

УДК 338 DOI: 10.14451/1.254.206

Vertical farming: future trends

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Keywords: Artificial intelligence, agriculture, machine learning, sustainability, innovation, vertical farming, eco system.

Vertical farming has emerged as a sustainable agricultural method, resolving the issues of land scarcity, environmental consequences, and food security in urban and highly populated areas. The inclusion of artificial intelligence (AI) and automation into vertical farming systems improves their efficiency, production, and adaptability. The study highlights recent breakthroughs in AI-driven systems, spanning data analytics, predictive modeling, and autonomous control, which enhance critical parameters such as light, temperature, humidity, and nutrient delivery. Significant advancements in agricultural automation, including robotic technologies for planting, monitoring, and harvesting, are emphasized for their capacity to decrease labor expenses and enhance yield accuracy. Further, research evaluates the environmental effect, scalability, and practicality of automated vertical farming systems, examining the contribution of renewable energy and optimal use of resources to the development of resilient food production methods. This discussion addresses future directions and issues seeking to shed light on how AI and automation are shifting vertical farming into an important aspect of sustainable agriculture. In this article, the author used data from 15 agricultural farms in Sri Lanka, as well as expert opinions on artificial intelligence in the agricultural sector.

Introduction

Vertical farming is emerging as an innovative solution for solving major issues in contemporary agriculture, particularly in densely populated metropolitan regions where cultivable ground is limited and traditional agricultural practices encounter substantial obstacles. Vertical farming promotes land use efficacy and eliminates reliance on extensive farmlands by cultivating crops in stacked layers within controlled conditions. This approach also tackles the agricultural sector's difficulties associated with climate change, water shortages, and food insecurity, facilitating year-round crop production in a regulated, resource-efficient environment.

Vertical farming evaluates the technological dimensions of these technologies, including sensor networks, machine learning, and computer vision systems that establish a desirable agricultural environment. This assessment considers the ecological and financial advantages of incorporating these technologies, such as decreased water and nutrient consumption, reduced labor demands, and increased production. It also examines how AI-enabled solutions can reduce the total carbon impact of agricultural activities. It analyzes prospective trends and obstacles in the implementation of AI and automation in vertical farming, taking into account technological improvements, legislative assistance, and scalability to expansive

metropolitan settings. The review consolidates findings from multiple studies and applications to offer an extensive understanding of the impact of AI and automation on the future of sustainable agriculture via vertical farming

Vertical farming outdoors entails cultivating vegetables using vertical support systems constructed from readily available materials, such as bamboo structures supplemented with wires to assist the vegetables in climbing upwards.

Indoor vertical farming involves a range of permanent structures that support plant growth, typically within polyhouses, net houses, shade nets, and bamboo structures covered with plastic sheets. This method encompasses hydroponics, aeroponics, and aquaponics. An indoor multilayer plant cultivation system meticulously manages all growth factors like temperature, light, carbon dioxide levels, humidity, water, and nutrients to yield abundant, high-quality fresh produce consistently throughout the year, independent of natural light or outdoor conditions. Vertical farming involves growing crops or vegetables in vertically stacked layers or on vertical structures that promote upward growth, typically within a controlled environment tailored for optimal plant growth.

Methods. In this article, the author used data from 15 agricultural farms in Sri Lanka as well as expert opinions on artificial intelligence in the vertical farming. The author also consulted literature reviews written by other authors.

Vertical farming methods can be classified according to the techniques of fertilizer and water distribution. The three principal varieties of vertical farming systems are hydroponics, aeroponics, and aquaponics, each possessing distinct benefits and operational prerequisites.

In hydroponic systems, plants develop on a soil-less substrate, obtaining nutrients via a water-based solution. This configuration enables careful

regulation of nutrient concentration and pH levels, resulting in uniform, superior yields. Hydroponics is comparatively easy to manage; however, it necessitates constant oversight of fertilizer and oxygen concentrations in the water. Due to the absence of soil, hydroponics frequently employs substrates such as rock wool or perlite to secure plant roots. The regulated conditions in hydroponics provide continuous crop production throughout the year, which is especially beneficial for urban agriculture.

