RESEARCH ARTICLE

Farming Upward: The TsingSky Guangzhou Future Agriculture Cluster as a County-Level Model for Context-Specific Smart Agriculture

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Abstract

Against the backdrop of global food-security concerns, climate change, farmland constraints, and accelerating urbanization, modern agriculture is shifting from a land-dependent model toward a new paradigm shaped by spatial reconfiguration, energy integration, advanced equipment, and digital intelligence. Food systems account for a large share of anthropogenic greenhouse-gas emissions, making low-carbon transformation a central issue. Projected global food demand and hunger risk highlight the need for both productivity and resilience. Emissions from long-distance transport also suggest that localized production near consumption centers deserves greater attention. Taking the TsingSky Guangzhou Future Agriculture Cluster as its central case, this article explores how county-level demonstration projects can serve as anchors for context-specific smart agriculture. Smart agriculture should be understood not merely as the application of sensors or data platforms, but as the creation of sustainable, replicable, and industrialized systems adapted to local conditions. Controlled-environment agriculture offers a promising pathway for high-yield, resource-efficient, climate-resilient production, but its viability depends on energy efficiency, cost structure, and system integration. The TsingSky Guangzhou Sky Farm redefines agricultural space by utilizing approximately 50 mu of factory rooftop area and integrating residual industrial heat, shallow-water source heat pumps, agricultural R&D, and intelligent equipment manufacturing into a unified county-level platform. This model preserves farmland, supports production near consumer markets, reduces pest and logistics pressures, improves spatial efficiency, and enhances economic performance. More importantly, it shows how a single demonstration project can evolve into a future agriculture cluster through integration of production, research, manufacturing, training, branding, and low-carbon energy systems.

Keywords: smart agriculture, controlled-environment agriculture, sky farm, county-level development, agricultural cluster, context-specific development, low-carbon agriculture, integrated rural industries.

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1 Introduction

Modern agriculture is entering an era in which land is no longer the only decisive production factor. Space, energy, industrial infrastructure, equipment capability, data systems, and regional market access are becoming equally important. In many regions, especially where farmland is limited and urban-industrial development is accelerating, agriculture must evolve beyond traditional ground-based expansion. The question is no longer whether agriculture can become intelligent, but how it can become intelligently localized.

This shift must be understood within the broader transformation of global food systems. Food-system emissions have become an important component of global climate-change mitigation discussions [1]. Future food demand and hunger risks also indicate that agricultural systems must become more productive, resilient, and resource efficient [2]. In addition, food miles-related emissions demonstrate that the spatial organization of production and consumption is not a secondary issue but a structural issue in food-system sustainability [3].

Controlled-environment agriculture, including modern greenhouses, plant factories, hydroponic systems, and vertical farms, has emerged as one possible response to these pressures. Vertical farming systems are often discussed as a way to produce fresh food near urban consumers while using less land and water than conventional agriculture [4]. However, recent reviews also show that controlled-environment agriculture faces major challenges related to energy use, profitability, crop diversity, automation, and public acceptance [5]. Therefore, controlled-environment agriculture should not be treated as a universal technological solution. Its value depends on whether it can be adapted to local resource conditions and integrated into a workable economic system.

The TsingSky Guangzhou Sky Farm offers one possible answer. It moves agriculture upward, connects it with local industry and energy systems, and uses a demonstration project to build a scalable county-level ecosystem. The project is not only a rooftop farm. It is a platform that integrates production, research, equipment testing, intelligent manufacturing, energy coupling, talent training, and market connection. This article uses the TsingSky Guangzhou Future Agriculture Cluster as a case to examine how county-level smart agriculture can be built from local adaptation rather than mechanical replication.

2 Why County-Level Smart Agriculture Must Begin with Local Adaptation

In the transition toward modern agriculture, many regions are promoting smart agriculture, digital agriculture, and controlled-environment production. Yet the projects that endure are not necessarily those with the largest amount of technology. They are usually those most closely aligned with local resources, industrial foundations, energy conditions, labor structures, and market demand. The true basis of county-level smart agriculture is therefore not technological sophistication alone, but systemic suitability. Two common mistakes often appear in agricultural planning. The first is mechanical replication: copying models that succeeded elsewhere without adapting them to local realities. The second is an excessive focus on high-tech concepts while ignoring energy costs, spatial efficiency, logistics radius, operating capability, and industrial linkages. Such projects may create impressive demonstrations in the early stage, but they often struggle to remain viable. A systematic review of controlled-environment agriculture research shows that the field has developed rapidly, but socio-economic dimensions remain less studied than technical topics such as lighting and plant growth [6].

