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# Assessment of the Investment Potential of Controlled Environment Agriculture in Sub-Saharan Africa

Pre-Feasibility Study - April 2026

## Acknowledgements

Authors: This report was written by Farrelly Mitchell Business Consultants Limited.

This report has been commissioned, financed and reviewed by the Subnational Climate Fund (SCF), which features a dedicated, grant funded facility for Technical Assistance (TA) that provides technical support to stakeholders in identifying and strengthening investment proposals for the fund.

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## Acronyms

| | |
|---|---|
| CAPEX | Capital Expenditure |
| CEA | Controlled Environment Agriculture |
| COGS | Cost of Goods Sold |
| DFI | Development Finance Institution |
| FMCG | Fast Moving Consumer Goods |
| HoReCa | Hotels, Restaurants, and Catering/Cafe (Services) |
| HVAC | Heating, Ventilation, and Air Conditioning (System) |
| LED | Light-Emitting Diode |
| LCAs | Life Cycle Assessment |
| LOI | Letter of Intent |
| NGO | Non-Government Organisation |
| OPEX | Operating Expenditure |
| PV | Photo Voltaic |
| SOP | Standard Operating Procedure |
| SME | Small and Medium Scale Enterprise |
| USD | United States Dollars |

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## Executive Summary

Urbanisation, climate variability, and rising dependence on imported horticultural products are exerting pressure on food systems across Sub-Saharan Africa (SSA), with mounting concerns over the region's ability to feed its rising population. Consequently, Controlled Environment Agriculture (CEA), encompassing protected greenhouses, hybrid systems, and indoor vertical farms, has emerged as a potential pathway to enhance urban food security, stabilise supply, and improve the region's climate resilience. Deploying a mixed methods approach, this study provides a regional landscape assessment, techno-economic benchmarking, and an enterprise-level case study to evaluate the viability and limits of CEA in SSA urban contexts.

The study reveals that CEA activity in the SSA region, while still nascent, is expanding remarkably across urban centres such as Johannesburg, Nairobi, and Lagos, and to some extent, Accra, Dakar, and Kigali, with the highest potential for deployment in Johannesburg, Nairobi, and Lagos. However, most recent initiatives in SSA cities are still pilot-scale or early commercial, often supported by donor finance, impact investors, or blended capital. The landscape is dominated by hybrid greenhouse systems, while indoor vertical farms remain limited to niche and premium markets due to their relatively high energy and capital intensity requirements. Hybrid greenhouse models offer the most robust near-term pathway in SSA, balancing productivity gains with affordability and resilience under the region's constrained infrastructure conditions. Products such as leafy greens, herbs, tomatoes, and peppers consistently emerge as the most viable crops, driven by their short crop cycles, import substitution potential, and demand from formal retail and food-service channels1. Further, techno-economic benchmarks uncovered by the study confirm that while CEA can deliver high yields and substantial water savings, profitability is highly sensitive to electricity cost, CAPEX, and market pricing power2.

To provide real-world insights into CEA potential in the region, the study uses VertiGenix (a South African-based CEA enterprise) as a case study, reinforcing the findings of the study by illustrating how careful crop selection, modular scaling, long-term off-take agreements, and operational discipline can mitigate CEA risks in SSA cities. While its theoretical or projected benchmarks often assume optimal energy efficiency and stable demand, the VertiGenix's case highlights real-world trade-offs between scale, cost control, and market depth. The case underscores that CEA viability depends less on technology alone and more on integration with local energy, water resources, logistics, and food distribution systems. However, CEA is unlikely to serve as a wholesale replacement for conventional horticulture in SSA. Instead, it should be positioned as a strategic complement within urban food systems, targeting high-value perishables, import-dependent segments, and climate-vulnerable supply chains. Moreover, successful CEA deployment requires patient capital, early alignment with anchor buyers, and clear go or no-go criteria. Such criteria include electricity and water resources, and that where electricity is not reliable and no backup power sources exist, high-intensity CEA systems including fully indoor vertical farms are generally not viable[3]. Similarly, although CEA systems have water efficiency of more than 70 – 90% less utilisation than open-field systems, reliability and affordability of water remain paramount.

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[1] Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustainability*, 9(1), 1–23.

[2] Graamans, L.; Baeza, E.; van den Dobbelsteen, A.; Tsafaras, I.; Stanghellini, C. Plant factories versus greenhouses: Comparison of resource use efficiency. *Agric. Syst*. 2018, 160, 31–43.

[3] Gan, C. I., Soukoutou, R., & Conroy, D. M. (2023). Sustainability Framing of Controlled Environment Agriculture and Consumer Perceptions: A Review. *Sustainability*, 15(1), 304. https://doi.org/10.3390/su15010304

Other factors such as climate, crop selection and market fit, robust off-take arrangements, as well as capital and technical capacity in SSA contexts are important considerations[4].

## 1. Introduction

Rapid urbanisation across Sub-Saharan Africa (SSA) is reshaping food demand trajectories, driven by rising urban populations, and increasing demand for year-round, perishable, high-value, and safe horticultural produce[5]. At the same time, many SSA countries remain import-dependent for fresh vegetables and specialty horticulture, exposing cities to international price volatilities and supply chain disruptions. Coupled with climate variability and extreme weather events, such factors further exacerbate supply risks by undermining rain-fed and open-field production in both peri-urban and rural landscapes[6]. Meanwhile, conventional horticulture in SSA faces structural limitations including limited smallholder production capacity, reducing land stocks per person, weak cold-chain and transport infrastructure, and substantial post-harvest losses that reduce effective supply and erode the competitiveness of domestic fresh produce[7,8]. These constraints mean that even where agronomic potential exists, delivered quantity, quality, safety, and consistency for urban markets are often inadequate. Against this backdrop, Controlled-Environment Agriculture (CEA), comprising greenhouses, hydroponics, vertical farms and other protected systems, has attracted growing interest as a resilience and import-substitution strategy. CEA promises higher yields per unit-area, enclosed climate control, reduced perishability, and the potential to locate production close to demand centres[9]. A recent study in Nigeria, for example, reports potential productivity and quality gains, though some national heterogeneity, driven by energy costs, capital intensity, and local market structures are also emphasised[10].

Despite the enthusiastic policy environment in many SSA countries and investor interest, the evidence base for CEA in SSA remains thin and uneven. Systematic techno-economic analyses that account for SSA-specific inputs (grid reliability, backup power fallback arrangements, local skills and wage structures, land tenure or rent regimes), and time-to-stability, are scarce. Much of the existing assessments rely on benchmarks from temperate or high-income countries that do not map cleanly onto SSA operating conditions. As well, firm-level data on metrics such as capital expenditure profiles, operating energy use, yield, and buyer contracts are particularly limited, constraining realistic scaling projections and financing models. This paper therefore aims at synthesising available SSA evidence, identifying key cost and infrastructure drivers, and outlining where CEA interventions are most likely to be economically viable given local constraints. By foregrounding firm-level performance metrics and contextual techno-economic parameters, the study aims to move the debate beyond optimistic narratives towards operationally useful guidance for investors, practitioners, and policymakers.

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[4] Nwanojuo, M. A., Anumudu, C. K., & Onyeaka, H. (2025). Impact of Controlled Environment Agriculture (CEA) in Nigeria, a Review of the Future of Farming in Africa. *Agriculture*, *15*(2), 117. https://doi.org/10.3390/agriculture15020117

[5] Sakketa, T. G. (2023). Urbanisation and rural development in sub-Saharan Africa: A review of pathways and impacts. *Research in Globalization*, *6*, 100133

[6] Yiridomoh, G. Y., Bonye, S. Z., Ahmed, A., Aasoglenang, T. A., & Derbile, E. K. (2025). Climate-Smart Agriculture Adoption and Food Security in Sub-Saharan Africa: A Systematic Review. *Climate Resilience and Sustainability*, *4*(2), e70017.

[7] Stathers, T. Onumah, G. and Lamboll, R. (2024). Postharvest loss reduction interventions in sub-Saharan Africa: experiences and perspectives. 130 pp.

[8] Affognon, H., Mutungi, C., Sanginga, P., & Borgemeister, C. (2015). Unpacking postharvest losses in sub-Saharan Africa: a meta-analysis. *World development*, *66*, 49-68.

[9] Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. Sustainability, 9(1), 1–23.

[10] Nwanojuo, M. A., Anumudu, C. K., & Onyeaka, H. (2025). Impact of controlled environment agriculture (CEA) in Nigeria, a review of the future of farming in Africa. *Agriculture*, *15*(2), 117.

Specifically, the study addresses the following key questions, among others:

a) Where does CEA make economic sense in SSA, by crop type and urban market segment?
b) Under what combinations of energy, labour, and logistics costs and infrastructure reliability does CEA become competitive with conventional and imported supply?
c) Which business and technology models (i.e. low-tech greenhouses, hybrid hydroponics, fully indoor vertical farms) are realistically scalable in the near term across heterogeneous SSA urban contexts?

# 2. Literature Review

This section reviews the CEA literature focusing on its conceptual foundations and the global evidence surrounding cost, yield, and resource utilisation. Evidence from the African region and other comparable contexts are also reviewed, and gaps identified to ground the current study.

## 2.1 Conceptualising Controlled Environment Agriculture

In Controlled Environment Agriculture (CEA) systems, growing conditions such as temperature, humidity, light intensity, carbon dioxide concentration, and nutrient supply are actively monitored and controlled to optimise plant performance[11,12]. CEA exists along a technological continuum, ranging from passively ventilated greenhouses to fully enclosed indoor vertical farming systems. Common system typologies are modelled around either greenhouse-based or indoor vertical farming systems. While greenhouses rely primarily on solar radiation which is augmented by heating, cooling, irrigation, and fertigation technologies, indoor vertical farms operate within fully artificial environments using LED lighting and stacked growing layers[13]. Hybrid greenhouse systems combining natural light with partial enclosures and automation, have gained traction as a lower-risk entry point into CEA, particularly in emerging markets[14].

The value proposition of CEA includes year-round production, yield stability, reduced exposure to climate variability, lower pesticide use, and proximity to urban consumers[15]. On the other hand, constraints such as high capital expenditure, energy dependence, skilled labour requirements, and uncertain economic viability limit its widespread adoption across many geographies[16], creating uncertainties about the suitability of CEA not just in advanced economies, but particularly in low and middle-income regions such as the SSA region.

