Ministry of Foreign Affairs

Scoping study protected horticulture and indoor farming in South West Nigeria

Commissioned by the Netherlands Enterprise Agency

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Towards Sustainable Food Production:
A Research on the Feasibility of Protected Horticulture Methods in South West Nigeria

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Uitgebracht door
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Background to this Scoping Study Report

This report on the Feasibility of Protected Horticulture Methods in South-West Nigeria is a result of two scoping studies conducted in alignment with each other. Both researches are conducted by Delphy as assignments for the Netherlands Enterprise Agency (RVO), with the purpose of identifying best practices and innovative solutions for sustainable development of (semi) controlled and protected production methods of vegetables (Greenhouse Farming and Indoor Farming) in Nigeria, and to trigger Dutch and Nigerian partners for the development and introduction of new technologies in the Nigerian food value chains.

The first report focusses on the feasibility of various types of covered cultivation methods. The aim of this research is to conduct an analysis on the successes and challenges of the operating farms that have adapted low-tech or mid-tech greenhouse technologies. It also includes an analysis on the technical feasibility of greenhouse farming in Nigeria, by analysing the types of technical designs suitable to the local conditions, identification of investments and operational costs and propose solutions for sustainable energy supply (such as solar energy or connect with running local energy projects). Additionally, it includes a market assessment of various markets fitting to the selected Controlled Environment Agriculture farming methods: greenhouse farming, and identifies gaps and proposes solutions to bridge the gaps for operating a Controlled Environment Agriculture farms (i.e., knowledge and skills and availability of inputs).

The second report focusses on the feasibility of fully controlled vertical farming in South West Nigeria. It includes an introduction to Indoor Farming and its benefits, an evaluation of the technical feasibility of an Indoor Farm, availability and gap identification of various resources, an evaluation of the financial feasibility, and finally, suggestions for opportunities and improvements in the conclusion.

Both researches have been conducted with desk research data collection, field visits, qualitative interviews with key stakeholders in Nigeria and relevant stakeholders from the Netherlands. In this combined report both studies will first be discussed separately, and then both outcomes will be compared, in order to give a clear overview of possible advantages and disadvantages of the protected horticultural methods.

Definitions for Controlled Environmental Agriculture (CEA)

1. **CEA 1 Low Tech: Open or semi open netting systems.**
   Low investment (< 10 Euro/m2); little more knowledge and skills on pest and disease management required. No automated systems. Main characteristic: lower the temperature on the warmest period during day time and lower the light intensity. Mostly used for nurseries

2. **CEA 2 Low Tech Tunnels: Closed single span tunnels, low gutter height <2.2 meters.**
   Moderate investment (20 Euro/m2[1]), often with plastic or nettings, no separate entrance. One side open with netting for ventilation. Simple gravity irrigation system. More knowledge and skills needed related to temperature management, pests and disease control and soil/ substrate composition. Irrigation and knowledge needed on water and fertilization management. Challenging to manage the temperature and humidity in tunnels. Often used as a nursery.

3. **CEA 3 Medium Tech Tunnels/ Greenhouses with (manual) single sided butterfly ventilation systems; gutter height between 2 and 3 meters.**
   Medium to high investment (25-35 Euro/m2). Tunnels are single or multispan, are equipped with single sided butterfly ventilation system; separate entry with double door system; gravity irrigation and fertigation facility and small pumping house. No artificial lights. Higher quality materials used to be more sustainable and UV plastic in the top of the greenhouse. Active climate control: technical designs need to be adapted to local climate conditions, investments are relatively high, controlled climate and pest management, knowledgeable, well-trained manager and staff is required. This model is observed and reported to be profitable for farmers.

4. **CEA 4 High Tech Multispan greenhouses gutter heights >3 meters, total height up to 5 - 6 meters.**
   High investment (140 Euro/m2), high quality materials used, butterfly ventilations systems, sensor driven automated ventilation and temperature system; controlled irrigation systems with pumping house, fully automated. Shade nets available (manual or automated). Substrate farming only. Separate entrance (double door system/hygiene room), hygiene protocol actively applied. High level indoor farming knowledge and skills needed among manager and staff. Specialized, well-trained staff needed for pest and disease control, fertigation, very timely interventions needed, access to high quality inputs needed. Steady supply of electricity and internet is a must.

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[1] Reference is made to study Optimal Greenhouse Design Ghana, Delphy 2016

5. **CEA 5 High Tech vertical farming system: Addressed in Section B of this report**. Very high investment (600-5000 Euro/m2). Requires a steady supply of electricity, internet, clean water, and high-quality inputs and labour. It is highly important that the growers/staff are very knowledgeable. There is no ‘standard format’ vertical farm, so every building is different, with their own equipment.

Introduction to Nigeria

Today more than ever, the world is facing food production challenges. These are the result of new trends, which characterize the current and future growing and urbanizing population. These trends are particularly noticeable in developing countries: in Africa, population has grown from around 100 million in the last centuries to close to 1.2 billion with the expectation to grow to 2 billion by 2050. In the 60's, only 20% of the African population lived in an urban context, while nowadays, a sevenfold rise has been representing the current urban population. Nigeria's population alone has grown from 158 million in 2010 to over 200 million in 2019. Worldwide many metropolitan areas have emerged and expanded, among these is Lagos, Nigeria, with a counted population of over 14 million (UNFPA, 2022).

Nigeria's Food Problem Analyses

The Nigerian growth rate comes with socio-economic challenges for a population that includes an impoverished majority and a wealthy minority. One of the biggest challenges is the continuous supply of nutritious food to all. Assessing the status of food supply requires a broad approach, evaluating food security, food safety and food production sustainability.

Firstly, food security refers to when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet dietary needs for a productive and healthy life (United Nations). This relates to the amount and nutritional value of the food available on the one hand and to the distribution of it and people's financial means to food within the distribution network on the other hand. Urban food insecurity in developing regions can relate to urban poverty and social inequalities (Maxwell, 1999), inadequate distribution networks and/or to insufficient local food production. Impoverished people can spend the majority of their income to feed themselves, but food intake, expressed in calories, is often not enough and also is low in nutritional value (Orsini et al., 2013). As most of the urban diets are characterized by high-energy foods and low micronutrients content, there is an increasing risk of obesity and related diseases, such as heart disorders and hypertension (FAO, 2012). In Lagos particularly, this trend is confirmed in recent studies showing high prevalence of obesity and overweight among adults (Adegoke et al., 2021).

Also, Nigeria's food distribution network poses challenges for current and future food security. Currently, most of the food that feeds the Southwestern region is produced in the Northern regions of Nigeria by small farmers. Crop production is therefore fragmentated among smallholders that often do not collaborate (Posthumus et al., 2018). This type of production is mainly done during the dry season, as during the wet season cereals are cultivated and there is a high disease risk. However, during the dry season, water is a limiting factor for the vegetable production and the use of irrigation has been linked with higher economic returns. As the Southwestern region is distant from the vegetable production, traders have a key role in supplying the products. Normally, crops are transported by trucks to Lagos city. However, the production supply chain from the North is threatened by several issues, namely poor infrastructure, food losses during the transport, and high transport costs (van der Waal, 2015). Moreover, there is an increasing insecurity in the northern regions where terrorist attacks are becoming more frequent. On top of that, climate change is provoking desertification and unstable weather conditions in this area, limiting crop production. Food retailers characterize the final step of supply chain. The retail sector can be divided into three: open air traditional markets (65% of total food sales), convenience stores and small groceries (34%), and formal supermarkets (1%) (van der Waal, 2015). Therefore, supply chain is constraining food security at two different levels. At production level, rain-fed agricultural production is threatened by climate change and by limited inputs availability and often do not meet the food demand. At trade level, high transportation costs and long distances from farms to markets limit the accessibility to products (PwC, 2017).

Secondly, food safety refers to the prevention of foodborne illnesses in all steps of the supply chain, aiming for the protection of food stuff from pathogenic microbes and chemicals residuals (Regional Committee for Africa, 2011). In Nigeria, food safety risks can be divided into three groups: risk of chemical contamination (e.g., crop protection products); risk of contaminated wastewaters from industries; and risk for contamination with pathogenic microbes from irrigation, washing water, and/or unhygienic conditions (van der Waal, 2015). When it regards food production inside the city of Lagos itself in particular, food safety hazards related to the presence of heavy metals in soils, air pollution and polluted irrigation and washing water sources form a continuous threat to urban food safety.

Thirdly, food production sustainability needs to be addressed when assessing the food supply status in Nigeria and in particular Lagos. Food production sustainability is a very broad term, which relates to the long-term environmental, social and economic impacts of the food production practices. Regarding environmental sustainability, aiming for a food system that is resilient to climate change, prevents deprivation of natural resources and on the long run ensures adaptability of the production systems to its natural ecosystem is the goal (Aiking & De Boer, 2004). Climate change is expected to affect rain-fed agriculture in Nigeria by increasing temperatures and limiting rainfall predictability. As Lagos is situated at the coast, in addition to a decrease of production or an increase of loss due to temperature and rainfall changes, flooding of nearby agricultural fields could be another climate change related problem the local food production is facing (FAO, 2012). On top of climate change, the growing population numbers make social and economic sustainability of food production even more challenging. City expansion and intensified land-use diminishes the arable farmland available for agricultural production, while at the same time the plot size per farmer reduces each generation, as farmland is inherited from parents to their children.

Given the wide range of challenges related to the food supply chain that feeds Nigeria, it is unlikely that the current system can continue to feed the growing population in the future.

Hence, innovations are needed to respond to the above-mentioned challenges. These innovations could entail on the one hand sustainable intensification of traditional arable farming practices, but on the other hand could also entail a bolder change in agricultural production, looking into novel agro-systems, such as greenhouse or indoor farming systems.

The figure below shows in a nutshell the Value Chain of fresh vegetables, including greenhouse production, in Nigeria.

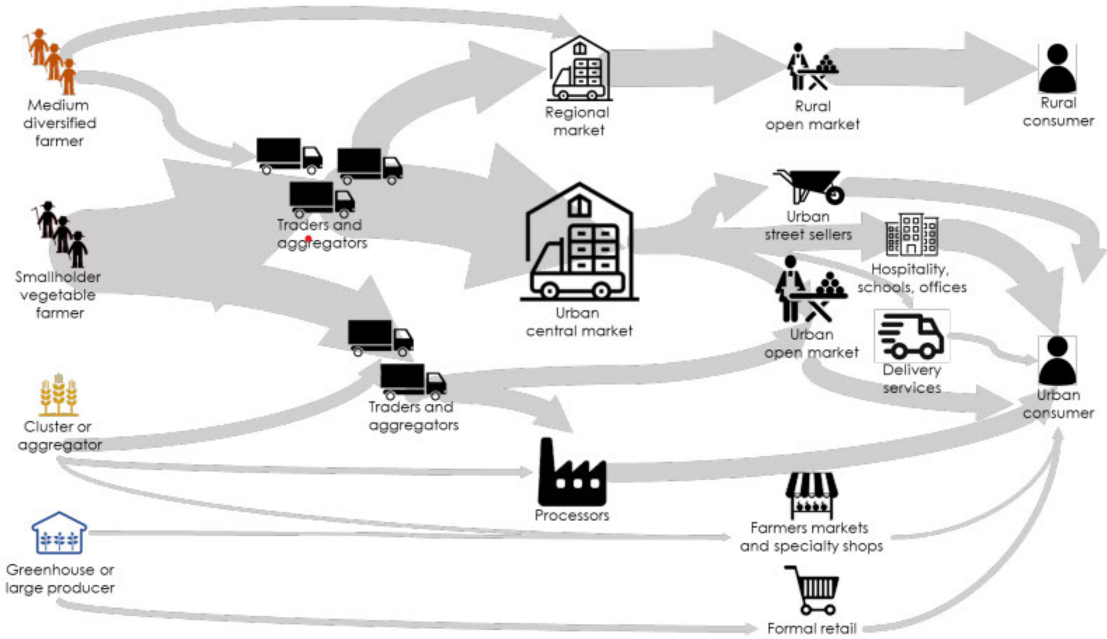

Figure 1: Value chain mapping vegetables in Nigeria (Van den Broek ea., 2021)

Location of this report: South West Nigeria

Considering the logistical issues in Nigeria in combination with the fact that most of the food that feeds the Southwestern region is produced in the Northern regions, substantial challenges of food supply are being experienced by the population in the Southern regions of the country. A great solution would be to increase food production in the Southwestern region itself. The South West region includes two of Nigeria's three largest cities: Lagos and Ibadan. The population of the South West region is estimated to be over 33 million people. The population of Lagos alone is estimated at over 14 million, with the eighth fastest growth rate population in Africa: an increase of 85 people per hour (Cheeseman & de Gramont, 2017). The continuous city expansion results in limited arable land, increasing land prices and land use intensification (Obia, 2016).

