

Article

Modelled Adoption Trajectories of Vertical Farming Systems in Two African Cities Using the ADOPT Tool

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Abstract

Vertical farming (VF) holds potential for urban food security in African cities, yet adoption of VF systems by farmers remains poorly understood across diverse urban contexts. This study modeled VF system diffusion across three settlement types in Lagos and Nairobi using the ADOPT Tool framework. A total of 60 urban farmers from the 2 cities participated in the focus group discussions at six sites. The study provides an exploratory, model-based contribution to understanding context-specific adoption of vertical farming in selected African urban settings. Predictions revealed substantial spatial heterogeneity. Peak adoption ranged from 2 to 98%, with time-to-peak spanning 10–25 years. Intra-city variation in basic system adoption exceeded inter-city differences (61–97% in Nairobi versus 16–52% in Lagos). CEA systems approached saturation in affluent neighborhoods (Langata 98%, Lekki 95%) while remaining constrained in informal settlements (<25%). Sensitivity analysis identified three population-level binding constraints: Financial Capacity, Management Skill, and Environmental Orientation. Each constraint generated an 18–24 percentage-point impact in resource-constrained settlements but less than 6 percentage points in affluent areas. On the other hand, four innovation-level factors (Complexity, Trialability, Observability, Training Requirements) accelerated the diffusion rate by 1.2–1.4 years across all sites. These findings demonstrate that adoption is determined by context-specific constraint configurations rather than uniform urban conditions. Effective scaling requires settlement-differentiated interventions: in informal settlements, finance and extension; in high-density areas, space-efficient design and market linkages; in affluent zones, regulatory enablement. The study illustrates that technology adoption models developed in wealthy contexts often fail to apply to resource-constrained African cities where local constraints vary dramatically over short distances. The study also finds that adoption can be improved by implementing targeted policies and strengthening supporting infrastructure. These findings provide actionable pathways to increase vertical farming adoption in rapidly growing African megacities.



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1. Introduction

1.1. Background on Urbanisation and Food Systems

Global population growth and rapid urbanisation continue to intensify pressure on food systems, amplifying the risk of widespread food insecurity reminiscent of the

long theorised “Malthusian” concerns about population growth and food scarcity [1]. Scientific and technological progress have traditionally played a vital role in averting these crises, propelling agriculture from its early mechanisation stages to the ongoing Fourth Agricultural Revolution [2]. This current phase is characterised by data-driven systems, automation, and controlled-environment agriculture (CEA), including vertical farming (VF), which offers the potential to decouple food production from arable land and climatic variability. VF systems are recognised for their ability to maximise spatial efficiency, reduce water consumption, minimise pesticide use, and enable year-round cultivation, making them promising technologies for addressing urban food system challenges [3].

Africa makes a compelling case for similar innovations. The continent hosts the world’s fastest-growing urban populations. African megacities are expected to increase from four today to at least 17 by 2050 [4]. These cities face pressure to ensure food security amid complex challenges. Urban food systems report high post-harvest losses and weak cold-chain infrastructure [5]. They often experience recurring food contamination and additional climate-induced supply disruptions [6]. These factors lead to frequent food price volatility. Many urban residents are low-income and spend up to 40% of their income on food [7]. This reliance makes populations more vulnerable to systemic shocks.

Metropolitan regions worldwide have responded to these pressures through broadening and localising food production. Singapore’s “30 × 30” initiative is one example of how urban agriculture can build food system resilience [8]. Comparable strategies are emerging in African cities like Lagos and Nairobi [9]. These city-led initiatives work alongside existing efforts from international organisations, such as FAO, ICLEI, and RUAF. FAO, through the Green Cities Network (GCN), promotes integrated solutions and strategies in Urban and peri-urban agriculture [10]. The GCN seeks to consolidate cities into a coherent global movement to make decisions on sustainable urban food planning. It is at this intersection between the urgency of city-led innovations and the coordinating ambition of the GCN that this study locates itself [10].

Despite VF’s considerable promise, the industry has experienced commercial failures even in well-resourced settings [11]. Well-resourced settings here refer to environments where sufficient financial capital, technological infrastructure, and reliable physical infrastructure are available to facilitate successful adoption. The wave of failures raises questions about the conditions for sustainable adoption of VF in resource-constrained African cities. Barriers in African cities include financial constraints and limited access to investment channels suited to VF’s unique risk profile. Consequently, this places most systems beyond the reach of small- and medium-scale urban farmers who operate on slim margins [12]. Infrastructure deficits, cultural scepticism towards soilless cultivation, and weak policy support structures also present additional obstacles [13]. At the same time, early evidence points to a gradual rise in diverse VF initiatives across Sub-Saharan Africa [12,14], suggesting latent potential if these constraints are effectively addressed. Table 1 shows some of the VF systems being used in Africa.

Basic VF systems (e.g., outdoor vertical bags and stacked units) are low-cost, low-energy systems typically deployed in open urban spaces or household compounds, requiring minimal technical skills and relying primarily on manual irrigation and locally available materials, with small-scale vegetable production (mainly leafy greens).

Medium-tech VF systems (e.g., outdoor hanging frames) involve moderate capital investment and slightly improved structural design, requiring basic training for assembly and maintenance, and are suited to peri-urban and dense residential settings where small-scale commercial production is feasible.

CEA VF systems (greenhouse-based systems with controlled environments) require the highest capital investment, greater technical skills, and more consistent water and

energy inputs, and are primarily used in commercial or semi-commercial production settings targeting higher-value crop output and more stable yields.

Table 1. VF Technology Types Being Used in SSA (adapted from [12]).

Technology Complexity	VF Concept	Key Benefits and Drawbacks
Basic VF systems	Outdoor vertical bag	Benefit—thrives in a low-sanitation environment Drawback—Limited growing surface
	Outdoor vertical stack units	Benefit—earthworm chamber provides natural fertilizer Drawback—limited growing surface
Medium Technology VF Systems	Outdoor hanging frames	Benefit—can be assembled and disassembled Drawback—limited growing space
	Greenhouse Controlled Environment Agriculture (CEA) with sunlight	Benefit—climatic effect resistant Drawback—high import costs for components, energy-intensive, and limited skill availability

Detailed specifications of each system type, including expected capital costs, energy and water requirements, spatial configurations, crop suitability, labour skill requirements, technological components, user groups, and production scales, are provided in Supplementary Material S1.

1.2. Research Gap

While existing scholarship has begun to explore the feasibility of VF in Africa, much of this work remains concentrated at the macro level, with country-scale analyses that do not sufficiently account for city-specific adoption dynamics [15]. Factors such as energy reliability, consumer perceptions, policy environments, land use, and cost structures vary substantially within cities themselves, yet the literature fails to address these city-specific adoption dynamics. This constitutes the central research gap that this study addresses.

1.3. Study Aims and Research Questions

This study, therefore, aims to predict and compare VF adoption in two African cities, Lagos and Nairobi, estimating both the likely peak adoption levels and the time required to reach them across different settlement types and levels of system complexity. “Prediction” in this context refers to projecting technology adoption trajectories under specified parameter assumptions rather than estimating adoption from population surveys. The paper identifies the key drivers influencing adoption levels and the speed of diffusion and suggests evidence-based priorities for scaling urban VF in both cities. Three research questions guide the analysis:

1. What are the predicted peak adoption levels and diffusion timelines for Basic, Medium-tech, and CEA vertical farming systems in informal, high-density, and low-density urban settlements in Lagos and Nairobi?
2. What factors primarily drive the magnitude of adoption and the pace of technology diffusion, and how do these drivers vary by settlement type and system?
3. Which variables offer the most effective intervention points to accelerate adoption, and how should strategies differ across city contexts?

Lagos and Nairobi were selected because they represent two distinct urban growth trajectories and contrasting conditions for VF adoption in Africa. Lagos is an established megacity [16], while Nairobi represents an emerging megacity candidate [17], enabling analysis of how different stages of urban development shape technology adoption. The

two cities also anchor distinct regional agritech investment ecosystems, with West and East Africa receiving the largest shares of agritech venture funding on the continent [18]. The existing literature further suggests stronger baseline feasibility conditions for VF in Nigeria than in Kenya [15], providing a useful contrast across adoption contexts.

The findings seek to inform policymakers, entrepreneurs, urban planners, and investors seeking to integrate VF into Africa's evolving urban food systems. To position the study within existing scholarship, the next section reviews the conceptual and empirical literature on vertical farming, technology adoption, and the current evidence base from African urban contexts.

2. Literature Review

2.1. Defining Vertical Farming

Vertical farming has emerged as a promising response to urban food security challenges, yet its definition remains contested in the literature. Some scholars define VF strictly as production-scale crop-growth systems within enclosed structures that precisely control the plant environment using electric lighting and climate control. They therefore insist on VF comprising both complete environmental control and operation at scale [19–21]. Others adopt a broader and less technically restrictive interpretation, defining VF as the practice of growing crops in vertically stacked layers, including outdoor or semi-outdoor configurations [22,23]. Despite these definition differences, there is broad agreement that VF aims to maximise production per unit area while minimising water consumption, pesticide use, and use of soilless-based systems.

This definition plurality has direct implications for the African context. The capital-intensive requirements of fully controlled indoor VF systems [23] place such approaches beyond the financial reach of most smallholder and peri-urban farmers across Sub-Saharan Africa. Consequently, the VF practices documented in African literature tend to reflect the broader definition, encompassing outdoor and semi-outdoor vertically stacked systems that require lower upfront investment [12,14]. This study, therefore, adopts an inclusive definition of VF that accommodates both indoor and outdoor forms, recognising that the dominant form encountered in Sub-Saharan African cities is shaped less by technological preferences than by structural economic constraints.

2.2. Dimensions of Vertical Farming Adoption

The concept of adoption in the context of vertical farming can be separated into two interrelated dimensions: consumer adoption and producer adoption. Consumer adoption refers to consumers' willingness to purchase vertically farmed produce. Existing studies identify environmental benefits as a key driver of uptake [24–26]. Research on willingness to pay introduces further nuances, including demographic influences such as gender and age. Some studies suggest that male consumers may be more willing to pay premium prices for VF produce [27], while younger consumers appear more inclined to accept VF than older populations [28].

Producer adoption, on the other hand, focuses on farmers' and entrepreneurs' willingness to invest in and operate VF systems. This dimension is largely framed around economic viability, with studies examining operator failure, business model weaknesses, market misalignment, and cost-structure constraints [11]. This study focuses on the latter type of adoption.

A critical limitation of the literature on VF is its strong geographic concentration in high-income contexts, including Europe, the United States, Singapore, and Japan [29]. Consumer adoption studies consequently focus on educated, urban, middle-class populations with prior exposure to VF produce, while producer adoption studies are dominated by

commercially scaled indoor operations [30]. This high-income bias limits the direct transferability of findings to African urban contexts, where smallholder producers, low-income consumers, and low- to medium-tech systems predominate.

2.3. Vertical Farming in Africa: Existing Evidence and Research Gaps

The literature on VF adoption in Africa remains limited, though three studies are particularly instructive. Reference [15] identifies nine African countries as favourable for indoor VF using a methodological framework based on 147 development indicators, providing important macro-level insights into national feasibility conditions across the continent. At the practice level, [12,14] demonstrate that VF currently practised in Africa is predominantly low- to medium-tech and chiefly operated by smallholder farmers, suggesting that the African VF landscape differs substantially from the high-tech, indoor systems that dominate global literature.

However, important gaps remain. Neither the [15] study nor the broader scoping literature model VF adoption at the city level or among smallholder operators under the inclusive, low-tech definition that characterises actual African practice. This is despite substantial intra-city variation in the key drivers of adoption, including energy access, consumer perceptions, city regulations, land use, and cost structures.

