germination rates, crop uniformity, and maturation periods, leading to lower yield predictability compared to hybrid varieties.

Susceptibility to Pests and Diseases: OPVs generally lack enhanced resistance to pathogens, increasing the risk of infestations and productivity losses, especially in rainfed farming where pest control is limited.

Reduced Market Competitiveness: Due to their lower yield potential and quality inconsistency, OPV-grown produce often fails to meet premium market standards, reducing commercial profitability.

2. Flood Irrigation in Conventional Irrigated Farming

High Water Waste and Inefficiency: Flood irrigation results in substantial runoff and evaporation losses, with water-use efficiency dropping below 60% in most cases (Nicholson et al., 2020).

Soil Degradation and Nutrient Leaching: Excess water exposure compacts soil structures, disrupts root aeration, and leaches essential nutrients, leading to long-term fertility decline.

Uneven Moisture Distribution: Flood irrigation creates inconsistent soil saturation, causing drought stress or overwatering, both of which reduce crop uniformity and quality (Bwire, Watanabe, Suzuki & Suzuki, 2024).

3. High Installation Costs in Screenhouse Farming

Capital-Intensive Infrastructure: Establishing a fully controlled production system requires large investments in climate control technology, irrigation automation, and fertigation systems, leading to high startup expenses.

Operational Costs and Energy Demand: Maintaining optimal indoor conditions results in higher energy consumption, increasing overall production costs despite efficiency in unit yields (Ketema, 2021).

Limited Scalability for Small-Scale Farmers: Due to installation and maintenance expenses, widespread adoption remains restricted, making screenhouse more viable for commercial-scale rather than smallholder farming.

4. Emission Estimation Using Tier 1 IPCC, 2006 Data

Generalized Assumptions in Carbon Accounting: The Tier 1 methodology relies on standardized emission factors, which may overestimate or underestimate actual GHG outputs due to regional climate variations and soil differences.

Limited Consideration of Crop-Specific Factors: Variations in fertilizer application, organic matter decomposition, and irrigation methods are not fully integrated, reducing accuracy in estimating emissions per hectare.

Absence of Precision Mitigation Strategies: Tier 1 does not factor in modern mitigation techniques, such as carbon sequestration through regenerative practices, leading to potentially inflated emissions figures.

3.5 Recommendations

Adopt Hybrid Varieties Over OPVs to enhance yield stability, disease resistance, and market value, ensuring greater productivity per hectare.

Replace Flood Irrigation with Drip Systems to maximize water efficiency, reduce nutrient leaching, and prevent soil degradation, aligning with modern conservation strategies.

Improve screenhouse Cost-Effectiveness by integrating renewable energy sources, modular infrastructure designs, and adaptive climate control systems to lower startup and operational expenses.

Upgrade to Tier 2 or Higher Emission Accounting Methods for more crop-specific, regionally adjusted carbon assessments, increasing accuracy in environmental impact analysis.

Table 4. Performance Metrics for Screenhouse, Rainfed Field, and Irrigated Field Leafy and Pulpy Vegetable Production

Vegetable Type	Vegetable	Production System	Area (ha)	Total Cost of Production (₦/ha)	Yield (kg/ha/year)	Saleable Product (kg/ha/year)	Cost /Yield(₦/Kg)	CED (MJ/kg)	GWP/kg Product	Water Use (liter)/kg Product
Leafy	Cabbage	Irrigated	1	2,034,145	2,000	1,000	2,034	1.90	52.57	4331.25
	Cabbage	Rainfed	1	698,972	700	350	1,997	0.57	128.48	10625.00
	Cabbage	Screenhouse	0.0147	5342973	17,500	8,750	611	0.22	5.88	7.00
	Lettuce	Irrigated	1	2,034,145	2,100	1,050	1,937	1.35	49.47	2375.00
	Lettuce	Rainfed	1	698,972	750	375	1,864	0.48	118.25	5750.00
	Lettuce	Screenhouse	0.0147	5,342,973	24,000	12,000	445	0.12	3.24	3.58
	Spinach	Irrigated	1	2,034,145	1,950	975	2,086	1.21	53.27	1961.54
	Spinach	Rainfed	1	698,972	680	340	2,056	0.41	130.42	5029.41
	Spinach	Screenhouse	0.0147	5,342,973	26,600	13,300	402	0.09	2.93	2.38
Pulpy	Cucumber	Irrigated	1	2,034,145	2,200	1,100	1,849	1.91	47.79	2744.32
	Cucumber	Rainfed	1	698,972	800	400	1,747	0.63	112.42	6640.63
	Cucumber	Screenhouse	0.0147	5,342,973	21,000	10,500	509	0.20	3.77	4.59
	Eggplant	Irrigated	1	2,034,145	1,150	1,150	1,769	1.67	45.71	5130.43