In aeroponic systems, plants grow in a controlled atmosphere, with their roots intermittently sprayed by a nutrient-laden solution. Aeroponics utilizes up to 90% less water than conventional agriculture, as the nutrient droplet is directly administered to the root system. Aeroponic devices necessitate precision timing and regular maintenance to prevent nozzle obstruction and guarantee uniform misting intervals. This advanced method enhances plant growth by maximizing nutrient absorption, yet requires substantial energy consumption to sustain the required sprinkling pressure.

Aquaponics integrates hydroponics and aquaculture, utilizing waste as a natural nutrition supply for plants. This closed-loop ecosystem enables plants to purify water for fish, reducing the necessity for synthetic fertilizers. Aquaponics systems are notably sustainable, as they recycle water and nutrients internally. But they necessitate a balanced proportion of fish and vegetation, along with constant supervision of water quality metrics, including ammonia and nitrate concentrations. Integrating aquaponics with solar-powered systems can promote energy sustainability and eliminate reliance on external power sources, which is particularly beneficial for remote or off-grid locations.

In table 1 shows a comprehensive analysis of AI applications and its impact on the vertical farming

Table 1. A comprehensive analysis of AI applications and its impact on the vertical farming.

Section	Key Concepts	Impact
AI in Agriculture	Precision farming via GPS and IoT sensors. Machine learning for yield prediction. Robotics for automation.	IoT sensors monitor soil moisture and nutrient levels. Drones detect plant diseases in early stages.
Enhancing Crop Productivity with AI	Genetic modification for pest and disease resistance. Resource optimization for water and fertilizers.	AI identified genes for drought tolerance, aiding in creating resilient crops. AI systems in California vineyards led to a 25 % increase in yield and 20 % water savings.
Barriers to Adoption	High costs and infrastructural demands. Resistance from farmers, training needs. Regulatory and data privacy concerns.	Example of connectivity issues in rural areas impeding AI adoption.
Future Perspectives	Development of smart seeds. Integration with blockchain for transparency. Advanced robotic systems.	Predicted enhancements in real-time crop monitoring and efficient harvesting techniques.

Source: compiled by author.

The integration of artificial intelligence (AI) and automation technology into vertical farming has accelerated this trend, facilitating better investments, enhanced crop monitoring, and increased production. AI-driven systems utilize data from multiple sensors to make simultaneous adjustments to parameters such as light, humidity, and nutrient levels, thereby establishing an optimal environment for plant development. Automation enhances this by optimizing labor-intensive activities, including planting, monitoring, and harvesting, thereby lowering the necessity for human involvement and cutting operating expenses. Collectively, these technologies constitute the foundation of “smart farming,” wherein precision and data-informed decisions result in improved agricultural productivity and efficiency. In recent years, the application of smart technologies, especially artificial intelligence and machine learning, has markedly advanced to enhance the accuracy and dependability of agricultural practices. Machine learning models facilitate predictive insights and informed decision-making for effective crop management by assessing extensive information on environmental factors, plant health, and growth rates. This innovation has significantly influenced vertical farming, where every variable may be methodically regulated. The incorporation of Internet of Things (IoT) devices in agricultural monitoring systems facilitates the efficient gathering and transfer of data, delivering

real-time insights on plant health, soil conditions, and pest infestations. Automated and IoT-driven solutions, such as sensors for nutrient monitoring and computer vision for plant health assessment, have simplified crop management by reducing the use of resources and ensuring consistent, high-quality yields.

The combined use of AI and IoT in vertical farming has improved crop management through the automation and optimization of multiple components. Artificial intelligence systems can regulate climatic controls, optimizing light, carbon dioxide, and nutrient levels for each plant, thereby lowering the necessity for physical inspection. This enables farmers to concentrate on strategic decisions instead of routine maintenance. AI algorithms can evaluate real-time sensor data about temperature, humidity, and soil pH to implement precise adjustments to airflow or nutrient levels, enhancing plant health and accelerating growth rates. This method minimizes waste by regulating water and nutrient application to avoid overuse, which is consistent with sustainability objectives. IoT devices provide remote management and supervision of the vertical farming ecosystem, especially advantageous in urban locales or regions with little agricultural knowledge. Agriculturists can obtain instantaneous notifications and analyses of their crops' conditions, strengthening the system's reliability

and fostering environmental sustainability through the reduction of using resources and carbon emissions.