In this sense, "local adaptation" is not a traditional slogan. It is the foundational method of modern controlled-environment agriculture. A county-level smart agriculture demonstration site should begin with local resource conditions and evolve into a scalable industrial cluster.

For counties, the most valuable form of smart agriculture is one that can integrate local waste heat, geothermal resources, rooftop space, nearby consumer markets, and relevant industrial chains into a coherent production model. Local adaptation is not a traditional slogan. It is the foundational method of modern controlled-environment agriculture.

3 From Single Projects to a Regional Method: TsingSky's Place-Based Practice

The TsingSky system's projects in different regions illustrate a shared direction implemented through different pathways. Rather than replicating a uniform template, each project is reconfigured around the most valuable local resource conditions. In Xinxiang, Henan Province, the TsingSky Mengdian Negative-Carbon

Vegetable Factory is built around power-plant waste heat and carbon dioxide (Figure 1). It couples industrial by-products with modern vegetable production, showing that energy and emissions from conventional industry can be transformed into agricultural inputs (Figure 2). The logic of agro-industrial symbiosis is also supported by recent research on alternative heating systems for greenhouse production [7].

Figure 1. TsingSky Mengdian Vegetable Factory.

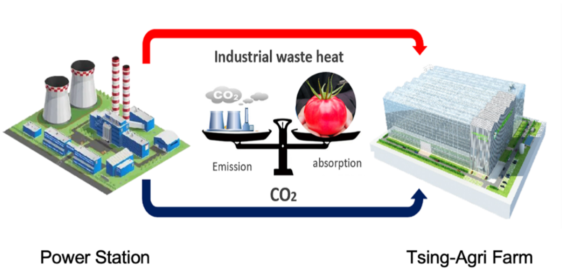

Figure 2. New planting models integrating industrial by-products with modern vegetable production systems.

In the TsingSky Jiaotong Vegetable Factory, geothermal energy plays a similarly foundational role. The project does not simply construct a standard greenhouse. Instead, it incorporates geothermal conditions into thermal design, energy structure, and year-round production strategy. Research on ground-source heat-pump systems for horticultural greenhouses suggests that local geothermal and ground-source conditions can become part of greenhouse energy design when site conditions are properly assessed [8].

The TsingSky Guangzhou Future Agriculture Cluster extends this logic further. Rather than relying on conventional ground-based expansion, it moves agriculture upward. By using approximately 50 mu of factory rooftop space for a sky farm and combining that space with factory waste heat, shallow-water source heat pumps, agricultural equipment manufacturing, scientific research, and pilot testing, the project creates a new county-level industrial unit in which agriculture, industry, energy, and innovation become mutually reinforcing (Figure 3).

Figure 3. TsingSky Guangzhou Future Agriculture Cluster.

4 Farming Upward: The Spatial Innovation of the TsingSky Guangzhou Sky Farm

The most significant innovation of the TsingSky Guangzhou Sky Farm lies in its redefinition of agricultural space. Historically, agriculture has depended on ground-based land. The sky farm transforms industrial rooftops, previously secondary or underused spaces, into high-value agricultural production platforms. For regions under pressure to protect farmland, yet rich in industrial space and close to consumer markets, this model is highly practical.

First, the sky farm does not occupy conventional farmland. In many counties, tensions exist among farmland protection, urban expansion, industrial development, and the growth of high-value agriculture. The sky farm helps resolve this tension by introducing a new spatial division of labor: quality farmland remains dedicated to grain and basic agricultural security, while vegetables, fruits, flowers, and other high-value crops move into rooftop facilities and intelligent controlled environments. A global review of rooftop agriculture cases shows that rooftop farming is increasingly used as a building-based urban agriculture strategy to address land access, food security, and climate-related concerns [9].

Second, the sky farm brings food production closer to consumers. Rooftop agriculture is especially suited to industrial parks, peri-urban areas, and locations with convenient transportation access. This allows harvesting, sorting, packaging, and delivery to be completed more quickly. For premium fresh produce, shorter supply chains mean better freshness, greater food safety, lower cold-chain pressure, and reduced post-harvest losses. Research on global food miles shows that transport-related emissions are a significant part of food-system emissions, which strengthens the case for production models located closer to consumption centers [3].