## 2.2 Global Evidence on Cost, Yield, and Resource Use

CEA systems can significantly outperform conventional agriculture in terms of yield per unit area, particularly for leafy greens and herbs[17], with indoor vertical farming reporting yields of up to 10 – 20 times greater than

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[11] Al-Kodmany, K. (2018). The vertical farm: A review of developments and implications for the vertical city. *Buildings*, *8*(2), 24

[12] Kozai, T., Niu, G., & Takagaki, M. (Eds.). (2019). Plant factory: an indoor vertical farming system for efficient quality food production. Academic press.

[13] Graamans, L.; Baeza, E.; van den Dobbelsteen, A.; Tsafaras, I.; Stanghellini, C. Plant factories versus greenhouses: Comparison of resource use efficiency. *Agric. Syst*. 2018, 160, 31–43.

[14] Beacham, A. M., Vickers, L. H., & Monaghan, J. M. (2019). Vertical farming: a summary of approaches to growing skywards. *The Journal of Horticultural Science and Biotechnology*, *94*(3), 277–283. https://doi.org/10.1080/14620316.2019.1574214.

[15] Despommier, D. (2013). Farming up the city: the rise of urban vertical farms. *Trends in biotechnology*, *31*(7), 388-389.

[16] Van Delden, S. H., SharathKumar, M., Butturini, M., Graamans, L. J. A., Heuvelink, E., Kacira, M., ... & Marcelis, L. F. M. (2021). Current status and future challenges in implementing and upscaling vertical farming systems. *Nature Food*, *2*(12), 944-956.

[17] Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustainability*, 9(1), 1–23.

open-field systems, enabled by crop stacking and accelerated growth cycles[18]. However, productivity gains come with high resource utilisation, consistent with high-input, high-output production regimes. For example, energy use, primarily for lighting and climate control, remains a major operating cost in indoor vertical systems, accounting for up to 70 % of operational expenditure in some cases[19,20]. Capital costs per square metre in CEA also far exceed those of greenhouse or open-field production, increasing its financial exposure.

Although life-cycle assessments (LCAs) suggest that CEA reduces water use by 80 – 95 % compared to conventional systems, net environmental performance depends heavily on the carbon intensity of the power supply used[21]. Again, due to the significant role of energy in CEA systems, commercially successful ventures are typically located in markets with low electricity costs, advanced logistics, and premium consumer demand.

### 2.3 Evidence from Africa and Comparable Contexts

Evidence on successful CEA systems in continental Africa is comparatively limited, skewed toward greenhouse systems, and studies from East and Southern Africa increasingly document expanding adoption of protected horticulture, particularly for tomatoes, peppers, and cucumbers[22,23]. These systems show yield gains and improved quality, but face constraints related to financing, input availability, technical capacity, and related market entry hurdles[24]. Consequently, CEA systems such as indoor vertical farming in SSA remain largely experimental with pilot initiatives in Kenya, Nigeria, Rwanda, and South Africa demonstrating technical feasibility but difficulties with high capital costs, unreliable electricity, and limited premium market depth[25].

Studies from other comparable regions suggest that vertical systems only scale where import dependence, energy subsidies, or strategic food security objectives justify the relatively higher associated production costs[26]. Therefore, key uncertainties persist regarding long-term operational performance, labour and skill requirements, and consumers' willingness to pay in African urban centres, where the affordability of food is a critical consideration in consumer purchasing decisions. These uncertainties create major knowledge gaps in fully ascertaining the investment potential of CEA systems in SSA contexts.

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[18] Touliatos, D., Dodd, I. C., & McAinsh, M. (2016). Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. *Food and energy security*, *5*(3), 184-191.

[19] Barbosa, G. L., Gadelha, F. D. A., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., ... & Halden, R. U. (2015). Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods. *International journal of environmental research and public health*, *12*(6), 6879.

[20] Graamans, L.; Baeza, E.; van den Dobbelsteen, A.; Tsafaras, I.; Stanghellini, C. Plant factories versus greenhouses: Comparison of resource use efficiency. *Agric. Syst*. 2018, 160, 31–43.

[21] Gómez, C., Currey, C. J., Dickson, R. W., Kim, H. J., Hernández, R., Sabeh, N. C., ... & Burnett, S. E. (2019). Controlled environment food production for urban agriculture. *HortScience*, *54*(9), 1448-1458.

[22] Nwanojuo, M. A., Anumudu, C. K., & Onyeaka, H. (2025). Impact of controlled environment agriculture (CEA) in Nigeria, a review of the future of farming in Africa. *Agriculture*, *15*(2), 117.

[23] Ayinde, T. B., Nicholson, C. F., & Ahmed, B. (2024). A Review of Controlled Environment Agriculture (CEA) Vegetable Production in Africa with Emphasis on Tomatoes, Onions and Cabbage. *Climate Smart Greenhouses-Innovations and Impacts*.

[24] Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustainability*, 9(1), 1–23.

[25] Nwanojuo, M. A., Anumudu, C. K., & Onyeaka, H. (2025). Impact of controlled environment agriculture (CEA) in Nigeria, a review of the future of farming in Africa. *Agriculture*, *15*(2), 117.

[26] Aborujilah, A. (2025). Towards Sustainable Vertical Farming: A Systematic Review of Energy Return on Investment Efficiency and Optimization Strategies. *Sustainability*, *17*(18), 8142.

## 2.4 Research Gap and Contribution of Current Papper

Given the heavy focus of the existing CEA literature on high-income countries, where CEAs rose sharply in the early years (*circa* 1999) but fell after some two decades of experimentation with chequered outcomes, questions remain about when CEA will fulfil its promised potential[27]. Further, the applicability of the literature to SSA cities faced with energy volatility, fragmented value chains, and heterogeneous consumer markets is limited. Yet, studies on African CEA systems tend to focus on production outcomes rather than integrated food system performance, leaving gaps around scaling, affordability, distribution, and climate resilience impacts.

This paper addresses these gaps by combining an SSA-specific CEA landscape assessment with techno-economic benchmarking and urban market comparison using three top African cities. Further, by situating CEA within broader food system and infrastructure constraints, the study contributes a context-specific framework for evaluating when and where CEA investments are justified in SSA contexts.

# 3. Methodology

This study applied a mixed-methods approach combining desk-based landscape analysis, techno-economic benchmarking, and an enterprise-level case study coupled with a targeted stakeholder consultation. Together, these methods generated a multi-scalar understanding of the CEA landscape in SSA, linking regional trends with firm-level operational realities and projections (Figure 1).

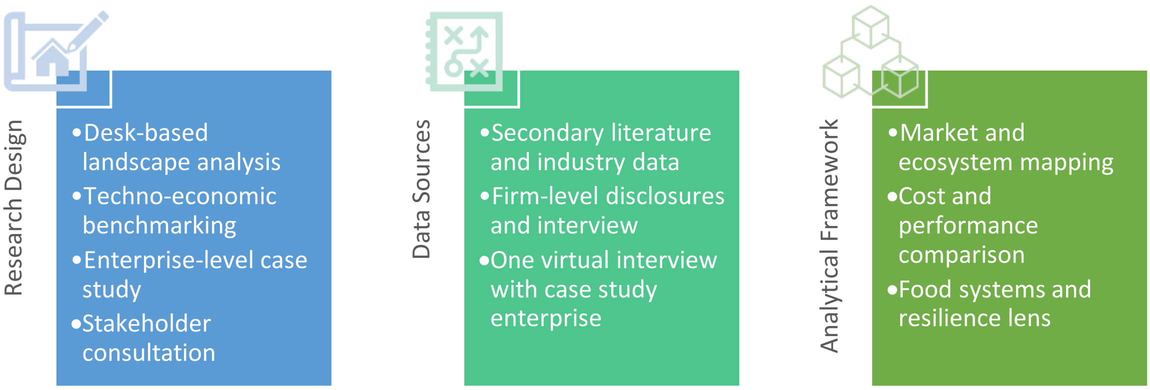


*Figure 1: Methodological Approach*

## 3.1 Approach

The desk-based assessment synthesised regional CEA developments, focusing on market dynamics, geographic hotspots, crop selection patterns, and emerging business models. This provided the contextual basis required to evaluate the enabling conditions for different CEA typologies across East, West, and Southern Africa. Techno-economic benchmarking (from the broader CEA literature) complemented this by comparing *indicative* CAPEX, OPEX, and resource-use parameters for representative CEA systems such as hybrid greenhouses and vertical farms. Three top SSA cities were also compared based on selected investment criteria and *Go or No-Go* decisions derived through a weighted multi-criteria scoring, translating qualitative city characteristics into measurable investment risk and viability signals. Each investment criterion was scored on a 0 – 5-point scale, weighted, and aggregated to generate an overall *Viability Index (V*I): $\sum (Score_i \text{ x } Weight_i)$. The enterprise-level case study and follow-up interview provided a micro-level perspective, examining the technology choices, operational model,

[27] Burritt, M., Valle de Souza, S., & Peterson, H. C. (2025). When Will Controlled Environment Agriculture in Its Vertical Form Fulfill Its Potential?. Sustainability, 17(7), 2957.

and market positioning of a selected enterprise in South Africa where CEA systems are relatively well-developed. This helped ground broader regional insights in real-world commercial practice and projections, capturing practitioner perspectives, and triangulating the findings of the landscape assessment.

### 3.2 Data Sources

The analysis drew on peer-reviewed literature, market reports, and industry datasets. In addition, firm-level disclosures such as operational summaries or estimates, financial estimates, and qualitative insights from a virtual call with the case study enterprise provided further insights. Where data gaps existed, ranges and comparative benchmarks from global studies were cautiously adopted.

### 3.3 Analytical Framework

The analytical framework integrated (a) market and ecosystem mapping to assess demand drivers, enabling conditions, and sector maturity, (b) cost and performance comparison to evaluate economic and technical viability of CEA models, and (c) a food systems and resilience lens to gauge contributions to urban food security, climate adaptation, and supply-chain stability. This combined lens enabled a holistic evaluation of CEA's potential role in SSA urban food systems.

## 4. Research Findings

This section presents the findings of the study, broadly addressing the CEA landscape in SSA, infrastructure and food system constraints, as well as the techno-economic performance of CEA systems in the region.

### 4.1 CEA Landscape in SSA

While still nascent compared to global hubs in Europe or East Asia, the SSA CEA landscape increasingly demonstrates pockets of commercially oriented activity, especially around major city centres where demand for premium vegetables, herbs, and salad greens is concentrated. Following below is an overview of the market context and geographic hotspots for CEA activities, the crop focus and demand structure, industry actors and their business models, as well as key trends observable in the SSA region.