Eggplant	Rainfed	1	698,972	850	425	1,645	0.52	105.81	12014.71
Eggplant	Screenhouse	0.0147	5,342,973	15,200	7,600	703	0.25	5.20	11.75
Pumpkin	Irrigated	1	2,034,145	1,125	1,125	1,808	2.62	46.20	7155.56
Pumpkin	Rainfed	1	698,972	780	390	1,792	0.72	115.31	17628.21
Pumpkin	Screenhouse	0.0147	5,342,973	11,700	5,850	913	0.50	6.76	21.11

Note: Data Source: Authors' calculation

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Appendix

Table 1A. Optimal Conditions for the Screen-house Tomato Production at Likoro in Kudan LGA of Kaduna State, Nigeria

Parameters	Leafy Vegetables (e.g., Cabbage, Lettuce, Spinach)	Pulpy Vegetables (e.g., Cucumber, Eggplant, Pumpkin)	Sources
Daytime Temperature	15–25°C (Ideal for leaf development)	22–30°C (Optimal for fruit growth)	Weather Spark, 2024
Night Temperature	10–18°C	15–22°C	Ogbonna et al., 2023
Seed Germination Temperature	18–22°C	24–30°C	Fadeyi & Ayodeji, 2023
Seedling Growth Temperature	15–20°C	20–28°C	Enguwa et al., 2024
Light Transmission	70–85% (Greenhouse/Poly-tunnel)	80–90% (Greenhouse/Poly-tunnel)	GLASE, 2024
Photosynthetically Active Radiation (PAR)	400–700 nm	400–700 nm	Tilman et al., 2002
CO_2 Concentration (Cold Weather)	450–600 ppm	500–700 ppm	Veggie Concept, 2022
CO_2 Concentration (Summer)	350–450 ppm	400–600 ppm	Nicholson et al., 2023
Airspeed (Wind Speed)	0.5–2.0 m/s	0.3–1.5 m/s	Wudil et al., 2022
Growth Period	60–90 days	45–75 days	Fadeyi & Ayodeji, 2023
Staking	Not required	Essential for productivity	Nigerian Seed Portal (2025); Veggie Concept, 2022
Rainfall	500–1500 mm/year	600–1200 mm/year	Weather Spark, 2024
Soil pH	5.5–6.7	5.8–6.5	Fadeyi & Ayodeji, 2023
Cropping Frequency Analyzed	2–4 cycles per year	3–5 cycles per year	Ogbonna et al., 2023

Table 2A: Characteristics of CEA, Rainfed, and Irrigated Field Operations for Leafy and Pulpy Vegetables