Third, elevated production environments have distinctive environmental advantages. Because they are less exposed to the complex conditions of ground-level ecosystems, pest pressure may be lower. Rooftops can also provide good light conditions, depending on surrounding buildings and structure design. When combined with digital climate control, integrated water-and-fertilizer systems, soilless cultivation, and AI-based crop monitoring, agriculture can move from experience-driven management to standardized, precise, and predictable production (Figure 4). A meta-analysis of urban agriculture indicates that urban production can contribute meaningful food output when yields and spatial conditions are realistically evaluated [10].

Figure 4. Cherry Tomatoes in TsingSky Guangzhou Sky Farm.

In this sense, the sky farm is not only a physical relocation of agriculture. It is a change in the way agriculture uses space. It allows counties to protect farmland while creating new agricultural production capacity in industrial and urban spaces. It also allows agriculture to become visible, visitable, and integrated into the urban landscape.

5 From Production to Research to Manufacturing: The Full Structure of a Future Agriculture Cluster

The significance of the TsingSky Guangzhou Sky Farm does not lie only in the spatial innovation of rooftop cultivation. Its deeper value lies in the way it works together with the agricultural science and innovation center and the integrated equipment manufacturing platform to form a composite agricultural industry platform. Traditional agricultural projects often serve only one core function. They are usually planned as production bases. The Guangzhou platform, by contrast, was designed from the outset as a comprehensive platform for future agriculture.

On the production side, the sky farm serves as a high-standard platform for the controlled cultivation of high-quality and high-value crops. Supported by rooftop space, intelligent climate control systems, integrated water-and-fertilizer systems, and soilless cultivation, the platform can produce premium tomatoes, strawberries, leafy greens, muskmelons, small watermelons, flowers, and other crops in a stable way. This production model differs from traditional cultivation because it emphasizes standardization, controllability, and continuity. A recent meta-analysis comparing controlled-environment production systems with conventional systems found that controlled-environment systems can achieve higher yields, although they often require greater energy input [11].

The value of the production side goes beyond the crops themselves. It also creates a real, continuous, and verifiable application scenario for agricultural technology. Many agricultural technologies, equipment systems, and digital tools may appear effective under laboratory conditions. However, once they enter continuous production environments, they often face adaptation problems caused by more complex variables. The sky farm provides exactly this kind of technical validation space within a real production setting.

On the research side, the functions carried by the TsingSky Guangzhou Sky Farm and its supporting agricultural science and innovation center are even more important in the long term. Once agriculture enters a stage defined by facilities, digital systems, and equipment, research is no longer an external support function. It becomes a central part of long-term competitiveness. Digital twins are increasingly discussed as tools for simulating, monitoring, and optimizing agricultural systems [12].

The platform can support continuous work in varietal screening, cultivation model optimization, digital agriculture system validation, environmental-control model improvement, pilot testing of energy-saving materials, adjustment of water-and-fertilizer strategies, and pest-warning systems. In other words, the platform does not only produce current products. It improves the methods through which production takes place. A review of digital twins in greenhouse horticulture shows that greenhouse applications are already moving toward data-driven monitoring, control, and predictive decision support [13].

On the manufacturing side, the integration of an equipment manufacturing platform further deepens the project's industrial value. Future agriculture cannot depend forever on fully outsourced equipment and external system integration. Such dependence increases cost and limits the speed of technical iteration and application adjustment. The TsingSky Guangzhou Future Agriculture Cluster brings intelligent agricultural equipment, sensor systems, robotics applications, environmental-control modules, and greenhouse support equipment into one platform for testing, validation, and display (Figure 5).

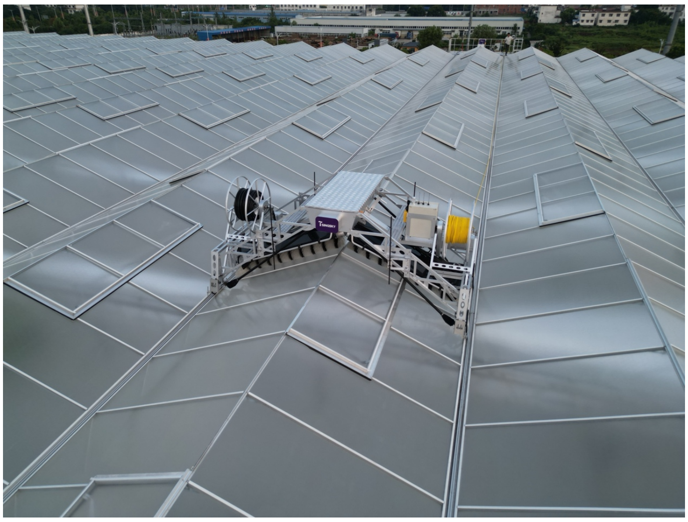

Figure 5. TsingSky's self-developed glass washing machine.

