Towards Global Food Security: Vertical Farming as an Innovative Solution

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Abstract

Vertical farming is becoming the focus of attention as an innovative solution to the challenge of global food security. Urbanization and rapid population growth give rise to the need for efficient agricultural approaches to land use. This research aims to investigate the potential and impact of vertical farming on global food security through a descriptive qualitative approach. The data used in the research comes from various relevant previous research and studies. This research method involves the process of collecting data from scientific literature and previous studies, which are then processed by researchers to produce relevant findings. Through descriptive qualitative analysis, this research highlights the contribution of land use efficiency, adaptation to urban environments, and integration of advanced technologies in the context of vertical farming. The results of this research then found that vertical farming is not only an alternative but also a significant step forward in the transformation of the global agricultural sector. Supportive agricultural regulations and policies, as well as adapting technology to the local environment, are critical challenges in implementing vertical farming. However, opportunities for developing innovations in vertical farming system design and active stakeholder involvement provide a strong foundation for the growth of this industry. This research highlights that vertical farming has great potential to have a positive impact on global food security, by understanding and overcoming existing challenges.

Keywords: *Global Food Security, Vertical Farming, Innovative Solutions.*

A. INTRODUCTION

Global food security is a serious challenge faced by the international community in the 21st century. The increase in world population, climate change, and limited fertile agricultural land are increasingly complicating efforts to ensure sufficient food is available to meet human needs. According to estimates by the Food and Agriculture Organization of the United Nations (FAO), the world population is expected to reach more than 9 billion people by 2050, increasing pressure on the global agricultural system to increase food production (Paudel et al., 2023).

On the other hand, fertile agricultural land is increasingly limited due to rapid urbanization and land degradation. As agricultural land decreases, agricultural experts and practitioners are looking for innovative solutions to increase crop productivity without sacrificing increasingly valuable land. Vertical farming, as an

innovative solution, has emerged as an attractive alternative to meet increasing food needs (Dibaba et al., 2020).

Vertical farming involves stacking layers of plants vertically, often inside buildings, using advanced technology such as hydroponics or aquaponics. This approach offers significant benefits, including more efficient land use, water savings, and better environmental control. Additionally, vertical farming can be implemented in urban areas, minimizing the need for long-distance transportation and reducing the carbon footprint (Halgamuge et al., 2021).

As a response to the complexity of global challenges related to food security, vertical farming promises innovative solutions that can make a positive contribution to the sustainability of the global food system. Therefore, this research aims to explore the potential of vertical farming as a solution that can face global food security problems effectively and sustainably. By understanding this background, it is hoped that this research can provide valuable insights to support efforts to achieve sustainable and inclusive global food security.

B. LITERATURE REVIEW

1. Food Security

From a historical perspective, the term food security began to emerge when the food crisis and famine hit the world in 1971. As a world food policy, the term resilience was first used by the UN to free the world, especially developing countries, from a crisis in the production and supply of basic foods. The focus of food security at that time, according to the UN definition, was to focus on fulfilling basic needs and freeing the world from the food crisis (Clapp & Moseley, 2020). This definition was then refined at the International Conference of Nutrition in 1992 which was agreed upon by the leadership of UN member countries, namely the availability of food that meets everyone's needs, both in quantity and quality for each individual to live a healthy, active, and productive life. This means that every person at all times has physical and economic access to sufficient food to live a healthy and productive life (Raharjo et al., 2022).

The World Food Summit in 1996 defined food security as occurring if all people continuously, physically, socially, and economically have access to adequate/sufficient, nutritious, and safe food, that meets their food needs and food choices for an active and healthy life (Sumsion et al., 2023).

Several experts agree that food security contains at least two main elements, namely food availability and people's accessibility to that food. Availability and sufficiency of food include the quantity and quality of food so that each individual can meet the standard calorie and energy needs to carry out economic activities and daily life. Food provision can be achieved through own production and imports from other countries (Clapp et al., 2022). The second component, namely each individual's accessibility to foodstuffs, can be maintained and improved through empowering market systems and effective and efficient marketing mechanisms, which can be

perfected through trade policies, or the distribution of foodstuffs from production centers to consumers (Zhanbayev et al., 2023).

In Indonesia, the concept of food security is outlined in Law No. 7 of 1996 concerning Food. This definition emphasizes five parts in the concept of food security, namely:

a. The provision of sufficient food in terms of quantity (availability aspect), namely that food is available and in sufficient quantity for the community, both vegetable and animal.
b. Fulfillment of food quality (health aspect), namely that the food available or provided meets good quality standards and is suitable for human consumption. This is related to meeting nutritional needs to meet the need for carbohydrates, protein, fat, vitamins, and minerals.
c. Safe (health aspect), namely that the food consumed meets health standards for the body and does not contain ingredients that can endanger human health.
d. Equitable (distribution aspect), namely that food is guaranteed to be distributed evenly to each region so that food is easily obtained by the community.
e. Affordable (access aspect), namely that food is possible for people to obtain easily and at reasonable prices (MacRae & Reuter, 2020).