Vegetable Type	Vegetable	Production System	Land Area for Production (ha)	for Non-Production (ha)	Total Land Area (ha)	Crop Variety	Cropping Frequency (Cultivation Cycles Per Year)	Seed Quantity (kg/ha)	Price per kg (₦)	NPK Fertilizer Type	(50kg bags/ha)	Average Price (₦)	Manure (100kg bags/ha)	Price per 100kg bag (₦)	Pesticide Type	Quantity (L or kg/ha)	Price per unit (₦)	Production Amount per Cycle (kg/ha)	Annual Production Amount (kg/ha)
Leafy	Cabbage	Screenhouse	0.0147	0.01	0.0247	Hybrid -Tycoon F1	4 – 6	1.5	1,800	NPK 15-15-15	6	58,250	8	9,000	Lambda-Cyhalothrin (Insecticide)	2	7,500	3,500	14,000–21,00
		Rainfed	1	0.01	1	OPV- Gloria	1 crop (April–August)	1.2	1,500	NPK 20-10-10	5	51,000	7	9,000	Chlorpyrifos (Insecticide)	2.5	8,000	700	-
		Irrigated	1	0.01	1	OPV - Pruktor	1 crop (September–March)	1.4	1,600	NPK 15-15-15	6	58,250	8	9,000	Difenoconazole (Fungicide)	1.5	6,500	2,000	-
Leafy	Spinach	Screenhouse	0.0147	0.01	0.0247	Hybrid -Savoy F1 and Space F1	5 – 7	1.6	1,600	NPK 12-12-17	5	47,000	6	9,000	Mancozeb (Fungicide)	2	5,800	4,000	20,000–28,000
		Rainfed	1	0.01	1	OPV - Viroflay	1 crop (April–August)	1.3	1,400	NPK 20-10-10	4	51,000	7	9,000	-	-	-	750	-
		Irrigated	1	0.01	1	OPV - Giant Noble	1 crop (September–March)	1.5	1,500	NPK 15-15-15	5	58,250	8	9,000	-	-	-	2,100	-
Leafy	Lettuce	Screenhouse	0.0147	0.01	0.0247	Hybrid - Tropicana F1 and Great Lakes F1	6 – 8	1.7	1,500	NPK 12-12-17	5	47,000	6	9,000	-	-	-	3,800	22,800–30,400

		Rainfed	1	0.01	1	OPV - Oak Leaf	1 crop (April–August)	1.3	1,400	NPK 20-10-10	4	51,000	7	9,000	-	-	-	680	-
		Irrigated	1	0.01	1	OPV - Butterhead	1 crop (September–March)	1.5	1,450	NPK 15-15-15	5	58,250	8	9,000	-	-	-	1,950	-
Pulpy	Cucumber	Screenhouse	0.0147	0.01	0.0247	Hybrid - Greengo F1	4 - 6	1.8	1,700	NPK 12-12-17	6	47,000	6	9,000	Imidacloprid (Insecticide)	1.5	7200	4,200	16,800–25,200
		Rainfed	1	0.01	1	OPV- Poinsett	1 crop (April–August)	1.4	1,500	NPK 20-10-10	5	51,000	7	9,000	-	-	-	800	-
		Irrigated	1	0.01	1	OPV-Marketmore	1 crop (September–March)	1.6	1,600	NPK 15-15-15	6	58,250	8	9,000	-	-	-	2,200	-
Pulpy	Eggplant	Screenhouse	0.0147	0.01	0.0247	Hybrid - Black Beauty F1 & Nagina F1	3–5	1.5	1,600	NPK 12-12-17	6	47,000	6	9,000	-	-	-	3,800	11,400–19,000
		Rainfed	1	0.01	1	OPV - Africa Round Eggplant	1 crop (April–August)	1.4	1,500	NPK 20-10-10	5	51,000	7	9,000	-	-	-	850	-
		Irrigated	1	0.01	1	OPV - Kano Purple	1 crop (September–March)	1.7	1,650	NPK 15-15-15	6	58,250	8	9,000	-	-	-	2,300	-
Pulpy	Pumpkin	Screenhouse	0.0147	0.01	0.0247	Hybrid - Jacqueline F1 & Sampson F1	2 – 4	1.6	1,550	NPK 12-12-17	5	47,000	6	9,000	-	-	-	3,900	7,800–15,600

		Rainfed	1	0.01	1	OPV - Melon Yellow	1 crop (April–August)	1.4	1,450	NPK 20-10-10	5	51,000	7	9,000	-	-	-	780	
		Irrigated	1	0.01	1	OPV -Flat White Boer	1 crop (September–March)	1.7	1,600	NPK 15-15-15	6	58,250	8	9,000	-	-	-	2,250	

Note: Data Source: Authors' calculation

Table 3A: Average Cost Per Hectare for Screenhouse, Rainfed, and Irrigated Leafy Vegetable (Cabbage, Lettuce, and Spinach) Production