This manufacturing structure has two important meanings. First, it serves the farm itself. The sky farm does not only use equipment in one direction. It also creates direct feedback and practical demand that help improve the equipment. Second, it serves a wider regional market. Intelligent agricultural equipment that has been tested and validated locally is more likely to develop into standardized products and system solutions that can be supplied to nearby counties, industrial parks, and controlled-environment agriculture projects. Reviews of greenhouse robots show that automation can help reduce repetitive labor and improve protected-cropping operations [14].

Traditional agricultural projects often focus mainly on output volume. By contrast, the three-part structure of production, research, and manufacturing in the TsingSky Guangzhou Future Agriculture Cluster focuses on system capacity. The platform does not produce only agricultural goods. It also produces standards, equipment, technical solutions, scenario-validation capacity, service capacity, and talent systems. Its value no longer ends with one cycle of cultivation revenue. It extends into technology revenue, equipment revenue, service revenue, and brand revenue.

6 Digital Intelligence and the Shift from Experience-Based Farming to System-Based Operation

Smart agriculture is often misunderstood as the simple installation of sensors or the use of a digital dashboard. In practice, digital agriculture becomes valuable only when it changes production decisions, reduces uncertainty, and improves operating efficiency. For controlled-environment agriculture, digital intelligence should support crop growth monitoring, microclimate prediction, irrigation control, energy management, disease warning, labor scheduling, yield forecasting, and cost accounting.

Deep learning has already been applied to crop monitoring, stress detection, irrigation, microclimate prediction, energy-efficient control, and crop-growth prediction in controlled-environment agriculture [15]. This indicates that the future competitiveness of facility agriculture will increasingly depend on the ability to collect, process, interpret, and apply data in real production conditions.

For the Guangzhou Sky Farm, digital systems should not only monitor plant growth. They should connect production, energy, equipment, labor, maintenance, logistics, and finance into a unified operating system. For example, climate-control data should relate to energy cost. Labor data should relate to crop operations such as pruning, harvesting, lowering, twisting, and crop protection. Water-and-fertilizer data should be connected with yield, quality, and cost per kilogram. Maintenance data should be connected with equipment life-cycle management.

This is why the sky farm should be understood as an agricultural operating system rather than a simple greenhouse. In the future, the project can accumulate crop recipes, energy strategies, equipment maintenance records, pest-warning models, and labor-performance data. These data assets can then become the basis for replication across other counties. Digital intelligence therefore has value not only at the farm level but also at the cluster level.

7 Energy Integration and Low-Carbon Development: The Cost Logic of County-Level Smart Agriculture

If controlled-environment agriculture is to become a sustainable, replicable, and scalable industry, it must first answer a practical question: cost. Whether the project takes the form of a greenhouse, a plant factory, or a rooftop sky farm, early construction often attracts public attention. However, the factor that truly determines whether such a project can operate for the long term, expand in scale, and move toward industrialization is not technology alone. The deeper question is whether its cost structure is reasonable and whether its operating model is sustainable.

The TsingSky Guangzhou project offers an important lesson. Agricultural energy systems should not be designed in isolation. They should be coordinated with local industrial conditions, building conditions, and regional energy structures. The project combines factory waste heat with shallow-water source heat pumps to build a more flexible and efficient energy support system. Research on waste-heat utilization from data centers to ecological farms shows that surplus heat can be assessed from technical, economic, and environmental perspectives as a resource for agricultural systems [16].

The value of this kind of energy integration lies not only in saving cost. It also changes the underlying logic of controlled-environment agriculture. Many people have traditionally viewed controlled agriculture as a sector defined by high technology and high energy use. This has raised concerns about long-term economics. However, if agriculture can actively connect with local energy systems and make use of industrial waste heat, geothermal resources, shallow water energy, building thermal conditions, or broader regional energy networks, then controlled-environment agriculture no longer needs to bear high energy pressure in a passive way.