#### 4.1.1 Market Context and Geographic Hotspots

Distinct geographic hotspots have emerged across three broad SSA regions, including East, West, and Southern Africa. Cities such as Nairobi, Addis Ababa, and Kigali constitute the core East African zone, supported by a strong culture of horticulture production, export-oriented agribusiness, and growing agri-tech entrepreneurship[28]. In West Africa, cities such as Accra, Abidjan, and Lagos have become centres of experimentation, frequently driven by import substitution logics, and premium supermarket chains that require consistent quality and year-round availability of vegetables. Southern Africa, led by Johannesburg, Cape Town, and Durban, represents the most mature CEA environment in the SSA region, with longer commercial experience in greenhouse horticulture and more developed input supply chains[29].

East Africa has seen some of the most rapid regional proliferations of greenhouse adoption in SSA, largely through low and medium-tech polyethylene-covered structures with drip irrigation that extend production

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[28] Reardon, T., Echeverria, R., Berdegué, J., Minten, B., Liverpool-Tasie, S., Tschirley, D., & Zilberman, D. (2019). Rapid transformation of food systems in developing regions: Highlighting the role of agricultural research & innovations. *Agricultural systems*, 172, 47-59.

[29] Gómez, C., Currey, C. J., Dickson, R. W., Kim, H. J., Hernández, R., Sabeh, N. C., ... & Burnett, S. E. (2019). Controlled environment food production for urban agriculture. *HortScience*, *54*(9), 1448-1458.

environments for vegetables and other high-value crops[30]. These are used predominantly for tomato, capsicum, and cucumber production, supported by relatively established horticultural advisory networks. West Africa, by contrast, shows a more fragmented landscape where hybrid greenhouses supported by impact investors or agritech incubators coexist with micro-scale greenhouses run by youth enterprises and donor-funded initiatives[31]. Southern Africa combines commercial-scale high-tech greenhouses, often using Dutch or Israeli technology packages, with emerging interest in vertical farming and hydroponic container systems targeting urban niche markets[32]. Overall, three broad models characterise the SSA CEA sector, including:

a) Pilot-scale demonstration systems, typically financed by donors, NGOs, or public-sector agricultural institutions. These emphasise technology transfer and training rather than commercial viability.
b) Investor-backed ventures (still few but growing) that deploy hybrid greenhouse or modular vertical systems tailored to local cost structures. Examples include container farms in Kenya and investor-financed hydroponic greenhouses in South Africa.
c) Donor-supported agritech and youth entrepreneurship programmes using small-scale greenhouses (50 – 500 m²), hydroponic units, or vertical growing towers as tools for enterprise development.

### 4.1.2 Crop Focus and Demand Structure

CEA projects in SSA tend to focus on a small set of high-value, short-cycle crops where the combination of urban demand and unit value makes the economics feasible. As such, across the regional literature and market reports, three to four representative crop clusters, namely leafy greens and herbs, tomatoes, peppers and cucurbits, and high value berries and vegetables consistently appear[33,34] (
Figure 2).

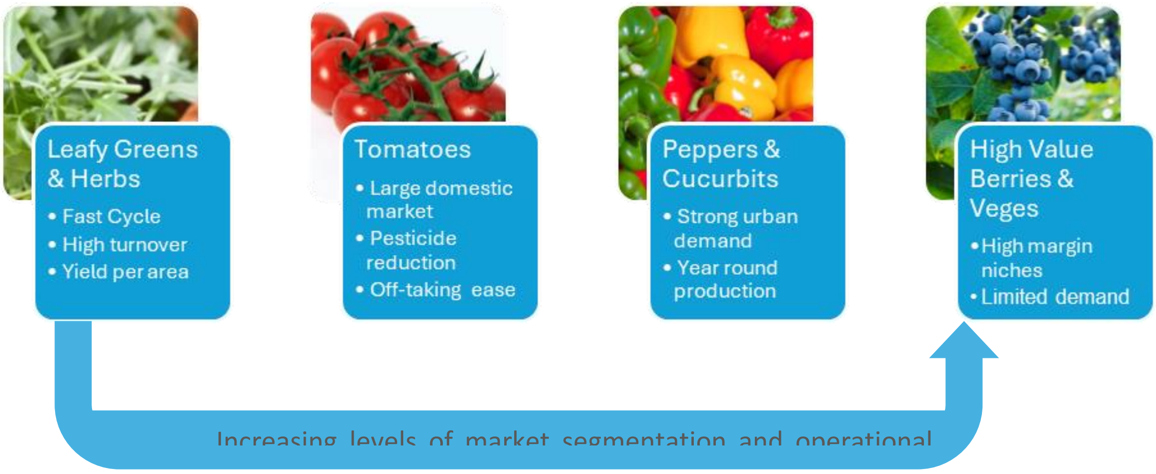


*Figure 2: Common Crop Clusters for SSA CEA*

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[30] Cambaza, E. M. (2022). A short review on African horticultural greenhouses. *Mozambican Journal of Applied* Sciences, 1(1).

[31] https://www.agriimpactgroup.com/projects/youth-greenhouse-enterprise-project-yugep (Accessed: January 5, 2026)

[32] Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustainability*, 9(1), 1–23.

[33] Dsouza, A., Newman, L., Graham, T., & Fraser, E. D. (2023). Exploring the landscape of controlled environment agriculture research: A systematic scoping review of trends and topics. Agricultural Systems, 209, 103673.

[34] https://umbrex.com/resources/industry-primers/agriculture-food-industry-primers/controlled-environment-agriculture-cea-industry-primer/ (*Accessed*: January 5, 2026).

Among these crop clusters, leafy greens and culinary herbs are well suited to vertical and container farming because they grow quickly, require little space, and turn over rapidly. They are often produced to supply premium markets such as supermarkets, hotels, and meal-kit providers, and are strong candidates for replacing imports of specialty herbs and ready-to-eat salad mixes. Tomatoes, typically grown under protected cultivation in greenhouses or tunnels, benefit from reduced seasonality and pesticide use, and serve both fresh and light processing markets, especially where there are reliable off-take arrangements. Peppers, cucumbers, and related cucurbits thrive in hybrid greenhouse systems that regulate temperature and humidity, meeting steady urban demand for high-quality produce. In a few specialised urban pilots, investors also explore niche high-value crops such as strawberries, blueberries, or baby vegetables, though these remain limited by small volumes and shallow market demand[35,36,37].

There is also an import-substitution logic in the SSA region, manifesting through increased technology adoption and selection of crop production regimes. For example, where cities rely on imported high-quality herbs or off-season vegetables, existing CEAs capture premiums by offering fresher and traceable produce with shorter supply chains. However, price sensitivity remains a significant factor in consumer choice as many consumers purchase food through informal channels where price usually trumps traceable quality. Therefore, CEA products often target wealthier consumer segments and institutional buyers including hotels, and high-end supermarkets. Due to the prevailing consumer affordability challenges in SSA, CEA initiatives will, in the initial phases of implementation, continue to serve higher-income segments where willingness to pay (due to higher preference for quality) covers the cost premium. For broader affordability across multi-level consumer segments, however, CEA models must achieve cost reductions through scaling, ensuring there are reliable local supply chains for structures and inputs, or securing subsidies that lower upfront costs for growers.

### 4.1.3 Industry Actors and Business Models

The CEA ecosystem in SSA comprises interlinked categories of actors, ranging from technology providers to development finance agencies (
Figure 3). Technology providers and integrators supply essential CEA components such as greenhouse structures, hydroponic systems, LED lighting and automation, sourced from both local and international firms, although local fabrication of items like greenhouse frames and shade nets can significantly lower CAPEX exposure[38]. There are also producers and operators which include small and medium enterprises running container farms, and vertical urban systems or peri-urban greenhouses using models that range from owner-operated setups to managed-service arrangements with shared revenues or fees.

[35] Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustainability*, 9(1), 1–23.

[36] Al-Kodmany, K. (2018). The vertical farm: A review of developments and implications for the vertical city. *Buildings*, *8*(2), 24

[37] Kozai, T., Niu, G., & Takagaki, M. (Eds.). (2019). Plant factory: an indoor vertical farming system for efficient quality food production. Academic press.

[38] Graamans, L., Baeza, E., Van Den Dobbelsteen, A., Tsafaras, I., & Stanghellini, C. (2018). Plant factories versus greenhouses: Comparison of resource use efficiency. *Agricultural systems*, *160*, 31-43.


*Figure 3: Interlinked Group of Actors in the CEA Sector*

Similarly, energy and water service providers such as solar PV and battery integrators, pump manufacturers and water-treatment firms are critical enablers, providing solar irrigation models that support pump-dependent greenhouses. Off-takers and distributors, including supermarkets, processors and HoReCa buyers, also create essential market pull, with contracted off-take arrangements helping to de-risk CAPEX finance. Finally, development finance institutions, impact investors and blended-finance vehicles also provide catalytic or concessionary capital to early projects, especially where local commercial finance is limited or risk premiums for energy and foreign exchange are high.

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### 4.1.4 Key Trends

Within the SSA CEA ecosystem, at least four key trends can be identified. These include a noticeable shift of CEA initiatives from donor-funded pilots toward commercially oriented proof-of-concepts backed by investors or revenue-sharing models, though fully commercial scale-ups remain uncommon[39]. Consequently, there has been the emergence of private equity and impact investors who are increasingly showing interest in agritech and climate-resilient urban production, often using blended-finance structures to offset early technology and market risks[40]. Alongside these trends are growing efforts to localise technology and inputs such as greenhouse fabrication and supply of key materials to cut upfront capital expenditure across the region.

With respect to costs, however, energy and water challenges remain among the most significant operational constraints that continue to impact the CEA environment in SSA. High cost or unreliable electricity supply, and inconsistent municipal water availability and quality continue to shape investor risk assessments, as seen in

[39] Nwanojuo, M. A., Anumudu, C. K., & Onyeaka, H. (2025). Impact of controlled environment agriculture (CEA) in Nigeria, a review of the future of farming in Africa. Agriculture, 15(2), 117.

[40] Church, M., Schellhase, J., Cashin, M., Dunford, M., &Holden, W. (2023), Agritech in Africa: Why an AgriTech Innovation Competition? Milken Institute. Santa Monica, California. United States.

cases of severe urban water stress and variable grid reliability in Nigeria's electricity market and other SSA cities[41,42]. As a result, hybrid renewable energy designs, and robust water treatment and recirculation systems, are now standard components of investor due diligence.

## 4.2 Infrastructure and Food-System Constraints

Following below is a more detailed assessment of the challenges related to energy and water, as well as value chain integration constraints and their related food system implications.