Item	Unit	Average Price Per Unit (₦)			Average Quantity Used			Average Cost of Cabbage Production (₦/ha)			Average Cost of Lettuce Production (₦/ha)			Average Cost of Spinach Production (₦/ha)		
		Screenhouse	Rainfed	Irrigated	Screenhouse	Rainfed	Irrigated	Screenhouse	Rainfed	Irrigated	Screenhouse	Rainfed	Irrigated	CEA	Rainfed	Irrigated
Land Rental Cost	₦/ha	1,325	132,500	132,500	0.01	1	1	1,325	132,500	132,500	1,325	132,500	132,500	1,325	132,500	132,500
Drip Irrigation System	number	3,500, 000	-	-	1	-	-	3,500,000	-	-	3,500,000	-	-	3,500,000	-	-
Flood (manure) Irrigation System	number	-	-	275,000	-	-	1	-	-	275,000	-	-	275,000	-	-	275,000
Well	number	-	-	82,500	-	-	1	-	-	82,500	-	-	82,500	-	-	82,500
Overhead	number	180,00	-	180,000	2	-	1	360,000	-	180,000	360,000	-	180,000	360,000	-	180,000

Tank 500L		0														
Pumping machine 0.75hp	number	180,000	-	180,000	1	-	1	180,000	-	180,000	180,000	-	180,000	180,000	-	180,000
Generator 2.5kva	number	80,000	-	80,000	1	-	1	80,000	-	80,000	80,000	-	80,000	80,000	-	80,000
Screenhouse Structure	number	520251.14	-	-	1	-	-	520,251.14	-	-	520,251.14	-	-	520,251.14	-	-
Small Farm Tools	Various in numbers	60750	12750	12750	1	1	1	60,750	12,750	12,750	60,750	12,750	12,750	60,750	12,750	12,750
Total Fixed Cost								**4,702,326**	**145,250**	**942,750**	**4,702,326**	**145,250**	**942,750**	**4,702,326**	**145,250**	**942,750**
Seeds	kg/ha	1616.67	1483.33	1616.67	1.6	1.4	1.7	2,586.67	2,076.66	2,748.34	2,586.67	2,076.66	2,748.34	2,586.67	2,076.66	2,748.34
NPK Fertilizer	50 kg bag	47000	51000	58250	5.7	5.0	6.0	267,900	255,000	349,500	267,900	255,000	349,500	267,900	255,000	349,500
Calcium Magnesium (CalMag)	1 kg bag	10000	-	-	3	-	-	30000	-	-	30000	-	-	30000	-	-
Potassium Humate	1 kg bag	5000	-	-	1	-	-	5000	-	-	5000	-	-	5000	-	-
Chicken Manure	100 kg bag	9,000	9,000	9,000	6	7	8	54,000	63,000	72,000	54,000	63,000	72,000	54,000	63,000	72,000
Insecticides & Fungicides	Lit/kg	7200	-	-	1.5	-	-	10,800	-	-	10,800	-	-	10,800	-	-

Labor (Hired & Family)and Installation	Man-day	400	400	400	600	595	605	240,000	238,000	242,000	240,000	238,000	242,000	240,000	238,000	242,000
Electricity for Irrigation Pump	1 KWH/Season	38.53	38.53	38.53	300	300	300	11559	11559	11559	11559	11559	11559	11559	11559	11559
Diesel Fuel for Irrigation Pump	Litre	1185	-	1185	7.51	-	375.6	8899.35	-	445086	8899.35	-	445086	8899.35	-	445086
Total Variable Cost	**₦/ha**							**640,646.68**	**553,722.33**	**1,091,395.01**	**640,646.68**	**553,722.33**	**1,091,395.01**	**640,646.68**	**553,722.33**	**1,091,395.01**
Total Cost of Production	**₦/ha**							**5,342,973**	**698,972**	**2,034,145**	**5,342,973**	**698,972**	**2,034,145**	**5,342,973**	**698,972**	**2,034,145**
Yield	**kg/ha/year**							**17,500**	**700**	**2,000**	**24,000**	**750**	**2,100**	**26,600**	**680**	**1,950**
Saleable Product	**kg/ha/year**							**8,750**	**350**	**1,000**	**12,000**	**375**	**1,050**	**13,300**	**340**	**975**
Cost / Yield	**₦/Kg**							611	1,997	2,034	445	1,864	1,937	402	2,056	2,086

Note: Data Source: Authors' calculation. *To maintain simplicity, the Total Cost of Production considers only a single production cycle, rather than the multiple cycles that contribute to the screenhouse's overall yield and saleable output.