Heat-pump systems also have practical relevance for greenhouse energy design. A study on air-to-water heat-pump modeling for greenhouse heating shows that heat-pump performance can be simulated and validated for greenhouse applications [17]. This supports the argument that heating and cooling design should be treated as a core component of greenhouse engineering rather than as an auxiliary system added after construction.

Beyond direct cost reduction, this kind of energy integration creates clear low-carbon value. Agriculture is increasingly being evaluated through green development, carbon reduction, and sustainable investment. If a controlled-environment agriculture project focuses only on output but cannot explain whether its energy sources are clean, whether its resource use is efficient, or whether carbon emissions per unit of product are under control, it may face pressure in future policy and market environments. By contrast, if a project can use local resources such as waste heat, geothermal energy, or water-source heat pumps, and if it can improve energy efficiency through intelligent control systems, its low-carbon profile becomes much clearer.

8 Environmental Assessment and the Need for Realistic Evaluation

Controlled-environment agriculture is often promoted as sustainable because it can save land and water, reduce pesticide use, and produce food close to consumers. However, a serious evaluation must also consider energy consumption, construction materials, equipment life cycles, electricity mix, crop type, packaging, and logistics. The environmental performance of CEA is not automatically superior. It depends on system design. A life-cycle assessment of a large-scale commercial vertical farm found that environmental performance depends strongly on electricity use, system boundaries, packaging, and comparison products [18]. This suggests that future agriculture projects should avoid simple slogans and instead build transparent evaluation systems.

A Finnish case study comparing lettuce production in vertical farming and greenhouse production found that renewable energy and waste-heat recovery can strongly affect climate-change impact and resource-use efficiency [19]. This finding is highly relevant to the Guangzhou project because its logic is not to build an isolated high-energy system, but to combine rooftop agriculture with local energy integration.

A 2025 life-cycle assessment of controlled-environment hydroponic lettuce also shows that fully controlled hydroponic systems can have high energy consumption, especially due to artificial lighting, while open-field systems may have higher impacts in other categories such as pesticides, land, and water [20]. Therefore, the correct question is not whether controlled agriculture is always better or worse. The correct question is under what energy structure, crop structure, climate conditions, and market radius it becomes environmentally and economically reasonable.

Recent research on indoor farming also emphasizes that high energy consumption remains a major challenge for systems designed to shorten supply chains [21]. This means that any future replication of the Guangzhou model should begin with careful energy, economic, and operational calculations.

The TsingSky Guangzhou Sky Farm responds to this challenge by emphasizing natural light, rooftop space, local energy coupling, controlled hydroponics, and short-distance market access. This combination does not eliminate the need for life-cycle assessment, but it creates a stronger foundation for improved environmental performance.

9 Integrated Industries and Urban Value: A Sky Farm Is More Than an Agricultural Facility

Traditional agricultural projects are often understood as relatively simple forms of production. Their main function is to grow crops, raise animals, or supply primary agricultural products. As a result, many people still judge agricultural projects mainly by output volume, land area, and sales revenue. However, with the rise of controlled-environment agriculture, digital agriculture, and scenario-based agriculture, the functional boundaries of agricultural projects are expanding.

From the perspective of industrial structure, the sky farm naturally supports the integration of primary, secondary, and tertiary industries. Agricultural production itself belongs to the primary sector. However, once agriculture enters a stage defined by facilities, digital systems, and branding, it begins to extend into the secondary and tertiary sectors. The TsingSky Guangzhou Future Agriculture Cluster offers a clear example. The sky farm produces high-value crops, but it is also linked to an agricultural equipment manufacturing platform, an agricultural science and innovation center, a pilot-validation system, training functions, and brand-display scenarios.

At the level of the secondary sector, the project's link with the integrated equipment manufacturing platform is especially important. Once agricultural production is combined with equipment manufacturing, the production process itself becomes a real application setting for the development and improvement of equipment. Intelligent greenhouse devices, sensor systems, robots, environmental-control modules, and water-and-fertilizer systems are no longer just tools that are purchased and used. They become industrial products that can be tested, improved, and displayed within a real production environment.

The extension into the tertiary sector is even broader. The sky farm has a strong display function by nature. Compared with traditional farmland, a rooftop sky farm has stronger visual impact and stronger scene recognition. It can function as a technology display window, a brand communication carrier, and a calling card for the local area. Government officials, investors, industry partners, schools, and consumers can all use this space to understand how future agriculture operates.