### 4.2.1 Energy and Water Constraints

Electricity tariffs in many SSA countries are high relative to global competitors, while grid reliability is often inconsistent, resulting in operational disruptions and increased post-harvest losses[43,44,45]. Given that greenhouse and vertical farming systems, particularly those reliant on active climate control, irrigation automation or supplemental lighting, are sensitive to outages, the high electricity cost and their unreliability in turn necessitate costly back-up power systems. Therefore, CEA operators increasingly adopt solar PV and battery hybrid systems to mitigate energy risks, reduce operational expenditure, and stabilise production.

While solar hybridisation offers substantial benefits, it has inherent limitations. For example, high-capacity battery storage remains expensive, and solar intermittency restricts the degree to which energy-intensive vertical farming systems can be decoupled from the grid without escalating CAPEX significantly[46,47,48]. Typically, greenhouse systems achieve higher solar integration because they rely more heavily on passive climate control, and deploy supplemental energy for irrigation pumps, ventilation, and cold-chain infrastructure. However, hybridisation is a partial rather than comprehensive solution to energy insecurity, making the need for reliable electricity and their competitive pricing in SSA cities key success factors.

Further, water supply constraints compound the operational risk in major cities such as Johannesburg and particularly, Lagos, where intermittent municipal water availability and poor water quality have increased the need for on-site filtration, storage, and recirculation systems[49,50]. For hydroponic and hybrid greenhouse

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[41] Nwanojuo, M. A., Anumudu, C. K., & Onyeaka, H. (2025). Impact of controlled environment agriculture (CEA) in Nigeria, a review of the future of farming in Africa. Agriculture, 15(2), 117.

[42] Kiribou, R., Bedadi, B., Dimobe, K., Ndemere, J., Neya, T., Ouedraogo, V., & Dejene, S. W. (2024). Urban farming system and food security in sub-Saharan Africa: Analysis of the current status and challenges. Urban Agriculture & Regional Food Systems, 9(1), e70007.

[43] Timilsina, G. R (2025). What Underlies the Poor Financial Performance of Electric Utilities in Sub-Saharan Africa? Policy Research Working Paper 11257. World Bank Group.

[44] Klug, T. W., Beyene, A. D., Meles, T. H., Toman, M. A., Hassen, S., Hou, M., ... & Jeuland, M. (2022). A review of impacts of electricity tariff reform in Africa. Energy Policy, 170, 113226.

[45] https://empowerafrica.com/africa-by-the-numbers-600-million-africans-still-lack-electricity-2024/ (Accessed: January 5. 2026)

[46] Ren, H. K., McCulloch, M., & Wallom, D. (2023). Optimal sizing of solar photovoltaic and lithium battery storage to reduce grid electricity reliance in buildings. arXiv preprint arXiv:2306.03581.

[47] Gowrisankaran, G., Reynolds, S. S., & Samano, M. (2016). Intermittency and the value of renewable energy. Journal of Political Economy, 124(4), 1187-1234.

[48] Teo, Y. L., & Go, Y. I. (2021). Techno-economic-environmental analysis of solar/hybrid/storage for vertical farming system: A case study, Malaysia. Renewable Energy Focus, 37, 50-67.

[49] Kumpel, E., & Nelson, K. L. (2016). Intermittent water supply: prevalence, practice, and microbial water quality. Environmental science & technology, 50(2), 542-553.

[50] Loubser, C., Chimbanga, B. M., & Jacobs, H. (2021). Intermittent water supply: a South African perspective. Water SA, 47(1), 1-9.

systems, water quality directly affects nutrient solution stability and crop health. Therefore, water availability and reliability are also primary risk factors that are often mitigated by constructing on-site boreholes.

### 4.2.2 Value Chain Integration Challenges

Although products such as leafy greens, herbs, tomatoes, and cucurbits require reliable cold chain logistics to maintain quality, cold chain capacity in SSA are uneven, with insufficient packhouse infrastructure, inconsistent refrigerated transport availability, and significant last-mile logistical gaps. In addition, temperature variabilities during transport reduce shelf life and undermine both the quality and the market premium often required to justify the comparatively higher CEA production costs. At the same time, as supermarkets and HoReCa (Hotels, Restaurants, and Catering) buyers tighten quality specifications, new entrants into the sector would need to address existing deficiencies in cold chain systems in the region to remain viable.

Additionally, inefficiencies in distribution networks significantly elevate the cost of CEA products delivered to consumers. For example, poor urban distribution networks and high fuel prices increase logistics costs for both greenhouse and vertical farms[51]. Consequently, while CEA systems often target premium urban consumers, distance between production hubs and consumption centres, traffic congestion, and short product shelf lives could create narrow margins. Therefore, in the absence of coordinated aggregation or third-party distribution services, producers are compelled to internalise logistics costs, thereby reducing their competitiveness relative to imported produce.

### 4.2.3 Food-System Implications

Even though CEA systems in SSA deliver important food-safety, water-efficiency, and productivity benefits, they are constrained by high costs, capital intensity, and environmental trade-offs in a region that already struggles with food affordability and capital accessibility limitations. Compared with subsidised and large-scale imports, locally produced CEA crops often require premium pricing, confining accessibility to higher-income consumers and underscoring the need to reduce energy, logistics, and input costs to be competitive even in open markets. Again, while CEA can generate skilled and semi-skilled employment, particularly in modular and hybrid greenhouse systems, it risks excluding smallholders who currently dominate the SSA agricultural landscape, due to the technology gap between current practices and what CEA offers. This could heighten the risk of labour availability and productivity especially as new recruits take time to upskill, extending the time-to-stability when optimal system performance is achieved. Environmentally, CEA reduces water use and pesticide reliance but can increase carbon intensity where energy demand is high and electricity grids are fossil-fuel based, highlighting the importance of renewable integration and careful system design[52]. Figure 4 below summarises the key food system implications around cost competitiveness, capital intensity, and environmental trade-offs.

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[51] Nicholson, C. F., Eaton, M., Gómez, M. I., & Mattson, N. S. (2023). Economic and environmental performance of controlled-environment supply chains for leaf lettuce. European Review of Agricultural Economics, 50(4), 1547-1582.

[52] Casey, L., Freeman, B., Francis, K., Brychkova, G., McKeown, P., Spillane, C., ... & Styles, D. (2022). Comparative environmental footprints of lettuce supplied by hydroponic controlled-environment agriculture and field-based supply chains. Journal of Cleaner Production, 369, 133214.

**Cost Competitiveness**

- CEA systems in SSA face persistent cost-competitiveness challenges.
- Imported produce such as tomatoes, peppers, and leafy greens from North Africa and Europe, often benefit from larger-scale operations, subsidies, and lower production costs.
- While CEA offers consistency and food-safety advantages, its higher cost base translates into premium pricing that limits reach to the upper middle and high-income consumers.
- Achieving broader food-system integration therefore hinges on lowering energy and logistics costs, improving local capacity, and enabling contracted off-take arrangements.

**Capital Intensity**

- CEA can create skilled and semi-skilled employment in horticulture, engineering, and post-harvest handling, but its labour intensity varies significantly by system type.
- Indoor vertical farms are highly automated and generate fewer low-skilled jobs, whereas modular and hybrid greenhouses provide more inclusive employment opportunities.
- Nevertheless, the capital intensity of CEA risks marginalising smallholders unless inclusive business models such as revenue-sharing operations, franchise systems, or outgrower greenhouse schemes are adopted.

**Environmental Trade-offs**

- CEA systems offer notable resource-efficiency benefits, such as reduced water use per kilogram of produce and lower pesticide requirements; however, these gains come with trade-offs.
- Energy use, especially for vertical farms, can exceed that of conventional agriculture, potentially increasing carbon intensity if grid electricity is reliant on fossil-fuel.
- Greenhouses relying on hybrid solar systems reduce the energy footprint, yet embodied emissions from imported greenhouse materials remain significant.
- Water recirculation mitigates water stress but requires additional filtration energy, illustrating the inherent balancing act in CEA system design.

*Figure 4: Key Food System Implications*

## 4.3 Techno-Economic Performance of CEA Systems

This section presents the techno-economic performance of three main archetypes of CEA Systems in SSA highlighting their resource efficiencies and productivity in addition to their CAPEX and OPEX benchmarks. The section concludes with a summary of the investment ecosystem in three top SSA cities, namely Johannesburg (South Africa), Nairobi (Kenya), and Lagos (Nigeria), where CEA has the highest potential of succeeding. By comparing several CEA investment criteria in these cities, the report then provides go or no-go investment recommendations.

### 4.3.1 System Archetypes, Resource Efficiency and Productivity

Three main CEA systems are used in SSA which vary in cost, system control, and energy intensity. They include indoor vertical farms which provide full environmental control and high productivity for crops like lettuce and herbs, although their high energy and capital requirements confine them largely to premium urban and HoReCa markets. In contrast, hybrid greenhouses balance passive solar design with active irrigation and climate controls, enabling year-round production of crops such as tomatoes, peppers, and leafy greens at relatively moderate energy use[53]. Much simpler in form, modular greenhouses are often locally fabricated and low-cost systems that are suited to SMEs and peri-urban markets, offering resilience through low CAPEX and minimal energy dependence[54]. While there are no consistent benchmarks (likely as a result of a global CEA technology landscape

[53] Espitia, J. J., Velázquez, F. A., Rodriguez, J., Gomez, L., Baeza, E., Aguilar-Rodríguez, C. E., ... & Villagran, E. (2024). Solar energy applications in protected agriculture: a technical and bibliometric review of greenhouse systems and solar technologies. Agronomy, 14(12), 2791.