This gap is precisely what the present study addresses by applying the ADOPT tool across six sites in Lagos and Nairobi, thereby capturing the city-level and intra-urban dynamics absent from existing research.

3. Materials and Methods

To estimate the likely adoption and diffusion of three selected vertical farming systems in two African urban contexts (Lagos, Nigeria and Nairobi, Kenya), the ADOPT (Adoption and Diffusion Outcome Prediction Tool) model developed by the University of South Australia was applied [31,32]. ADOPT predicts potential adoption rates, maximum diffusion levels, and the influence of variables affecting innovation uptake within a user-defined target group. Although originally designed for agricultural systems, the tool has been widely applied across sectors. The tool has demonstrated strong practical correlations with real-world adoption outcomes in various innovation domains [32–34]. For example, the Adopt tool has been used to assess the adoption of photovoltaic systems for water extraction in Australian sugarcane irrigation [35]. Lately, it has also been used to predict and evaluate innovation adoption among target German dairy farmers [36], demonstrating its usefulness in forecasting adoption.

3.1. Adopt Framework

The ADOPT framework consists of four major categories of influence. Central to the model is the capacity of potential users to learn about and evaluate the relative advantages of innovation. The tool captures this through 22 structured variables, grouped as follows:

1. Characteristics of vertical farming systems that determine their relative advantage.
2. Characteristics of the user population and the surrounding urban environment, which mould perceptions of benefits and constraints.
3. Ease and speed of learning, which affect willingness and motivation to adopt.
4. Capabilities of potential users, which determine their ability to implement the systems in practice.

3.2. Site Selection

We administered the 22 questions through focused group discussions with 10 people at each of the 6 sites. The use of approximately ten participants per focus group was con-

sidered appropriate because the objective was not to statistically represent the populations of Lagos and Nairobi, but to elicit informed assessments of the factors influencing vertical farming adoption within specific settlement contexts [37]. The ADOPT framework requires context-specific judgements on adoption drivers and barriers rather than large population samples. Accordingly, three focus groups were conducted in each city to capture variation across informal, high-density, and low-density settlements, with each group comprising participants familiar with the local urban agriculture environment. This approach enabled the study to characterize differences between settlement types while maintaining manageable group sizes that allowed meaningful discussion and consensus-building on the ADOPT parameters. Ten participants were considered sufficient to capture a range of experiences and perspectives while still allowing all participants to contribute meaningfully to the assessment of the ADOPT parameters [38]. Site selection followed a purposive sampling approach to ensure that the main forms of urban stratification relevant to vertical farming adoption were represented. Within each city, three sites were purposively selected to capture intra-urban differences in socioeconomic and spatial conditions. This selection resulted in informal settlements, high-density low-affluence areas, and low-density high-affluence areas. In Nairobi, these correspond to Korogocho, Pipeline, and Langata; in Lagos, to Shomolu, Oworonshoki, and Lekki, respectively. Consultations with local extension workers informed site selection. They helped identify areas with residents already engaged in, or expressed interest in, urban agriculture technologies. This approach ensured that the analysis focused on contexts with realistic adoption potential rather than purely hypothetical scenarios. The selected three city typologies map directly onto key ADOPT population variables, including Financial Constraints (Question 16), Environmental Orientation (Question 19), Market Integration (Question 20), and Management Skill Levels (Question 17), as well as access-related factors such as Information Access (Question 11) and Technical Support (Question 10) (See Table 2). By structuring site selection along these gradients, the study enables interpretation of adoption outcomes in relation to underlying economic capacity, environmental attitudes, and human capital, while maintaining comparability across cities. Sites were chosen in consultation with local extension officers and city stakeholders, focusing on districts with established or emerging urban agriculture activity and that are broadly characteristic of each settlement type in their respective cities. This approach enabled comparisons across socioeconomic and spatial contexts that are directly relevant to anticipated dynamics of vertical farming adoption.

Table 2. Participant demographics summary.

Demographic Characteristic	Participant Demographics Summary					
	Korogocho (Informal Settlement)	Pipeline (High-Density (Low Affluence))	Langata (Low-Density (High Affluence))	Shomolu (Informal Settlement)	Oworonshoki (High-Density (Low Affluence))	Lekki (Low-Density (High Affluence))
Total Participants (<i>n</i>)	10	10	10	10	10	10
Gender Distribution						
Male (%)	60	60	50	40	70	100
Female (%)	40	40	50	60	30	0
Average Age (years)	27	40	38	41	44	30
Age Range (min-max)	24–34	23–60	26–51	35–65	30–60	26–40
Farming Experience						
<1 year (%)	30					
1–5 years (%)	60	40	50	70	30	60
5–10 years (%)	10	40	40	20	70	40
>10 years (%)		20	10	10		
Enterprise Type						
Full-time (%)	30	40	20	30	20	10
Part-time (%)	70	60	80	70	80	90

3.3. Participant Selection

The target population comprised urban agricultural entrepreneurs, small-scale commercial growers, and community-based vertical farming initiatives, representing the next generation of actors in urban food production in African cities. Participants were identified and recruited in collaboration with local agricultural extension workers, who were instructed to ensure diversity in gender, age, and experience wherever possible. Inclusion criteria required that participants currently be involved in urban agriculture or vertical farming initiatives; individuals without any agricultural engagement were excluded to maintain relevance. Efforts were made to achieve a representative mix by drawing on both established growers and newer entrants within each site (Table 2).

The data shows that urban farming in these settlements is relatively new (mostly 1–10 years of experience), practiced primarily as part-time work, and involves a diverse mix of ages with a strong male representation. The sites represent a spectrum from informal settlements to affluent neighborhoods, allowing for comparison across different urban contexts.

Before the focus group discussions, participants were shown pictures of the system under discussion, given explanations of how the discussions would proceed, and asked for their consent. Then they responded to the questions individually.

Table 3 presents the ADOPT tool framework, the connections between the 22 questions and the variables they represent, and how they may be understood.

Table 3. Variable Classification and Interpretation Framework.

Category	Sub-Category	Variable	Q#	Interpretation
Relative Advantage	Innovation	Short-term Profitability	1	Economic return within 12 months
		Long-term Profitability	2	Economic return beyond 12 months
		Environmental Benefit	4	Non-market ecosystem services
		Risk Reduction Benefit	5	Variance reduction in outcomes
		Profit Orientation	15	Focus on maximum returns
	Population	Financial Constraints	16	Capital access limitations
		Future Profit Certainty	18	Confidence in long-term returns
		Environmental Orientation	19	Environmental values
		Market Integration	20	Access to output markets
		Ease of Trial	6	Divisibility of innovation
Triability	Innovation	Complexity of System	7	Technical difficulty
		Observability of Results	8	Visibility of outcomes
		Training Requirements	12	Learning investment needed
		Risk Orientation	3	Risk tolerance
		Group Involvement	9	Collective action potential
	Population	Technical Support Access	10	Advisory service availability
		Information Access	11	Knowledge availability
		Peer Pressure	13	Social influence
		Upfront Cost Sensitivity	14	Initial investment barriers
		Management Skill Levels	17	Human capital
		Trial-ability Orientation	21	Experimentation propensity
		Innovation Proneness	22	Early adoption tendency

Adapted from [31].

3.4. Data Processing

To enhance transparency and reproducibility of the methodology, this stage of the data collection and scoring process followed a structured, stepwise protocol. First, participants were introduced to the ADOPT framework and provided with a standardized explanation of each variable and its corresponding scoring scale to ensure a shared understanding of the assessment criteria. Second, participants independently completed the initial scoring

exercise for all ADOPT variables without consultation, ensuring that individual judgements were captured prior to any group influence. Third, a facilitated discussion was conducted in which participants compared interpretations of the variables, clarified uncertainties, and reflected on differences in their initial responses. Fourth, participants were given the opportunity to revise their initial scores based on insights gained during the discussion, with revised responses replacing the original entries for analysis. Fifth, all final responses were converted into numerical values according to a predefined ADOPT scoring template (see Supplementary Material S2). Finally, mean scores were calculated for each variable at the site level by aggregating responses across the ten participants. Given the small sample size, these means should be interpreted as aggregated perception indicators rather than precise population estimates. Outlier responses were reviewed at the site level and were not excluded unless they reflected a clear misunderstanding of the scoring scale; instead, facilitated group discussion was used to reduce extreme interpretation differences before final aggregation.

3.5. Sensitivity Analysis

Along with estimating adoption and diffusion curves, ADOPT also includes a sensitivity analysis function that shows how small changes in variable values affect both the maximum adoption level and the time to reach it [31]. For this study, we used the 2018 CSIRO version of the Smallholder standard ADOPT to analyse the adoption potential of the three vertical farming systems. Figure 1 shows how the ADOPT Tool works:

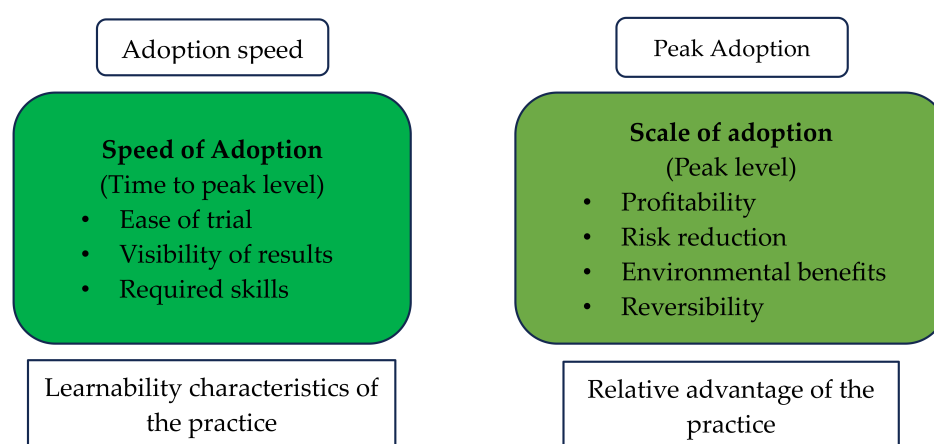


Figure 1. How CSIRO ADOPT's (Adoption and Diffusion Outcome Prediction Tool) works (adapted from [36]).

A subsequent sensitivity analysis was performed to determine how changes of ± 1 scale point for each variable affect (i) maximum adoption level and (ii) time to peak adoption. For example, reducing the scaling for the variable “Environmental orientation of users” (Question 19) by 1 point for the medium tech system in Korogocho, Nairobi resulted in a decrease in the projected adoption level by 21.4% and a delay in adoption by 0.17 years. The complete sensitivity analysis, covering both peak adoption level and time to peak adoption across all sites and systems, is presented in Section 4.2. These results show which factors exert the strongest influence on the speed and saturation of vertical farming adoption in each urban context. Figure 2 below illustrates how the Adopt tool framework was used for the study.