In order to understand the possibilities to improve food security, food safety and accessibility in this region, the protected horticulture methods studies within this report are focused on the geopolitical zone of South West Nigeria, which consists of six states: Ekiti, Lagos, Ogun, Ondo, Osun and Oyo.

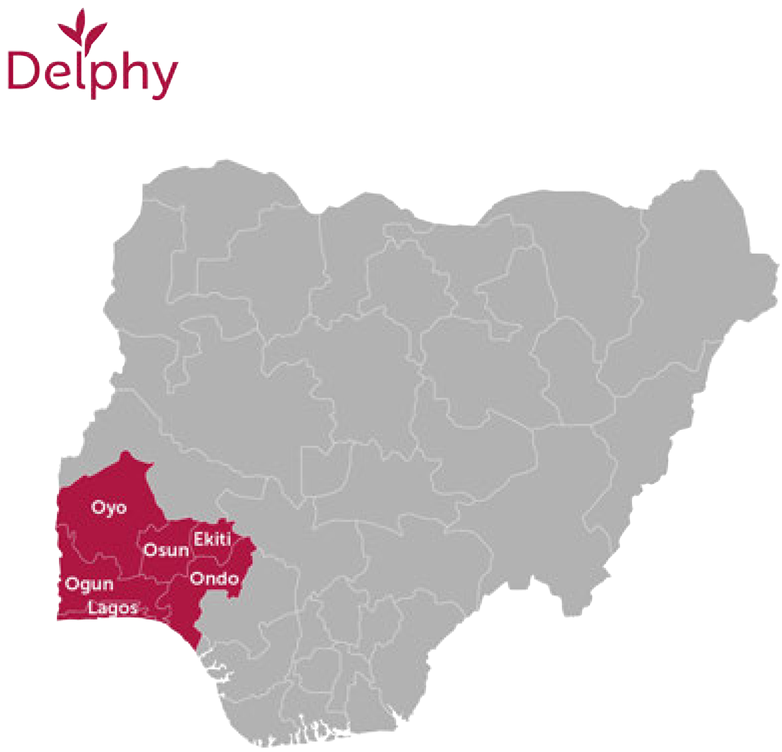

Figure 2: the six states of South West Nigeria included in this research.

South West Nigerian climate

Nigeria's climate is mainly controlled by the heating of the Sahara Desert in the north and cooling by the ocean in the south. This results in Southwestern Nigeria having a warm humid climate with two distinct seasons: the dry season, from November to March and the rainy season, from April to October.

Adepitan, J. O., Falayi, E. O. and Ogunsanwo, F.O. (2017) have investigated rainfall and temperature variability between 1980 to 2010 in four meteorological stations of the region, namely, Abeokuta (lat.7.01o N, long.3.2o E, alt. 67m), Ibadan (lat.7.43o N, long.3.9o E, alt. 227m), Ikeja (lat.6.58o N, long.3.33o E, alt. 39m) and Ondo (lat.7.1o N, long.4.83o E, alt. 287m). The report shows the rainfall and temperatures per station per year from 1980 to 2010 and the temperature and rainfall averages and changes per month.

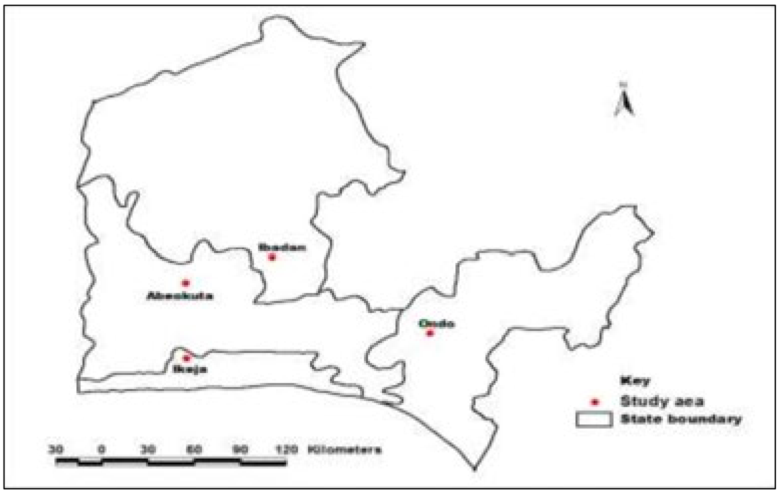

Figure 3: Location of the four meteorological stations on the southwestern map of Nigeria.

Their study shows that overall, the duration of the rainy season decreases from south to north. The south also knows an interruption of the rain season in August, creating a short dry period. Precipitation is heavier in the south than in the north, with about 1,800 mm (70 inches) in the southwest. They also note that there was no month of the year that recorded zero as mean rainfall in all the stations considered. Generally, the monthly average temperature in all the stations showed the maximum mean temperature occurring in February-March and the minimum mean temperature occurring in August.

Station	**Abeokuta**	**Ibadan**	**Ikeja**	**Ondo**
Temperature	28.27 Celsius	27.22 Celsius	27.56 Celsius	26.87 Celsius
Altitude	67 meters	227 meters	39 meters	287 meters

Table 1: Average annual mean temperature per station

An introduction to Controlled Agricultural Production Systems

A classification of agricultural production systems can be made based on the level of technology input. By adding more technology to an agro system, a farmer can increase the level of control they have on the production of crops, and with that improve the yield and stability of the agricultural production. The other side of this is that more technology implies a higher investment and operational cost. Also, a higher knowledge of agronomy is required with increasing levels of control. When producing in arable systems with few inputs, less cultivation decisions can be made by the farmer itself compared to when several or all production parameters are controlled by technology rather than by nature (Fig. 12).

Figure 4: Level of control by nature vs. by technology in agricultural production systems with increasing levels of technology input.

Following this analogy, Kozai & Niu (2019) distinguish agricultural production systems into four categories: 1) Open field production, 2) Greenhouse production with soil culture, 3) Greenhouse production with hydroponics and 4) Indoor systems (Fig. 12). The impact on stability, controllability, investment and yields is characterized per production system. It is clear that improvement in yield and stability come at an increasing cost. The sidenote, indicating that in hydroponic and indoor systems, the actual output increase depends on the managers skills is important to highlight and relates to the comment made above that states a higher level of technology requires a higher level of agronomy knowledge to operate the agricultural production system.

Table 2.1 Classification of four types of plant production systems by their relative stability and controllability, and other factors.				
Stability and controllability	**Open fields**	**Greenhouses**		**Indoor systems[a]**
		Soil culture	**Hydroponics[a]**	
Natural stability of aerial zone	Very low	Low	Low	Low
Artificial controllability of aerial zone	Very low	Medium	Medium	Very high
Natural stability of root zone	High	High	Low	Low
Artificial controllability of root zone	Low	Low	High	High
Vulnerability of yield and quality	High	Medium	Relatively low	Low
Initial investment per unit land area	Low	Medium	Relatively high	Extremely high
Yield	Low	Medium	Relatively high	Extremely high

[a]*High/low evaluation is valid only when the manager's skills are fairly high.*

Table 2: Table from Kozai & Niu (2019) indicating the characteristics of four agricultural production systems with increasing level of control.

The first study in this combined report focusses on the feasibility of various types of covered cultivation methods (CEA type 1, 2 and 3), such as: Low-tech netting, Tunnels, Low-tech, and Mid-tech greenhouse farming. The second study focusses on the feasibility of fully controlled indoor farming (CEA type 4).

Urban Agriculture in Lagos

Urban agriculture has been identified as a possible solution to tackle some of the above-mentioned challenges related to food supply of the growing population of Lagos. Urban agriculture refers to any type of agricultural production within or near cities. This means that within the concept of urban agriculture, the wide technology range described previously can be found. Urban agriculture can improve urban food security by the local supply of fresh, nutritious food. Moreover, urban food production systems can positively impact food sustainability and safety by providing ecosystem services and by reducing the length of the supply chain, respectively. Applying the classification system of Kozai & Niu (2019) (Fig 13) to the concept of urban agriculture production systems specifically: community rooftop and home gardens fall within the first category (Open field production); greenhouse and shaded cloth systems to the second and third (Greenhouse production with soil culture & Greenhouse production with hydroponics); and indoor farming systems to the fourth (Indoor systems).

In more detail: the urban agriculture systems with the lowest level of technology input are soil-based systems, such as the concept of home gardens and rooftop gardens. Because the soil-based urban agriculture systems have low input and technology levels, the level of control on the cultivation of the crop and the total yield is also limited. However, these soil-based urban agriculture systems are the cheapest per square meter of growing surface to start and operate. Moving to a medium level of technology, we find greenhouse systems, which are medium controlled environments and therefore have more control over the growing conditions of the crop. Within the greenhouse category there is a wide range of technology options: shaded cloth systems, screen houses, crop top structures, plastic tunnel systems, and glasshouses. Furthermore, a distinction is made on whether crops are sown directly into the soil, having less control over the rootzone, or whether hydroponic irrigation systems are used as growing system, which are more complex systems but enable the grower to control the rootzone conditions more precisely. Given the increased level of control, medium-tech greenhouse systems have higher output levels per square meter of growing surface, but also come at higher investment and operational costs. At the far end of the urban agriculture technology spectrum there are the indoor farming systems, which have fully controlled growing environment systems. In these production systems, all growth parameters can be controlled by technology, which makes these systems produce the highest output (kg $m^{-2}y^{-1}$) at constant, high quality levels when managed well. They require therefore also the most expensive investment per square meter of growing surface.

The below infographic made by the Dutch Indoor Farming company "PlantLab" shows a comparison between water use, yield and food miles of lettuce production along the different production systems (Naus, 2018).

Figure 5: Comparison of water usage, yield and food miles along the technology spectrum of agricultural production systems. Credit: PlantLab (Naus,2018).

Transferring the above spectrum of agro systems to the current Lagos situation, various production methods can be identified: On the left side of the spectrum, requiring the lowest input are the diverse home gardens often comprising several useful trees and a vegetable garden. Home gardens have been indicated as a source of food, income, and efficient land use (Galhena et al., 2013). Their short supply chain and high biodiversity entails ecological benefits. However, food safety could be harder to improve in home gardens, given the potential presence of heavy metals in the city soils and air, polluted water used as irrigation source and pesticide residuals, which are often the cause of health concerns related to home gardens (Orsini et al., 2013). In addition to home gardens as a type of urban agriculture in Lagos, some recent initiatives of Lagos urban agriculture fall within the medium-tech category with a higher level of control over the crop's growing conditions. Examples of such initiatives in Lagos are hydroponic systems in greenhouses or under shade cloths by Soilless Farming Lab and Gartner Callaway. Examples of high-tech Indoor Farming production systems (as defined in this research as "a fully controlled growing environment system") that are currently up and running have not been found in South-West Nigeria or Nigeria overall, however, there is a local initiative in Lagos using a mid-tech Indoor Farming production system (Fresh Direct NG). In Fig. 15 an overview shows different initiatives of urban agriculture in Lagos, following the technology spectrum.