The World Health Organization (WHO) puts forward three pillars of food security, namely food availability, food accessibility, and food utilization (utility). Food availability concerns an individual's ability to have sufficient food for their basic needs. Meanwhile, food accessibility is related to how a person obtains food. Meanwhile, food utility is the ability to utilize quality food ingredients (Sulaiman et al., 2021).

The Indonesian government through the Food Security Council in collaboration with the World Food Program (WFP) created a district-level Food Insecurity Atlas (FIA). The Food Insecurity Atlas was first launched in 2005, then updated again by creating the Food Security and Vulnerability Atlas (FSVA) in 2009 which was based on the approach: of food availability, food access, and food utilization (Setiadi et al., 2022).

2. Vertical Farming

Agriculture is one of the main economic sectors in Indonesia, which supports food sustainability and contributes significantly to national income. However, with the rapid development of urban areas, agricultural land is decreasing, especially in urban areas. Increasing urbanization and population density have resulted in limited available agricultural land, making it a challenge for farmers in urban areas to increase their income (Putra et al., 2020). Vertical farming innovation has emerged as a promising solution to overcome limited agricultural land and increase farmers' income in urban areas. In this article, we will discuss vertical farming innovation, its working principles, benefits, and positive implications for increasing farmers' income in urban areas (Petrovics & Giezen, 2022).

Vertical farming is a farming system that utilizes space efficiently by planting various types of plants in layers or vertically. This farming can be done in special buildings or structures that are designed in such a way as to accommodate many plants in one place. Vertical farming relies on advanced technology such as the use of LED lights, automatic irrigation, and temperature and humidity controls to create an optimal environment for plant growth. Various types of plants such as vegetables, fruit, and ornamental plants can be grown in this vertical farming system (Saad et al., 2021).

The working principle of vertical farming is based on the concept of efficient use of space, where plants are grown in different layers or levels on top of each other. This farming can be done hydroponically, in aeroponics, or using planting media such as soil, cocose, or other fibers (Jürkenbeck et al., 2019). Some of the working principles of vertical farming include:

a. Plant Selection. Selecting the right type of plant is critical to the success of vertical farming. The plants selected must be suitable for their growing environment and have a life cycle that is compatible with the tiered system.
b. Providing Nutrition. Vertical farms often use hydroponic or aeroponic systems that allow nutrients to be delivered directly to plant roots. This ensures the plants get proper and optimal nutrition.
c. Providing Light. Because vertical farming is often done indoors or in enclosed buildings, providing light is a key factor. Special LED lights are used to provide the right light spectrum for plant growth.
d. Environmental Controller. Environmental temperature and humidity must be maintained to suit the needs of the plant. The use of automated technology helps maintain an optimal environment without the need for manual intervention.

Vertical farming has several benefits and advantages of its own. Some of these benefits include:

a. Increasing Land Efficiency. By planting vertically, this farming allows more plants to grow on a limited land area. For example, one vertical plant column can accommodate dozens of plants, effectively increasing land productivity.
b. Reducing Water Use. The hydroponic system in vertical farming uses water more efficiently than conventional farming. The water used in this system can be recycled, thereby reducing overall water consumption.
c. Easier Pest Control. Indoor vertical farming or enclosed buildings provide better pest control. This reduces the use of pesticides and maintains the quality of agricultural products.
d. Increasing Local Food Availability. With vertical farming, food can be produced in urban areas themselves. This means reducing dependence on food imported from rural areas or abroad (Beacham et al., 2019).

The use of vertical farming innovations can open up new business opportunities for farmers and contribute to increasing their income. The following are several factors that cause an increase in farmer income through vertical farming:

a. Increased Productivity. By increasing land efficiency, vertical farming allows farmers to grow more crops on limited land. As a result, agricultural production increases, and farmers can sell more of their crops (Van Delden et al., 2021).
b. Added Value of Agricultural Products. Vertical farming often produces crops that are high quality and different from those available in traditional markets. This provides added value to their agricultural products, so the selling price is higher (O'sullivan et al., 2019).
c. Stable and Guaranteed Market. By utilizing advanced technology, vertical farming can guarantee a stable food supply throughout the year. This means farmers can sell their crops regularly, without being too dependent on seasons and weather conditions (Lubna et al., 2022).
d. Diversification of Agricultural Products. With vertical farming, farmers can grow various types of crops in one system. This diversification of agricultural products allows farmers to reach a wider market and face lower risks in the agricultural business (Stringer et al., 2020).