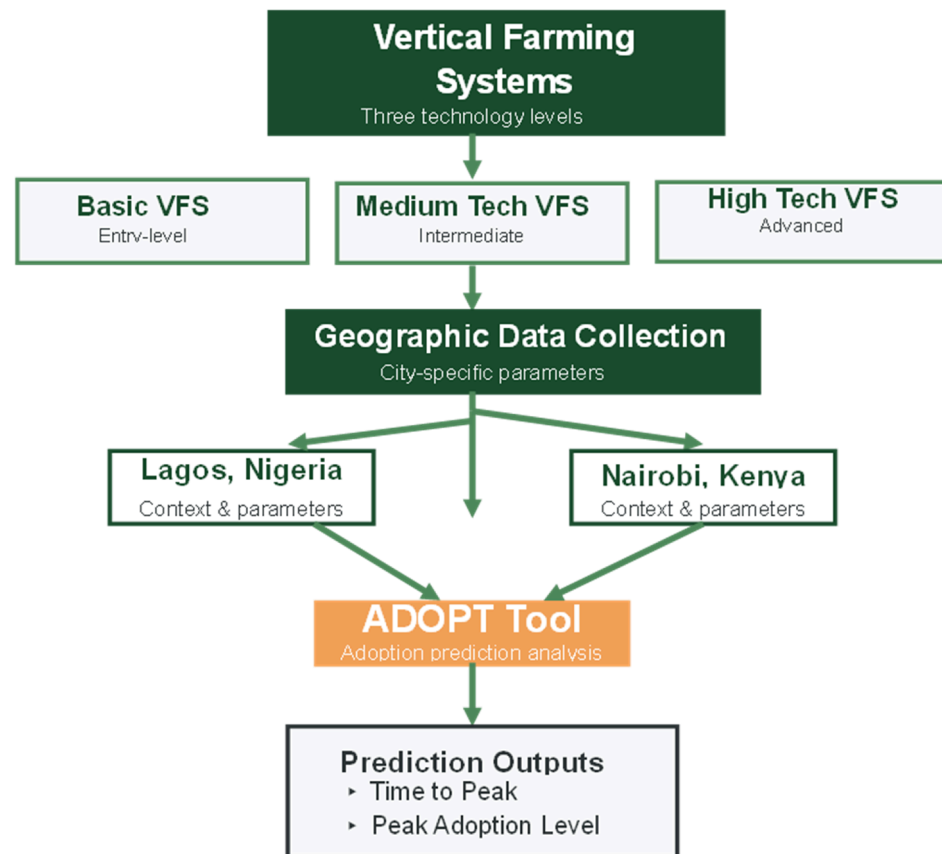


Figure 2. How the Adopt Tool framework was used for the study.

4. Results

We applied the ADOPT Tool to three VF systems (Basic, Medium technology, and High-tech) across two African cities (Lagos, a megacity, and Nairobi, an emerging megacity candidate) and three site-specific contexts per city (informal settlements, high-density areas, and low-density areas). This design enabled us to assess both system-level and context-level variation to predict adoption outcomes while maintaining comparability. The outputs of the ADOPT Tool include predicted peak adoption, time to peak adoption, time to 50% of peak adoption, and adoption levels at 5 and 10 years (Table 4).

Fieldwork in Shomolu coincided with imminent settlement demolition (formal demolition orders issued approximately one month after data collection). During the FGD period, residents faced documented displacement risk. Consequently, Shomolu adoption estimates should be interpreted as reflecting acute tenure insecurity shock rather than stable settlement conditions. Shomolu predictions are not directly comparable to other informal settlements (Korogocho, Oworonshoki), where tenure conditions were more stable during data collection.

The results across all scenarios predicted peak adoption levels varied widely, ranging from 2% to 98%, with time to peak adoption spanning 10 to 25 years. None of the sites exhibited rapid adoption within the first five years, with 5-year adoption levels remaining below 50% in all cases.

We used the ADOPT Tool's sensitivity analysis feature to identify the key drivers influencing both the magnitude (peak adoption level) and timing (time to Peak) of technology diffusion across the three agricultural systems (Basic, Outdoor Medium Technology, and VF CEA) in six urban sites. The sensitivity analysis showed considerable variance in the determinants of vertical farming (VF) adoption across settlement types and technological systems.

Table 4. Summary of Adoption prediction and diffusion (by system type and site).

System Type	Site	Peak Adoption (%)	Time to Peak Adoption (Years)	Time to 50% Adoption (Years)	5-Year Adoption (%)	10-Year Adoption (%)
Basic	Shomolu, Lagos	52	11	5	28	51
Basic	Korogocho, Nairobi	61	15	7	19	51
Basic	Oworonshoki, Lagos	29	10	5	17	28
Basic	Pipeline, Nairobi	86	16	7	23	69
Basic	Lekki, Lagos	16	10	7	3	8
Basic	Langata, Nairobi	97	12	5	47	94
Outdoor Medium tech	Shomolu, Lagos	2	18	8	0	2
Outdoor Medium tech	Korogocho, Nairobi	93	19	8	18	62
Outdoor Medium tech	Oworonshoki, Lagos	45	14	6	15	39
Outdoor Medium tech	Pipeline, Nairobi	67	18	8	13	46
Outdoor Medium tech	Lekki, Lagos	5	16	7	1	4
Outdoor Medium tech	Langata, Nairobi	96	17	7	23	73
CEA	Shomolu, Lagos	2	25	11	0	38
CEA	Korogocho, Nairobi	22	21	9	3	13
CEA	Oworonshoki, Lagos	62	20	11	10	38
CEA	Pipeline, Nairobi	96	21	9	14	53
CEA	Lekki, Lagos	95	19	8	18	63
CEA	Langata, Nairobi	98	20	9	17	62

Across all cities and systems, population-related economic parameters consistently exerted the largest influence on peak adoption levels. Innovation parameters such as learning and trialability tended to primarily influence adoption speed rather than the ultimate adoption ceilings.

4.1. Predicted Adoption Levels and Diffusion Timelines Across Systems and Settlement Types

The first research question was to estimate the predicted peak adoption levels and diffusion timelines for Basic, Outdoor Medium-tech, and High-tech VF CEA systems across informal, high-density, low-affluence settlements and low-density, high-affluence settlements in Lagos and Nairobi.

Across all modelled site–system combinations, predicted peak adoption ranges from 2% to 98%, while time-to-peak spans 10–25 years. Five-year adoption stays below 50% in every scenario and below 25% in most cases, indicating uniformly gradual early-stage diffusion. These trajectories indicate that adoption patterns are not determined solely by technology but by the interaction between system complexity and settlement-level contexts.

Adoption Trajectories by Technology and Settlement Context

Basic systems achieve peak adoption between 16% and 97%, with time-to-peak typically 10–16 years. In informal, high-density, low-affluence settlements, predicted peaks cluster between 52% in Shomolu and 61% in Korogocho, and between 29% in Oworonshoki and 86% in Pipeline. In low-density high-affluence areas, divergence becomes pronounced: Langata reaches 97%, whereas Lekki remains at 16% (Figure 3).

Figures 3–5: Adoption levels and time in years for Lagos and Nairobi Sites.

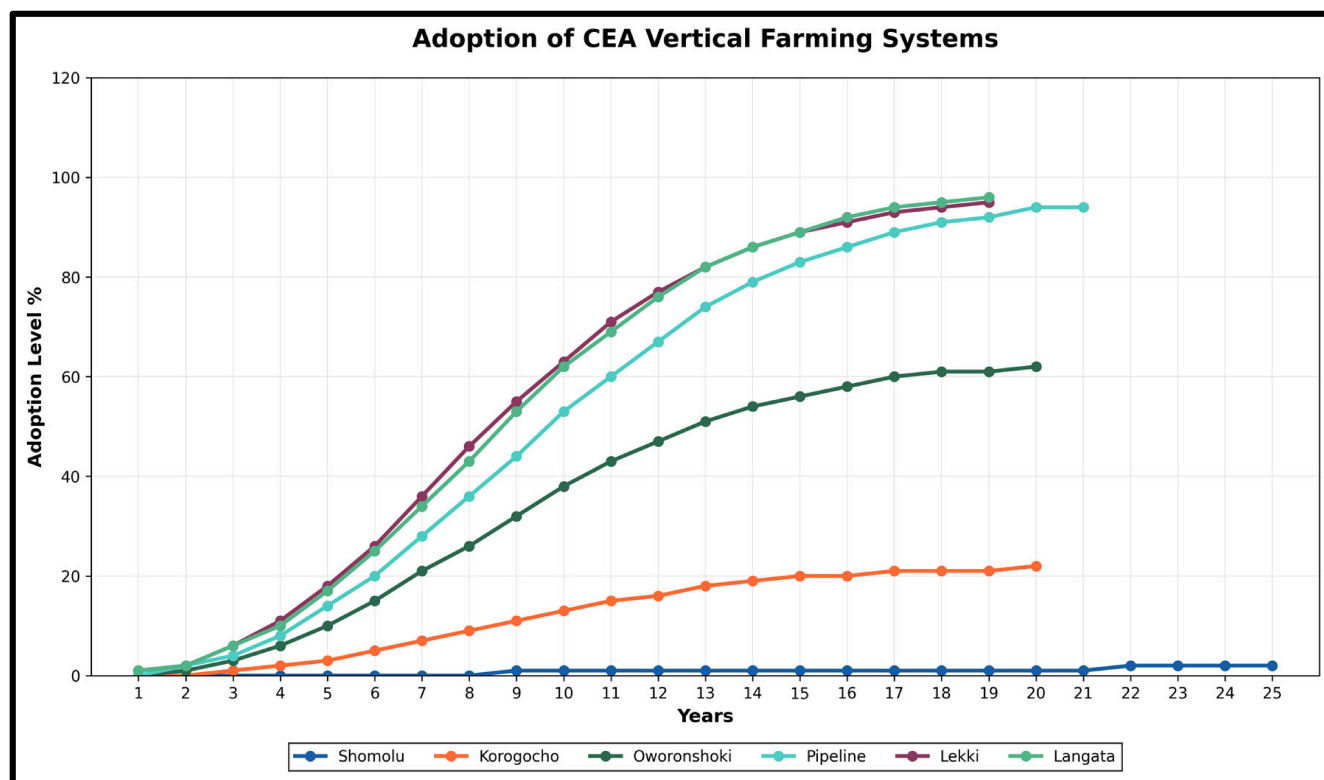


Figure 3. Adoption of CEA Vertical farming systems.

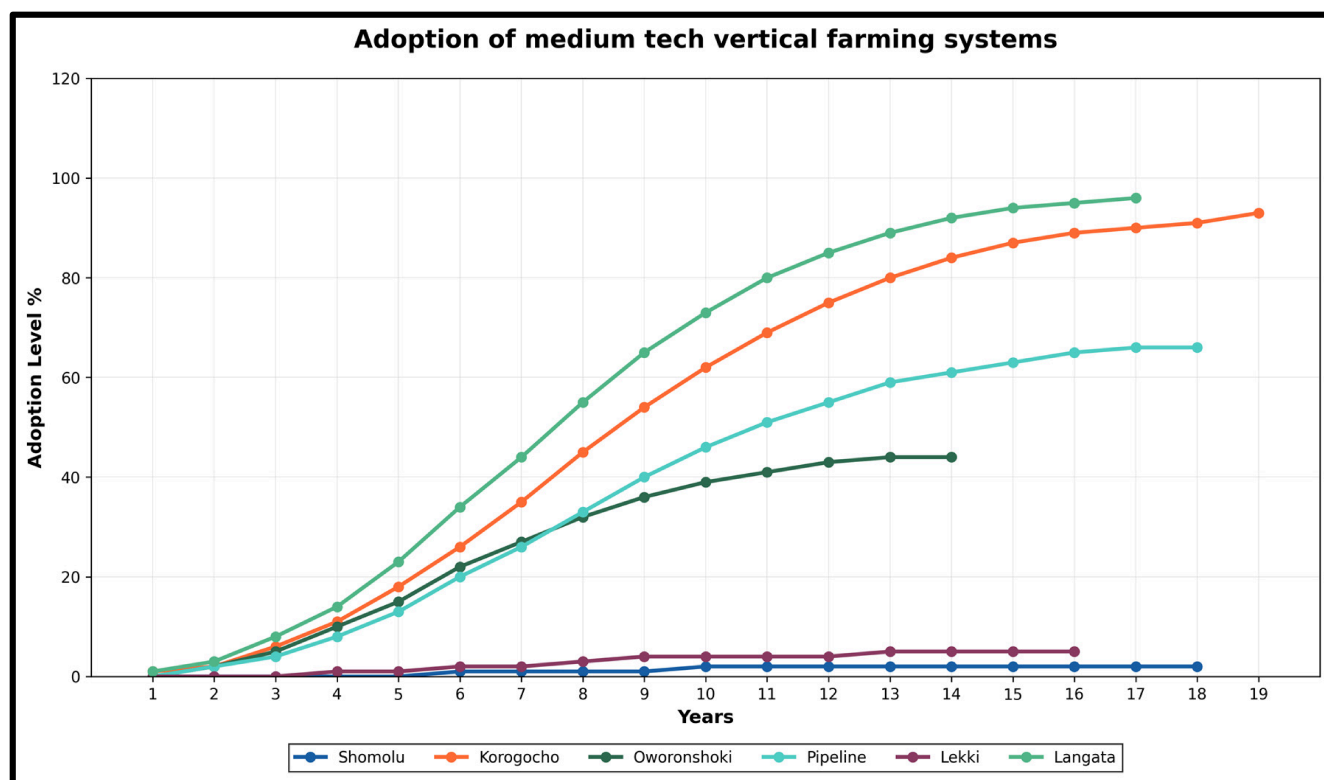


Figure 4. Adoption of medium-tech VF systems.