[54] Baudoin, W., Nono-Womdim, R., Lutaladio, N., Hodder, A., Castilla, N., Leonardi, C., ... & Duffy, R. (2013). Good agricultural practices for greenhouse vegetable crops: Principles for mediterranean climate areas (No. 217).

presenting an array of systems), Figure 5 below shows the three main systems and a compilation of their *indicative* techno-economic benchmarks gleaned from the global CEA literature[55].

| | Indoor vertical farming | Hybrid greenhouse farming | Modular greenhouse |
|---|---|---|---|
| Technology |  |  |  |
| Functional Descriptors | • Provide full environmental control using LEDs, HVAC, and closed-loop hydroponics.<br>• Achieve high productivity and uniform quality but require substantial energy inputs and high CAPEX.<br>• In SSA, they are typically used for lettuce, herbs, and microgreens targeting premium urban segments or HoReCa clients | • Combine passive solar heating and natural ventilation with active controls for irrigation, fertigation, and humidity.<br>• Suitable for tomatoes, peppers, leafy greens, and cucumbers, for year-round production at comparatively lower energy loads.<br>• Typically include partial solar hybridisation, and evaporative cooling in hotter regions | • Modular greenhouses are simplified, lower-cost structures often produced locally with shade nets, steel frames, and drip irrigation.<br>• Used by SMEs and peri-urban growers targeting local markets.<br>• While less controlled than hybrid greenhouses, they offer low CAPEX and low energy dependence, making them suitable for resilient, small-scale production models |
| Indicative Costs | • Approximately $1,200 – 2,500 / m² (high-tech)<br>• Between 11 and 350 kWh / kg (high variation)<br>• More than 90 % water recycled (very high) | • Between $80 – $160 / m² (greenhouse shell)<br>• About 20 – 40 kWh / kg (supplemental lighting)<br>• 70 – 90 % savings vs. field irrigation) | • $25 – $80 / m² (when locally fabricated)<br>• 20 – 40 kWh / kg<br>• 70 – 95 % water reuse when recirculating systems applied |
| Yield | • About 80 – 120 kg / m² / year (leafy greens) | • 40 – 80 kg / m² / year (greens lettuce etc.) | • 30 – 70 kg / m² / year (greens and herbs typical) |

*Figure 5: System Archetypes and Characterisations*

### 4.3.2 CAPEX and OPEX Benchmarks

Among the three system archetypes, vertical farms exhibit the highest capital intensity of between USD 1,200 and 2,500 per square metre, largely due to LED lighting, HVAC, and automation. Hybrid greenhouses fall in the mid-range (between USD 80 and 160 per m²), depending on cooling systems and material sourcing while modular greenhouses cost the lowest of between USD 25 and 60 per m², especially when locally fabricated. Energy is the dominant OPEX driver for vertical farms, often representing 30 – 45% of operating costs, and up to about 70% in some cases. For hybrid greenhouses, where energy costs are relatively lower, labour and

[55] https://farmonaut.com/blogs/vertical-farming-energy-consumption-per-kg-2025-cea (Accessed: January 8, 2026)

logistics commonly dominate. For example, labour represents some 25 – 40% of OPEX in SME greenhouse models[56,57,58]. In Table 1 below the potential for CEA deployment in three top SSA cities are compared against a set of investment criteria. City attributes are scored on a 5-point scale (0 –5) ranging from "binding constraint" to "highly supportive", and investment recommendations provided based on a Farrelly Mitchell's CEA *Viability Index* (VI) calculated as $\sum (Score_i \times Weight_i)$ and normalised on a 0 – 100 scale. The decision criteria are as follows: a viability index (VI) of more than 70% indicates a *Go Decision*; between 55 – 69% is a *Selective Go*, while a VI of less than 55% is a *No-Go Decision.* (see appendix 8.1for the full city scores and decision criteria).

[56] Al-Kodmany, K. (2018). The vertical farm: A review of developments and implications for the vertical city. *Buildings*, *8*(2), 24

[57] Nina, N., Lucas, L & Sridar, K. (2024). Vertical Farming Innovation in Urban Netherlands: Sustainable Solutions with Modern Hydroponics. Techno Agriculturae Studium of Research, 1(1), 102-112. httsps://doi.org/10.55849/agriculturae.v1i1.172

[58] https://farmonaut.com/blogs/vertical-farming-energy-consumption-per-kg-2025-cea (Accessed: January 8, 2026)

*Table 1: Top Three SSA Cities with Highest Potential for CEA Deployment*

| Criteria and FM Assigned Weight (%) | A comparison of top three SSA cities (with viability index scores) | | |
|---|---|---|---|
| | Johannesburg (South Africa) | Nairobi (Kenya) | Lagos (Nigeria) |
| Energy Cost and Availability (25%) | Stable grid with comparatively lower outages; electricity cost moderate but rising. Suitable for hybrid greenhouses and selective high-tech systems. VI of 20.0% | Moderate reliability but subject to periodic outages; electricity cost relatively high for vertical farming. Requires backup systems for intensive CEA. VI of 15.0% | Unreliable grid; high diesel generator dependence; electricity cost among the highest in SSA. Severe constraint for high-tech CEA models. VI of 7.5% |
| Water Access and Pricing (15%) | Reliable municipal supply; water tariffs stable; supplemental boreholes feasible. VI of 13.5% | Moderate access; growing pressure on urban utilities; greenhouse hydroponics selectively viable. VI of 10.5% | Chronic shortages; high-priced private water supply; limits scalability of water-intensive climate control systems. VI of 4.5% |
| Import Dependence for Fresh Produce (10%) | Moderate import levels; strong domestic horticulture limits substitution potential except in premium leafy greens. VI of 6.0% | High seasonal import reliance, especially for leafy greens and herbs. Strong case for substitution. VI of 9.0% | Very high dependence on imported vegetables; Lagos markets rely heavily on interstate supply chains prone to disruption. Strong import-substitution demand. VI of 10.0% |
| Market Demand and Consumer Purchasing Power (15%) | High purchasing power; strong premium retail and hospitality sector; good penetration of modern supermarkets. VI of 13.5% | Expanding middle-income class; rising willingness-to-pay for quality produce. VI of 10.5% | Large population; high demand but highly price-sensitive, only premium niche viable. VI of 9.0% |
| Cold-Chain and Logistics Infrastructure (10%) | Strongest among the three cities; established distribution systems. VI of 10.0% | Improving but fragmented; donor-driven cold-chain expansions ongoing. VI of 6.0% | Weak cold chain; high post-harvest losses; logistics costs are high. VI of 4.0% |
| Local Technology and Input Availability (10%) | Mature suppliers for greenhouse materials, fertigation, sensors; domestic capability rising. VI of 9.0% | Local fabrication of greenhouses common; inputs accessible; fewer advanced components available. VI of 7.0% | Limited availability; heavy reliance on imports for technical components; supply chain delays. VI of 4.0% |

| Criteria and FM Assigned Weight (%) | A comparison of top three SSA cities (with viability index scores) | | |
|---|---|---|---|
| | Johannesburg (South Africa) | Nairobi (Kenya) | Lagos (Nigeria) |
| Investment Ecosystem (10%) | Strong investor base; private equity active in agritech; favourable regulatory environment.<br>VI of 9.0% | Active innovation ecosystem; incubators and impact investors support agritech start-ups.<br>VI of 7.0% | Large potential but investor caution high; macroeconomic volatility constrains long-term CAPEX investments.<br>VI of 5.0% |
| Food System Readiness for CEA (5%) | High readiness due to stable utilities, strong FMCG sector, and advanced retail structure. Good fit for scalable commercial CEA.<br>VI of 5.0% | Medium to high readiness; rapid urbanisation and strong horticulture sector create fertile ground for medium-scale CEA.<br>VI of 3.5% | Medium to low readiness; high demand but infrastructure and energy constraints limit feasibility of intensive CEA models.<br>VI of 2.5% |
| Total Viability Index Score | 86.0% | 68.5% | 46.5% |
| High Level Investment Assessment | High Potential | Medium Potential | Low Potential |
| Farrelly Mitchell's Go or No-Go Investment Recommendation | **GO**: Conditions favourable for hybrid and selective high-tech CEA. Energy reliability and strong markets create viable scaling environment:<br>• Deploy medium-tech greenhouse (ventilated and shading)<br>• Be selective on high-tech systems<br>• Limited LED supplemental lighting is optional, not required<br>• Recommended for leafy greens and herbs (salad | **GO (Selective):** Suitable for medium-tech CEA, donor-commercial hybrids, and market-driven greenhouses. High-tech vertical systems only viable with targeted subsidies or niche markets:<br>• Use medium-tech greenhouse and small modular or vertical container units targeted at premium B2B buyers (hotels, supermarkets, export niche)<br>• Suitable for leafy greens and herbs (primarily for vertical farms), tomatoes and cucumbers (for greenhouse) | **NO-GO for High-Tech, but CONDITIONAL GO for Low-Tech**: Severe energy and water constraints restrict CEA viability. Only low-tech or modular greenhouses may succeed with careful siting and off-grid solutions:<br>• Low or medium-tech protected cropping (shaded and ventilated greenhouses, net-houses)<br>• Plan for renewables and backup energy source<br>• Grow leafy greens and herbs (primarily), short-cycle high-value crops for B2B |

| Criteria and FM Assigned Weight (%) | A comparison of top three SSA cities (with viability index scores) | | |
|---|---|---|---|
| | Johannesburg (South Africa) | Nairobi (Kenya) | Lagos (Nigeria) |
| | lettuce, basil, microgreens), tomatoes, peppers | | |

Source: Author's compilation FM = Farrelly Mitchell; VI= Viability Index; Decision Thresholds (≥ 70% = Go; 55 -69% = Selective Go; and <55% = No Go (for High-Tech).

# 5. A Case Study of Commercial CEA in SSA

A South African based CEA enterprise, VertiGenix, is presented as a case study of SSA CEA deployment to provide added on-the-ground insights into the potential of CEA in SSA contexts. Though at the pre-operational and deployment stage, this enterprise represents a best-practice, commercially oriented CEA etched within the constraints of SSA urban markets. A detailed rationale for its selection, and other techno-economic considerations are outlined.

## 5.1 Case Study Selection and Rationale

Unlike many donor-driven pilots or early-stage demonstration farms, VertiGenix exhibits characteristics associated with emerging enterprises that show commercial viability, including a clearly articulated business model, defined target markets, and operational experience under real market conditions (Figure 6).

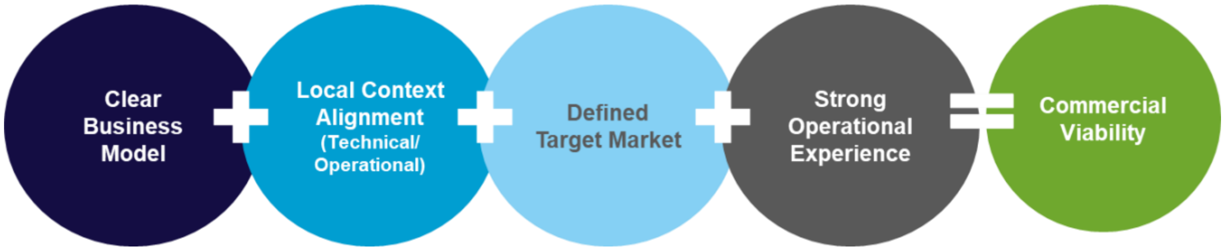



*Figure 6: Commercial Characteristics of VertiGenix*

The enterprise is particularly relevant to SSA urban food systems given its focus on high-value, perishable horticultural crops, proximity to urban consumers, and emphasis on import substitution in premium fresh produce segments. These attributes align with documented gaps in SSA urban food supply chains, where dependence on imports and long domestic supply chains contribute to price volatility, quality losses, and food safety risks[59]. Within the wider SSA CEA landscape, VertiGenix occupies an intermediate position between experimental pilots and large-scale capital-intensive vertical farms. It illustrates a context-adapted CEA pathway, choosing technologies that are matched to local market demand and structure, making it a relevant reference point for investors, policymakers, and new entrants assessing scalable CEA models in SSA cities.