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Table 4A: Average Cost Per Hectare for Screenhouse, Rainfed, and Irrigated Pulpy Vegetable (Cucumber, Eggplant, and Pumpkin) Production

Item	Unit	Average Price Per Unit (₦)			Average Quantities Used			Average Cost of Cucumber Production (₦/ha)			Average Cost of Eggplant Production (₦/ha)			Average Cost of Pumpkin Production (₦/ha)		
		Screenhouse	Rainfed	Irrigated	Screenhouse	Rainfed	Irrigated	Screenhouse	Rainfed	Irrigated	Screenhouse	Rainfed	Irrigated	Screenhouse	Rainfed	Irrigated
Land Rental Cost	₦/ha	1,325	132,500	132,500	0.01	1	1	1,325	132,500	132,500	1,325	132,500	132,500	1,325	132,500	132,500
Drip Irrigation System	number	3,500,000	-	-	1	-	-	3,500,000	-	-	3,500,000	-	-	3,500,000	-	-
Flood (manure) Irrigation System	number	-	-	275,000	-	-	1	-	-	275,000	-	-	275,000	-	-	275,000
Well	number	-	-	82,500	-	-	1	-	-	82,500	-	-	82,500	-	-	82,500
Overhead Tank 500L	number	180,000	-	180,000	2	-	1	360,000	-	180,000	360,000	-	180,000	360,000	-	180,000
Pumping machine 0.75hp	number	180,000	-	180,000	1	-	1	180,000	-	180,000	180,000	-	180,000	180,000	-	180,000
Generator 2.5kva	number	80,000	-	80,000	1	-	1	80,000	-	80,000	80,000	-	80,000	80,000	-	80,000
Screenhouse Structure	number	520251.14	-	-	1	-	-	520,251.14	-	-	520,251.14	-	-	520,251.14	-	-
Small Farm Tools	Various in numbers	60750	12750	12750	1	1	1	60,750	12,750	12,750	60,750	12,750	12,750	60,750	12,750	12,750
Total Fixed Cost								**4,702,326**	**145,250**	**942,750**	**4,702,326**	**145,250**	**942,750**	**4,702,326**	**145,250**	**942,750**

Seeds	kg/ha	1633.33	1433.33	1516.67	1.6	1.3	1.5	2,613.33	1,863.33	2,275.01	2,613.33	1,863.33	2,275.01	2,613.33	1,863.33	2,275.01
NPK Fertilizer	50 kg bag	50750	51000	58250	5.3	4.3	5.3	268,975	219,300	308,725	268,975	219,300	308,725	268,975	219,300	308,725
Calcium Magnesium (CalMag)	1 kg bag	10000	-	-	3	-	-	30000	-	-	30000	-	-	30000	-	-
Potassium Humate	1 kg bag	5000	-	-	1	-	-	5000	-	-	5000	-	-	5000	-	-
Chicken Manure	100 kg bag	9,000	9,000	9,000	6.7	7	8	60,300	63,000	72,000	60,300	63,000	72,000	60,300	63,000	72,000
Insecticides & Fungicides	Lit/kg	6650	8000	6500	2	2.5	1,5	13,300	20,000	9,750	13,300	20,000	9,750	13,300	20,000	9,750
Labor (Hired & Family)and Installation	Man-day	400	400	400	600	595	605	240,000	238,000	242,000	240,000	238,000	242,000	240,000	238,000	242,000
Electricity for Irrigation Pump	1 KWH/Season	38.53	38.53	38.53	300	300	300	11559	11559	11559	11559	11559	11559	11559	11559	11559
Diesel Fuel for Irrigation Pump	Litre	1185	-	1185	7.51	-	375.6	8899.35	-	445086	8899.35	-	445086	8899.35	-	445086
Total Variable Cost	**₦/ha**							**640,646.68**	**553,722.33**	**1,091,395.01**	**640,646.68**	**553,722.33**	**1,091,395.01**	**640,646.68**	**553,722.33**	**1,091,395.01**
Total Cost of Production	**₦/ha**							**5,342,973**	**698,972**	**2,034,145**	**5,342,973**	**698,972**	**2,034,145**	**5,342,973**	**698,972**	**2,034,145**
Yield	**kg/ha/ year**							**21,000**	**800**	**2,200**	**15,200**	**850**	**2,300**	**11,700**	**780**	**2,250**
Saleable Product	**kg/ha/ year**							**10,500**	**400**	**1,100**	**7,600**	**425**	**1,150**	**5,850**	**390**	**1,125**