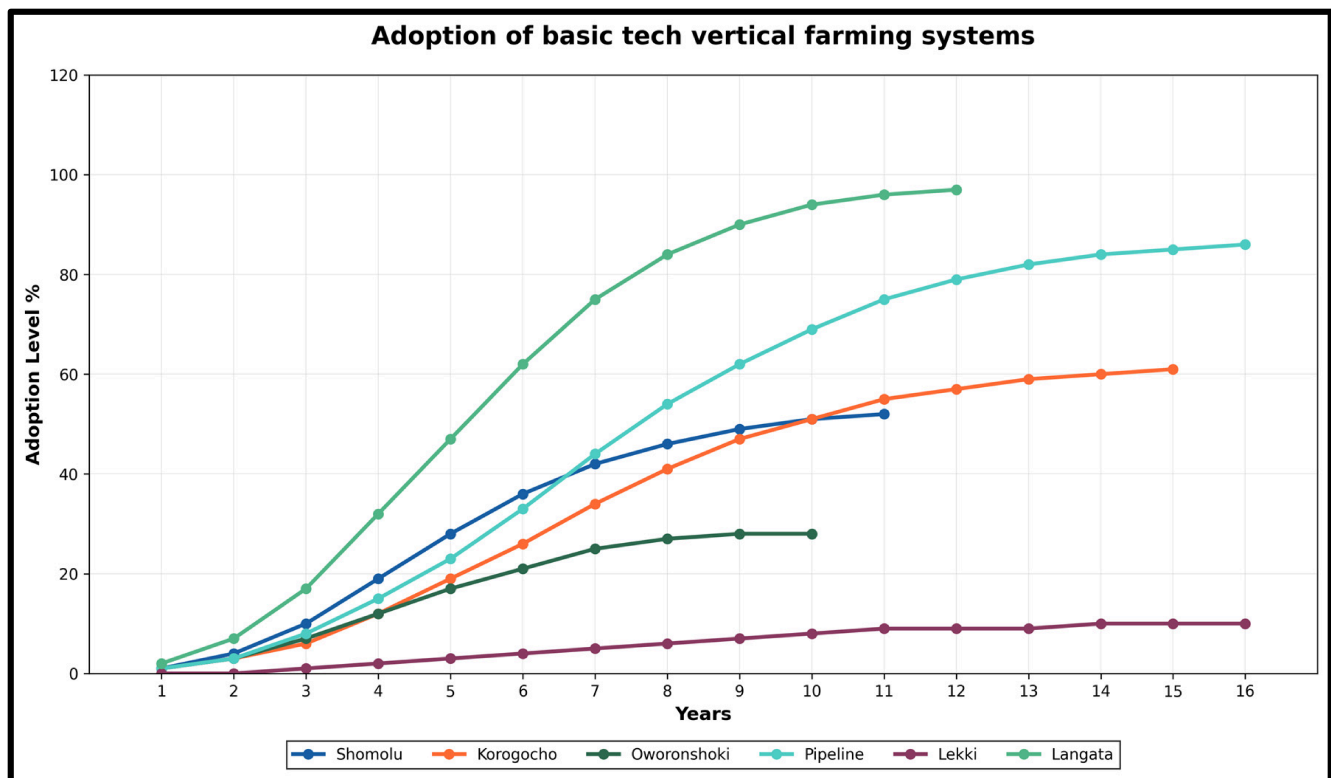


Figure 5. Adoption of basic tech VF systems.

Outdoor Medium-tech systems show the greatest cross-city divergence. In informal settlements, peak adoption ranges from 2% (Shomolu) to 96% (Korogocho). In the high-density low-affluence areas, peak adoption is higher with a slight margin of 40% (Oworonshoki) to 60% (Pipeline). In low-density, affluent areas, adoption remains extremely low in Lekki (5%) but much higher in Langata (96%). Time-to-peak ranges from 14 to 19 years across systems (Table 5).

Table 5. Gives a summary of System-Settlement Interaction.

System Type	Adoption Level	Diffusion Speed	Settlement-System Alignment
Basic	16–97%	Fast (10–15 yrs)	Informal/High-Density (Both cities)
Medium-Tech	2–96%	Moderate (14–19 yrs)	Nairobi (All types)
High-Tech CEA	2–98%	Slow (19–25 yrs)	High-density Lagos High-Affluence (Both Cities)

High-tech CEA systems display both the longest diffusion timelines (19–25 years) and the widest dispersion in predicted peak adoption (2–98%). Informal settlements show low adoption rates of 2% to 22% in Shomolu and Korogocho, respectively. Peak adoption ranges from 50% to 96% in high-density areas (Oworonshoki and Pipeline). Meanwhile, in the low-density areas, both Langata and Lekki approach near saturation (96%). (Figure 3).

Across the study sites, variation in ADOPT-predicted adoption levels corresponds to systematic differences in underlying contextual variables, including income levels, population density, infrastructure quality, land availability and values, market proximity, and access to extension services. For example, higher predicted adoption in Korogocho (Nairobi) is associated with very small plot sizes (25–50 m²), high population density, and proximity to multiple informal markets within 500 m, while Pipeline (Nairobi) reflects

moderate incomes, higher service reliability, and access to nearby institutional buyers such as schools. Similarly, Langata (Nairobi) combines high income levels (KES 80k+), secure infrastructure, larger land parcels (500–2000 m²), and access to formal high-value markets such as hotels and restaurants.

In contrast, lower predicted adoption in Shomolu (Lagos) is associated with greater distances to markets, higher transport constraints, and less consistent informal trading networks, while Lekki (Lagos) reflects very high land values, large plot sizes (500–2000 m²) within planned gated estates, high-income households (₦250k+), and reliance on formal retail supply chains, which together reduce the relative economic necessity and attractiveness of urban farming. Oworonshoki (Lagos) shows intermediate adoption patterns reflecting mixed infrastructure conditions and moderate market access.

These patterns indicate that differences in ADOPT input variables across sites correspond to variation in predicted adoption outcomes. A full breakdown of all contextual indicators and site-specific input values is provided in Supplementary Material S3.

4.2. Drivers of Adoption Magnitude and Diffusion Speed

The sensitivity analysis shows that distinct parameter clusters govern the magnitude of adoption and the diffusion speed.

4.2.1. Drivers of Peak Adoption

Population-level variables predominantly shape peak adoption levels. Across most site system combinations, the largest marginal effects are associated with Financial Constraints (Q16), Environmental Orientation (Q19), Management Skill Levels (Q17), and Environmental Benefit (Q4).

For instance, in Oworonshoki, one-step improvements in Financial Constraints (Q16) increase predicted peak adoption by 23–24 percentage points across systems. Environmental Orientation (Q19) generates increases exceeding 21 percentage points. Similar magnitudes are observed for Management Skill Levels (Q17).

In contrast, in Langata, equivalent one-step adjustments typically produce effects below 5 percentage points. This sharp contrast reveals differential elasticity structures.

High-Elasticity (Constraint-Bound) Contexts

High elasticity is observed primarily in Nigerian settlements such as Oworonshoki and, to a lesser extent, in Korogocho. These contexts exhibit large marginal responsiveness (18–24 percentage points) to changes in financial and skill variables (Table 5). Structural bottlenecks, rather than low demand, suppress adoption levels.

Low-Elasticity (Near-Saturation) Contexts

Langata exhibits minimal responsiveness (<5 percentage points). Financial and skill variables are largely non-binding, and predicted adoption operates near structural ceilings. Marginal improvements, therefore, yield diminishing returns.

Negative adjustments produce larger absolute impacts than positive adjustments. For example, the absence of Environmental Benefit (Q4) reduces adoption in Korogocho (Basic) by 26.34 percentage points, exceeding the largest positive interventions. Adoption levels are more vulnerable to negative shocks than they are responsive to positive improvements.

Drivers of Diffusion Speed

In contrast to peak adoption, our results show that time-to-peak is governed almost exclusively by innovation-level characteristics. The strongest accelerators are: Complexity (Q7), Observability (Q8), Training Requirements (Q12), and Ease of Trial (Q6).

Across nearly all sites and systems, one-step improvements in Complexity, Observability, or Training Requirements reduce time-to-peak by approximately 1.17–1.42 years. These effects are remarkably consistent across cities and settlement types.

Population-level variables such as Financial Constraints (Q16) or Environmental Orientation (Q19) exert minimal influence on diffusion speed. These results show that adoption levels and adoption speed are independent. Adoption magnitude, on the one hand, is determined primarily by configurations of socioeconomic constraints. Diffusion speed, on the other hand, is mainly determined by the learning and design characteristics embedded in the innovation itself.

4.3. High-Leverage Intervention Variables and Context Differentiation

The third objective was to identify variables offering the greatest leverage for accelerating adoption and to assess how leverage varies across metropolitan contexts. Our results from the sensitivity structure reveal sharply differentiated leverage profiles. First, we observe high-sensitivity contexts (e.g., Oworonshoki, Korogocho). These contexts display large responsiveness to financial and skill variables (18–24 percentage points per adjustment). Environmental Orientation and Environmental Benefit also rank among the highest-impact parameters. In these areas, adoption is at a tipping point: even small improvements can trigger a massive surge in users.

Secondly, our results also show medium-Sensitivity Contexts (e.g., Shomolu, Pipeline, Lekki). These sites show moderate responsiveness (10–18 percentage points). Financial constraints and environmental variables remain relevant but generate smaller marginal effects.

Finally, the study results show low-sensitivity contexts (Langata). Here, the marginal responses to population-level variables remain below 5 percentage points. The adoption appears structurally bounded or near saturation.

We also observe that across all contexts, innovation-level redesign variables (Complexity, Observability, Training Requirements) consistently accelerate diffusion timelines by approximately 1.2–1.4 years, independent of elasticity regime.

Integrated Empirical Synthesis

In the final analysis, we observe that three structural regularities emerge. First, predicted adoption ceilings vary dramatically across systems and settlements (2–98%), and diffusion timelines are prolonged (10–25 years) across all contexts.

Second, adoption magnitude and diffusion speed are governed by distinct parameter domains: population-level characteristics determine ceilings, while innovation-level characteristics determine timing.

Third, settlement contexts fall into differentiated elasticity regimes, implying that identical parameter changes produce widely varying adoption responses.

These findings suggest that interactions among technological and complexity-related factors and site-specific constraints could govern the uptake of vertical farming across African megacities. Complexity amplifies contextual divergence, producing high ceilings in aligned contexts and severe suppression in constraint-bound ones.

Tables 6 and 7 present the heat maps of peak-level impacts across all variables and sites.