The sky farm also supports education, training, and talent services. At present, both county revitalization and agricultural upgrading face a common challenge: a lack of people who understand technology, industry, and operations at the same time. When the sky farm is combined with the science and innovation center, it can support training for government officials, professional farmers, returning entrepreneurs, agricultural business managers, vocational students, and youth study groups.

At a broader level, the sky farm creates distinct urban value. For a long time, agriculture and cities have often been separated in spatial terms. Agriculture has been seen as an industry of the countryside or the suburban fringe, while industrial parks and factory buildings have been linked mainly with manufacturing, storage, and logistics. The TsingSky Guangzhou Sky Farm changes this traditional division of space. It brings agriculture into industrial rooftops and edge-of-city areas, so that green production systems are embedded into urban and industrial environments.

Dynamic vertical farming research also suggests that future controlled production systems should optimize resource-use efficiency, product quality, and energy costs together rather than treating these goals separately [22]. This principle is also applicable to rooftop sky farms. A sky farm should not be evaluated only by its novelty or visual effect. It should be evaluated by whether it can integrate production, energy, technology, market, and urban value into a viable operating system.

For county-level development, this combination of industrial integration and urban value is especially important. Many counties face several linked challenges when they try to upgrade their economies. Traditional agriculture often has low added value. Industrial projects can become highly similar to one another. Service industries may remain underdeveloped. A platform-based project such as the TsingSky Guangzhou Future Agriculture Cluster can help bridge these gaps. It can support agricultural upgrading and industrial innovation at the same time. It can also provide functions in education, training, and public display while creating new service and consumption scenarios. In other words, it does not simply add one more project to the existing industrial system. It reorganizes the way industrial relationships work at the county level. Once such a platform matures, it can generate not only agricultural sales income, but also revenue from equipment sales, training services, scientific and innovation services, brand communication, and even cultural tourism and exhibition activities.

More importantly, this kind of integrated value can help change the way society understands agriculture. For a long time, agriculture has often been seen as a sector with low returns, a traditional image, and limited added value. This perception has affected the willingness of capital, talent, and young people to enter the field. When a sky farm becomes part of the urban landscape, part of a technology showcase, and part of innovation, manufacturing, and education, the public image of agriculture begins to change. Agriculture is no longer seen only as work in the field. It starts to be understood as a modern industry that combines technology, design, manufacturing, services, and green development. This change in perception has deep importance for attracting talent, investment, and partnerships into the field of future agriculture.

At a higher level, what the TsingSky Guangzhou Future Agriculture Cluster represents is not simply an extension of agriculture. It represents a restructuring of agricultural functions. A sky farm is not only a production space. It is also a research space. It is not only an industrial space. It is also a service space. It is not only an economic carrier. It is also a carrier of urban landscape and public education. This is why such a project deserves serious attention. Its importance does not lie only in its novel form. Its importance lies in the fact that it shows a new possibility for county-level development: agriculture can become a key platform that connects manufacturing, technology, education, branding, and urban renewal. In this sense, the future agriculture represented by the sky farm is not only an upgrade of agriculture itself. It is also an active reshaping of county-level industrial structure and spatial value.

10 Investment Protection and Institutional Innovation: Making Agriculture Investable

To scale modern agriculture, project funding alone is not enough. Long-term capital, industrial capital, and financial instruments must also enter the sector. For that to happen, agricultural projects need stronger asset characteristics and greater institutional predictability.

Compared with traditional open-field agriculture, facility agriculture integrated with standardized industrial buildings, rooftop space, equipment systems, and R&D platforms often has stronger potential in terms of property registration, asset management, financial evaluation, and operational organization. Such facilities may be better positioned to support clearer property-rights arrangements and therefore stronger protection for agricultural investment.

This reflects an important transition. Agriculture is gradually moving from a weakly capitalized and weakly protected sector toward one that can be defined, assessed, financed, and operated on a more stable basis. For county-level development, this is especially important. Only when agricultural projects have clearer ownership boundaries and more predictable return structures will social capital be more willing to participate and local governments more capable of nurturing a full agricultural ecosystem.

The Guangzhou model attempts to make agriculture more investable through several mechanisms. First, it uses rooftop and facility assets rather than only open farmland. Second, it combines crop production with equipment, R&D, training, and services. Third, it creates measurable operating indicators. Fourth, it connects production with nearby markets. Fifth, it integrates energy design into the cost structure from the beginning. These mechanisms reduce the dependence of the project on crop sales alone and create a more diversified return structure.