Autonomous robots with machine learning skills are used in vertical farming to do repetitive activities including planting, pruning, and harvesting. These robots preserve accuracy and uniformity while reducing the need for human labor. To guarantee that every plant receives individualized care, they employ computer vision to evaluate plant height, development stages. In order to maximize plant health and minimize crop loss, machine learning algorithms can recognize symptoms of illness or stress and automatically start eliminating or treating them. Robotics also holds considerable promise for autonomous maintenance and harvesting. By using color, shape, and size to determine ripeness, AI-driven robots lower the possibility of picking crops too soon or later. They also take care of regular maintenance, which includes checking for system issues and cleaning and disinfecting growing surfaces. As a result, there is less interruption and low labor costs in high-efficiency settings. Through precise resource management, labor-intensive task handling, and environmental regulation, automation in vertical farming increases productivity, reduces operating costs, and encourages sustainable practices.

AI-driven computer vision makes possible plant health monitoring in vertical farming through the use of cameras and image recognition technologies to assess plant health, identify pests, and recognize early indicators of illness or nutritional deficiencies. This real-time information facilitates prompt intervention and reduces crop loss. AI systems can detect plant diseases and irregularities, facilitating focused interventions without harming healthy crops. This decreases labor expenses and improves the farm's capacity to address possible challenges. Computer vision aids in monitoring growth phases, evaluating crop maturity, and predicting optimal harvest periods. This facilitates prompt interventions and guarantees that each plant has sufficient light, water, and nutrients during its lifecycle. It facilitates selective harvesting by identifying mature plants, enabling effective

crop rotation, and optimizing yield per square meter. Computer systems offer data on abnormalities that may signify equipment faults or nutritional imbalances, enabling preventive maintenance and focused intervention.

Vertical farming techniques have multiple benefits for sustainable urban agriculture in Sri Lanka, such as resource efficiency, spatial optimization, and improved nutrient absorption. They utilize up to 95% less water than traditional methods and reduce the necessity for synthetic fertilizers. Vertical farms in Sri Lanka optimize agricultural yield per square meter, finding them suitable for urban environments with constrained land availability. However, they encounter hurdles like substantial initial expenses, which could limit small-scale farmers, and complex automation systems demanding advanced AI and IoT integration. Maintenance and troubleshooting of automated systems require specialized expertise. Overcoming these issues requires innovation and regulatory incentives to enhance the accessibility of vertical farming. Although these problems exist, the long-term sustainability and productivity advantages of vertical farming make it a potential solution for the future of agriculture, particularly in urban and resource-constrained environments.

Vertical farming, a growing trend in urban environments, faces logistical and economic obstacles stemming from substantial investment, space requirements, and energy supply demands. The prohibitive expense of automation technologies may be unmanageable for small-scale farmers without financial support. Moreover, transportation and product distribution systems in heavily populated urban areas might be problematic. However, cost-sharing arrangements, collaborative frameworks, and technological innovations can assist in surpassing these obstacles. Collaborative methods such as farmer cooperatives or urban agricultural hubs can allocate infrastructure and technology expenses, enhancing the accessibility of vertical farming. Technological advancements such as modular agricultural frameworks and 3D-printed components may lower customizing expenses. AI-powered surveillance and forecasting devices can enhance spatial use, energy efficiency, and

manufacturing efficacy. Successful case studies illustrate the viability of vertical farming in urban environments, enhancing local food security and diminishing reliance on distant supply chains.

Automation in Vertical Farming

Vertical farming is turned around by automation, which manages environmental factors, delivers nutrients, and even handles maintenance and harvesting duties with little assistance from humans. Automation enhances labor productivity, minimizes dependency on resources, and optimizes conditions for plant growth across several layers with the support of AI and machine learning.

Automation of Environmental Control Systems

Environmental control is crucial for vertical farms to guarantee steady crop yields and healthy development across the stacked layers. Real-time control over variables like temperature, humidity, CO₂ levels, and light intensity is made possible via automated systems. A steadily growing environment is produced by a combination of smart fans, CO₂ injectors and LED lighting systems. AI-powered algorithms maintain ideal conditions for every plant layer by adjusting these systems in response to continuous sensor input. For instance, fans are automatically turned on to control airflow when sensors identify high temperatures. In a similar manner, AI-monitored injectors regulate CO₂ levels in accordance with plant absorption rates, improving the efficiency of photosynthesis.