Key: Green cells mark the STEP UP (positive shock) results, with darker green indicating a larger increase in peak adoption; red/pink cells mark the STEP DOWN (negative shock) results, with darker red indicating a larger decrease. Tables 8 and 9 present the sensitivity analysis of time to peak adoption in Nairobi and Lagos under positive (step-up) parameter shocks and negative (step down) shocks, highlighting the temporal responsiveness of adoption dynamics.

Table 6. Sensitivity analysis of peak adoption levels (%) in Nairobi under positive (step-up) and negative (step-down) parameter shocks across innovation, population, and system characteristics.

Variable Domain	Q	▲ STEP UP									▼ STEP DOWN								
		Informal (Korogocho)			High-Density (Pipeline)			Low-Density (Langata)			Informal (Korogocho)			High-Density (Pipeline)			Low-Density (Langata)		
		Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA
Relative Advantage for the Population	Q1	2.3	8.8	n/a	4.9	5.0	1.4	0.7	n/a	0.5	3.9	6.7	0.6	7.7	5.5	3.5	1.3	0.4	0.4
	Q2	1.5	4.4	0.2	3.0	5.6	1.0	0.4	0.1	1.2	2.0	3.8	0.2	3.9	6.2	1.6	0.6	0.1	0.9
	Q3	0.4	—	—	—	3.2	n/a	0.3	n/a	−0.3	0.4	—	—	—	3.4	0.2	0.3	0.1	0.4
	Q4	3.9	16.9	0.4	7.7	19.1	1.9	1.3	0.2	1.7	13.4	10.7	1.6	18.1	28.5	7.7	5.5	1.6	1.2
	Q5	1.0	3.5	0.1	1.2	2.1	n/a	0.2	0.1	0.8	1.2	2.8	0.1	1.2	2.1	0.8	0.2	0.1	0.6
	Q6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Learnability Characteristics of the Innovation	Q7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Q8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Q9	—	—	No peak-level effect (Q6–Q13) Speed/timing drivers only						—	—	—	—	—	—	—	—	—	—
Learnability of Population	Q10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Q11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Q12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Q13	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Relative Advantage of the Innovation	Q14	2.5	10.0	0.3	5.3	10.0	0.8	0.7	0.1	3.3	4.4	7.4	0.7	8.7	12.1	1.1	1.1	n/a	1.8
	Q15	1.7	4.7	n/a	2.5	5.3	0.6	0.4	0.0	1.1	2.4	4.0	0.4	3.0	5.9	0.7	0.5	0.0	0.9
	Q16	2.9	14.2	0.4	7.0	14.8	1.4	1.0	0.2	6.0	6.2	9.5	1.2	14.8	20.0	3.1	2.7	0.6	2.4
	Q17	2.6	10.9	0.3	6.8	14.2	1.4	1.0	0.2	4.3	5.0	7.9	0.9	13.7	18.8	3.0	2.4	0.4	2.1
	Q18	0.8	2.4	0.1	1.1	2.0	0.1	0.2	0.1	0.4	1.8	3.7	0.3	1.2	2.0	0.1	0.2	0.2	0.6
	Q19	2.4	13.4	0.4	7.3	15.6	1.6	1.0	0.2	4.4	4.2	9.2	1.0	16.2	21.4	4.6	2.8	0.5	2.1
	Q20	1.4	2.9	0.1	1.3	2.3	0.3	0.2	0.1	0.8	3.1	4.3	0.2	2.7	4.4	0.7	0.6	0.1	1.1
	Q21	2.6	13.9	0.3	6.2	11.6	1.5	0.9	0.2	3.9	4.8	9.4	0.7	11.6	14.5	3.5	2.1	0.4	2.0
	Q22	2.4	12.8	0.3	5.9	12.0	1.3	0.9	0.2	4.1	4.4	8.8	0.6	10.6	15.2	2.7	1.8	0.3	2.0

Table 7. Sensitivity analysis of peak adoption levels (%) in Lagos under positive (step-up) and negative (step-down) parameter shocks across innovation, population, and system characteristics.

Variable Domain	Q	▲ STEP UP									▼ STEP DOWN								
		Informal (Oworonshoki)			High-Density (Shomolu)			Low-Density (Lekki)			Informal (Oworonshoki)			High-Density (Shomolu)			Low-Density (Lekki)		
		Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA
Relative Advantage for the Population	Q1	2.8	7.6	12.0	9.0	0.7	−0.1	2.6	0.5	1.6	2.7	7.3	14.0	9.2	0.5	0.1	2.1	0.4	3.7
	Q2	3.0	3.9	3.3	3.4	−0.2	0.1	−1.2	1.2	0.8	2.9	3.8	3.4	3.4	0.2	0.1	1.3	0.9	1.1
	Q3	—	2.3	4.1	n/a	n/a	n/a	0.8	−0.3	0.3	—	2.2	4.3	n/a	n/a	n/a	0.8	0.4	0.3
	Q4	11.5	19.9	18.5	19.1	0.3	0.1	5.4	1.7	2.1	9.2	18.4	23.7	20.0	0.2	0.1	3.5	1.2	7.8
	Q5	2.3	2.0	3.2	1.6	0.0	0.1	0.0	0.8	0.7	2.0	1.8	3.1	1.5	0.0	0.1	0.0	0.6	0.8
Learnability Characteristics of the Innovation	Q6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	n/a	n/a	—	n/a
	Q7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Q8	n/a	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Q9	—	—	No peak-level effect (Q6–Q13) Speed/timing drivers only						—	—	—	—	—	—	—	—	—	—
Learnability of Population	Q10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Q11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Q12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Q13	n/a	—	—	—	—	—	—	—	—	—	—	—	—	—	n/a	—	—	—
Relative Advantage of the Innovation	Q14	14.8	16.0	11.0	18.0	1.2	0.3	7.2	3.3	1.4	11.2	15.0	12.6	18.8	0.6	n/a	4.2	1.8	2.6
	Q15	11.7	6.5	5.8	n/a	0.4	0.1	2.5	1.1	0.7	9.3	6.3	6.2	9.7	0.3	0.1	2.0	0.9	0.8
	Q16	23.2	23.5	18.7	19.1	1.2	0.8	12.5	6.0	1.8	15.5	21.5	24.1	20.0	0.6	0.3	5.6	2.4	4.6
	Q17	20.5	21.9	17.1	18.2	1.1	0.6	9.1	4.3	1.6	14.2	20.1	21.5	19.0	0.6	0.3	4.8	2.1	3.7
	Q18	1.1	—	2.4	2.3	0.1	0.0	0.9	0.4	0.5	1.9	—	4.6	2.2	0.1	0.1	1.3	0.6	1.3
	Q19	22.0	24.1	18.0	20.2	1.3	0.8	9.3	4.4	1.7	15.0	21.9	22.9	21.2	0.6	0.3	4.9	2.1	4.2
	Q20	2.4	2.1	2.6	1.3	−0.1	0.0	−0.8	0.8	0.2	3.8	3.6	4.6	2.4	0.1	0.1	1.5	1.1	0.4
	Q21	19.0	19.9	16.2	16.2	1.4	0.7	9.7	3.9	1.6	13.5	18.4	20.1	16.9	0.7	0.3	5.0	2.0	3.5
	Q22	17.5	18.5	15.2	15.1	1.4	0.7	8.8	4.1	1.5	12.7	17.2	18.6	15.7	0.7	0.3	4.7	2.0	3.2

Table 8. Sensitivity analysis of time to peak adoption (yrs) in Nairobi and Lagos under positive (step-up) parameter shocks, highlighting the temporal responsiveness of adoption dynamics.

Variable Domain	Q	▲ STEP UP																	
		Nairobi									Lagos								
		Informal (Korogocho)			High-Density (Pipeline)			Low-Density (Langata)			Informal (Shomolu)			High-Density (Oworonshoki)			Low-Density (Lekki)		
		Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA
Relative Advantage for the Population	Q1	0.17	0.08	–	0.08	–	0.17	0.08	–	0.08	0.08	0.08	–	0.08	0.08	0.08	0.08	0.08	0.08
	Q2	0.08	0.08	0.08	–	–	0.08	–	–	0.08	0.08	–	–	0.08	0.08	–	–	0.08	–
	Q3	0.08	–	–	–	–	–	–	–	–	–	–	–	–	0.08	0.08	0.08	–	–
	Q4	0.25	0.17	0.25	0.17	0.17	0.25	0.25	0.25	0.08	0.17	–	0.08	0.08	0.17	0.17	0.08	0.08	0.17
	Q5	0.08	0.08	0.08	–	–	–	–	–	0.08	0.08	–	–	0.08	0.08	–	–	0.08	–
	Q6	0.83	0.83	0.83	0.75	0.75	0.75	0.75	0.75	0.83	0.83	0.75	0.83	0.83	0.83	0.83	0.83	0.83	0.75
Learnability Characteristics of the Innovation	Q7	1.25	1.17	1.25	1.17	1.17	1.17	1.17	1.17	1.25	1.25	1.17	1.17	1.25	1.25	1.17	1.25	1.25	1.17
	Q8	1.25	1.17	1.25	1.17	1.17	1.17	1.17	1.17	1.25	1.25	1.17	1.17	–	1.25	1.17	1.25	1.25	1.17
	Q9	0.58	0.58	0.33	0.25	0.42	0.50	0.50	0.50	0.50	0.33	0.42	0.67	0.25	0.50	0.42	0.58	0.50	0.50
Learnability of Population	Q10	1.25	1.17	0.08	0.83	0.83	0.83	0.17	0.17	0.58	0.17	0.75	0.92	0.25	0.33	0.92	0.25	0.58	0.58
	Q11	0.83	0.83	0.08	0.58	0.58	0.58	0.17	0.17	0.42	0.17	0.58	0.67	0.25	0.25	0.67	0.25	0.42	0.33
	Q12	1.17	1.42	0.58	1.17	1.17	1.42	0.58	0.58	1.17	0.58	0.75	1.42	0.58	1.17	1.17	0.58	1.17	1.17
Relative Advantage of the Innovation	Q13	0.58	0.58	0.33	0.25	0.25	0.50	0.25	0.42	0.33	0.33	0.42	0.58	–	0.33	0.42	0.33	0.33	0.42
	Q14	0.17	0.92	0.17	0.83	0.83	0.83	0.83	0.83	0.92	0.17	0.92	0.83	0.17	0.92	0.92	0.92	0.92	0.83
	Q15	0.08	0.08	–	–	–	–	–	–	0.08	–	–	–	0.08	0.08	0.08	0.08	0.08	–
	Q16	0.17	0.17	0.25	0.17	0.08	0.08	0.17	0.17	0.17	0.17	0.08	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	Q17	0.17	0.08	0.17	0.08	0.08	0.08	0.08	0.08	0.17	0.17	0.08	0.17	0.17	0.17	0.17	0.17	0.17	0.08
	Q18	0.08	–	0.08	–	–	–	–	–	–	0.08	–	–	0.08	–	–	0.08	–	–
	Q19	0.17	0.17	0.17	0.17	0.08	0.17	0.17	0.08	0.17	0.17	0.08	0.17	0.17	0.17	0.17	0.17	0.17	0.08
	Q20	0.08	0.08	0.08	–	–	–	–	–	0.08	–	–	–	0.08	0.08	–	–	0.08	–
	Q21	0.17	0.17	0.17	0.08	0.08	0.17	0.08	0.08	0.17	0.17	0.08	0.17	0.17	0.17	0.17	0.17	0.17	0.08
	Q22	0.17	0.08	0.17	0.08	0.08	0.08	0.08	0.08	0.17	0.17	0.08	0.17	0.17	0.17	0.17	0.17	0.17	0.08

Table 9. Sensitivity analysis of time to peak adoption (yrs) in Nairobi and Lagos under negative (step-down) parameter shocks, highlighting delays and resilience in adoption dynamics.