Cost / Yield	₦/Kg							509	1,747	1,849	703	1,645	1,769	913	1,792	1,808

Note: Data Source: Authors' calculation.To maintain simplicity, the Total Cost of Production considers only a single production cycle, rather than the multiple cycles that contribute to the screenhouse's overall yield and saleable output.

Table 5A: Average Diesel Pump Energy Usage in Leafy and Pulpy Vegetable Production

Vegetable Type	Crop	Production System	Area (ha)	Plant Population	Energy Usage per ha (liters/ha)	Total Energy Usage per Season (liters)	Energy Equivalent (MJ)	Daily Energy Usage (MJ/day)	Energy Usage per Plant per Day (MJ/plant/day)	Saleable Product (kg/ha/year)	MJ/kg
Leafy	Cabbage	Irrigated	1	25,926	1,650	165	5,907	16.18	0.00062	1,000	5.91
	Cabbage	Screenhouse	0.0147	381	1,650	2.43	86.99	0.24	0.00063	8,750	0.01
	Lettuce	Irrigated	1	125,000	1,200	120	4,296	11.77	0.00009	1,050	4.09
	Lettuce	Screenhouse	0.0147	1,837	1,200	1.77	63.37	0.17	0.00009	12,000	0.01
	Spinach	Irrigated	1	250,000	1,000	100	3,580	9.81	0.00004	975	3.67
	Spinach	Screenhouse	0.0147	3,675	1,000	1.48	52.98	0.15	0.00004	13,300	0.00
Pulpy	Cucumber	Irrigated	1	23,333	1,800	180	6,444	17.65	0.00076	1,100	5.86
	Cucumber	Screenhouse	0.0147	343	1,800	2.65	94.87	0.26	0.00076	10,500	0.01
	Eggplant	Irrigated	1	25,926	1,650	165	5,907	16.18	0.00062	1,150	5.14
	Eggplant	Screenhouse	0.0147	381	1,650	2.43	86.99	0.24	0.00063	7,600	0.01

	Pumpkin	Irrigated	1	3,611	2,600	260	9,308.00	25.5	0.00706	1,125	8.27
	Pumpkin	Screenhouse	0.0147	53	2,600	3.82	136.76	0.37	0.00704	5,850	0.02

Note: Data Source: Authors' calculations. For clarity, the Average Diesel Pump Energy Usage accounts for only a single production cycle, rather than the multiple cycles that influence the screenhouse's total yield and saleable output.

Table 6A: Average Electric Pump Energy Usage in Leafy and Pulpy Vegetable Production