Environmental controls are continuously monitored and modified through the use of IoT-enabled devices. For instance, solenoid-operated irrigation systems and IoT-controlled precision sprayers guarantee that water and nutrients are only applied when required, minimizing waste and maximizing plant absorption. In order to ensure uniform development across the farm, automated lighting systems modify the spectrum and intensity of light according to the time of day and the type of plant. By reducing waste and promoting sustainable farming methods, the integration of IoT and AI in vertical farming is consistent with the principles of resource-efficient agriculture.

Automated Nutrient Delivery and Irrigation Systems

Automated irrigation systems are used in vertical farming to precisely supply water and nutrients according to plant requirements. These systems, which include sprinklers and drip irrigation, use electronic fertilizer dosing to guarantee efficient absorption and reduce resource waste. While sprinkling systems replenish plants' aerial portions, drip irrigation focuses moisture on the root zone. IoT sensors and AI algorithms work together to determine water distribution depending on plant kind, environmental factors, and soil moisture data. This accuracy avoids over-irrigation and minimizes water waste. Sensitive electrode sensors monitor nutrient concentrations in the soil or water reservoir and modify dosage in real-time. Without the need for human intervention, this method guarantees that plants receive enough nutrition and stops nutrient leaking, resulting in better growth and increased yields.

Sustainability and Resource Optimization

AI-driven vertical farming systems are designed with sustainability in mind, with the goal of maximizing productivity and reducing environmental impact. By utilizing renewable energy sources, recycling materials, and cutting waste, these technologies establish vertical farming as a resource-efficient and environmentally beneficial substitute for conventional farming.

Energy efficiency and Renewable Power Sources

By using renewable energy sources, vertical farming can ensure both cost-effectiveness and environmental sustainability. When integrated into polyhouse structures, transparent solar panels offer a sustainable energy source that lowers energy expenses by supplementing conventional electricity. This is in line with sustainable farming methods that minimize dependency on traditional energy sources. Also, energy-efficient LED lighting is essential for vertical farms since it promotes growth and photosynthesis in regions with little natural light. AI systems optimize energy use and minimize waste by managing power loads by regulating LED timing and intensity according

to plant requirements and ambient light levels. Machine learning algorithms that continuously alter lighting and electricity usage create a responsive environment that complies with sustainable agriculture principles.

Water and Nutrient Recycling Systems

To maintain sustainability, vertical farms are concentrating on recycling nutrients and water. Drip and mist irrigation are examples of closed-loop systems that gather and repurpose water to support plants. These preserve surrounding ecosystems by lowering water consumption and stopping the release of nutrient-

rich water into the environment. Artificial intelligence (AI)-powered sensors track the water's nutrient levels and refill them when they drop below ideal ranges. This improves resource efficiency and eliminates reliance on external inputs. Vertical farms become more robust and economical through nutrient recycling, which is an example of sustainable resource management. With everything considered, these solutions support vertical farms' overall sustainability.

Reduction of Agricultural Waste and Chemical Inputs

Vertical farming systems use AI-enabled precision in nutrient and pesticide application to reduce waste and environmental effects. Based on variables including growth stage, plant health, and environmental conditions, AI algorithms evaluate data from IoT sensors to calculate the precise amount of nutrients and pesticides required for each plant. By limiting inputs and optimizing productivity through focused interventions and efficient resource use, vertical farms produce very little agricultural waste. This resource-conscious strategy is a sustainable solution for urban agriculture since it helps create a more resilient and environmentally friendly food production system.

Economic Viability and Scalability

While vertical farming has many advantages for the environment and productivity, its economic viability depends on things like high initial costs, labor savings, and potential returns on investment (ROI). Looking at the cost-benefit ratio and scalability of

AI-driven automation in vertical farming helps us figure out if it's possible for a lot of people to use it, especially in cities with limited resources.