		▼ STEP DOWN																	
		Nairobi									Lagos								
Variable Domain		Informal (Korogocho)			High-Density (Pipeline)			Low-Density (Langata)			Informal (Shomolu)			High-Density (Oworonshoki)			Low-Density (Lekki)		
	Q	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA	Sys1 Basic	Sys2 Med-Tech	Sys3 CEA
Relative Advantage for the Population	Q1	0.08	0.08	0.08	0.17	0.08	0.17	0.17	0.17	—	—	0.08	—	—	—	0.08	—	—	0.17
	Q2	—	—	—	0.08	0.08	0.08	0.08	0.08	—	—	—	—	—	—	—	—	—	0.08
	Q3	—	—	—	—	0.08	—	0.08	0.08	—	—	—	—	—	—	—	—	—	0.08
	Q4	0.17	0.08	0.17	0.25	0.25	0.25	0.25	0.33	—	0.08	0.08	—	0.08	0.08	0.17	0.08	—	0.25
	Q5	—	—	—	0.08	0.08	0.08	0.08	0.08	—	—	—	—	—	—	—	—	—	0.08
	Q6	0.75	0.75	0.75	0.83	—	0.83	0.83	0.83	0.75	0.75	0.83	—	0.75	0.75	0.75	—	0.75	—
Learnability Characteristics of the Innovation	Q7	1.17	1.17	1.17	1.25	1.25	1.17	1.25	1.25	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.25
	Q8	1.17	1.17	1.17	1.25	1.25	1.17	1.25	1.25	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.25
	Q9	0.50	0.50	0.25	0.33	0.50	0.58	0.58	0.58	0.42	0.25	0.42	0.67	0.17	0.42	0.42	0.50	0.42	0.58
	Q10	1.17	1.17	0.25	0.92	0.92	0.92	0.92	1.25	0.58	0.50	0.92	0.83	0.83	0.25	0.83	0.83	0.58	0.58
Learnability of Population	Q11	0.75	0.83	0.17	0.67	0.67	0.67	0.67	0.83	0.33	0.33	0.67	0.58	0.58	0.17	0.58	0.58	0.33	0.42
	Q12	—	—	0.58	1.25	1.25	1.42	0.58	—	1.08	0.58	0.83	1.42	0.58	1.08	1.08	0.58	1.08	1.25
	Q13	0.50	0.50	0.25	0.33	0.33	0.58	0.33	0.50	0.33	0.25	0.42	—	0.25	0.25	0.42	0.25	0.33	0.50
	Q14	0.83	0.83	0.08	0.92	0.92	0.92	0.92	—	0.83	0.92	0.92	—	0.08	0.83	0.83	0.83	0.83	0.92
Relative Advantage of the Innovation	Q15	—	—	0.08	0.08	0.08	0.08	0.08	0.08	—	—	0.08	—	0.08	—	—	—	—	0.08
	Q16	0.08	0.08	0.17	0.17	0.17	0.17	0.17	0.25	0.17	0.08	0.08	0.17	0.08	0.17	0.17	0.17	0.17	0.17
	Q17	0.08	0.08	0.17	0.17	0.17	0.17	0.17	0.17	0.08	0.08	0.08	0.08	0.08	0.08	0.17	0.08	0.08	0.17
	Q18	—	—	—	0.08	—	—	0.08	0.17	—	—	—	—	—	—	—	—	—	0.08
	Q19	0.08	0.08	0.17	0.17	0.17	0.17	0.17	0.17	0.08	0.08	0.17	0.17	0.08	0.17	0.17	0.08	0.08	0.17
	Q20	—	—	—	0.08	0.08	0.08	0.08	0.08	—	—	—	—	—	—	—	—	—	0.08
	Q21	0.08	0.08	0.08	0.17	0.17	0.17	0.17	0.17	0.08	0.08	0.17	0.08	0.08	0.08	0.08	0.08	0.08	0.17
	Q22	0.08	0.08	0.08	0.17	0.17	0.17	0.17	0.17	0.08	0.08	0.17	0.08	0.08	0.08	0.08	0.08	0.08	0.17

Sys1 (Basic): Low-cost, low-technology vertical farming systems; Sys2 (Med-tech): Intermediate technology vertical farming systems with moderate capital and operational requirements; Sys3 (CEA): Advanced controlled environment vertical farming systems; Step-up (▲): Positive shock applied to a variable (increase in parameter value); Step-down (▼): Negative shock applied to a variable (decrease in parameter value); n/a: Not applicable (parameter not relevant to the system or context); “—”: No measurable or negligible effect; Q1–Q22: Model variables grouped into 4 domains: (Characteristics of the innovation, Characteristics of the target population, Relative advantage of using the innovation, Learning of the relative advantage of the innovation. City zones under study; Informal: Low-income, high-density settlements (Korogocho, Shomolu); High-density: Planned, middle-income urban areas (Pipeline, Oworonshoki); Low-density: Higher-income, lower-density urban areas (Lekki, Langata); Cities analysed: Nairobi and Lagos. Darker orange/red cells indicate a bigger shift in the timing of peak adoption under the positive (step-up) shock — meaning adoption reaches its peak noticeably earlier than the baseline (Table 8). For Table 9, under the negative step-down shock, the same darker shading would instead indicate peak adoption occurring later than the baseline.

5. Discussion

The objective of this study was to predict how various VF systems will spread in 2 selected African cities, addressing three research questions. First, how do adoption trajectories differ across VF systems and urban contexts? Second, what mechanisms cause these adoption differences, and how do they relate to adoption magnitude and diffusion speed? Third, what context-specific leverage points can accelerate adoption? Our results reveal that predicted peak adoption ranged from 2–98% and time to peak adoption ranged from 10–25 years (Table 3). However, Shomolu requires separate interpretation. Fieldwork occurred during imminent settlement demolition, with formal demolition orders issued one month post-FGD. During the FGD period, residents faced acute displacement risk and uncertainty about tenure security. The extremely low adoption predictions for Shomolu (2% for both Medium-tech and CEA systems) likely reflect this acute displacement shock rather than stable settlement adoption potential. In comparable informal settlements with stable tenure (Korogocho, Oworonshoki), adoption predictions for complex systems (Medium-tech, CEA) range from 22% to 86%, substantially higher than Shomolu's 2%. For cross-settlement comparative analysis, Shomolu should therefore be treated as a contextually distinct “shocked case” rather than a typical informal settlement. The Adopt tool thus assists in making quantified statements about VF system diffusion compared with case studies or surveys. The findings should also be interpreted within the broader context of agricultural innovation adoption in Africa, which has historically been low [39,40]. This section explores the key issues emerging from the results, compares them with the global literature, and contextualises them within broader technology adoption theory.

5.1. Understanding Divergence Across Systems and Contexts

A central finding of this study is that settlement-level context exerts a stronger influence on VF adoption than city-level macroeconomic conditions or technology complexity. Intra-city variation was as large as Inter-city variation. Basic systems, for instance, ranged from 61–97% in Nairobi versus 16–52% in Lagos; CEA systems approached saturation in affluent neighbourhoods (Langata 98%, Lekki 95%) while remaining constrained in informal settlements (Korogocho and Shomolu <25%). This finding aligns with African technology adoption studies, which show that adoption varies more within countries than between them due to localised institutional and socioeconomic conditions [41,42].

To assess the plausibility of the projected adoption levels, we compared them with empirical evidence from related controlled-environment agriculture technologies in Africa. Observed adoption rates of comparable technologies range from approximately 25% to 52%, while willingness-to-adopt studies report values of up to 60%. Specifically, approximately 52% of sampled farmers in Ghana had adopted greenhouse farming [43], while hydroponic adoption rates of 34% and 25% have been reported in Uganda and among low-income urban farmers in Cape Town, respectively [44,45]. Furthermore, 60% of surveyed tomato farmers in Nigeria expressed willingness to adopt hydroponic systems [46]. At a regional level, Kenya accounts for approximately 63% of total horticultural greenhouse earnings in Sub-Saharan Africa [47], highlighting its position as a leading hub for controlled-environment agriculture. Notably, this aligns with the present study's findings, which identify Nairobi among the cities with the highest predicted adoption rates of vertical farming technologies. Collectively, these findings suggest that the relatively high adoption levels projected by the ADOPT model are not outside the range of diffusion observed for related innovations, particularly when considering the study's 20-year forecasting horizon, during which technological learning, cost reductions, urbanization, financing availability, and policy support are expected to further influence adoption.

However, the significance of this finding becomes clear when contrasted with resource-rich contexts. [35] applied the same ADOPT tool to model energy system adoption across three German regions, finding less than 2% variation between regions. This stark contrast, with 70+ percentage points in Lagos/Nairobi versus less than 2% in Germany, suggests that spatial heterogeneity emerges in resource-constrained contexts where constraints vary dramatically over short distances. In Germany, relatively uniform infrastructure, access to financing, and institutional support across regions create homogeneous adoption conditions [48]. In Lagos and Nairobi, informal settlements lack secure tenure and infrastructure, while affluent neighborhoods have both, creating spatially varying binding constraints that drive divergence in adoption. However, it is worth noting that whilst the ADOPT tool has been used elsewhere, ADOPT was originally developed for low-cost, triable smallholder innovations. Vertical farming, particularly capital-intensive CEA systems, represents a different technology class where trialability is limited, irreversibility is high, and observability is incomplete. Consequently, specific ADOPT parameters (particularly Ease of Trial, Q6) do not capture CEA's true trial costs, and adoption ceilings may reflect incomplete risk assessment due to irreversibility constraints. However, ADOPT's core hypotheses regarding financial access, skill availability, and perceived profitability determinants remain valid for capital-intensive technologies, as validated in irrigation technology and precision agriculture adoption research. The predictions presented here should therefore be interpreted as scenario-based diffusion forecasts conditional on ADOPT's model structure, for extreme scenarios where design simplification or major external shocks alter the capital-intensity constraints.

Another point worth considering in explaining the wide disparity in adoption results is that fieldwork in Shomolu took place shortly before demolition activities occurred in parts of the area, as mentioned before [49]. Anticipation of displacement or housing instability may have influenced respondents' perceptions of investment risk and long-term planning. As a result, responses from Shomolu may partially reflect short-term uncertainty rather than stable structural attitudes toward adoption. The modelled outcomes for this district, therefore, need to be interpreted with caution. The result, however, gives evidence about how tenure insecurity affects adoption.

The implications of the contrast above are that technology adoption models developed in resource-rich contexts often assume uniform conditions, which may limit their applicability in resource-constrained settings where local constraints vary significantly. The 70+ percentage-point variation observed is not a failure of theory but rather evidence that context-specific constraint configurations determine adoption outcomes. Scaling vertical farming and achieving the SDGs (SDG 2: Zero hunger, SDG 11: Sustainable cities) in African cities, therefore, requires settlement-differentiated interventions, not uniform programmes.

5.2. Mechanisms Shaping Adoption Ceilings and Diffusion Speed

5.2.1. Peak Adoption Magnitude: Population-Level Binding Constraints

The Adopt tool, through its sensitivity analysis, enables the identification of mechanisms shaping adoption ceilings and diffusion speed. Our study identified that adoption ceilings are determined by three population-level variables, namely Financial Capacity (Q16), Management Skill (Q17), and Environmental Orientation (Q19) (Table 2). These operate as binding constraints in resource-constrained settlements, generating 18–24 percentage-point adoption responses, while remaining non-binding in affluent settings (<5 percentage-point responses).

5.2.2. Financial Capacity

Global evidence consistently shows that limited access to finance reduces the adoption of new technologies, particularly in low-income and capital-constrained settings. Banerjee and Duflo (2011) [50] found that when farmers and small enterprises gain access to credit, adoption rates of productivity-enhancing technologies rise substantially, especially where financial barriers are severe. Similarly, [40] shows that credit interventions can increase agricultural technology adoption by approximately 25–30 percentage points in financially constrained communities, while generating only marginal improvements in areas where credit access is already adequate. These findings suggest that finance matters most in contexts with the strongest liquidity constraints.