## 5.2 Enterprise Background and Market Context

VertiGenix is positioned as a commercial urban agriculture enterprise specialising in CEA-based production of fresh horticultural crops for metropolitan markets. Its business model centres on supplying consistent, traceable, and high-quality produce to buyers that value reliability over lowest-cost sourcing. The company's target markets include modern retail outlets, hospitality and food-service operators, and selected institutional buyers. Notably, demand from these segments is driven by rising urban incomes, expanding supermarket penetration, and increased emphasis on food safety and year-round availability[60]. VertiGenix further positions

[59] Reardon, T., Echeverria, R., Berdegué, J., Minten, B., Liverpool-Tasie, S., Tschirley, D., & Zilberman, D. (2019). Rapid transformation of food systems in developing regions: Highlighting the role of agricultural research & innovations. Agricultural systems, 172, 47-59.

[60] Reardon, T., Echeverria, R., Berdegué, J., Minten, B., Liverpool-Tasie, S., Tschirley, D., & Zilberman, D. (2019). Rapid transformation of food systems in developing regions: Highlighting the role of agricultural research & innovations. *Agricultural systems,* 172, 47-59.

itself competitively by offering freshness, predictable volumes, and reduced supply-chain risk compared to imported or long-haul domestic alternatives (Figure 7).

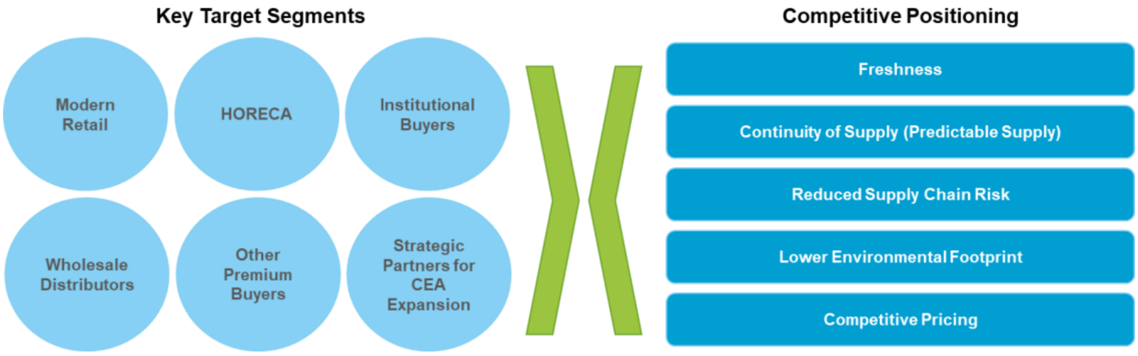



*Figure 7: VertiGenix Target Market and Competitive Positioning*

The company's off-take arrangements are currently being negotiated with premium and volume buyers combining short-term supply agreements with recurring buyers. Its pricing strategies reflect a premium-but-competitive positioning, anchored on import-parity pricing, while remaining competitive with open-market wholesale prices for some of its products. However, the robustness of these arrangements hinges on a successful rollout of its impending pilot production, as many prospective buyers await to see its products.

## 5.3 Technology, Production Approach, and Margin Benchmarks

VertiGenix uses greenhouse-based controlled environment agriculture (CEA) with aeroponic and hydroponic vertical grow towers, leveraging natural sunlight and naturally ventilated semi-controlled greenhouses (Figure 8). The system design prioritises operational resilience, particularly in relation to energy supply, climate variability, and space constraints common in SSA cities. In terms of crop clusters, the company focuses on leafy greens and culinary herbs, selected for their short production cycles, high value-to-weight ratios, and suitability for CEA systems[61]. Production cycles are tightly planned to enable frequent harvests and rapid turnover, supporting its steady cash flow projections.


[61] Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustainability*, 9(1), 1–23.

*Figure 8: VertiGenix's Technologies and Substaminale Solutions*

VertiGenix's energy management strategies include efficiency-oriented energy design and load management, utilising between 0.13 – 1.30 kWh per kg of produce (dependent on crop type and greenhouse schedule), which is about 5–10 times lower than LED-based indoor farms and aligns with the low-energy logics of greenhouse models appropriate for SSA. Its water and nutrient use rely on closed-loop hydroponic systems that would significantly reduce water consumption relative to open-field production[62] (Table 2). It plans to deploy digital tools for monitoring, crop scheduling, and quality control, although automation levels would remain calibrated to balance labour costs and capital intensity. With respect to profitability, estimates obtained from the enterprise suggest positive margins for all crop categories as benchmarked against prevailing fresh produce market prices in Port Elizabeth, South Africa (see
Table 3, Table 4, and Table 5 below).

*Table 2: Comparison of VertiGenix's Water Consumption vs. Open Field Production by Crop*

| Crop Type | Crop | Open-Field (L/kg) | VertiGenix GH (L/kg) | VG Water Saving (%) |
|---|---|---|---|---|
| Herbs | Sweet Basil | 146 | 7 | 95% |
| | Parsley | 135 | 8 | 94% |
| | Rocket | 146 | 7 | 95% |
| | Sage | 135 | 8 | 94% |
| Lettuce | Crisphead | 111 | 7 | 93% |
| | Butterhead | 89 | 8 | 91% |
| | Oakleaf | 146 | 7 | 95% |
| | Frilly | 139 | 8 | 95% |
| Berries | Strawberry | 83 | 25 | 71% |

Source: VertiGenix. L/kg = litres of water used per kg of crop produced

*Table 3: Lettuce Prices and Margin Benchmark (USD/kg)*

| Crop | Open Market Price PE-RSA ($/kg) | VertiGenix Selling Price ($/kg) | COGS ($/kg) | Gross Margin ($/kg) | Gross Margin (%) |
|---|---|---|---|---|---|
| **Crisphead** | 1.30 | 1.30 | 0.90 | 0.40 | 31% |
| **Butterhead** | 1.30 | 1.30 | 0.90 | 0.40 | 31% |
| **Oakleaf** | 1.30 | 1.30 | 0.85 | 0.45 | 35% |
| **Frilly** | 1.30 | 1.30 | 0.80 | 0.50 | 38% |

*Table 4: Herbs Prices and Margin Benchmark (USD/kg)*

| Crop | Open Market Price PE-RSA ($/kg) | VertiGenix Selling Price ($/kg) | COGS ($/kg) | Gross Margin ($/kg) | Gross Margin (%) |
|---|---|---|---|---|---|
| **Basil** | 10.50 | 10.50 | 5.50 | 5.00 | 48% |
| **Parsley** | 10.50 | 10.50 | 4.00 | 6.50 | 62% |
| **Rocket** | 10.50 | 10.50 | 3.00 | 7.50 | 71% |

[62] Barbosa, G. L., Gadelha, F. D. A., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., ... & Halden, R. U. (2015). Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods. *International Journal of Environmental Research and Public Health*, 12(6), 6879.

| | | | | | |
|---|---|---|---|---|---|
| **Sage** | 10.50 | 10.50 | 4.00 | 6.50 | 62% |

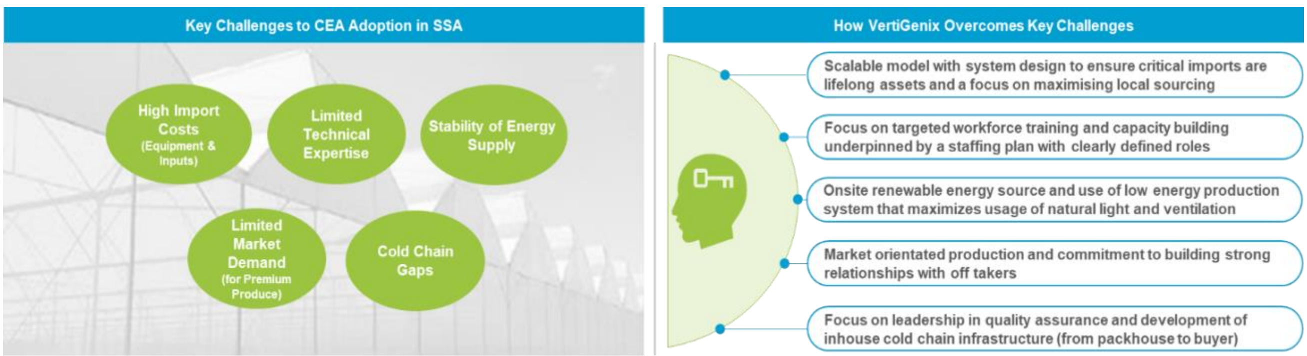
*Table 5: Strawberries Prices and Margin Benchmark (USD/kg)*

| Pack Size | Open Market Price PE-RSA ($/kg) | VertiGenix Selling Price ($/kg) | COGS ($/kg) | Gross Margin ($/kg) | Gross Margin (%) |
|---|---|---|---|---|---|
| **250g** | 3.15 | 3.15 | 0.88 | 2.27 | 72% |
| **400g** | 3.15 | 3.15 | 0.80 | 2.35 | 75% |
| **600g** | 3.15 | 3.15 | 0.75 | 2.40 | 76% |
| **160g** | 3.15 | 3.15 | 1.06 | 2.09 | 66% |

## 5.4 Indicative Operational and Commercial Performance

VertiGenix is poised to operate at a modest but commercially meaningful scale sufficient to service anchor buyers while maintaining production discipline, given that anchor buyers typically require reliable volumes, consistency, and food-safety assurance, rather than maximum output *per se*. Initially servicing two or three anchor buyers allows VertiGenix to lock in predictable demand through forward contracts or rolling supply agreements, reducing market risk during early operations. Additionally, demonstrated performance at modest scale strengthens the enterprise's credibility with investors, lenders, and regulators, and creates a validated operating template that can be replicated or expanded modularly. In this sense, modest scale is not a ceiling but a risk-managed entry point, ensuring that growth is driven by proven demand and operational maturity. The enterprise's indicative yield levels align with global benchmarks for leafy greens under controlled environments, substantially exceeding open-field productivity on a per-area basis[63]. Its projected cost profile is dominated by labour, energy, and logistics, which is again consistent with CEA enterprises globally, except for energy where more realistic costing would be required. Energy cost represents a critical sensitivity metric, particularly in contexts with unreliable grids or high tariffs and as such very optimistic cost structures could significantly impact operations. The company's labour requirements would be significant, reflecting its scaled-down automation and the need for skilled operational oversight, while its logistics costs would be mitigated through proximity to end markets, reducing cold-chain dependency. VertiGenix has internal quality control and food safety arrangements (GlobalGap compatible) to enhance buyer confidence and enable access to formal retail and hospitality channels that typically exclude informal suppliers. However, the company is not without its own challenges, having clearly articulated and outlined specific measures to mitigate them once they are occasioned (Figure 9).