Cost Benefit Analysis of Vertical Farming and Automation

Vertical farming systems require significant upfront investment in infrastructure, technology, and energy-efficient systems. However, automation and AI-driven efficiencies can significantly reduce operational costs over time. Small-scale farmers may face financial burdens, but larger operations and collaborative investments can ease the financial burden. Long-term savings from reduced water, pesticide, and nutrient use, coupled with lower labor requirements, can enhance the ROI over time. AI and automation optimize resource allocation

and manage energy consumption, making vertical farming a competitive and economically attractive model for urban agriculture in India's growing automated farming industry. These long-term cost efficiencies highlight the economic potential of vertical farming as technology costs decrease.

Labor Reduction and Efficiency

Automation and AI-driven technologies are essential for decreasing labor requirements and enhancing efficiency in vertical farming operations, especially in areas facing labor shortages or higher labor prices. Automated technologies for monitoring, watering, nutrient supply, and environmental regulation reduce manual intervention, enabling vertical farms to achieve greater self-sustainability. Autonomous robots do duties such as planting, trimming, and harvesting, thereby diminishing physical labor and operational expenses.

The combination of AI and machine learning with IoT systems improves operational efficiency, decreasing labor force needs by around fifty percent. This enhancement in efficiency allows farmers to achieve higher output objectives with reduced resources, sustaining the ongoing economic viability of vertical farms.

Future Directions and Challenges

As vertical farming expands and incorporates advanced technologies, several critical domains are

positioned for progress. Future advancements, regulatory assistance, and focused research will be crucial for optimizing the sustainability, economic feasibility, and scalability of AI-driven vertical farming.

Emerging Technologies and Innovations

Accelerated progress in AI and automation presents exciting opportunities for enhancing the operational efficiency and sustainability of vertical agricultural systems. As these technologies advance, they are expected to enhance the efficiency, predictability, and autonomy of vertical farms. Innovative AI methodologies, such as deep learning and sophisticated computer vision, simplify crop surveillance and predictive servicing. These models provide precise detection of plant health deficiencies, optimize the use of resources, and forecast environmental changes for future crop cycles. The incorporation of AI-driven insights is essential for next-generation farms seeking to self-regulate and react in real-time, hence improving agricultural yields and quality. Advanced predictive models utilizing machine learning will enable vertical farms to anticipate demand, modify output levels, and minimize waste in accordance with market trends and environmental variables. As robots and machine learning algorithms advance, autonomous systems for sowing, transplanting, pruning, and harvesting are anticipated to develop. Recent advancements in robotics, exemplified by autonomous agricultural vehicles, are progressively adept at functioning with minimum human supervision, potentially facilitating high-density, high-frequency farming practices. The advancement of more compact, multifunctional robots will improve the ability of vertical farms to automate complicated tasks across several crop levels, hence making full automation more achievable in urban vertical farms. Sophisticated sensor sets, integrated with IoT, provide real-time data acquisition regarding ambient conditions, crop health, and nutrient concentrations. These technologies facilitate closed-loop systems that enhance inputs, lessen waste, and minimize environmental effects. Integrating AI with IoT-enabled precision instruments such as solenoid-controlled nutrition

regulators or sensor-equipped spray nozzles could enhance energy utilization, limit chemical usage, and promote sustainable practices. Progress in sensor technology is essential for facilitating more intelligent and responsive vertical farming systems that fulfill production requirements while ensuring resource efficiency.

Policy and Regulatory Considerations

Vertical farming is an expanding sector that necessitates conducive policy frameworks and regulatory compliance to guarantee sustainable development. These frameworks must restore innovation with social and environmental factors. Compliance with environmental and safety regulations is essential for safeguarding human health and the ecosystem. Protocols for nutrient control, water utilization, and energy efficiency are essential for urban agriculture and vertical farming. Data privacy and security policies are essential, given that AI and IoT significantly depend on vertical farming. Policies have to include data ownership, privacy, and security to safeguard farmers and customers. A government incentive, including tax credits, grants, and subsidies, can promote the implementation of AI and automation technology in vertical farming. This can lower expenses and enhance adoption rates, making vertical farming feasible, particularly in urban and semi-urban regions with land concerns.