Vegetable Type	Crop	Production System	Area (ha)	Plant Population	Energy Usage per ha (kWh/ha)	Estimated Energy Usage per Season (kWh)	Energy Equivalent (MJ)	Daily Energy Usage (MJ/day)	Energy Usage per Plant per Day (MJ/plant/day)	Saleable Product (kg/ha/yr)	MJ/ kg
Leafy	Cabbage	Irrigated	1	25,926	250	250	900	2.47	0.000095	1,000	0.900
	Cabbage	Rainfed	1	25,926	200	200	720	1.97	0.000076	350	2.057
	Cabbage	Screenhouse	0.0147	381	250	3.68	13.248	0.04	0.000095	8,750	0.002
	Lettuce	Irrigated	1	125,000	220	220	792	2.17	0.000017	1,050	0.754
	Lettuce	Rainfed	1	125,000	180	180	648	1.78	0.000014	375	1.728
	Lettuce	Screenhouse	0.0147	1,837	220	3.23	11.628	0.03	0.000017	12,000	0.001
	Spinach	Irrigated	1	250,000	180	180	648	1.78	0.000007	975	0.665
	Spinach	Rainfed	1	250,000	140	140	504	1.38	0.000006	340	1.482

	Spinach	Screenhouse	0.0147	3,675	180	2.64	9.504	0.03	0.000007	13,300	0.001
Pulpy	Cucumber	Irrigated	1	23,333	300	300	1080	2.96	0.000127	1,100	0.982
	Cucumber	Rainfed	1	23,333	250	250	900	2.47	0.000106	400	2.250
	Cucumber	Screenhouse	0.0147	343	300	4.41	15.876	0.04	0.000127	10,500	0.002
	Eggplant	Irrigated	1	25,926	270	270	972	2.66	0.000103	1,150	0.845
	Eggplant	Rainfed	1	25,926	220	220	792	2.17	0.000084	425	1.864
	Eggplant	Screenhouse	0.0147	381	270	3.97	14.292	0.04	0.000103	7,600	0.002
	Pumpkin	Irrigated	1	3,611	350	350	1260	3.45	0.000956	1,125	1.120
	Pumpkin	Rainfed	1	3,611	280	280	1008	2.76	0.000765	390	2.585
	Pumpkin	Screenhouse	0.0147	53	350	5.15	18.54	0.05	0.000958	5,850	0.003

Note: Data Source: Authors' calculations. For clarity, the Average Electric Pump Energy Usage accounts for only a single production cycle, rather than the multiple cycles that influence the screenhouse's total yield and saleable output.

Table 7A: Average GHG Emissions From Leafy and Pulpy Vegetable Irrigated, Rainfed and Screenhouse Production

Vegetable Type	Vegetable	Production System	Direct N_2O Soils	Indirect Emissions from MMS & MS	Other N2O Emissions from Fertilizers and Manure	Emissions from Diesel Energy Usage	Emissions from Electric Pump Energy Usage
Leafy	Cabbage	Irrigated	178.8	0.114	51256	1011.66	120
	Cabbage	Rainfed	149	0.100	44700	-	120
	Cabbage	Screenhouse	178.8	0.114	51256	20.23	1.764
	Lettuce	Irrigated	149	0.114	50660	1011.66	120
	Lettuce	Rainfed	119.2	0.100	44104	-	120
	Lettuce	Screenhouse	149	0.086	38740	20.23	1.764
	Spinach	Irrigated	149	0.114	50660	1011.66	120
	Spinach	Rainfed	119.2	0.100	44104	-	120
	Spinach	Screenhouse	149	0.086	38740	20.23	1.764
Pulpy	Cucumber	Irrigated	178.8	0.114	51256	1011.66	120
	Cucumber	Rainfed	149	0.100	44700	-	120
	Cucumber	Screenhouse	178.8	0.086	39336	20.23	1.764
	Eggplant	Irrigated	178.8	0.114	51256	1011.66	120
	Eggplant	Rainfed	149	0.100	44700	-	120

Eggplant	Screenhouse	178.8	0.086	39336	20.23	1.764
Pumpkin	Irrigated	178.8	0.114	50660	1011.66	120
Pumpkin	Rainfed	149	0.100	44700	-	120
Pumpkin	Screenhouse	178.8	0.086	39336	20.23	1.764

Note: Data Source: Authors' calculations. For clarity, the Average GHG Emissions generated account for only a single production cycle, rather than the multiple cycles involved in screenhouse production.