11 From Phase I Demonstration to Phase II and Phase III Cluster Expansion

County-level smart agriculture should not aim for a one-time "large and complete" project. A phased strategy is often more realistic and more resilient. The TsingSky Guangzhou Future Agriculture Cluster offers a clear pathway: Phase I establishes the sky farm, science and innovation center, and equipment manufacturing platform as a visible, operable, and verifiable demonstration project. Phase II expands production capacity, fills upstream and downstream gaps, and strengthens research and testing capabilities. Phase III then builds a regional future agriculture cluster through multi-project deployment and industrial chain integration.

The value of this pathway lies in the fact that it does not construct an isolated production base. From the beginning, it places production, innovation, manufacturing, services, and talent within a single industrial logic. This produces a more sustainable operating model and makes cross-regional replication more feasible.

For other counties, the lesson is not simply to replicate the physical form of a rooftop farm, but to replicate the underlying method: identify the most valuable local resources, find the best point of integration among agriculture, energy, space, manufacturing, and market access, and then allow one demonstration project to evolve into a wider industrial cluster.

12 Discussion: The Guangzhou Model as a County-Level Development Method

The Guangzhou Sky Farm should be understood as a development method rather than a single project form. Its first contribution is spatial. It shows that modern agriculture can move upward and make use of industrial rooftops without occupying conventional farmland. Its second contribution is energetic. It shows that agriculture can connect with local industrial heat, water-source heat pumps, and low-carbon energy systems. Its third contribution is industrial. It shows that agriculture can become a platform for equipment manufacturing, technology testing, and service development. Its fourth contribution is organizational. It shows that a project can produce not only crops but also standards, data, talent, and regional development capacity.

This method has global relevance. Many regions around the world face similar challenges: limited farmland, climate risk, urbanization, labor shortages, food safety concerns, and pressure for low-carbon development. However, these regions do not need identical agricultural facilities. They need locally adapted systems. In some places, the core resource may be waste heat. In others, it may be geothermal energy, rooftop space, solar energy, port logistics, consumer markets, or industrial manufacturing capacity. The Guangzhou case suggests that the correct starting point is not "what greenhouse model should be copied," but "which local resources can be reorganized into a viable agricultural system."

At the same time, the model should be evaluated carefully. Controlled-environment agriculture is not automatically sustainable. Energy structure, material inputs, crop selection, market pricing, labor productivity, and system maintenance all determine whether the project can succeed. This means that any future replication of the Guangzhou model should begin with careful energy, economic, and operational calculations.

The strength of the Guangzhou model lies precisely in its attempt to avoid a purely technology-driven approach. It starts from local space, local energy, local industry, and local markets. It then uses controlled-environment agriculture as the carrier to create a cluster-based development pathway. This is why the project is more than a greenhouse. It is a county-level future agriculture system.

13 Conclusion

Today, agricultural modernization is no longer only about improved varieties or upgraded equipment. It is about the deep restructuring of agricultural organization, spatial forms, energy systems, and industrial relationships. The TsingSky Guangzhou Future Agriculture Cluster shows that future agriculture does not need to remain confined to conventional land boundaries. It can move onto rooftops, into industrial parks, and into new spatial forms. It can also move beyond single-function production and become deeply integrated with energy systems, equipment manufacturing, scientific research, and rural-urban service networks.

In this sense, bringing modern agriculture into the sky is not merely a communication slogan. It is a development logic with practical foundations and real industrial potential. It points toward a new direction for county-level smart agriculture: local adaptation as the premise, controlled-environment agriculture as the carrier, low-carbon energy as the support base, science and equipment as the engine, and phased cluster development as the pathway.

What the TsingSky Guangzhou Sky Farm represents is not simply the possibility of one successful project. It represents a pathway through which a county can grow a future agriculture cluster from a single demonstration site. For Chinese counties, and for many regions around the world searching for new models of agricultural modernization, this approach offers valuable insight.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

Yiyi Wang and Xiaoqing Wang are affiliated with the Beijing TsingSky Technology Co., Ltd, Beijing, China. The authors declare that this affiliation had no influence on the study design, data collection, analysis, interpretation, or the decision to publish, and that no other competing interests exist.

AI Use Statement

The authors declare that no generative AI was used in the preparation of this manuscript.

Ethical Approval and Consent to Participate

Not applicable.

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