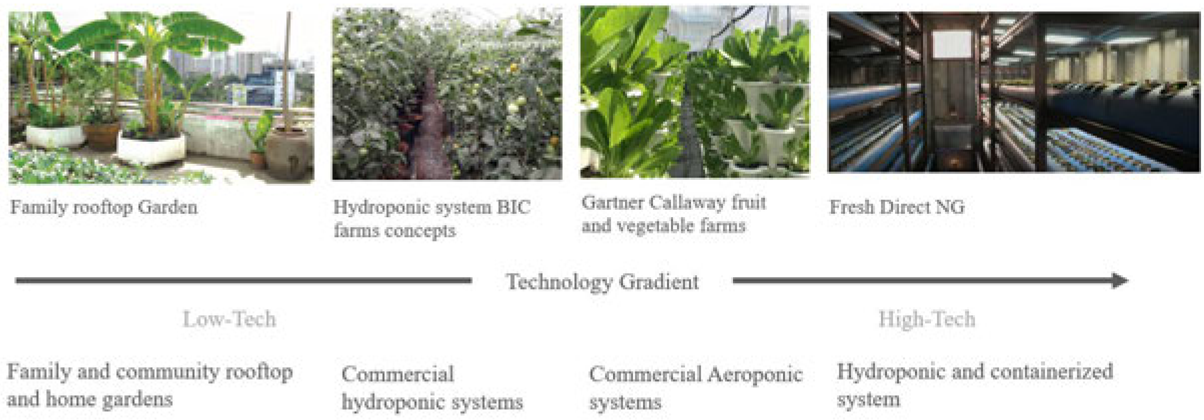

Figure 6: Urban agriculture systems in Lagos along the agricultural technology spectrum.

Study A: Scoping Study Protected Horticulture in Nigeria.

A1 Introduction to Study A

With a rapid growing population of 3.26% per year according to the UN World Urbanization Prospects, Nigeria needs to prepare for upscaling and intensification of the agricultural productivity, especially near to highly densely populated areas such as the South Western part, including Lagos. The high rate of urbanization and consequent growing population in Lagos are reducing the available arable land. This puts pressure on the farmers to farm their land continuously, going against the traditional practice of leaving the land fallow for a relatively long time. Given the wide range of challenges related to the food supply chain that feeds Nigeria, it is unlikely that the current farming methods can continue to feed the growing population in the future. Hence, a scoping study into the feasibility of various horticultural innovations related to Controlled Environmental Agriculture or protected horticulture is commissioned in order to identify the most suitable Controlled Environment Agriculture (CEA) options.

In order to describe and differentiate the various development stages of CEA, it is important to realize that the development stages in terms of technology levels are not universal, and strongly depend of the context of the area a person operates in. In order to have a common understanding of the various development stages of CEA, definitions are given of five stages of CEA observed in Nigeria (see Background). What is referred to as High Tech in Nigeria, might be considered medium tech in for example Western Europe. Different (micro) climates require adapted technologies in green house design, and there is no 'one size fits all' greenhouse design in mid or high-tech greenhouse farming.

The development from low to medium to high technological innovations goes step by step, and knowledge levels should keep the same pace as the introduction of more advanced technology levels. Investing in a high-tech greenhouse, without investing in the capacity building of the manager and the staff will result in failure. The practical examples are already in Nigeria: big greenhouses established that are not producing crops at the moment. It must be realised that high tech is not necessarily the best option for improving the horticultural sector, one should follow a logic step by step approach that suits the geography as well as the technical knowledge and skills levels of the people involved and targeted, and it must match the financial capacity of the target groups. Also, availability of required inputs determines what tech level will be most suitable.

Within this study CEA type 1 'Low-tech netting' and type 2 'low tech Tunnels' will only be considered in relation to the gaps for operating these farms, while CEA type 5 'High-tech vertical farming systems' is further detailed in Report B included in this report "Study Indoor Vertical Farming Systems Nigeria".

This study focuses especially on CEA type 3 and 4 'medium-tech and high-tech greenhouse farming'. The key difference between CEA 3 and CEA 4 is the introduction of fully automated systems in CEA 4 especially for irrigation and fertilization, as well as automated systems for ventilation and shading during the hot period of the day. Such fully automated systems are expensive and a large investment. Hence, single span greenhouses will disappear in CEA 4. Economies of scale are crucial when making such investments.

Mid- and High-tech greenhouses are supposed to overcome the following challenges: long and insecure supply chains; less knowledge of cultivating in greenhouses; No specific education in greenhouse farming; no real example of successful crop production on large scale in greenhouses yet; no stable supply and availability of crop protection; difficulty of getting long term (>5years) loans for agricultural investments; anti-regulatory regulations; market does not yet seem to put much value on the nutritional facts of their produce but is more attracted to appearance and taste; increasingly difficult growing conditions due to climate change and food safety issues. Other advantages of greenhouse farming are its high water and nutrient use efficiency, which reduces its demand for fresh water and fertilizer input.

The purpose of this study is:

1. To identify best practices and innovative solutions for sustainable development of (semi) controlled and protected production methods of vegetables (greenhouse farming) in Nigeria
2. To trigger Dutch and Nigerian partners for the development and introduction of new technologies in the Nigerian food value chains, with focus on Lagos city
3. To contribute to food security and nutrition, promote Dutch and Nigerian investments and stimulate job creation and entrepreneurship

Methodology

This study includes four steps:

1. Preparatory phase: desk research and interviews with protected horticultural actors: technical suppliers, crop experts based in The Netherlands and in Nigeria; Prepare for the field visit to Nigeria (in total 14 persons interviewed).
2. Field visit to Nigeria: Qualitative interviews with 12 actors and stakeholders in the surroundings of Lagos area. Focus on qualitative data collection, field observations, in order to get a hand on and realistic feel with protected horticulture in the context of SW Nigeria.
3. Completing the last interviews and Report writing

   Presenting the report findings in close coordination with EKN Abuja/CG Lagos, RVO

A. Online event: Feeding the Cities: Meet Nigerian partners in protected horticulture Trade mission (Outgoing) | RVO, Ministry of Foreign Affairs, 2 March 2022.
B. Physical presentation on 29 March 2022 in the Haque for an incoming delegation from Nigeria to the Netherlands and about 75 Dutch horti-related companies.

A2 An overview of CEA in South-West Nigeria

SOUTH-WEST Nigeria has quite some experience with greenhouse farming, and various types of greenhouses have been introduced and installed in the country. Often free of costs or subsidized by donors, NGOs, projects etc.

The experiences with protected cultivation are usually not too bad in the first year: the greenhouse is constructed and usually part of the deal is that the greenhouse construction company places a farm manager for the first months or year in order to ensure that proper technical assistance or farm management is there. Once this person leaves, and the ownership and management lie with the Nigerian farmer, research institution etc., the challenges come in as minimization of costs is often applied. This has impact on the yields, and usually this declines considerably. Being unmotivated and disappointed, the owner may either abandon the greenhouse or sell it off. After a bad season, the interest in continuation quickly disappears.
Regardless the type or tech level of the greenhouse it is evident that good farm management; well trained workers and timely availability of quality inputs are the key factors for successful protected cultivation, whether low, mid or high tech.

The interviewees active in Nigeria have a wide range of answers on the question if greenhouse farming was profitable for them, and it was not easy to obtain reliable data about this. Some open field farmers were very interested to start cultivation in a more protected environment to get more produce. Small holders (till 5 hectares open field or maximum of 5 single span greenhouses) often do not keep records in a systematic way. Large or commercial farmers do not want to share (all) the records. We doubt if they apply a systematic way of record keeping. Most greenhouse farms visited are classified as small farms (CEA 2) or medium farms (CEA 3), applying either low tech or medium tech technologies. Large commercial farmers (CEA 4) with functional high-tech greenhouses were not visited, as the team could not find them. Few non-functional high tech green houses were visited.

Climate impact and climate control

The climate in South-West Nigeria is one the most challenging parts in the design and feasibility of a greenhouse.

Due to high temperatures and the low difference between day and night temperatures, the plant is not able to come in a dormancy period. Lack of dormancy period results in stressed plants, with a short lifespan as result. High night-time temperatures greatly impact yield and quality because the plants are burning their stored energy reserves due to high rates of respiration. Hot day temperatures and related high evaporation requires lots of water for the plants. The stress levels experienced by plants results in high absorption of nutrients. A very precise pH level of the (irrigation) water; enough nutrients and regular watering is key to deal with the high temperatures.

Applying successful Controlled Environmental Agriculture depends on the characteristics of the region like climate, water quantity and quality, access to inputs (technical) and availability of electricity; the type of grower (knowledgeable and skilled) and the financial aspects: investment potential versus expected profits.

A3 Description of Observed Greenhouses or CEA designs

As indicated in the introduction, this study concentrates on the mid tech and high-tech CEA systems, but it is important to describe also the experiences with the low-tech CEA systems, as usually a step-by-step approach will be applied by farmers. One cannot introduce high tech before low tech systems have been piloted and tested, so lessons learned can be included in the design of next level solutions. The skills and know how, the availability of the needed inputs for the various steps of CEA determine also the pace of introducing higher technology levels. Hence, a gradual introduction of Controlled Environment Agriculture is logic and necessary, in order to keep pace between technology, supply chain and capacity of Human resources.

CEA 1 Low tech: Netting Systems

Small net nursery

Advantages	Disadvantages
▪ No direct sunlight on the product ▪ Small reduction of temperature ▪ No direct rain drip on the product ▪ Net gets away the first attacks of pests ▪ Easy to install ▪ Not very costly	▪ Trips and other diseases can easily enter ▪ Complicated to every time open/close and make sure it's completely closed after

High net, open sides

Advantages	Disadvantages
▪ Covered cultivation ▪ No direct sunlight on the crops ▪ A lot of ventilation in the greenhouse ▪ Good to regulate water ▪ Rainwater regulated on the crop (not direct)	▪ Still very open for pests ▪ Low walls, if the net is too tight, wind is hard to come through, so it becomes very hot inside ▪ No top ventilation

High net, closed sides

Advantages	Disadvantages
▪ No direct sunlight on the product ▪ Small reduction of temperature ▪ No direct rain on the product ▪ Easy to install ▪ Not very costly	▪ Pests can easily enter ▪ No other protection

CEA 2 Low Tech Tunnels: single span tunnels, low gutter height <2.2 m

This is a very common tunnel and can be seen also at smallholder farms. It is affordable and relatively simple to construct. Dizengoff is the most common brand found. The experiences are not so positive for vegetable production. The main limitation is the height (max 2.2 meter, not enough for tomato and cucumber) and it is small. Tit is often used to raise seedlings only, as temperatures are lowered. However, a small holder farmer may not truly benefit from an economic return if the greenhouse is only used for seedling production. Dizengoff tunnels have been donated widely free of costs by several projects.