Our findings follow a similar pattern. Improvements in financial conditions (Q16) increase the probability of vertical farming adoption by 18–24 percentage points in lower-income and financially constrained urban areas. However, the same improvements generate less than 6 percentage points in affluent urban zones such as Lekki and Langata, where households and businesses already possess relatively stronger purchasing power, savings capacity, and access to formal financial services. This difference suggests that financial constraints are not equally distributed across urban populations. In wealthier districts, access to capital is less of a limiting factor because potential adopters already have the resources needed to invest in vertical farming systems. By contrast, in lower-income areas, even small improvements in financing conditions, such as affordable loans, subsidies, or flexible payment mechanisms, can significantly increase adoption by reducing the upfront investment burden.

The broader comparison between Nairobi and Lagos further reinforces this interpretation. Kenya's (by extension, Nairobi) relatively stable macroeconomic environment, characterised by lower inflation volatility and more predictable financial conditions [51], has supported higher levels of vertical farming adoption compared to Lagos. In contrast, Nigeria's (by extension Lagos) macroeconomic instability, including exchange-rate volatility, inflationary pressures, and foreign currency shortages, raises the cost of imported inputs, equipment, and financing for vertical farming systems [52]. These conditions reduce both investor confidence and the purchasing power of potential adopters. Consequently, even when awareness and technical feasibility exist, financial instability constrains adoption by increasing investment risk and limiting access to affordable capital.

Taken together, the evidence suggests that financial capacity is a foundational determinant of vertical farming adoption in African megacities. Empirical evidence shows that imperfect credit markets significantly limit smallholder investment in productivity-enhancing technologies. [50] argue that even profitable technologies may not be adopted when households lack access to liquidity or face borrowing constraints. [40] demonstrate that relaxing credit constraints can substantially increase investment and adoption in agricultural settings.

The results indicate that policies aimed at improving access to affordable finance, such as low-interest credit schemes, equipment leasing, subsidies, and blended financing mechanisms, are likely to have the greatest impact in lower-income and financially constrained urban areas, where unmet demand for adoption is highest.

5.2.3. Management Skill

The operation of VF systems requires skills that many African countries lack [53]. Diffusion theory emphasises that the learning burden of technology suppresses adoption, particularly for complex systems [54]. Ref. [55] point out that farmer training increased complex technology adoption by 11.4–15.7 percentage points in areas with limited agricultural extension, but generated minimal gains where farmers already possessed relevant

knowledge. Our finding that Q17 improvements generate 18–24 pp adoption gains in resource-constrained settlements reflects this knowledge gap. The farmers in Korogocho and Oworonshoki show strong interest in adopting when they understand system operation, but limited access to formal training suppresses uptake. In Langata, where residents have relatively higher educational attainment and easier access to private consultants, Q17 improvements generate minimal gains; therefore, knowledge constraints are less binding. The Africa-specific policy implication is that technology scaling requires substantial investment in extension services tailored to urban contexts. This includes demonstration sites, farmer field schools, peer learning networks, and locally adapted training systems.

5.2.4. Sustainability Motivation

Global studies show that environmental values motivate technology adoption when relative advantage aligns with ecological concerns [56]. Recent work on climate-resilient agriculture and sustainable intensification emphasises that environmental motivation amplifies technology uptake when it aligns with farmer priorities [57]. As a case in point, Nairobi's environmental orientation toward water-efficient technologies may be explained in part by the severity of its water scarcity context. Demand is projected to increase at 6% annually while supply consistently falls short of demand [58]. Consequently, technologies such as vertical farming, which use significantly less water than conventional agriculture, may be perceived not only as agronomic innovations but as direct responses to a limited resource challenge, potentially raising adoption rates in Nairobi relative to cities where water stress is less acute, such as Lagos. However, in the studied informal settlements, environmental orientation (Q19) operates within a constrained context of immediate survival needs.

Our sensitivity analysis shows that improvements to Q19 generate substantial adoption gains (15–22 pp), suggesting that addressing basic livelihood security makes environmental benefits a stronger adoption motivator. This reflects that environmental motivation is not absent in low-income African populations but is suppressed by competing survival priorities. Once food security and livelihood concerns are addressed, environmental benefits (water savings, reduced chemical use, increased local food access) become significant drivers of adoption. In contrast, in affluent Langata, where survival needs are secure, Q19 improvements yield minimal gains (<5 pp) because environmental benefits are already well understood and incorporated into adoption decisions. Environmental orientation is already high; further improvements cannot increase adoption beyond structural ceilings determined by land economics and opportunity costs. The implication from this is that environmental framing of VF is effective for adoption scaling, but only when coupled with simultaneous attention to food security and livelihood outcomes. Environmental messaging alone, without addressing financial and livelihood constraints, will generate minimal adoption in resource-constrained contexts. However, our results also show that negative shifts in perceived environmental benefits reduce adoption more sharply than positive shifts increase it, consistent with loss aversion dynamics [59].

In summary, interventions must address all three constraints simultaneously to increase the adoption ceiling. Credit alone fails without management capacity; environmental messaging fails without livelihood security, especially in resource-constrained settings.

5.3. Diffusion Speed: Innovation-Level Attributes

The ADOPT tool's sensitivity analysis identified four key innovation-level factors driving diffusion speed, namely Complexity (Q7), Trialability (Q6), Observability (Q8), and Training Requirements (Q12). Our study established that across all sites, these factors reduced time-to-peak adoption by 1.2–1.4 years.

5.3.1. Complexity (Q7) and System Learnability

The Diffusion of Innovations framework states that technological complexity slows adoption by increasing learning burdens [56]. According to his framework, simpler technologies therefore diffuse faster than complex ones, regardless of context. Our finding that complexity reduction generates a 1.2–1.4-year acceleration in both resource-constrained and affluent settlements [56] is a universality claim. Innovation complexity has been widely identified as a barrier to the diffusion of agricultural technology in Africa, as farmers often face labour, knowledge, and resource constraints when implementing new practices [60]. These findings suggest that reducing technological complexity should be a key policy priority for accelerating VF adoption in African cities. Policymakers and developers should promote simple, user-friendly, and locally adapted systems supported by practical training, demonstration sites, and extension services. Improving system learnability and reducing technical burdens could significantly shorten adoption timelines, particularly in resource-constrained urban communities.

5.3.2. Observability

Our sensitivity analysis shows that observability improvements accelerate adoption by ~1.3 years across all sites, confirming this mechanism. In Zimbabwe, irrigators ranked observability as the single most important determinant of adoption, with farmers citing direct observation of neighbours' transformed work practices as the primary motivator [61]. One may conclude that observable innovations whose benefits are visible to potential adopters diffuse faster because they reduce perceived risk through demonstration [56].

Threshold dynamics could also further clarify the observability dimension [62]. This concept suggests that adoption does not increase linearly but depends on reaching a critical mass of adopters. Individuals are more likely to adopt once they observe others doing so, as this reduces uncertainty and perceived risk. As shown by [63], such threshold-based behaviour can lead to sudden shifts in adoption, where small changes in conditions trigger disproportionately large increases in uptake. In high-sensitivity Nigerian sites, diffusion appears stalled below critical mass. Modest constraint relaxation can trigger expansion, consistent with collective behaviour threshold models [63], as others adopt the innovation upon seeing those who have already adopted it. These findings suggest that policies aiming to accelerate VF adoption should prioritize visibility and demonstration effects. Governments, NGOs, and private actors should invest in pilot projects, demonstration farms, and community-based learning platforms that allow potential adopters to directly observe the benefits of VF systems.

5.3.3. Trialability

Technologies allowing small-scale trial adoption diffuse faster because they reduce perceived risk [56]. In developed-country contexts, this often means pilot programs or subsidised trial periods with professional support. Our finding that trialability improvements accelerate adoption by ~1.2 years confirms this mechanism.

As a case in point, in Zimbabwe irrigation schemes, trialability ranked as the second most important adoption attribute alongside observability, with farmers citing willingness to experiment on small plot areas before full-field adoption [61]. The trialability mechanism operates through three channels. First, risk reduction via small-scale testing. For example, Ethiopian divisible seed packages increased wheat adoption by allowing poor farmers to test with lower capital requirements [64]. Second, knowledge gain through learning-by-doing under farm-specific conditions. One example is on-farm trials in Senegal and the Gambia, which allowed farmers to test technologies alongside traditional practices,

reducing perceived risk [65]. Finally, peer demonstration effects occur when successful trials become visible, directly converting trialists into model farmers advocating adoption [66].

5.3.4. Leveraging Framework: Speed Versus Adoption Level

The sensitivity analysis for the Lagos and Nairobi sites reveals that the intervention choice should begin with diagnosing the policy bottleneck. That is, does the site face an adoption ceiling problem (too few farmers adopting) or a diffusion speed problem (farmers adopt slowly even when interested)? These situations will require fundamentally different leverage strategies.

5.3.5. Leverage for Adoption Level (Ceiling Expansion)

Leveraging for adoption level applicable mostly for resource-constrained contexts entails examining the population-level variables Q16 (Financial Capacity): 12.5–23.2% step-up/5.6–15.5% step-down, Q17 (Managerial Skill): 9.1–20.5% step-up/4.8–14.2% step-down, and Q19 (Environmental Orientation): 4.4–9.3% step-up/2.1–4.9% step-down. Nairobi has significantly higher adoption levels than Lagos in most categories. Financial support still matters in Nairobi, but its marginal effect declines. [67] observes that once affordability improves beyond a certain threshold, additional subsidies do not significantly increase adoption. This means that Lagos must come up with financing leveraging strategies such as phased payment models, reduced upfront burdens, tied credit, or cooperatives. However, examples of financial capacity interventions show that financial leveraging alone may be inadequate. For example, Rwanda's microfinance plus extension achieved 35% adoption, compared with 8–12% for credit alone [68]. Therefore, efforts to increase adoption should also consider environmental orientation and management skills, rather than finance alone.

5.3.6. Leverage for Diffusion Speed (Acceleration)

Leveraging for diffusion speed applies mostly to regions where adoption ceilings are already high or approaching saturation, but diffusion is slow. Our results show that Nairobi peak adoption levels range from 61% to 98%, compared to 2% to 95% in Lagos sites. However, diffusion in Nairobi remains protracted, with peak adoption ranging between 12 and 21 years. Studies have shown that farmers are substantially less likely to adopt technologies they find difficult to understand, regardless of potential benefits. [69]. Here, the bottleneck shifts from affordability to usability. Adoption responds more strongly to reductions in technical complexity and improvements in system design. When systems are modular, easier to install, and simpler to operate, diffusion accelerates [70]. The results also show that interventions in observability delay adoption by 1.17 to 1.25 years across the various systems. Evidence from the Great Lakes region in Africa shows that longer membership duration in farmers' groups resulted in shorter adoption lags, especially when combined with extension service delivery [71].

5.3.7. Leveraging in High-Value Land Markets Where Opportunity Cost Overrides Entrepreneur Finance

In affluent areas such as Lekki, land value appears as the dominant constraint on vertical farming adoption. Here, vertical farming competes with alternative land uses that may offer higher financial returns, shifting the analytical focus from entrepreneur-level barriers to structural urban economics. [72] document this same phenomenon in Melbourne, Australia, where the average land cost per square metre in the city centre is \$3491, compared to just \$0.40 in rural areas. This huge difference makes urban real estate values a primary driver of capital expenditure, regardless of entrepreneurial capacity or available finance. Even where entrepreneurs have sufficient capital and managerial skills, the opportunity cost of allocating premium land to food production erodes adoption incentives. [72] caution,

however, against a single-lens view, arguing that localised production near high-density population centres can substantially reduce transportation costs and may partially offset the land cost penalty.