Although vertical farming offers the potential to increase farmers' income, several obstacles need to be overcome to optimize the implementation of this innovation:

a. High Initial Investment. Establishing a vertical farming system requires significant initial investment, primarily to purchase the necessary equipment and infrastructure, such as LED lights, irrigation systems, and environmental control technology. This can be an obstacle for farmers with limited capital (Li et al., 2020).
b. Limitations of Technology and Knowledge. Not all farmers in urban areas have sufficient access to and knowledge regarding vertical farming technology. Training and technical assistance are needed so that farmers can operate the system effectively and successfully (Martin & Bustamante, 2021).
c. Availability of Raw Materials. Vertical farming uses certain planting media or substrates. The availability and price of raw materials such as cocose, fiber, or hydrogel can influence sustainability and production costs (Maluin et al., 2021).
d. Licensing and Regulations. Implementing vertical farming in urban areas often involves complex licensing and regulatory aspects. Complicated bureaucratic procedures can be a challenge for farmers who want to start a vertical farming business (Fussy & Papenbrock, 2022).
e. Changes in Consumer Behavior. Introducing vertical farming products to consumers requires appropriate education and promotion. Changing consumer behavior to switch and trust vertical farming products can sometimes be a challenge (Specht et al., 2019).

C. METHOD

Vertical farming has become an important topic in the search for innovative solutions to overcome global food security challenges. This research aims to

investigate the potential and impact of vertical farming through a descriptive qualitative approach. The data that will be used in this research comes from various previous research and studies that still have relevance to the research objectives. By utilizing existing data, this research will provide a comprehensive picture of the contribution of vertical farming to global food security. This research method involves the process of collecting data from scientific literature, previous studies, as well as related information from trusted sources. Furthermore, the data collected will be processed by researchers to produce findings that are relevant to the research objectives. With a descriptive qualitative approach, this research does not only focus on statistical figures but also provides an in-depth understanding of the dynamics and impact of vertical farming in the global food security scenario. Through this approach, it is hoped that this research can provide valuable insights to better understand the role of vertical farming as an innovative solution amidst the complexity of global food challenges.

D. RESULT AND DISCUSSION

1. Global Food Security Context

In facing the challenge of global food security, first of all, it is necessary to realize that the rapid growth of the world population has a significant impact on food availability. The increase in population places great pressure on conventional food production systems. With the global population expected to reach more than 9 billion people by 2050, there is an urgent need to optimize agricultural methods to meet increasing food needs. Increasing food production not only needs to involve technology innovation but also changes in the agricultural paradigm to ensure the sustainability of production.

Urbanization is an inevitable global trend, and this contributes to the complexity of food security issues. Changes in consumption patterns in big cities create new challenges in food distribution and supply chain sustainability. Rapid urbanization has also resulted in increasingly limited land for traditional agriculture. Therefore, agricultural solutions are needed that can adapt to these changes and remain effective in urban environments.

The impact of climate change on food production is a serious threat. Climate variability, including changes in rainfall patterns and extreme temperatures, affects crop productivity and the resilience of agricultural products. This phenomenon can result in crop failure, increase the risk of food disasters, and reduce food availability. Therefore, agricultural systems that are adaptive and resilient to climate change are crucial for ensuring global food security.

In overcoming these problems, vertical farming has emerged as an attractive innovative solution. Vertical farming promises higher land use efficiency, overcoming the limitations of increasingly limited agricultural land. The concept of stacking layers of plants vertically not only makes optimal use of space but also allows the implementation of farming in densely populated urban areas. By utilizing advanced technology such as hydroponics or aquaponics, vertical farming can be a sustainable

alternative for producing food in sufficient quantities to meet growing global needs. Its potential to help meet global food needs makes vertical farming an important part of achieving sustainable and inclusive global food security.

Apart from that, efficient land use by vertical farming can also be interpreted as a strategic step in responding to growing urbanization. By setting up vertical farms in urban areas, distribution distances between production sites and consumers can be minimized, reducing food losses during the transportation process, and supporting the sustainability of local supply chains. This not only has a positive impact on economic aspects but also cuts carbon emissions produced by long-distance food transportation, which in turn, contributes to climate change mitigation efforts.

By adapting to urban conditions, vertical farming could be the answer to the food security challenges faced in various cities around the world. Its potential to be integrated into urban infrastructure opens up new opportunities in bringing food production closer to consumers, creating sustainable local food sources, and stimulating innovation at the community level. Thus, seeing the contribution of vertical farming as an innovative solution, an opportunity opens up to change the global agricultural paradigm towards a more adaptive, efficient, and sustainable model in facing increasingly urgent food security challenges.