Single Span tunnels

Photo of Dizengoff single span greenhouse 1

Photo low tech single span greenhouse 1

Advantages	Disadvantages
▪ No direct sunlight on the product ▪ No direct rain on the product ▪ Half meter of plastic on the bottom to prevent entering walking animals and less damage on the bottom part of the net ▪ Concrete floor, so no influence of the soil ▪ Closed construction ▪ Wind steady	▪ No 2 doors (pest and diseases can enter easily through the door) ▪ Very hot due to the plastic top ▪ No ventilation in the top ▪ Low side walls, so less ventilation. Temperature will go up very easily ▪ Plastic is not very sustainable in hot, humid and windy environment

Photo Local constructed, low costs and simple small green houses in Nigeria

Advantages	Disadvantages
▪ Good greenhouse for research ▪ Strong construction ▪ Concrete frame on the bottom to prevent damage on the bottom ▪ Nice height for air circulation	▪ No 2 doors (pest and diseases can enter easily through the door) ▪ Costly construction ▪ Very expensive if bigger size

CEA 3: Medium Tech Tunnels/ Greenhouses with manual ventilation systems, gutter height between 2.2 and 3 meters

Photo: Single span green house in South West Nigeria

Advantages	Disadvantages
▪ Open and light greenhouse (UV filter) ▪ Good quite good ventilation due to height and bigger net ▪ Some experience with farming in greenhouses ▪ Farm with substrate ▪ Individual supply of each greenhouse with irrigation system ▪ Very nice maintained till now ▪ Some space between the different greenhouses for better ventilation	▪ No top ventilation: high temperatures ▪ Everything is done manually ▪ Shadow net during the hot hours between 11am and 2pm not available ▪ Gutter height too low, should be 3-4 meters ▪ Front side (half-moon) should be open (net) not plastic, or with flexible roll screen lower part ▪ single span: more impact of micro climate on the borders, intensive labour

Photo: Single span single side butterfly ventilation green house in South West Nigeria

Advantages	Disadvantages
▪ Open and light greenhouse (UV filter) ▪ Good quite good ventilation due to some height and net with some bigger holes ▪ Some experience with farming in greenhouses ▪ Farm with substrate gutters ▪ Central system for irrigation. Close attention on pH level of the water ▪ Very nice maintained till now ▪ Some space between the different greenhouses for better ventilation ▪ Transit lock in front of the entrance. For example, good to also add a disinfection floor ▪ Already flexible shade net inside the greenhouse for specific crop	▪ Can be a meter higher for better ventilation ▪ No further mechanization ▪ Floor not on an exact slope (so you can check very carefully if the plant has enough water ▪ First 50 cm is no hard plastic (most shatter able part for breaking the net) ▪ Top ventilation only one side (single butterfly system) ▪ Gutter height too low (should be at least 3 -4 meters) ▪ Single span: loss in yield on the borders, hygiene protocol difficult to comply with ▪ Distance between tunnels is not wide enough (should be 5-8m), not enough ventilation

CEA 4 High Tech: Multispan greenhouses gutter heights > 3-4 meters, total Height up to 5-6 meters

Photo: South West Nigeria, 14 ha greenhouse, not in use.

Advantages	Disadvantages
▪ Large scale solution ▪ Gutter height 3-4 meters ▪ Big compartments , multi span system= economies of scale ▪ Top ventilation ▪ Are going to try a solution with a combination of farming in the soil and with cocopeat ▪ Had a professional central irrigation system with one pump house, fully automated irrigation	▪ Top ventilation only single side butterfly ▪ Plastic top ▪ Requires highly skilled crop manager and fully dedicated team to ensure timely interventions ▪ No experience with large scale farming in greenhouses ▪ Not well maintained (a lot of broken plastic ▪ Very hot, almost no wind gone through ▪ No space between the greenhouse compartments, so very hard to get proper ventilation in the middle ▪ Extra ventilation needed: butterfly system and internal ventilation system recommended ▪ Due to struggles with central irrigation system transformation to decentralized system to be more secure of water

A4 Conclusion on the Technical aspects of CEA in South-West Nigeria

Critical point in protected cultivation is the temperature management in the green house, to allow plants to reach a stage of dormancy. In SOUTH-WEST Nigeria, night temperatures are high, day temperatures as well. We have not observed artificial cooling (actively bringing down the temperature). This is expensive, and requires a lot of additional infrastructure and regular electricity supply. Interviews with various experts show that this is economically not feasible.

The best solution to ensure enough ventilation under the said circumstances is:

- Butterfly ventilation (preferably double sided, automated systems)
- If butterfly system is absent or perceived too expensive there are two alternatives:
    - ventilation with fans inside the greenhouse: internal ventilation provides a drying effect and homogenous micro climate;
    - Recirculate ventilation: fans blow wind from outside into the greenhouse

Disadvantage of ventilation systems is that it requires electricity.

Most of the observed greenhouses in Nigeria classify as low or medium tech but if wanted the performance of such greenhouses can be improved by making the following first adjustments that are not super expensive:

1. Higher gutter height (to at least 3-4 meters)
2. Better ventilation system (butterfly system or internal ventilation)
3. Use less plastic and more netting to stimulate ventilation.

Photo: double sided butterfly ventilation system

A5 The Ideal Greenhouse in South-West Nigeria: Technical design

Based on the previous chapter, providing an overview of the current level and experiences with CEA in SOUTH-WEST Nigeria and further inspired by input from experts either from Nigeria and experts from the sector the study provides criteria to come towards an "ideal greenhouse" for this part of Nigeria, keeping in mind the climatic conditions, the financial resources of farmers, the knowledge and skill levels of farmers/workers. As said before, there is no one size fits all greenhouse.
The following recommendations are given to construct an "Ideal" Medium Tech green house (CEA 3) or CEA 4 (with automated systems) that should be able to perform relatively well in SOUTH-WEST Nigeria, provided that the management is good and adequate:

Size

1. Single span (around 300 m2) or Multispan greenhouse (of at least 1000m2): economies of scale come in especially when automated systems are introduced, so multispan is recommended.
2. Less walls means easier disease control, less microclimate effects on plants, so on average a better yield.
3. In case single span is opted for: Distance between single span greenhouses should be at least 5-8 meters for sufficient ventilation in between the greenhouses)
4. Greenhouses should not be longer than 40m because of air circulation.

Ventilation and temperature control

1. Butterfly ventilation it is recommended, preferably automated. Minimum is single sided butterfly ventilation
2. If butterfly system is absent or perceived too expensive there are two alternatives:
   a. ventilation with fans inside the greenhouse: internal ventilation provides a drying effect and homogenous micro climate
   b. Recirculate ventilation: fans blow wind from outside into the greenhouse
   Disadvantage of such ventilation systems is that it requires electricity.
3. Netting with hole size 0,4 x 0,45 mm is ok as this allows enough ventilation. Observed 0,2 mm is too small for proper ventilation (although thrips cannot enter) .
4. Limited / no use of plastic on the side walls, as this limits ventilation
5. As a rule; top ventilation must be at least 20% of the ground surface to achieve good airflow ("chimney" effect)
6. No automated systems to open screens; hence it requires full attention of staff. Automated systems will ensure timely ventilation, but has additional costs
7. Include diffuse netting (white colour) for shading in the greenhouse. This is often absent. The shade nets must be used during 11 am and 2 pm. Can be automated or hand driven.
8. Use netting instead of plastic on the side walls or in the front and back top (half-moon)

9. Gutter height is currently low: 2.2 meter. Better to have at least 3.0 meters, preferably 4 meters: with a higher height, ventilation and cooling down of plants becomes easier. Tomatoes are extremely sensitive to heat stress and need at least 3 m gutter height
10. Roof height should at least be 3-4 meters, preferably 5-6m, this allows for more ventilation.

Pest and diseases control

1. Instead of mostly observed long sink gutters, better to use the 1-meter substrate grow bags with holes. This controls the quick multiplication of pests and diseases.
2. Double door entry: allows for better insects and pests control. This must include: disinfection mat, hand sanitation, a little bench that “forces“ staff and visitors to change outdoor shoes for indoor shoes; basin with disinfecting water.
3. Strict visitors protocol: let visitors not enter the greenhouse, they easily bring (unknowingly) pests and diseases. This counts for all greenhouses.
4. Observations and scouting are crucial to determine in early-stage pests and diseases. Do not minimise on this, have trained and dedicated staff for this.

Irrigation and soil choice

1. Gravity fed irrigation is a simple and efficient solution, but requires timely refill of the reservoirs and is a bit more labour intensive.
2. For soil-based greenhouses the gravity fed (not automated) irrigation works well, provided that the team irrigates timely. Soil requires less frequent irrigation. It can be a good choice to grow in soil, if investing in high tech equipment is not profitable. Adding enough compost, manure etc. to the soil can result in good performance.
3. Substrate greenhouse farming: choice: cocopeat is good. Alternatives are local substrates. Best to use the substrate bags of 1 meter.
4. If substrate is used, automated irrigation becomes almost a must as sometimes up to 12x per 24 hrs a water gift is needed. If automated irrigation is applied, the gutter corners must be perfectly designed, and the gutters must be very well levelled (recommended: gutter supported by plastic legs or stones) to avoid water logging
5. Especially with substrate farming irrigation is key. Computer system needed for EC, PH waterflow, A and B fertilisers.
6. Water pump system in greenhouses is a must for substrate greenhouse farming, and there must be a backup system.

Use of (limited available) electricity

Advice is to use electricity first for the irrigation / fertigation systems. If sufficient available it can also be used for automated ventilations systems and nettings systems.

A6 Business case for mid and high-tech greenhouse Nigeria

Based on the main findings of chapter A4 and A5 related to the minimum required technical characteristics for a green house in SOUTH-WEST Nigeria, this study has further dived into the business model of 2 models:

1. CEA 3 Medium Tech single span greenhouses, 288m2, with single sided butterfly ventilation systems; gutter height between 2 and 3 meters. No automated irrigation system or ventilation system. Medium investment of around 27 Euro/m2.
2. CEA 4 High Tech Multispan greenhouses, 5.000 m2, gutter heights >3 meters, total height up to 5 - 6 meters. High investment of around 140 Euro/m2

The business case (CAPEX and OPEX) is developed for these two models using average prices as prevailing in January 2022 being captured from various interviews, reference is made to international average prices for high tech greenhouses. Predicted yields (mid-medium and high) are based on figures from other studies and interviews, and experiences in similar climatic areas. Market prices are based on market visits, interviews etc, but the vegetables prices fluctuate a lot in the market. The same counts for inputs: prices are volatile and change per day.

Therefore, it should be realized that the business case calculation are time bound and context specific, hence the business cases are indicative and not conclusive. Market information related to prices of both inputs and end products are volatile over the seasons. Hence, the examples worked out in this chapter should be seen as an example, and accurate facts and figures shall always be collected and applied in order to make the most accurate business case for every specific case.

Annex 2 and 3 show an indicative CAPEX/ OPEX calculation model for CEA 3 and CEA 4, on four major crops grown in greenhouses: tomatoes, cucumber, bell pepper and habanero pepper.

Business case CEA 3 Mid tech tunnels

The most common used greenhouse at the moment in Nigeria is the single span, low gutter height or medium gutter height greenhouse of 288m2. The envisaged model has single sided butterfly system for top ventilation.

The anticipated net profit of such a greenhouse varies, and the expected yields depends very much on the green house management. Rough calculations show the following possible net profit if such green houses are well managed, although yield prediction are categorised into low, medium and high.