The above discussion implies that vertical farming is economically viable primarily where it can compete with alternative land uses on financial terms, or where it is located in spaces with low opportunity costs. Global evidence supports this logic. Research from British Columbia revealed that competing land-use priorities and competitive commercial real estate markets were among the chief barriers to the adoption of vertical agriculture. Operators are forced to compete directly with warehousing and industrial sectors for the same building stock [27]. In addition, research on urban development potential identifies repurposing fallow land, old buildings, and areas unsuitable for competing uses as the most viable location strategies for vertical farming [73]. Existing vertical farms in North America also demonstrate this logic in practice, with operations established in abandoned warehouses and derelict sites where land economics are more favourable [74]. Literature on building-integrated vertical farming has further highlighted underutilised indoor spaces as productive zones. These zones can add rental value for property owners while simultaneously enabling food production, thereby converting a spatial liability into a co-benefit [75].

Some leading megacities reinforce this spatial logic. Singapore, for instance, has moved to offer entrepreneurs greater flexibility in land-use restrictions, targeting ways to overlap agricultural uses with commercial and residential classifications [76]. Carpark rooftops reused outdoor spaces, and retrofitted building interiors have become central to Singapore's domestic food production strategy [77]. The same applies to Sunqiao Urban District in Shanghai and Farm One in Brooklyn; similarly, vertical farming is embedded into spaces where agricultural use does not directly displace higher-value competing functions. [78].

Across sub-Saharan Africa, as cities continue to expand, agricultural land is increasingly converted into residential and commercial developments. This expansion threatens urban and peri-urban agriculture despite its recognized importance for food security and urban resilience [79]. Meanwhile, only 3.62% of sub-Saharan African countries have implemented national urban policies with a meaningful focus on integrating urban farming [80], leaving food production systems with virtually no policy protection against competing land uses.

In markets with high land values, zoning flexibility, rooftop integration policies, and land-use incentives thus have greater leverage than direct subsidies. The constraint is not affordability but spatial competition. This conclusion highlights that adoption models in megacities must integrate land economics. Without considering opportunity cost, policy interventions risk addressing the wrong bottleneck.

5.3.8. Policy Recommendations

Effective scaling of vertical farming in African megacities requires context-specific policy interventions aligned with distinct settlement constraints and adoption sensitivities identified in the analysis. In informal settlements, where adoption is highly responsive to financial and skill-related constraints, policy should prioritize affordability and capacity building. Key interventions include targeted microfinance schemes for Basic systems, intensive hands-on extension services, short-term land tenure guarantees for community demonstration farms, bundled solar-energy solutions to address power constraints, and strengthened local market aggregation mechanisms. These measures collectively address binding financial, technical, and tenure barriers that suppress adoption in these contexts.

In high-density settlements, adoption is primarily constrained by space limitations and market coordination failures. Policy priorities should focus on enabling space-efficient

system designs (e.g., rooftops and vertical installations), supportive zoning regulations, structured market linkages with institutional buyers, development of local technical service providers, and contract-based financing models tied to guaranteed offtake. These interventions enhance system feasibility while improving market access and operational reliability.

In low-density affluent areas, adoption is less sensitive to financial constraints and more dependent on regulatory conditions and investment incentives. Priority measures include zoning reforms to enable urban agriculture, public–private partnerships with real estate developers, investment incubation for commercial-scale vertical farms, premium market development strategies, and targeted fiscal incentives to improve investment returns.

Across all contexts, cross-cutting strategies are essential. These include establishing demonstration sites before scale-up, strengthening institutional and technical capacity, ensuring market integration as a precondition for adoption, promoting financially viable business models rather than subsidy dependence, and implementing adaptive monitoring systems. Effective rollout further requires sequencing interventions appropriately: addressing financial and skills constraints in informal settlements, market development in high-density areas, and regulatory enablement in affluent areas. A detailed matrix linking settlement types, key constraints, and corresponding intervention points is provided in the supplementary Material S4. This matrix synthesizes the context-specific barriers and policy responses outlined above, and supports the differentiation of strategies across informal, high-density, and low-density affluent settlements [81–97].

5.3.9. Limitations and Future Research

The ADOPT model generates deterministic point estimates conditional on farmer-elicited parameters and site characteristics. The predictions are therefore subject to three distinct sources of uncertainty that warrant explicit recognition.

5.3.10. Parameter Uncertainty

Farmer-elicited inputs (Financial Constraints, Environmental Orientation, Management Skills, Complexity, Observability, Training Requirements) are measured on bounded 0–10 ordinal scales. This approach reduces continuous heterogeneity to discrete categories and does not quite capture disagreement among respondents, while aggregation masks within-site variability. As a result, adoption magnitude estimates for individual site–system combinations carry an implicit uncertainty of approximately ± 15 –20 percentage points, while time-to-peak adoption estimates carry an uncertainty of ± 2 –3 years. Accordingly, differences in predicted adoption below ~ 15 percentage points should be interpreted as within the margin of uncertainty, whereas differences exceeding ~ 30 percentage points reflect robust contextual divergence.

5.3.11. Structural Uncertainty

The model assumes monotonic S-shaped diffusion trajectories, which may not fully capture real-world adoption dynamics. Actual diffusion may deviate due to non-monotonic adoption paths (e.g., early abandonment), external shocks (e.g., energy price volatility, policy changes, or competing technologies), and unobserved contextual variables not included in the ADOPT parameter set. The Shomolu case illustrates this limitation, where the very low Medium-tech adoption prediction (2%) coincides with documented impending settlement demolition during the data collection period. Such tenure insecurity and displacement risk are factors not explicitly represented in the model. In addition, the extremely low predicted values in constrained contexts (e.g., Shomolu and Korogocho) may reflect either slow convergence to a low equilibrium, structural infeasibility of the technology–context pairing, or omitted barriers that render adoption economically irrational. In the absence

of longitudinal validation from comparable African settings, these mechanisms cannot be empirically distinguished.

5.3.12. Elasticity Regime Differentiation

Sensitivity analysis further indicates strong context-dependent elasticity. Financial constraints produce large marginal effects in constraint-bound contexts (18–24 percentage points in Oworonshoki and Korogocho), moderate effects in intermediate contexts (10–18 percentage points), and minimal effects in affluent contexts (<5 percentage points in Langata). Moreover, negative shocks exhibit larger absolute impacts than positive changes, with the removal of Environmental Benefit reducing adoption by up to 26.3 percentage points in Korogocho. This asymmetry suggests that adoption ceilings are more vulnerable to adverse conditions than they are expandable through equivalent improvements. These elasticity regimes are derived from six urban sites and should therefore be interpreted as context-specific rather than universally generalisable.

While vertical farming profitability and business model structures are critical to long-term scalability, these aspects fall outside the scope of the present study, which focuses on adoption dynamics using the ADOPT framework. However, we acknowledge that limited empirical evidence currently exists on viable profit models for vertical farming in African urban contexts, and this remains an important area for future research.

In addition, the model shows which constraints matter but does not reveal the human dimensions behind adoption, such as gender dynamics, differences in risk perception, informal network influence, or entrepreneurial aspirations. These factors may shape adoption pathways in ways that structured variables cannot fully reflect. For instance, informal networks and social capital are significant drivers of technological improvements and adoption, with marital status, religion, and informal networks shown to shape women's participation in agricultural technology choice decisions [79]. A case in point is the gendered studies on innovation practice focusing on how marital status influences women's capacity to innovate in their rural livelihoods in Ethiopia [80]. Future work incorporating gender-disaggregated data and social network analysis would provide a more nuanced understanding of who adopts, and under what conditions.

A key limitation of this study relates to the selection of participants in the focus group discussions. Participants were purposively selected based on their involvement in or knowledge of urban agriculture and related activities, as required for the elicitation of informed ADOPT parameters. While this approach is appropriate for scenario-based diffusion modelling, it may introduce a degree of positive bias in the estimated adoption potential, as individuals already engaged in urban agriculture may be more familiar with, and potentially more receptive to, controlled-environment farming technologies than the general urban population. Consequently, the parameter estimates may reflect informed stakeholder perspectives rather than the attitudes of the broader population in Lagos and Nairobi. The results should therefore be interpreted as context-specific adoption scenarios derived from knowledgeable respondents, rather than population-representative forecasts.

A further limitation is the case study's scope, which focuses on only two cities. While these cases were selected to reflect contrasting socioeconomic conditions, they cannot capture the full diversity of institutional, economic, and infrastructural environments across African cities. Urban systems in Africa are highly heterogeneous, differing significantly in governance structures, market development, infrastructure provision, and levels of informality. As a result, adoption dynamics observed in one context may not translate directly to others.

Taken together, these uncertainties imply that the ADOPT outputs are more robust for comparative interpretation (i.e., relative differences across technologies and contexts)

than for precise point forecasting. The consistency of key macro-patterns, namely, diffusion horizons of 10–25 years and uniformly low 5-year adoption (<50%), is considered robust, whereas exact adoption percentages for individual site–system combinations should be interpreted with moderate confidence. Very low estimates (<5%) carry lower confidence due to potential structural ambiguity. Overall, the results should be treated as scenario-based diffusion pathways rather than precise forecasts, supporting adaptive and comparative policy interpretation rather than deterministic prediction.

5.3.13. Future Research

Further investigation should prioritise longitudinal validation of modelled adoption trajectories using real-world vertical farming initiatives. Specifically, panel studies tracking adopters and non-adopters over time could generate valuable empirical data on actual uptake and the persistence of adoption. Additionally, subsequent research could complement structural modelling with qualitative and mixed methods approaches, such as ethnographic interviews, in-depth case studies, and participant observation, to directly examine entrepreneurial motivations, risk narratives, and informal institutional dynamics. Gathering primary data from household surveys, community organisations, and urban farming networks would help illuminate who adopts and why, thereby deepening the interpretation of the constraint-based findings. Future research could strengthen generalizability by incorporating a broader set of cities or by combining modelling approaches with empirical validation across diverse institutional settings.

Finally, future studies could integrate adoption analysis with business-model performance by using financial records, supply chain assessments, and farmer income data from ongoing vertical farming projects. This would strengthen understanding of long-term sustainability, market viability, and the broader impacts of vertical farming integration in diverse urban contexts.

6. Conclusions

Our results from the Adopt tool provide an important benchmark for understanding the potential diffusion of vertical farming (VF) systems in African cities. The findings support established views that innovation characteristics, institutional support, and user capacity strongly shape adoption. They also highlight the importance of the urban context in determining the magnitude of adoption and the speed of diffusion. However, the findings also challenge uniform-scaling narratives. Rather than assuming that subsidies or technological improvements alone will drive adoption, the study shows that leveraging shifts depending on which constraints bind. Financial resources, managerial capability, and environmental orientation relative importance redistributes across contexts. Recognizing this redistribution is key to effective intervention design.

Theoretically, the study contributes by integrating constraint diagnostics, innovation diffusion theory, and urban land economics within an ADOPT-based modelling framework. It advances a context-sensitive understanding of the diffusion of sustainability innovation in fast urbanising environments, showing that adoption determinants are not constant but structurally conditional. By distinguishing between factors that shape adoption ceilings and those that influence diffusion speed, the study adds analytical clarity to adoption modelling in emerging megacity contexts.

In sum, vertical farming may take root in African megacities, maybe more effectively, where strategies correspond to local constraints. Its future is not determined solely by technical feasibility, but by how well interventions respond to the economic, spatial, and behavioural realities of each urban context.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Abbreviations

The following abbreviations are used in this manuscript:

ADOPT Tool	Adoption Diffusion Outcome Prediction of Technology Tool
CEA	Controlled Environment Agriculture
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ICLEI	International Council for Local Environmental Initiatives
RUAF	Resource Centres on Urban Agriculture and Forestry
VF	Vertical farming

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