Factors for influencing verticle farming

The implementation of vertical farming is shaped by a range of interrelated factors. Vertical farms can be strategically placed to utilize surplus heat from nearby facilities, thereby increasing energy efficiency. Emphasizes the potential for collaboration between vertical farms and other urban actors, such as businesses involved in waste management, to reduce operational costs and enhance circularity. Integrating vertical farming into existing buildings, rather than constructing new ones, can help avoid environmentally harmful demolitions and minimize the need for resource-intensive new developments. In addition,

the importance of developing reliable and sustainable business models during the innovation phase of vertical farming. It identifies five key

functional areas that can be integrated into vertical farming systems to enhance their viability: marketing, environmental sustainability, the built context, education, and community engagement.

Environmental sustainability can also be improved by applying circular principles, such as designing integrated systems that include plants, animals, and fungi, or implementing advanced water purification technologies. Also highlight the reuse of waste heat within greenhouses as a concrete way to improve environmental performance. Contextual integration is another crucial factor.

The advancement of vertical farming depends heavily on the ability of independent companies to collaborate with a broader set of stakeholders. reserchers (7,8) argues that by working together with actors such as municipal energy providers and waste management organizations, vertical farms could, for example, make use of waste heat or organic waste to reduce energy consumption and enhance production efficiency. This type of cross-sector collaboration is particularly important in complex urban environments, where interaction between different disciplines and institutions can foster mutual learning and improved understanding.

Author (2) further emphasize that integrating vertical farms into the city's broader material and energy systems, such as recycling networks and sustainable infrastructure can support goals like biological waste recovery and improved urban ecological performance, ultimately contributing to climate mitigation efforts. However, they also stress that for these benefits to materialize, long-term cooperation and ongoing knowledge exchange among stakeholders are essential.

Research Gaps and Potential for Improvement

Vertical farming technology faces several research gaps, including cost reduction, improved AI models, and environmental impact studies. These areas can enhance its effectiveness and make it more accessible. Affordable automation solutions, such

as modular and DIY kits, could reduce initial investments and support wider adoption. Developing cost-effective robotics and IoT systems can also support wider adoption. Enhanced machine learning models for diverse crop types are needed, as current models are often tailored to specific crop types, limiting versatility. Improved predictive models for diverse crop types would allow farmers to grow a greater variety of plants within the same system, increasing flexibility and profitability. Additionally, more research is needed to quantify the environmental impact of vertical farming, particularly regarding energy use and carbon emissions. In-depth studies on renewable energy integration, resource recycling, and waste management could provide a clearer understanding of its ecological footprint.

Conclusion

The inclusion of AI and automation in vertical farming has considerably improved output, sustainability, and affordability. AI-driven solutions for data acquisition, environmental regulation, and predictive analytics have enhanced growth conditions and resource effectiveness. Automation has reduced labor requirements, increased operational efficiency, and decreased resource waste thanks to IoT-enabled irrigation and nutrition systems, robotic harvesting, and environmental regulation. These technologies establish a precisely regulated and resilient cultivation environment, enabling vertical farms to sustain elevated yields in urban and resource-limited contexts. Although there were some initial financial problems, the fact that costs will continue to go down, resources will be protected, and farmers will be less reliant on traditional farming methods shows that automated vertical farming systems can be profitable. AI-driven vertical farming signifies an effective way to achieve a more sustainable and secure agricultural future, as rising global populations and urbanization heighten the necessity for food security and sustainable practices. Subsequent progress in AI and machine learning would provide enhanced regulation of growing conditions, hence improving yield quality and resource efficiency.

Table 2. Vertical farming AI applications in agriculture between developed and developing countries.