*Figure 9: VertiGenix's Approach to Overcoming Key Challenges to CEA Adoption in SSA*




[63] Graamans, L.; Baeza, E.; van den Dobbelsteen, A.; Tsafaras, I.; Stanghellini, C. Plant factories versus greenhouses: Comparison of resource use efficiency. *Agric. Syst*. 2018, 160, 31–43.

## 5.5 Implications for CEA Development in SSA

VertiGenix's choice of technology shows that CEA viability in SSA is less about technological sophistication and more about system fit. In addition to this choice, the key transferable lessons include the need for prioritising crops with strong urban demand, anchoring production to committed buyers, and aligning system design with local energy and logistics conditions. Moving forward, the policy and ecosystem dependencies within which it operates, particularly electricity pricing, access to finance, and food safety regulation, would remain decisive. At the same time, the case illustrates limits to replication. For example, capital-intensive indoor systems are unlikely to serve mass markets in the near term, due to the high initial cost outlay, and are best positioned as niche contributors to diversified urban food systems, rather than wholesale replacements for conventional agriculture.

# 6. Discussion

## 6.1 Alignments and Tensions

Findings from this study pointing to the conditional viability of CEA in SSA contexts are broadly reinforced by the VertiGenix case study. Across the regional landscape, CEA success is most consistently observed in dense urban markets, where import dependence, premium food service demand, and logistics inefficiencies create price arbitrage opportunities for investors. For example, VertiGenix's focus on urban proximity, short supply chains, and eventual contracted buyers aligns closely with these structural enablers.

However, the case study also highlights tensions not fully captured in regional overviews. For example, while other assessments often imply that technology adoption alone can unlock productivity gains[64], VertiGenix's experience underscores that commercial performance depends more on market integration than on yield maximisation. The enterprise appears to prioritise demand certainty, pricing discipline, and operational simplicity, challenging techno-centric narratives prevalent in the global CEA literature[65,66]. For investors, this suggests that CEA in SSA behaves less like a technology venture and more like a tightly managed agri-logistics business, where execution risk outweighs innovation risk.

## 6.2 Benchmark Expectations Versus Real-World Performance

Techno-economic benchmarks derived from secondary literature may assume stable energy supply, optimal utilisation rates, and continuous production cycles[67,68]. In practice, however, operational experience reveals a consistent performance gap between theoretical benchmarks and realised outcomes, particularly in energy efficiency, labour productivity, and utilisation rates during early operating phases. This is the area where VertiGenix's estimates would be most tested, especially its below-global-average energy estimates, as it enters into the upcoming pilot to validate its theoretical assumptions. In practice, energy intensity remains the single largest deviation from theoretical models. For example, while its benchmark models assume grid or renewable power availability at predictable tariffs, VertiGenix operates in a context of price volatility and reliability risk, necessitating backup systems and conservative production scheduling. These adaptations usually increase unit costs but reduce downside risk, an important trade-off often underestimated in feasibility studies.

Similarly, labour costs per unit output could exceed global averages due to skills scarcity and learning curves in SSA contexts, although these costs decline over time as processes standardise. This suggests that time-to-stability, rather than steady-state margins, should be a core metric in SSA CEA investment appraisals. Again, in this area, VertiGenix is yet to establish its threshold for labour cost per kilogram of produce beyond which its profitability could tip downwards. Put together, these cost thresholds must therefore be generated or calculated for water and energy utilization in addition to labour, to guide the enterprise's cost control mechanisms.

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64 Rodrik, D. (2018). New technologies, global value chains, and developing economies (No. w25164). National Bureau of Economic Research.

65 Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustainability*, 9(1), 1–23.

66 Kozai, T., Niu, G., & Takagaki, M. (Eds.). (2019). Plant factory: an indoor vertical farming system for efficient quality food production. Academic press.

67 Graamans, L.; Baeza, E.; van den Dobbelsteen, A.; Tsafaras, I.; Stanghellini, C. Plant factories versus greenhouses: Comparison of resource use efficiency. *Agric. Syst*. 2018, 160, 31–43.

68 Van Delden, S. H., SharathKumar, M., Butturini, M., Graamans, L. J. A., Heuvelink, E., Kacira, M., ... & Marcelis, L. F. M. (2021). Current status and future challenges in implementing and upscaling vertical farming systems. *Nature Food*, 2(12), 944-956.

## 6.3 Trade-Offs Between Scalability, Affordability, and Resilience

A central finding from the study is the structural trade-off between scalability, consumer affordability, and system resilience. The VertiGenix case study demonstrates that resilience, defined as the ability to operate under energy, logistics, and market shocks, often requires modularity and conservative growth pacing. While these features often improve downside protection, they slow rapid scaling. Additionally, affordability constraints could limit scaling such that while CEA can competitively substitute imports for premium leafy greens and herbs, it remains poorly positioned to serve mass urban consumers without either (a) energy cost reductions, (b) policy support, or (c) hybridisation with conventional supply chains. This reinforces regional evidence that CEA in SSA is complementary, not substitutive, to traditional horticulture[69].

For investors, the implication is instructive. That CEA opportunities in SSA favour disciplined, city-specific replication over aggressive regional scaling, with returns driven by operational reliability and *contracted demand* rather than volume expansion. Therefore, in the case of VertiGenix, contracted market or off-take arrangements and revenue certainty must remain a non-negotiable investment decision test, in order to de-risk demand before additional CAPEX is deployed. Having examined the enterprise's positive techno-economic benchmarks, albeit based on its projections and estimates, Farrelly Mitchell's recommendation is for VertiGenix to have at least 60 –70% of its first site capacity covered by written off-take arrangements (with a preference for Letters of Intent (LOIs)), to be bankable.

## 6.4 Time to Stability

For investors, it is important to recognise that CEAs in SSA would require an elapsed period between project commissioning and the point at which the operation consistently achieves *biophysical, operational, and financial equilibrium*[70] (Figure 10). This is important because in SSA, CEA systems are introduced into local food systems characterised by infrastructure variability, volatile input markets, and immature downstream value chains. There would therefore be the need for CEAs in the region to go beyond the biological crop cycles and capture the learning, adaptation, and institutional configurations required for sustained performance.

From a biophysical perspective, because imported CEA designs often assume stable electricity, predictable water quality, and temperate climate baselines, SSA CEAs would need to allocate time to calibrate climate control, nutrient delivery, water recycling, and pest management under local conditions. For example, the high heat loads, humidity spikes, water quality, and intermittent power in SSA cities typically extend the stabilisation phase, increasing early crop losses and the yield variance between temperate-based estimates and local realities. Generally, imported CEA systems with higher technological complexity (multi-tier vertical farms) exhibit longer time-to-stability than hybrid greenhouses or modular systems, particularly where technical support is remote.

Operationally, there would be human and institutional learning curves that would delay the attainment of optimal system performance. Especially relevant here is the limited availability of skilled operators, agronomists, and maintenance technicians, in addition to a narrow supplier ecosystem for spare parts, sensors, and consumables. As well, early-stage inefficiencies such as suboptimal labour deployment, delayed repairs, and inconsistent SOP adherence, are common and would materially affect output consistency. Projects that rely

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[69] Van Delden, S. H., SharathKumar, M., Butturini, M., Graamans, L. J. A., Heuvelink, E., Kacira, M., ... & Marcelis, L. F. M. (2021). Current status and future challenges in implementing and upscaling vertical farming systems. *Nature Food*, *2*(12), 944-956.

[70] Pompeo, J., Yu, Z., Zhang, C., Wu, S., Zhang, Y., Gomez, C., & Correll, M. (2025). Assessing the stability of indoor farming systems using data outlier detection. *Frontiers in Plant Science*, 15, 1270544.

heavily on expatriate expertise may shorten the initial ramp-up of the local skills base, but risk longer stabilisation if knowledge transfer is incomplete or costly.

Financially, investors should expect a time interval before cash-flow predictability and unit cost convergence are achieved. During this time interval, yields fluctuate, input costs are elevated, and market access is still being secured, until operations stabilise and unit economics become predictable. In SSA, this period is often prolonged by weak cold chains, price-sensitive consumers, and competition from subsidised imports. Where there is an extended time-to-stability, working capital needs would increase, heightening investor exposure, particularly where electricity tariffs, foreign exchange rates, or logistics costs are volatile.

Consequently, investors would want to use time-to-stability as a risk proxy in SSA CEA investments, where shorter stabilisation periods are typically associated with simpler technologies, climate-appropriate crop choices (leafy greens over fruiting crops), and strong local partnerships. Conversely, long time-to-stability amplifies downside risk and explains why many technically sound CEA projects in SSA underperform or fail before reaching scale. Therefore, incorporating time-to-stability explicitly into feasibility assessments, financing structures, and performance benchmarks is essential for realistic CEA deployment in the region.