		Tomatoes		bell pepper		Habanero Pepper		Cucumber	
market price	Yield prediction	Production kg/288m2	Profit in Euro/year	Productio n kg/288m2	Profit in Euro/year	Production kg/288m2	Profit in Euro/year	Production kg/288m2	Profit in Euro/year
low	low	5.760	€ -4.201,42	3.840	€ -1.686,14	2.304	€ -10.238,10	14.976	€ -7.722,82
low	medium	8.640	€ 829,15	5.760	€ 4.602,07	3.456	€ -8.225,87	23.040	€ -4.201,42
low	high	11.520	€ 5.859,72	7.680	€ 10.890,28	4.608	€ -6.213,65	28.800	€ -1.686,14
high	low	5.760	€ -1.686,14	3.840	€ 2.506,00	2.304	€ -8.225,87	14.976	€ 11.896,40
high	medium	8.640	€ 4.602,07	5.760	€ 10.890,28	3.456	€ -5.207,53	23.040	€ 25.981,99
high	high	11.520	€ 10.890,28	7.680	€ 19.274,56	4.608	€ -2.189,19	28.800	€ 36.043,12

Net profit/m2 in Euro					
market price	Yield prediction	tomato	bell pepper	habanero pepper	cucumber
low	low	€ -14,59	€ -5,85	€ -35,55	€ -26,82
low	medium	€ 2,88	€ 15,98	€ -28,56	€ -14,59
low	high	€ 20,35	€ 37,81	€ -21,58	€ -5,85
high	low	€ -5,85	€ 8,70	€ -28,56	€ 41,31
high	medium	€ 15,98	€ 37,81	€ -18,08	€ 90,22
high	high	€ 37,81	€ 66,93	€ -7,60	€ 125,15

Table 3: Net profit predictions CEA 3 single span greenhouse (in Euro) with low and high yields and low and high market prices

The table shows that with low yields and low prices there is always a loss. Good crop management is key to profitable greenhouse farming. Habanero pepper shows a loss even under the best circumstances, so this is not recommended in a greenhouse.

Return on investment is mostly possible when growing bell pepper, as this fetches relatively high prices (both low and high prices are quite good) hence the risks are minimised.

Cucumber seems only profitable if produced when the market prices are high, hence timely planting so the products is ready during the low season (fetching high prices) is a critical factor determining if there will be a loss or profit (more risk). Tomato gives a profit if medium production levels are reached, both with low and high market prices.

One should note that these calculations shall need more finetuning per farm and must be updated with actual prices and market information, in terms of labour costs, and actual inputs used. But it gives a reasonable, average impression.

Business Case CEA 4 High tech greenhouse

This high-tech greenhouse of 5.000m2, is based on experiences in South Ghana, having a very similar climate as South West Nigeria and experiences from Southern Africa. The design is suitable for the hot and humid climate, with fully automated irrigation and fertilisation systems, , using high end inputs. The photograph below shows that it lacks double butterfly ventilations systems, which is recommended. This design will require an enabling environment such as: guaranteed electricity supply, availability of the high-end quality inputs (seeds, fertilisers, chemicals) and highly technically skilled, well trained and dedicated manager(s) and farm staff.

		Tomatoes		bell pepper		Habanero Pepper		Cucumber	
market price	Yield prediction	Production kg/5000m2	Profit in Euro/year	Production kg/5000m2	Profit in Euro/year	Production kg/5000m2	Profit in Euro/year	Production kg/5000m2	Profit in Euro/year
low	low	50.000	€ -180.045,20	66.667	€ 79.382,43	40.000	€ -57.089,19	260.000	€ -26.568,66
low	medium	75.000	€ -136.377,08	100.000	€ 188.552,73	60.000	€ -22.154,69	400.000	€ 34.566,71
low	high	100.000	€ -92.708,96	133.333	€ 297.723,04	80.000	€ 12.779,81	500.000	€ 78.234,83
high	low	50.000	€ -158.211,14	66.667	€ 152.162,63	2.304	€ -120.921,50	260.000	€ 314.042,69
high	medium	75.000	€ -103.625,99	100.000	€ 297.723,04	3.456	€ -117.903,16	400.000	€ 558.584,17
high	high	100.000	€ -49.040,84	133.333	€ 443.283,45	4.608	€ -114.884,82	500.000	€ 733.256,66

Net profit/m2 in Euro					
market price	Yield prediction	tomato	bell pepper	habanero pepper	cucumber
low	low	€ -36,01	€ 15,88	€ -11,42	€ -5,31
low	medium	€ -27,28	€ 37,71	€ -4,43	€ 6,91
low	high	€ -18,54	€ 59,54	€ 2,56	€ 15,65
		€ -	€ -	€ -	€ -
high	low	€ -31,64	€ 30,43	€ -24,18	€ 62,81
high	medium	€ -20,73	€ 59,54	€ -23,58	€ 111,72
high	high	€ -9,81	€ 88,66	€ -22,98	€ 146,65

Table 4: Net profit predictions CEA 4 1 based on 5000m2 greenhouse fully automated

The calculations show that bell pepper and cucumber can be profitable crops in such a greenhouse, but tomatoes and habanero pepper may even in the best-case scenario provide the farmer with a loss.

Human Resources and Know How

Most greenhouses visited are not performing optimum, or not are not in use. Above we have pointed out what technical flaws can be, and how this can be improved from a technical perspective. The business case shows that if low yields are realized, net profits (with the relatively low market prices) will not be very encouraging, in in the current light of developments, it can be expected that production costs will rise severely due to shortages of various inputs as well as energy, hence prices will go up. However, the human factor makes or breaks the performance of a greenhouse. Hence, investing in well trained staff, 24/7 farm supervision and timely interventions by staff are crucial in any type of greenhouse.

The green house techniques are often new and it requires very skilled people, as well as strict and timely management. Greenhouse crop advisors that are 24/7 available with well trained staff are a prerequisite for successful greenhouse production. In general, there are not enough skilled people, or they are not motivated enough to take full responsibility. TA, hands on people on the ground are an indispensable aspect of protected horticulture. Investing in training, skill development and having experienced crop advisors on the farm are a bare necessity.

Most agronomists are not yet trained in protected horticulture, it is not yet part of the curricula of TVETs or Universities. Hence, CEA farms, must invest themselves in getting the knowledge and skills to their farms.

Input suppliers often give a bit of after sales services, but disappear after the first growing cycle. If the crop manager was assigned by the input supplier, but redraws after one season, one cannot expect that all knowledge and skills are transferred to others. This is confirmed by several interviews held in Nigeria. In conclusion: a mid tech CEA3 greenhouse requires also trained staff and good management. TA, professional staff and workers becomes even more critical in a CEA4 high tech greenhouse, in which large investments are made and breakeven is hence more complicated to achieve. The financial risks are high with CEA4, and thus it should go hand in hand with sufficient and quality technical Assistance, throughout the use of the greenhouse, and not only for the first growing season. Greenhouse farming is a technical profession, in an ever changing, unstable environment with unpredictable incidents (like weather, pests and diseases) .

A6 SWOT analysis of CEA 3 mid tech and CEA 4 high tech greenhouse farming

Based on interviews with about 30 different stakeholders and actors actively engaged in the greenhouse vegetable production value chain in Nigeria; greenhouse experts and greenhouse (input) suppliers in The Netherlands etc.; the literature desk review, the technical, human resources and financial feasibility a SWOT analysis has been made to summarise the key findings related to protected mid and high-tech horticulture in South West Nigeria.

Please note that a Strength Weaknesses Opportunities and Threats (SWOT) analysis is a simplification of the complex reality, and there is no one size fits all solution for protected cultivation in South West Nigeria.

Strength

1. Quite a lot of experience/ learning by doing expertise in Nigeria with Greenhouses;
2. Best performing greenhouse characteristics are now emerging based on practical experience in Nigeria and comparable climatic zones (i.e., South Ghana). Medium tech greenhouses (single span) with proper ventilation and management are profitable.
3. Mid to High tech greenhouse farming near main markets adds value: reduction of post-harvest losses, savings on transport costs, near to target groups: middle class that can afford to pay a higher price or better quality.
4. Greenhouse farming Suitable crops for greenhouses: bell pepper and cucumber.
5. Good greenhouse planning is a must in order to be able to fetch higher prices and thus compensate for higher production costs.
6. Mid tech greenhouses require less advanced Human resources and know how, cheaper inputs hence financial risks are less.
7. High Tech greenhouses can be profitable if close to high end markets, where high prices can be fetched and with optimum production.

Weaknesses

1. Hot, humid climate in Lagos area requires special constructions. For example; plastic lasts for max. 2 years and needs renewal, makes it very expensive; ventilation (to cool down) is a challenge due to always high temperatures (also during the night). Many greenhouses have bad ventilation and air circulation.
2. Crop protection difficult due to irregular supply, difficult to get the right inputs at the right time.
3. Hard to get the right fertilisers (lack of stock, banned, not approved).
4. Limited documented experiences (based on factual information and data) available.
5. Limited expertise and skills in greenhouse farming in Nigeria, not part of educational system, lack of well-trained farm manager and workers for green house farming.
6. Stable and affordable electricity supply for greenhouses in rural areas is a challenge: high tech greenhouse needs to rely on a constant energy supply.
7. High Tech: Stable internet is a challenge outside Lagos. Needed for the next steps of improvement, such as digital solutions.
8. Many greenhouses are used for demonstration purposes, instead of having a focus on full-fledged production.
9. Lack of good examples of commercially viable greenhouses.

10. Green house is often provided as free input; hence ownership feeling is low, this can contribute to extensive use and lack of sincere interest in managing it commercially.
11. After the first year of cultivation within the building contract, owners often directly start with reducing costs as much as possible, with bad yields and thereafter less interest as a result.
12. Limited investment potential for farmers (hard to get a loan).

Opportunities

1. Few greenhouses seem to perform well, if technical design AND management are good. Based on practical experience the ideal greenhouse for South West Nigeria can be designed.
2. High value vegetables/ crops like bel pepper, beef tomatoes, fresh leaf veggies can be grown in an economic way in greenhouses. For green veggies, greenhouse must be near the market to avoid post-harvest losses.
3. Rapidly growing demand for low price horticultural products.
4. High quality and/or off-season vegetables: limited but upcoming niche market for this in major cities of Nigeria.
5. Gradually experience and knowledge on greenhouse farming is build up among various educational institutions, extension officers, SME and commercial farmers, thanks to several projects.
6. Green house farming offers jobs for well trained staff (both low-medium and high level).
7. Set-up and subsidise in a long-term centre of expertise with a focus on production (PPP construction) where a blueprint can be made for the 'ideal' mid AND high-tech greenhouse for the Lagos area. In this centre various suppliers can also test how their solutions perform in this hot tropical climate. The centre is an open location for sharing information, demonstrations and learning from each other.
8. Invest in green house management consultants with experience in tropical hot climate, with creative adapted solution and capable of providing on-the-job-training.
9. International input suppliers are already active in Nigeria, and are adjusting their inputs for greenhouses to local needs, but the gaps need to be closed (*government policies*)
10. Supply of greenhouse inputs shall go hand in hand with consultancy. Consultancy must be part of the deal, to ensure a better rate of successful greenhouse farming.
11. Education and training institutions (vocational schools, universities) to include greenhouse farming in their curricula as for the future generations of agripreneurs (being agronomist, farm workers or entrepreneurs in agriculture) this is essential.
12. Offer online training on a regular bases on greenhouse management
13. Introduction of basic quality systems related to for example phytosanitary rules and nutritious value of crops will improve the quality of food.

14. Promote IPM in greenhouses: Using natural enemies to combat pests, bumblebees for pollination, microbials, and bio stimulants that support, protect, and strengthen crops, resulting in less dependency on chemicals.
15. If electricity is scarce: first priority to be given to proper ventilation systems to reduce temperatures, as super high temperatures must be avoided.
16. Invest in alternatives to endure steady electricity supply: generators, solar energy etc.

Threats

1. Safety and security in Nigeria, not easy to find people willing to be stationed there or even to travel and provide greenhouse management consultancy. Are foreign companies with knowledge, skills and good quality materials ready to do business in Nigeria?
2. Climate change affects the micro climate: recording of extreme high temperatures become more frequent.
3. Average consumer does not care about quality, but wants to purchase at low cost. Niche market for high end products available but often imported products.
4. The wish of input suppliers to copy concepts from other climates, without proper testing or making needed adjustments.
5. Ban on foreign fertiliser import.

Based upon the collected information as described in previous chapters, a condensed SWOT analysis has been made, which summarises the most important or critical aspects of the SWOT.