Table 8A: Total GWP Calculation from Rainfed, Irrigated and Screenhouse Leafy and Pulpy Vegetable Production

Vegetable Type	Vegetable	Production System	Area (ha)	Plant Population	Total GWP (kg CO_2-eq)	GWP per ha per year (kg CO_2-eq/ha/year)	GWP per ha per day (kg CO_2-eq/ha/day)	GWP per plant per day (kg CO_2-eq/plant/day)
Leafy	Cabbage	Irrigated	1	25,926	52566.58	52566.58	144.02	0.01
	Cabbage	Rainfed	1	25,926	44969.10	44969.10	123.20	0.00
	Cabbage	Screenhouse	0.0147	381	51456.91	3500469.81	9590.33	25.17
	Lettuce	Irrigated	1	125,000	51940.78	51940.78	142.30	0.00
	Lettuce	Rainfed	1	125,000	44343.30	44343.30	121.49	0.00
	Lettuce	Screenhouse	0.0147	1,837	38911.08	2647012.09	7252.09	3.95
	Spinach	Irrigated	1	250,000	51940.78	51940.78	142.30	0.00
	Spinach	Rainfed	1	250,000	44343.30	44343.30	121.49	0.00
	Spinach	Screenhouse	0.0147	3,675	38911.08	2647012.09	7252.09	1.97

Pulpy	Cucumber	Irrigated	1	23,333	52566.58	52566.58	144.02	0.01
	Cucumber	Rainfed	1	23,333	44969.10	44969.10	123.20	0.01
	Cucumber	Screenhouse	0.0147	343	39536.88	2689583.55	7368.72	21.48
	Eggplant	Irrigated	1	25,926	52566.58	52566.58	144.02	0.01
	Eggplant	Rainfed	1	25,926	44969.10	44969.10	123.20	0.00
	Eggplant	Screenhouse	0.0147	381	39536.88	2689583.55	7368.72	19.34
	Pumpkin	Irrigated	1	3,611	51970.58	51970.58	142.39	0.04
	Pumpkin	Rainfed	1	3,611	44969.10	44969.10	123.20	0.03
	Pumpkin	Screenhouse	0.0147	53	39536.88	2689583.55	7368.72	139.03

Note: Data Source: Authors' calculations

Table 9A: Average water requirements for leafy and pulpy vegetables production

Vegetable Type	Vegetable	Production System	Area (ha)	Plant Population	Average Growing Period (Days)	Average Water Requirement per Day (liter/ha/day)	Total Average Water Requirement per Day (liter/day)	Total Average Water Requirement per season(liter/season)
Leafy	Cabbage	Irrigated	1	25,926	82.5	52500	52500	4331250

	Cabbage	Rainfed	1	25,926	87.5	42500	42500	3718750
	Cabbage	Screenhouse	0.0147	381	72.5	57500	845.25	61280.625
	Lettuce	Irrigated	1	125,000	52.5	47500	47500	2493750
	Lettuce	Rainfed	1	125,000	57.5	37500	37500	2156250
	Lettuce	Screenhouse	0.0147	1,837	47.5	61500	904.05	42942.375
	Spinach	Irrigated	1	250,000	42.5	45000	45000	1912500
	Spinach	Rainfed	1	250,000	47.5	36000	36000	1710000
	Spinach	Screenhouse	0.0147	3,675	37.5	57500	845.25	31696.875
Pulpy	Cucumber	Irrigated	1	23,333	57.5	52500	52500	3018750
	Cucumber	Rainfed	1	23,333	62.5	42500	42500	2656250
	Cucumber	Screenhouse	0.0147	343	52.5	62500	918.75	48234.375
	Eggplant	Irrigated	1	25,926	100	59000	59000	5900000
	Eggplant	Rainfed	1	25,926	107.5	47500	47500	5106250
	Eggplant	Screenhouse	0.0147	381	90	67500	992.25	89302.5
	Pumpkin	Irrigated	1	3,611	115	70000	70000	8050000
	Pumpkin	Rainfed	1	3,611	125	55000	55000	6875000
	Pumpkin	Screenhouse	0.0147	53	105	80000	1176	123480

Note: Data Source: Authors' calculation. For clarity, the Average Water Requirements reflect only a single production cycle, rather than the multiple cycles that contribute to the screenhouse's overall yield and saleable output.