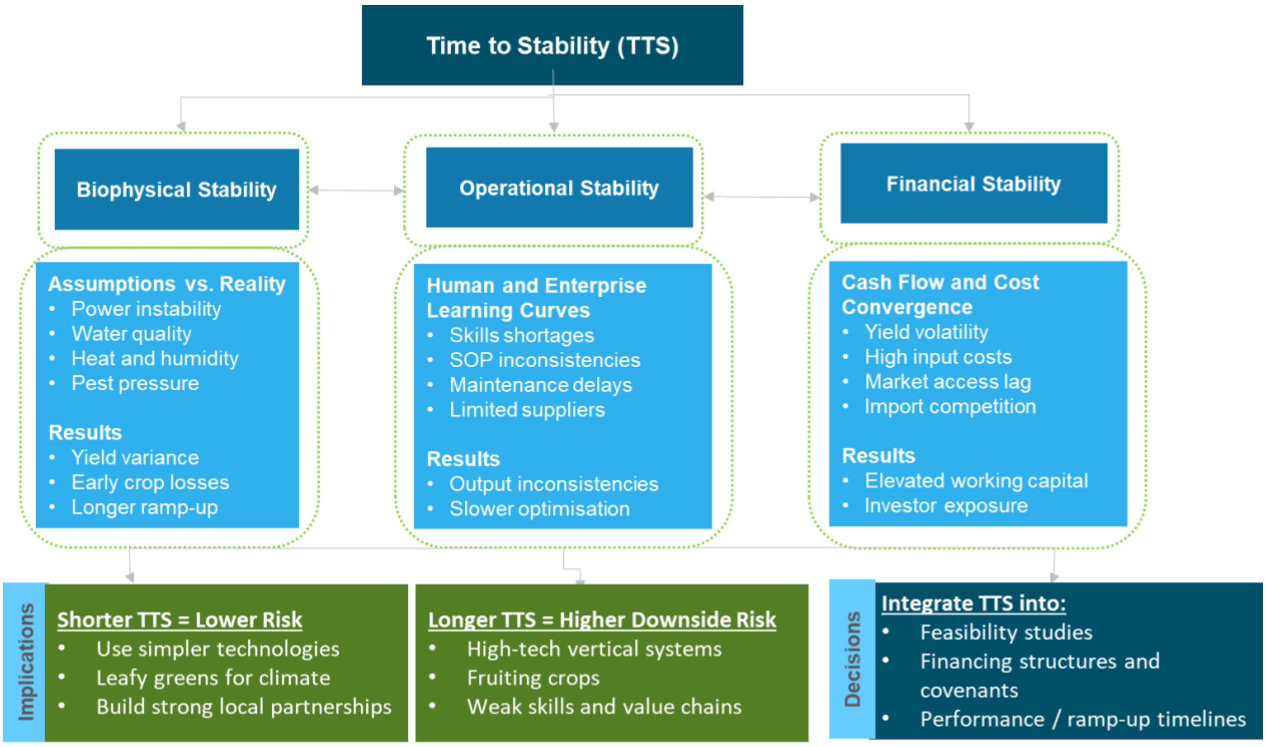


*Figure 10: Time to Stability Framework*

# 7. Conclusions and Implications

## 7.1 Key Findings

This study finds that CEA in SSA is commercially viable under narrow but identifiable conditions, namely contexts with dense urban demand, high import dependence for specific crops, reliable off-take arrangements, and adaptive system design. The VertiGenix case illustrates that enterprises that would succeed in this space must prioritise market access, cost control, and resilience over technological sophistication. With respect to crop clusters, the strongest opportunities lie in leafy greens, culinary herbs, and selected vegetables, where import substitution and quality differentiation support pricing above conventional supply. At the same time, fully indoor vertical systems would face heightened energy and capital risks, especially outside of South Africa, while hybrid and modular greenhouse systems present more balanced risk-return profiles.

From a policy or even investment perspective, CEA should not be framed as a standalone food security solution, given that its contribution is most meaningful in nutritional diversity, supply stability, and import risk reduction rather than calorie provision. Furthermore, policies that stabilise energy tariffs, support cold-chain infrastructure, and reduce import frictions for inputs would materially improve investment viability. For city deployments, urban authorities would play a critical enabling role in demonstrating zoning flexibility that allows for siting CEAs close to energy and water resources with expedited access to high-end consumer markets. Such support services should be linked to the provision of access to serviced industrial land and integrating these systems with wholesale markets to significantly reduce non-technical costs. Here again, the VertiGenix case demonstrates that location efficiency often matters more than system type in determining profitability.

## 7.2 Investment and Business Model Implications

For investment purposes, CEA in SSA should be approached as a capital-intensive, infrastructure-adjacent asset class, and not a high-growth technology-driven venture. Furthermore, viable ventures are anchored within off-take arrangements, phased CAPEX deployment and strong operational governance. Therefore, investment decisions should seek to:

a) Prioritise hybrid greenhouse and modular container pilots before large indoor vertical farms in most SSA cities. These models provide lower CAPEX, energy intensity, and better alignment with local markets for leafy greens, tomatoes, and peppers.
b) Design energy strategies up front by provisioning for grid and solar hybridisation with smart load management to reduce OPEX risks.
c) Link to off-takers and distribution early, through prior contract arrangements with existing supermarkets and foodservice providers to reduce market risk and justify CAPEX.
d) Focus crops strategically, starting with leafy greens and herbs for quick cycles and premium markets, and with greenhouse tomatoes and peppers where scale and retail or HoReCa demand exist.
e) Leverage local integrators and service models by considering leasing or managed service arrangements to avoid high up-front CAPEX.

Blended finance and patient capital remain critical during early market development, but pathways to commercial sustainability are achievable where execution discipline is strong. In Figure 11 below the key investment implications and thresholds are summarised focusing capital discipline, market anchoring, and systemic infrastructure risks[71,72,73].

**Key Investment Implications and Thresholds for CEA Deployment in SSA Contexts**

| | |
|---|---|
| **Capital Discipline**<br>Capital intensity thresholds are imperative | • Most commercially viable projects cluster below USD 250–400 / m² for hybrid greenhouses and modular systems.<br>• Fully indoor vertical farms typically exceed USD 800–1,500 / m², placing them outside bankable thresholds unless subsidised energy, concessional finance, or export-priced markets are secured.<br>• Projects that overshoot these thresholds face prolonged payback periods (often more than 8–10 years) and heightened sensitivity to input price shocks, particularly electricity. |
| **Market Anchoring**<br>Off-take certainty is a binding constraint | • Successful CEAs typically secure 60–80% of output under forward contracts with supermarkets, hospitality chains, or institutional buyers prior to financial close.<br>• Without contracted demand, exposure to volatile spot markets undermines revenue stability and limits access to debt financing.<br>• Import substitution narratives alone are insufficient. Price parity (or a clearly monetisable quality premium) relative to imports is required for sustained uptake. |
| **Systemic Infrastructure Risks**<br>Dominant risk drivers are structural rather than technical | • Energy reliability and tariff volatility are the single largest operational risk, followed by foreign-exchange exposure for imported inputs, and working-capital stress due to delayed receivables.<br>• Climate control and yield risks are generally manageable with proven technologies, but time-to-stability (expect 12–24 months in SSA contexts) creates early-stage cash-flow vulnerability that must be explicitly financed.<br>• Consequently, investors increasingly favour phased deployment, modular scaling, and hybrid technologies, which allow learning, demand validation, and capital recycling before full scale-up. |

*Figure 11: Key Investment Implications and Thresholds*

## 7.3 Limitations and Areas for Future Research

This research is constrained by reliance on a single enterprise case study that uses projected or theoretical estimates, limiting generalisability across diverse SSA contexts. Data gaps remain significant, particularly regarding multi-year operating performance, real-world energy utilisation data, overall system failure rates, and labour productivity trajectories. Therefore, future studies should prioritise longitudinal financial data and comparative city-level cost structures based on actual operational data, against the backdrop of the informal nature of food markets prevalent in many SSA cities. These insights will be essential for refining investment screening criteria and policy alignment in the ongoing evolution of urban food systems in SSA.

[71] Bhattarai, K., Ogden, A. B., Pandey, S., Sandoya, G. V., Shi, A., Nankar, A. N., ... & Dardick, C. (2025). Improvement of crop production in controlled environment agriculture through breeding. *Frontiers in Plant Science*, 15, 1524601.

[72] Mills, E. (2025). The emergence of indoor agriculture as a driver of global energy demand. *npj Sustainable Agriculture*, *3*(1), 52.

[73] Halliday, J.; Kaufmann, R. von; Herath, K.V. (2021). An assessment of controlled environment agriculture (CEA) in low- and lower-middle income countries in Asia and Africa, and its potential contribution to sustainable development. Colombo, Sri Lanka: Commission on Sustainable Agriculture Intensification. CGIAR Research Program on Water, Land and Ecosystems (WLE).

# 8. Appendix

## 8.1 Investment Screening Criteria and scoring

*Table 6: CEA Viability Indices in Three Top SSA Cities*

| Investment Criteria | Weight (%) | Johannesburg | | Nairobi | | Lagos | |
|---|---|---|---|---|---|---|---|
| | | Score (0–5) | Weighted Score | Score (0–5) | Weighted Score | Score (0–5) | Weighted Score |
| **Energy Cost and Availability** | 25 | 4.0 | 20.0 | 3.0 | 15.0 | 1.5 | 7.5 |
| **Water Access and Pricing** | 15 | 4.5 | 13.5 | 3.5 | 10.5 | 1.5 | 4.5 |
| **Market Demand and Purchasing Power** | 15 | 4.5 | 13.5 | 3.5 | 10.5 | 3.0 | 9.0 |
| **Cold-Chain and Logistics** | 10 | 5.0 | 10.0 | 3.0 | 6.0 | 2.0 | 4.0 |
| **Import Dependence (Substitution Potential)** | 10 | 3.0 | 6.0 | 4.5 | 9.0 | 5.0 | 10.0 |
| **Local Technology and Inputs** | 10 | 4.5 | 9.0 | 3.5 | 7.0 | 2.0 | 4.0 |
| **Investment Ecosystem** | 10 | 4.5 | 9.0 | 3.5 | 7.0 | 2.5 | 5.0 |
| **Food System Readiness** | 5 | 5.0 | 5.0 | 3.5 | 3.5 | 2.5 | 2.5 |
| **Total VI Score** | 100 | | 86.0 | | 68.5 | | 46.5 |

***Interpretation of Scores:*** 0 =binding constraint or deal breaker; 1= Severe constraint; 2 = Material constraint requiring mitigation; 3 = Neutral or conditional viability; 4 = Supportive with manageable risks; and 5 = Highly supportive of commercial CEA at scale. ***Decision Thresholds:*** ≥ 70% = Go; 55 -69% = Selective Go; and <55% = No Go.

## About the Subnational Climate Fund

The Subnational Climate Fund (SCF) is a global blended finance initiative that aims to invest in and scale mid-sized (5 – 75 M $USD) subnational infrastructure projects in the fields of sustainable energy, waste and sanitation, regenerative agriculture and nature-based solutions in developing countries.
The SCF finances projects with a blend of concessional and conventional capital, along with Technical Assistance grants that help mitigate risk and ensure financial and environmental goals are achieved.

For further information about the SCF, visit: www.subnational.finance