Strength		**Weaknesses**	
1	CEA3 with good staff is profitable	1	lack of good ventilation systems/ adapted CEA systems
2	CEA 3 and 4 near main markets is viable	2	Timely pest and disease control
3	CEA 4 can be profitable for bell pepper and cucumber	3	access to high quality fertilisers
4		4	limited expertise, knowhow and skills
5		5	no commercially viable greenhouses on the ground
Opportunities		**Threats**	
1	ideal greenhouse can be designed	1	Safety and security
2	Profitable to grow high value vegetables in CEA 3 and 4	2	Ban on foreign fertiliser import
3	Rapidly growing demand for low price vegetables	3	climate change

4	Investing in green house Knowhow and skills already started	4	energy prices
5	supply of GH inputs together with knowhow and consultancy	5	

Further down in this report, in Study B on Fully Controlled Indoor Farming in Nigeria, it also becomes clear that an Indoor Farm (CEA 5) has as a weakness that it is hard for an Indoor Farm to have a strong financial business case against, for example, a greenhouse farmer in Nigeria. This insecurity of a weak business case is only increasing during the current (April 2022) energy crises and the massive raise of operational costs experienced by businesses worldwide.

In the confrontation matrix the SWOT quadrants have been combined with each other to assess there is a serious issue to be addressed or not. Scores or weight is given to such issues, to support in defining the strategic direction for interventions to improve the CEA horticulture sector in SOUTH-WEST Nigeria. Issues with the score 5 show severe issues that need to be addressed if possible. In the next Chapter conclusion and recommendations are given how the CEA sector in SOUTH-WEST Nigeria can be improved and strengthened.

Waardeer iedere combinatie met een 0 (geen kwestie)
1 (issue van geringe waarde)
3 (issue)
5 (belangrijke issue)

			sterkten					zwakten				
			1	2	3	4	5	1	2	3	4	5
			CEA3 with good staff is profitatable	CEA 3 and 4 near main markets is viable	CEA 4 can be profitable for bell pepper and cucumber	Some young, energitic well educated entrepreneurs show interest in CEA	0	lack of good ventilation systems	Timely pest and disease control	access to high quality fertilisers	limited expertise, knowhow and skills	Few commercialy viable greenhouses on the ground
kansen	1	ideal greenhouse can be designed	3	5	5	3		5	5	5	5	3
	2	Profitable to grow high value vegetables in CEA	0	1	0	0		5	5	5	5	1
	3	Rapidly growing demand for low price vegetables	0	0	0	0		3	3	3	5	1
	4	Investing in green house Knowhow and skills already started	0	0	0	3		3	3	1	3	3
	5	supply of GH inputs together with knowhow and consultancy	5	0	5	5		3	3	3	5	3
bedreigingen	1	safety and security	3	1	0	1		0	0	0	5	1
	2	ban on foreign fertiliser import	0	3	5	5		0	0	5	5	1
	3	climate change	3	5	1	2		5	3	5	5	1
	4	Customers prefer low price products, no premium for high quality	1	3	3	1		0	3	3	3	3
	5	0										

Figure7: Confrontation matrix based on SWOT

Study B: Scoping Study Fully Controlled Indoor Farming in Nigeria.

B1 Introduction to Study B

This scoping study aims to investigate the feasibility of indoor farming practices in South-West Nigeria. Different terminology is used globally for the identification of indoor farming practices. In this study, the term “Indoor Farming” relates to “a fully controlled growing environment system”. It is a cropping system that produces food without natural daylight and with artificial (LED) lighting in a closed production system. Other terms globally used for this type of growing system are Vertical Farming (referring to the stacking of several layers of production surface on top of each other) and Plant Factory with Artificial Lighting (the term mostly used in Japan). The latter definition also means that, for instance, a hydroponic system in a greenhouse does not fall into the category of Indoor Farming and will be addressed in this study as “hydroponic greenhouse system”.

In the USA, however, the term Indoor Farming oftentimes is used in a broader context, referring to both greenhouse and fully indoor production. Similarly, in the USA, the term Controlled Environment Agriculture (CEA) is used to identify both these production systems. Given the partial overlap of challenges and opportunities between Indoor Farming systems and Hydroponic Greenhouse system being a semi-controlled environment, information on the latter will be used and discussed in this study but a clear distinction between both systems will continuously be made.

Indoor Farming and Its Benefits

Various sources address the increasing challenges of food production in Africa and in megacities, and therefore the double challenge Lagos is facing, being Africa’s fastest growing metropole. Even though in peak season of production a considerable number of vegetables are consumed in Nigeria, reports of micronutrient deficiencies are extensive. Agbelemoge (2014) has researched that possible reasons for this common trend of micronutrient deficiencies are: seasonal variations in vegetable production, and inadequate processing and preservation of vegetables for all year distribution. Among other things, Agbelemoge expresses a need for increase of production, processing, preservation and consumption of vegetables. This is one of the areas where Indoor Farming can have an impact.

Strikingly, the African continent is seldomly mentioned in relation to indoor farming opportunities, though in other continents and regions indoor farming is globally seen as a novel opportunity to improve food security in megacities. Reports that describe the current state or future prospects of the indoor farming industry and the vertical farming industry on a global level, address the general trends in each continent specifically, except for Africa. Examples of such reports are: Plant Factory (Kozai et al., 2019); IDTechEX: Vertical Farming

2020-2030 (Dent, 2020); and Global Market Insights – Vertical Farming Market (Pulidindi & Prakash, 2019).

From this lack of literature being available on indoor farming in Africa or Nigeria specific, it is concluded that large-scale indoor farming initiatives (as they are popping up around the globe) have not yet taken off in Nigeria, although it could pose an interesting opportunity to the food supply chain challenges that Nigeria and Lagos specifically are facing. Indoor farming generates a constant local supply of high quality and clean produce independent from the outside conditions. Challenges related to long insecure supply chains, increasingly difficult growing conditions due to climate change and food safety issues, can be overcome with this novel way of growing. Other advantages of indoor farming are its high water and nutrient efficiency, which reduces its demand for fresh water and fertilizer input and the option to monitor and control the growing conditions of the farm remotely – all factors that are highly important to a megacity such as Lagos.

The absence of initiatives related to fully controlled indoor farming systems in Lagos could be because at first sight there are potential limitations to the establishment of an indoor farm. As mentioned by Kozai & Niu (2020), general potential limitations to the adoption of indoor farming have mainly to do with:

1. High starting- and production costs, which considers that high investments need to be made to start an indoor farming business;
2. Marketing of the high-end produce, which takes into account the fact that the agricultural product produced, is a niche product due to its constant high quality. This requires a demand-market for such high-end vegetables;
3. Lack of understanding of the optimal growing environment for various types of crops;
4. Absence of cultivated varieties (cultivars) specifically bred for indoor farms;
5. Availability of inputs for the operations of the farm, which relates to the operational challenges regarding input availability (a constant high supply of electricity and agricultural inputs such as seeds, substrate, and (in)organic fertilizer);
6. Availability of specific know-how, which refers to the human resources involved in the production. As operating an indoor farm requires specific know-how such as electrical/climate engineering, irrigation/plumbing engineering and agronomy.

These six potential limitations are aspects that always need to be taken in account at every location where an indoor farming facility is built. Therefore, these have been the common thread for our research, by investigating them in order to understand the potential of implementing this new technology in Lagos.

Method of Research

To gather the data for this research, various methods have been used: on distance desk research, individual interviews via digital means and telephone with stakeholders in The

Netherlands and in Nigeria, and a 7-day field visit to multiple stakeholders in South-West Nigeria. The interviewees included public research institutes, agricultural and economics research professors, commercial farmers, agroeconomic experts, agripreneurs and innovators, input suppliers for all areas of indoor farming (technology and hardware structures, plant materials and seeds, nutrients and substrate), product off-takers, and possible investors. The main objective of the field visit was to get a better understanding of the activities and innovations happening on the ground, especially the challenges and opportunities that various actors are experiencing, and the possible off-taking market.

B2 The Feasibility of Fully Controlled Indoor Farming in South-West Nigeria

As mentioned previously, Kozai & Niu (2020) describe six main potential limitations to the establishment of an indoor farm, which include challenges regarding finance, organic & technical input supply, and human resources and know-how. These six main potential limitations are discussed below, according to the current South-West Nigerian context.

Hard-and Software Supply

Indoor farming is defined as a fully controlled growing environment system that produces food without natural daylight and with artificial (LED) lighting in a closed production system. In order to start an indoor farm, the main hardware that is required includes heating and cooling systems, dehumidification systems, LED lights, and irrigation system(s). Current providers of materials:

Company	Supplied Materials	Supplies to NL	Supplies to NIG
Infinite Acres/80 Acres	Hardware	Yes	Yes
Logiqs	Hardware	Yes	Not yet
Certhon	Software	Yes	Yes
Priva	Software	Yes	Yes
Meteor System	Floaters	Yes	Not yet
Herkuplast	Trays	Yes	Not yet
2Grow	Sensors	Yes	Not yet
30MHz	Sensors	Yes	Yes
iMonnit	Sensors	Yes	Not yet
Sigrow	Sensors	Yes	Not yet
Sendot	Sensors	Yes	Not yet
Signify	LED lights	Yes	Yes
Fluence	LED lights	Yes	Yes

Table 5: Companies from the Netherlands who supply materials for Indoor Farming.

The majority of these hardware materials are regulated with software that controls the climate (temperature and humidity), lights (spectra and duration), and irrigation (volume, duration, frequency etc.). This software can be provided by the companies Priva and Certhon. Their software allows the full control of climate, irrigation, and lights inside an indoor farm. In this way, the grower can define via the software the growing strategy specific for each crop. Moreover, the companies providing sensors allow the continuous check of the set parameters also at crop level. This helps the grower to understand possible issues ongoing in the facility.

Water and Electricity Supply

Additional main requirements for an indoor farm are electricity and clean water. In terms of water, at all the locations visited during the field research, water was accessible and clean. According to observations, water is predominantly stored in tanks next to the facilities and in some cases, it is taken from a river and sterilized. Irrigation is then gravitationally provided via pipes. Farmers running a high-tech greenhouse use an automatic system to irrigate the crops directly from the tanks. For an Indoor Farm in South-West Nigeria, when stored properly, water does seem to pose any large issues.

However, to start an Indoor Farm in South-West Nigeria, there are issues concerning electricity: the electricity supply in Lagos is not stable. When operating an Indoor Farm, a constant stable supply of electricity is a must. Electricity is mainly needed for the LEDs and climate system to work. Within the climate system, a large amount of electricity is spent in dehumidifying and cooling because the extra energy coming from the LEDs is transformed into heat, which needs to be lowered via a cooling system. In addition, when crops transpire, the relative humidity increases and the additional relative humidity needs to be taken out from the system. To do so, a dehumidification system (which also requires electricity) is fundamental. Kozai et al., (2015) assessed that the electricity use of LEDs in an indoor farm is about 70-80%; whereas, the remaining percentage is characterized by air cooling and dehumidification.

To tackle the problem of unstable electricity for an Indoor Farm in South-West Nigeria, a private co-generator plant would be needed to provide a constant amount of electricity. Together with this possible solution, solar panels could also satisfy part of the energy requirements. Solar energy is a growing market in Nigeria, especially in the Lagos area and, together with a co-generator, technically it could be a good opportunity to provide enough energy and from a renewable source.

Suitable Crops & Seeds and Other Input Suppliers

Technically, all types of plants can be produced in an indoor growing environment, given that the indoor system supplies all the required growing conditions for a plant. However, due to the design of an indoor farming facility and the high investment and operational cost, only a specific selection of crops is suitable to be commercially produced in an Indoor Farm nowadays. Characteristics that make a crop suitable to grow in an indoor farm reflect both these aspects. Firstly, the aim within an indoor farm is to produce as many kilograms of fresh produce per m^3 of farming facility. Therefore, desirable characteristics of the crop are:

1. Short in height to fit as many tiers as possible on top of each other;
2. Fast growing at high CO_2 concentrations;
3. Good growth under low light intensities and high planting densities;
4. The majority of the biomass (fresh weight) of the plant can be sold as produce.