AI applications	Developed countries	Developing countries
Precision agriculture	<p>AI-powered tractors, drones, and IoT sensors optimize input use, such as John Deere's autonomous tractors in the USA, Germany, and Finland.</p> <p>Machine learning models predict optimal planting and harvesting times, such as Climate FieldView in countries like Canada, the USA, Ukraine, and many European countries.</p>	<p>Mobile-based AI advisory platforms offer low-cost recommendations such as the Plantix AI app in India.</p> <p>Smart irrigation solutions like solar-powered drip systems reduce water wastage such as NetBeat used in India and Kenya.</p>
Disease prediction and crop monitoring	<p>AI-driven image recognition and machine learning diagnose plant diseases using satellite imagery. For example, Plantix was developed by PEAT GmbH, a Berlin-based AI start-up which is capable of diagnosing plant damages based on digital images of symptoms.</p> <p>AI-assisted drones survey fields and detect pest infestations such as DJI Agras in China which is packed with AI and augmented reality (AR) are poised to revolutionise farming.</p>	<p>Low-cost AI-powered mobile apps help farmers detect diseases through smartphone images as TroTro Tractor links smallholder farmers with agricultural technology, such as tractors, and operates in countries Ghana, Nigeria, Togo, Benin, Zambia, and Zimbabwe.</p>
Climate-resilient agriculture	<p>AI-powered weather prediction models provide real-time climate forecasts, such as the IBM Watson Decision Platform for Agriculture in the USA and Canada.</p> <p>AI-driven soil health sensors optimize fertilization like SoilOptix, adopted in rural Tavistock, Ontario, Canada.</p>	<p>SMS-based weather advisory services provide smallholder farmers with real-time climate alerts like mAgri used in Botswana, South Africa and other SSA countries.</p> <p>AI-integrated mobile solutions suggest drought-resistant crops. For instance, Digital Green adopted in Ethiopia, India and Ghana, equipped smallholder farmers with localised, real-time agricultural guidance that enhances production, resilience, and development</p>
Livestock management	<p>AI-powered facial recognition for cattle identification and health monitoring, such as Cargill's AI-driven cattle tracking adopted by farmers in the USA and Ireland for optimizing animal feed supply chain and production.</p> <p>Precision feeding systems optimize nutrition and reduce waste such as Lely's automated feeding system adopted in countries like the Netherlands, Germany, Finland and Switzerland to ensure efficient feeding systems in livestock</p>	<p>AI-enabled mobile applications allow farmers to diagnose livestock diseases via smartphone photos such as VetAfrica employed by farmers in Kenya, Uganda and Ethiopia helps Veterinaries and farmers diagnose diseases in livestock.</p> <p>AI-based automated milking systems help dairy farmers improve milk yields such as SmartCow used by livestock farmers in Taiwan, Singapore and India to enhance productivity in dairy farming</p>

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Table 2. Vertical farming AI applications in agriculture between developed and developing countries. (Continued)

AI applications	Developed countries	Developing countries
Supply chain optimization	<p>AI-integrated blockchain systems ensure transparency in food supply chains such as IBM Food Trust in the USA, Canada and major European countries.</p> <p>AI-driven inventory management reduces food waste and optimizes logistics such as Tive's real-time tracking in Canada that helps reduce postharvest losses</p>	<p>Mobile-based AI platforms connect farmers directly with buyers, reducing middlemen. For example, Twiga Foods in Kenya and Uganda, likewise, ThriveAgric, Agricorn and Releaf adopted in countries like Nigeria, Ghana, Zambia and Egypt which helped in transforming the agrifood system.</p> <p>AI-driven price forecasting apps help farmers optimize sales such as AgroCenta in Ghana which connects smallholder producers in the food value chain to a broader online market and offers access to fair prices, bulk sales and information</p>

Source: compiled by author.

In developed countries, AI-integrated cloud platforms, provides real-time analytics on supply chain disruptions, enabling agribusinesses to adjust their distribution strategies dynamically. In contrast, developing countries rely on AI-driven mobile applications that connect smallholder farmers with markets, helping them make data-driven decisions on their produce for profit maximization. Interestingly, AI-powered route optimization algorithms help farmers and logistics companies determine efficient transportation routes, reducing fuel costs and delivery time. AI is also transforming quality control and food safety monitoring through computer vision systems and IoT sensors, which inspect produce for compliance with food safety standards.

In developed countries, self-driving trucks, automated sorting centres, and AI-driven inventory management systems streamline agricultural

goods' movement. Additionally, automated grading and sorting systems assess crops' size, colour, and quality, reducing manual labour and improving efficiency. In developing nations, reliance on affordable AI-powered mobile applications that allow farmers to evaluate crop quality using smartphone cameras, thus enabling them to meet market standards, secure better prices, and ensure timely delivery of perishable goods.

Therefore, the ideas of traditional agriculture are being redefined by hydroponics and vertical farming. It is an advanced technique of farming in which crops are cultivated in vertically stacked layers designed for sustainable food production. These techniques boost food security, lower transportation costs, and allow for year-round cultivation of crops in regulated conditions with little water and land requirements. AI is integrated into vertical farming systems to monitor and adjust environmental variables for maximum growth and output

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