Secondly the aim is to produce high quality produce, of which the relatively many kilos produced can be sold at a high market price. Characteristics of the crop that help increase the market price relative to its competition grown in conventional growing systems are

5. Fresh, clean, tasty, nutritious and pesticide-free produce;
6. The product value can be effectively improved by environmental control

In addition to the above characteristics for crops that are generally suitable for indoor farming, some high yielding green crops that are currently popular for consumption in Nigeria and are also suitable for Indoor Farming include:

Lettuce	Herbs	Greens	
Butterhead Lettuce	Basil	Baby spinach	Pac Choi
Romaine lettuce	Mint	Malabar spinach	Mustard Greens
Oak Leaf Red lettuce	Coriander/Cilantro	Arugula	Curly kale
Red Leaf lettuce	Parsley	Celery	Dinosaur kale
Additional crops that are suitable			
Ginseng	Saffron	Strawberries	Tomatoes

Table 6: Crops that are suitable to grow in an Indoor Farm for Nigerian context

The seeds of suitable crops for an Indoor Farm are largely available in South West Nigeria. It is possible to easily find seeds from Dutch companies. Additionally, substrates suitable for indoor farming such as cocopeat, and peat, are available as well. They are suitable substrates for hydroponic production, but they need fertilizers to achieve higher yields. Next to these, farmers in the region are already also using substrates from organic residues such as rice hulls and compost from leaves. However, with these substrates, yields are expected to be lower compared to the above-mentioned substrates combined to fertigation.

Current providers of organic inputs and plant materials:

Company	Supplied Materials	Supplies to NL	Supplies to NIG
Enza Zaden	Seeds	Yes	Yes
Rijk Zwaan	Seeds	Yes	Yes
Pop Vriend	Seeds	Yes	Yes
Yara	Fertilizer	Yes	No
Grodan	Substrates	Yes	
BVB Substrates	Substrates	Yes	Yes
Klasmann Deilmann	Substrates	Yes	
Growfoam	Substrates	Yes	
Koppert	Biological pest control	Yes	

Table 7: Companies from the Netherlands who supply organic inputs and plant materials suitable for Indoor Farming.

Lack of fertilizers and nutrients

Although the supply of seeds and substrates do not seem to pose any issues, availability of fast release type fertilizers is lacking. Since December 2018, the Nigerian government has banned NPK fertilizer import. This has entailed difficulties in finding and using enough fertilizers, especially the fast release types, at farms. All the interviewees expressed the same issue and currently some farmers do not use any type of fertilizer and only rely on organic materials to fertilize their substrates. This entails lower yields and lower-quality plants. Farmers in these conditions try to produce their own fertilizers via organic residues, especially through compost. For an Indoor Farm, this lack of quality fertilizers and nutrients can pose large issues.

Production of Medicinal Herbs

Besides the production of leafy greens for food purposes, also the application of Indoor Farming for the production of medicinal herbs can be of interest for Lagos and Nigeria overall. According to Zobayed (2020) up to 80% of the African population make use of traditional medicines to meet their health care needs. Noting that the term "traditional medicine" covers a wide range of therapies and practices, which vary greatly from country to country and from region to region (World Health Organization, 2003). There are numerous studies done on leafy vegetable and herb consumption and usage among people from specific regions of Nigeria: Agbelemoge, 2014; Arowosegbe, 2013; Chinwe, 2018; Ezuruike, et al., 2014; and Sunday Arowosegbe, et al., 2018. These studies show that in many parts of Nigeria, green leafy vegetables have gained widespread acceptance as dietary elements that form a substantial part of the diet in soups and stews (Sunday Arowosegbe, et al., 2018). There are also many herbal medicine and medicinal plants traditionally used for diabetes management (Ezuruike, Udoamaka F, & Prieto, Jose M. 2014) and in the South East various vegetables are highly famed because of their reputation of curing and managing illnesses (Chinwe, 2018).

International trade has resulted in an explosive growth of plant-based medicine consumption, though in most countries there is virtually no cultivation of these crops and current consumption is fulfilled by harvesting wild plants. Besides the threat this international trade poses on biodiversity, it also creates health hazards for the consumers, given the (inconsistency of) quality the supply is facing (Sma, 2015). An indoor farming production system could lift these hazards, ensuring a continuous supply of good quality medicinal plants. The fact that in an indoor farm all growing conditions of the plant are fully controlled makes the production system highly suitable for this application. By fine-tuning the growing parameters, the concentration of functional components, the medicinal metabolites for which the plant is used, can be steered and optimized for the purpose of the medicinal use.

Post-harvest Packaging and Logistics

In 2017, APM Terminals, Naija Pride, and Technoserve, launched a refrigerated truck transport solution in Northern Nigeria. However, such a solution is not yet implemented in the South West. Therefore, high post-harvest losses characterize the vegetable supply chains in Nigeria; tomatoes losses can go up to 40%. Most of the vegetable losses happen during storage and transportation. It has become clear that currently most famers do not have any storage facilities on site and sell immediately after harvest to avoid losses on farm level – often loading the freshly harvest crop directly from field into truck. However, the transportation process is still problematic: road infrastructures are low-grade, there are almost always traffic issues and there are no to limited trucks available with refrigeration capacity.

For an Indoor Farm to reduce the supply chain length and lead-time overall, it is common practice among Indoor Farms to package the fresh products directly at the production site and then deliver it. This helps to limit the steps between production and consumption. To do so, a packaging plant is needed at the Indoor Farm. Although this increases the operational costs, it could economically benefit the Indoor Farm if the product benefits from a higher market value when the supply chain is fastest and shortest.

Human Resources and Know-how

For an Indoor Farm, specific know-how is involved in the production, such as electrical/climate engineering, irrigation/plumbing engineering, agronomy and farm management. An Indoor Farm needs various specialists (among different fields) and workers. Before a farm can start producing the required people include:

- Electrical engineers
- Climate engineers
- Biosystem engineers
- Software engineers

While the farm is producing, human know-how is fundamental to set the right growing conditions (temperature, humidity, CO_2 concentration, airflow, light spectrum, intensity and photoperiod, and fertigation recipe & timing) to maximize the productivity of each crop. Next to these, normally the company supplying the Indoor Farming facility also provides technical training and maintenance of the facility itself. Depending on the automation level of the indoor farm, more or less workers are needed for the main time-consuming operations. These are namely sowing, transplanting, and harvest, as well as daily cleaning. In case the automation level is high, the labour requirements would be reduced.

In Nigeria, as there are no high-tech fully controlled growing environment systems yet, there are also no human resources specifically geared towards such a niche market. The available relevant courses, diplomas and degrees in South West Nigeria are:

- Electrical & Electronics engineering

- Mechanical engineering
- Systems engineering
- Civil engineering (including irrigation and plumbing).

The courses, diplomas and degrees, which are limited in offering are:

- Civil geotechnical
- Climate engineering courses
- Agronomy – none of the institutions currently offer any courses specifically relevant for high-tech fully controlled growing environment systems.

Evaluation of the Financial Feasibility

Besides evaluating the technical feasibility of an Indoor Farm, it is just as important to see whether setting up an Indoor Farm is also a good business model for the Nigerian market.

Setting up and operating an Indoor Farm requires a high amount of start-up and operational capital: The operational costs of any Indoor Farm are estimated to be between 2.5 to 5 times higher than Dutch high-tech greenhouse per square meter crop. Yet, worldwide Indoor Farming has shown to be financially interesting because they can be built anywhere where there is electricity and clean water available, regardless of local climatic conditions and sunlight availability. And thanks to the isolation from external condition, production can take place throughout the whole year and productivity can be much higher for leafy greens than in open field and greenhouse farming (Kozai & Niu, 2020).

In order to calculate the financial feasibility of starting an Indoor Farm, one needs to know the fixed capital expenditure prices and operating expenses. However, it is difficult to make such calculations because there are many variables to take into account (Farm size, Location, Company supplying the facility, Company supplying lights, Growing strategy, Crop produced, Number of employees, and the Salary of employees). In order to give some examples, Annex 5 “Businesscase Indoor Farm Nigeria - CEA5” provides rough estimated calculations on the Capex and Opex of Indoor Farms producing lettuce, from 30m2, 100m2 and 300m2.

Market

In order to make any Indoor Farm financially feasible, not only are yields needed to be high in quantity and quality, but the market must also be willing to pay the requested prices. With the optimal growing conditions for yield, Indoor Farming allows to reach higher productivity levels compared to conventional farming and greenhouses in terms of resource usage of water, CO_2, and land in particular (Graamans et al., 2018). At the same time, Indoor Farming technology is advancing and operation and investment costs are reducing, resulting in an expansion of the range of crops that can be interesting to produce commercially.

Besides freshness, appearance and taste characteristics, the Indoor Farming industry keeps a strong focus on marketing their produce for their nutritional value. The latter, however, would not yet work in the Nigerian market. According to the interviewees who participated in this research, the Nigerian market does not yet put much value on the nutritional facts of their produce but instead, are more attracted to appearance and taste. Off takers (private individuals, supermarkets, hotels and restaurants, private hospitals, and private schools and universities) first look at price and then at the appearance and taste of produce. Often, nutritional facts are barely taken into account. This results in an Indoor Farm competing in price with open field, greenhouse and other farming methods.

Currently, in Lagos there is a definite need of better-quality fresh produce at supermarkets and on retailer level. Fresh produce for sale at large international supermarkets chains located in Lagos, such as Shoprite and Spar are of extremely poor quality: rotting vegetables, browning leafy greens, mouldy cauliflower and broccoli, and also various packaged imported vegetables, herbs and leafy greens from i.e., Italy and South Africa. While, these heads of iceberg lettuce with brown leaves are being sold for 10 USD per piece on retailer level. These retail prices could be financially interesting for an Indoor Farm.

However, the fact that consumers pay these prices seems to be more out of necessity rather than willingness. On top of that, the wholesale prices that the produce is sold for on farm level is significantly lower than the retailer's selling prices, as the retailers are holding the financial power in the market. Retail prices of most of the products is often double or triple the wholesale price. At the same time, as seen in the supermarkets, there has also been an increase in post-logistical food waste because since the 2020 COVID-19 pandemic, prices have skyrocketed due to inflation and buyers are often limited in choice. Pre-pandemic, a head of iceberg lettuce retailed on average for 6-7$ USD and is currently retailing on average for 9-11$ USD. If wholesalers want to move their products quickly, especially if they have large volumes, they have to sell at lower price points.

To give a brief indication of what wholesale prices to take into account, the table below shows the wholesale prices per product per kilogram in $ USD of three greenhouse and hydroponics growers in Lagos area:

Product	**Latin name**	**Grower 1**	**Grower 2**	**Grower 3**
Lettuce				
Iceberg lettuce	Lactuca sativa var. capitata	$2.41	$2.60	$4.80
Romaine lettuce	Lactuca sativa var. longifolia	$2.41	$2.60	-
Red leaf lettuce	Lactuca sativa var. crispa	$2.41	$2.60	-
Oak Leaf red lettuce	Lactuca sativa var. crispa	$2.41	$2.60	-
Herbs				
Basil	Ocimum basilicum	$4.83	$3.50	$3.60
Mint	Mentha	$4.83	$3.50	
Coriander/Cilantro	Coriandrum sativum	$3.62	$3.50	$6.00
Parsley	Petroselinum crispum	$4.83	$3.50	$3.60
Leafy greens				
Baby spinach	Spinacia oleracea	$7.24	-	-
Malabar spinach	Basella alba	$2.41	-	$3.60
Arugula	Eruca vesicaria ssp. sativa	$2.41	$1.75	-
Celery	Apium graveolens	$3.62	$3.50	-

Pac Choi	Brassica rapa subsp. chinensis	$2.41	$1.75	-
Mustard Greens	Brassica juncea	$2.41	$1.75	-
Curly kale	Brassica oleracea var. sabellica	$3.62	$2.10	-
Dinosaur kale	Brassica oleracea var. palmifolia	$3.62	$2.10	-
Fruit and vegetables				
Strawberry	Fragaria × ananassa	$3.62	-	-
Roma tomatoes	Solanum lycopersicum 'Roma'	$1.21	$1.40	-
Cherry tomatoes	Solanum lycopersicum var. cerasiforme	$2.41	$2.60	-
Beefsteak tomatoes	Solanum lycopersicum	$2.41	$2.40	-
Bell pepper (yellow, red)	Capsicum annuum	$4.83	$3.50	$4.80
Bell pepper (green)	Capsicum annuum	$3.62	-	$3.60

Table 8: wholesale price list of greenhouse and hydroponics growers in Lagos area.

Conclusions and Recommendations

The Nigerian environment, characterized by challenges of logistical and political issues from North to South, lack of climate change adaptation, post-harvest logistical losses, and the need for import, can greatly benefit from the development and implementation of Controlled Environment Agriculture (CEA) systems. With the rapid growing population, value chains need to become more efficient and CEA can play a critical role in availability of highly nutritious and high quantities of fresh products, produced relatively close to the major markets.

Technical design

1. CEA offers on one hand a solution for climate change, as input use is very efficient. On the other hand, climate change can be a threat for CEA as temperatures might rise even more. Hence this calls for continuously adapting designs.
2. Many greenhouses are placed at compounds of research or educational institutions and are not commercially run. It is recommended to invest (co funding) in commercially run model greenhouses (various models/ sizes) with entrepreneurs to have more examples of commercially run greenhouses.
3. There is no one size fits all greenhouse design for South West Nigeria, as local circumstances vary and request for logic and affordable adaptations. Input suppliers are recommended to adapt their "standard" greenhouses to the local context. For example; higher the gutter height of single span tunnels, ensure proper ventilation systems (butterfly system or indoor ventilation).
4. Most critical factor is temperature control through ventilation (CEA 3 and 4): Never compromise on reducing the costs related to ventilation and ensure that maximum ventilation is the main focus of greenhouse construction
5. Electricity is crucial in CEA4 but very critical CEA 5. It must be reliable 24/7 and affordable otherwise CEA 5 will not work

CEA Knowledge and Skills

There is a shortage of well trained and skilled managers and labourers that master CEA (mid tech- High tech). Green house farming is not (yet) part of or not enough included in the training curricula of TVET and universities, and there are not many people with experience in it. Capacity building is a fundamental necessity to uplift and improve CEA in Nigeria.

Lobby

1. Create an enabling environment (policy level) so high-quality inputs are available. The current ban on fertiliser import, without a local substitute creates crisis in Controlled Environment Agriculture.

2. Lobby with the government about rules, regulations and prices related to: input supply, energy/ electricity prices and availability; capacity building and import/export of inputs and products

CEA 3: Mid tech greenhouses

1. Is (proven concept) and can be a profitable investment in South-West Nigeria if the technical designs are adjusted and comply with a set of minimum requirements:
   - Gutter height at least 3 meters
   - Good ventilation: at least single sided butterfly system on top and at least 50% netted sidewalls, reduced use of plastic and use of shade nets. Gravity irrigation including fertilization will work well.
   - When substrate is used, irrigation becomes more critical as well as complex. Hence, mid tech cultivation on soil is a good option if there is no money for high tech irrigation systems
2. Input suppliers: Apply a step-by-step approach in upscaling from low to medium to high tech. Smaller adjustments, such as making the gutter hight higher, replace plastic with good quality nets can make the difference.

CEA 4: High tech greenhouses

1. CEA4 is a major investment and only profitable if very well managed. It requires that managers, staff and workers are well trained and coached to ensure proper crop management. The investment in training and education will pay off by higher productivity.
2. CEA 4 can still be profitable even with lower production levels if the crops are harvested during off season. Hence farm planning is a critical factor to make CEA 4 profitable
3. In high tech greenhouses all aspects need to be in balance: technical design, substrate choice, pest and disease management, HR management and availability of resources, including electricity. If one component underperforms or if in the technical design certain elements are left out to minimise costs, it has a dramatic impact on the business case.
4. Recommended crops for CEA 4 are Bell pepper and Cucumber. The business case shows that with the current market prices, CEA 4 is not profitable for tomatoes and habanero pepper.

CEA 5: Indoor Farm

1. The major requirements to operate an Indoor Farm are available or accessible in South West Nigeria, such as: hardware materials, software, clean water, seeds and other organic inputs, and some human resources. At the same time, there are also other major requirements unavailable or inaccessible, such as: a stable and constant

electricity supply, quality fertilizers and nutrients, and human resources specialised in high-tech fully controlled growing environment systems. If all these obstacles would be resolved, technically an Indoor Farm would be feasible in South West Nigeria.

2. Financially the feasibility of an Indoor Farm seems doubtful. When looking at the Capex/Opex calculations, a fully controlled indoor farm is feasible but these are quite idealistic calculations. In reality, there could always be problems that don't allow the expected production to be reached. When competing in the Nigerian market, where wholesale prices are determined by the wholesale off takers, and individual consumers and other buyers value the price, appearance and taste of produce much more than nutritional value, it is hard for an Indoor Farm to have a strong financial business case against, for example, a greenhouse farmer. At the same time, due to the high number of variables, it is not possible to make a precise generalized calculation of the capital expenditure and operational expenses for an Indoor Farm – just estimations. So, in theory a fully controlled indoor farm is financially feasible but in practice it wouldn’t be advisable.

Action plan

1. Lobby with government and decision makers for an enabling environment to further promote professional, commercial greenhouse farming in Nigeria with focus on
   - Ensure a steady supply of high-quality inputs for CEA, especially fertilisers and pesticides/ IPM
   - Include CEA farming in curricula of agronomy students at TVET, Agricultural Universities
2. (Dutch) Greenhouse input supply companies: make the necessary adaptations to current often used CEA models in Nigeria, so the greenhouse is designed for the hot and humid climate. Simple but indispensable requirements are good ventilation and enough gutter height
3. Invest (soft loan/ partial subsidies) in commercially run Greenhouses (contrary to CEA for research purposes only) and liaise with entrepreneurs that have a track record of good management and good HR; as making available the right know how and skills and willingness to invest in this is critical in the successful management of CEA
4. CEA capacity building and skill development:
   - invest in capacity building and training and skills development of green house managers, staff and workers
   - Include CEA in curricula of TVET and universities so the young generation has a basis in CEA
   - Allign (Netherlands) input suppliers and knowledge consultants / experts together, when CEA is further introduced, so technical designs come together with TA
   - (Dutch) Knowledge institutions can cooperate with TVETs, Universities to develop CEA modules and courses that can be offered in a blended way, including international teachers, including practical skills training in green houses as well.
5. Invest in alternative and renewable energy sources for CEA 4 and CEA 5, as energy prices will hike and electricity is often unreliable.
6. Set fair prices for fresh products and create consumer awareness on quality fresh food.

PSD projects and investment opportunities for the Dutch Government:

1. TVET and University training and teaching material development: linking Dutch experienced advisory services companies/ educational institutions to Nigerian TVET and Universities and work together on preparing training modules, courses and practical skill training curricula on CEA for BSc student. This will allow for a next generation extension officer who can work with CEA.
2. Introduce technically improved CEA3 small greenhouses with a group of 10-20 young entrepreneurs, willing to co-invest and develop their knowledge, and have a market-oriented focus. Such a group of young dedicated farmers can without high-risk experiment with an improved greenhouse. As a group, hiring of technical assistance or

a crop manager becomes a financially viable option. AT least 50% own investment needed in both hard ware as well as software.

3. Develop online learning courses for CEA crop managers, farm manager etc on a regular bases in which issues can be discussed and addressed, sharing experiences
4. Impact cluster to demonstrate CEA 4 from a commercial perspective: the local partners must be a commercial entity with a good track record in doing business in the Agri sector, but is ready for a next step. The CEA4 greenhouse shall not focus on research and pilots, but on full-fledged commercial production. This requires a serious focus on: good and adapted technical design; investing in knowledge and skills; access to affordable but good quality inputs and focusing on commercially viable crops and good marketing strategies. No research focus, but a business focus.

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Annex 1: Persons and organisations interviewed

In the Netherlands

	Organisation	Name	Function	Interview date
1	Infinite Acres	Marc Bruins Justin Schoenmaker	Supplier of VF techniques I containers	5-10-2021
2	Greenspan Agritech	Arnold Vermeulen	GH input and construction	12-10-2021
3	Profyta	Ewout Schurink	GH High Tech iput and construction and management	12-10-2021
4	East West Seeds	Rutger de Groot Coen Everts	Seed input supply	28-10-2021/ 02-11-2021
5	RijkZwaan Seeds	Eugene Agbicode	Seed input supply	03-11-2021
6	WUR-CDI	Flip van Koesveld	Horticultural capacity building and research	03-11-2021
7	Syngenta	John van Brussel	Seed input supply	06-01-2022
8	Bosman van Zaal	Robert van Donk	Greenhouse construction	06-01-2022
9	Hoogendoorm Automation	Bart 't Hoen	High tech Green House automation (irrigation, temp control)	17-01-2022
10	Priva	Fred Ruijgt	Distant digital control of green houses	18-01-2022
11	Farm Forte Valley	André Schaap	Commercial farm Nigeria incl GH	20-01-2022
12	TU Delft	Coen Hubers	Capacity building, resercah,Seed2Feed	21-01-2022
13	Delphy BV	Eric van Rees Vellinga	Greenhouse management consultant Ghana	Various dates
14	Access to energy	Hannah Kabir	Renewable energy consultant GIZ	03-02-20222
15	Delphy BV	Herbert Stolker	Greenhouse expert	Multiple

In Nigeria

	Organisation	Name	function	Interview date
1	Afri-Agriek	Monique Krombach	Input supply, consultancy	21-01-2022
2	Consulate-Lagos	Michiel Deelen Brian Udoh	Consul EKN Agricultural attaché	23-01-2022
3	Soiless Farm lab	Samson Ogbole	Owner of net greenhouse, trainer	Multiple (Oct ’21 & Jan ’22)
4	Federal University of Agriculture Abeokuta	Prof. Isaac Aiyelaagbe	Professor	Multiple (Oct ’21 & Jan ’22)
5	Obasanjo Farms	Oyeniyi Samuel Kehinde	Farm engineer, 15ha greenhouse farming	25-01-2022
6	BIC soilless Farm Hub	Pastor Debo Femy	Farm manager of greenhouses at research centre	Multiple (Oct ’21 & Jan ’22)
7	Mibic Organic Integrated Ltd.	Maureen Ebele Ajaba	Aggregation and sales of organic vegetable powders	25-01-2022
8	Lightline 55 farmers cooperative	Emmanuel Ajao	Lead farmer interested in greenhouse farming	26-01-2022
9	Embraise Agric	Shulamite	Mushroom production and processor of mushrooms	26-01-2022
10	HigHill Groups	Shola Adeniyi	UN ambassador and open field pepper grower	27-01-2022
11	FreshForte	Ms. Faith	High end shop of fresh products	28-01-2022
12	Agricultural Fresh Produce Growers and Exporters Association of Nigeria (AFGEAN)	Akin Sawyer Adetiloge	Farmers Organisation, Representation and Lobby	28-01-2022
13	NIHORT	Dr. Henry Akintoye	Public research institution	28-10-2021
14	Gartner Callaway	Yomi William	Entrepreneurial farm	30-10-2021

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