2. Principles and Technology of Vertical Farming

Vertical farming represents a revolution in the way we view and approach food production. The basic concept of vertical farming involves stacking layers of plants vertically, utilizing air space to increase production capacity. This use of vertical crop layers allows vertical farming to maximize the use of limited land, which is becoming increasingly critical in the context of population growth and urbanization. By arranging plants vertically, vertical farming is also able to increase the efficiency of resources such as water and soil nutrients, helping to create a more sustainable farming system.

Hydroponic and aquaponic systems are key components of the basic concept of vertical farming. In vertical farming, plants grow without using soil, replacing traditional growing media with a special nutrient solution in a hydroponic system. Meanwhile, aquaponic systems integrate fish farming with plant farming, creating a symbiotic environment where water and nutrients can be used optimally by both systems. This advantage not only increases plant productivity, but also creates a sustainable cycle where fish waste provides nutrients for the plants, and the plants clean water that returns to the fish's system. This approach shows the sustainability of vertical farming in reducing its ecological footprint.

On the technological side, vertical farming relies not only on innovative basic concepts but also on the integration of advanced technologies. The application of environmental sensors and controls has become essential to control plant growth parameters such as temperature, humidity, and CO2 levels. Automated monitoring systems enable real-time monitoring of vertical farming conditions, enabling rapid response to necessary changes. In addition, the integration of Internet of Things (IoT)

technology provides the ability to connect all aspects of agricultural production in a connected manner, enabling remote management and optimization of production processes. This innovation not only increases efficiency but also increases the involvement of stakeholders, including farmers and consumers, in supporting the success of vertical farming as an innovative solution for global food security.

Furthermore, the use of hydroponic systems in vertical farming opens up the potential for increasing water use efficiency. Plants grow in a nutrient solution that they access through their roots, eliminating the need for soil as a growing medium. This not only reduces overall water use but also reduces the risk of soil contamination by pesticides and herbicides. In the context of increasingly acute climate change, water use efficiency is key to ensuring global food security.

Apart from that, advanced technology in vertical farming also extends to a circular economic approach through the aquaponic system. By integrating fish and crop farming, vertical farming creates an environment that allows for interdependence between system components. Nutrient-filled fish waste is treated as a natural fertilizer source, providing benefits to plants growing in hydroponic systems. Likewise, plants clean the water of fish waste, creating a mutually beneficial cycle. This model illustrates how vertical farming is not only an innovative solution for food production but also plays an important role in maintaining ecosystem balance and minimizing negative impacts on the environment. By adopting holistic vertical farming technology, we can explore new potential in achieving sustainable and environmentally friendly global food security.

3. Environmental Impact of Vertical Farming

The significant environmental impact of vertical farming can be seen in the reduced carbon footprint. One of the main contributions is the reduction of long-distance food transportation. By setting up vertical farms in urban centers, agricultural products can be produced and consumed locally, reducing dependence on long-distance transportation that uses fossil fuels. This reduction not only reduces carbon emissions produced during transportation but also minimizes the ecological impact and food losses that often occur during the product's journey from field to consumer. Additionally, vertical farming can utilize renewable energy sources, such as solar power or wind energy, to power hydroponic or aquaponic systems, creating higher energy efficiency in food production.

Sustainable water management also has a positive impact on vertical farming. The use of water in a hydroponic system is said to be more efficient compared to conventional farming because the water is used directly by the plants without the need for soil. The recirculating system generally used in vertical farming also minimizes water waste, because water can be collected again and used repeatedly in the system. Furthermore, vertical farming can utilize technology that reduces the impact of water pollution. By reducing the use of pesticides and herbicides commonly found in conventional farming, vertical farming has the potential to reduce water pollution and improve local water quality. Through wise water management, vertical farming can

become a model for sustainable and environmentally friendly agricultural practices. By combining resource efficiency and smart water management, vertical farming can play a key role in supporting ecosystem balance and maintaining the sustainability of natural resources.

In addition to reducing carbon footprints and sustainable water management, vertical farming can also have a positive impact on local biodiversity and the preservation of natural habitats. By reducing the need for conventional agricultural land which often involves deforestation or destruction of natural habitat, vertical farming can help maintain biodiversity in a region. This can create green corridors between urban areas, provide habitat for wildlife, and support the sustainability of local ecosystems. In addition, the vertical farming approach that uses advanced technology allows for more careful monitoring of the surrounding environmental conditions. This includes monitoring soil sustainability and preventing erosion, ensuring that vertical farming not only provides benefits in terms of food production but also in preserving the ecosystem.

Another positive impact is seen in the role of vertical farming in reducing the risk of soil pollution. By eliminating reliance on chemical pesticides and herbicides often used in conventional farming, vertical farming reduces the risk of soil contamination by harmful chemicals. In addition, the use of non-soil planting media in a hydroponic system prevents soil from degradation and soil fatigue which generally occurs on conventional agricultural land. By reducing the risk of soil pollution, vertical farming creates a cleaner and more sustainable environment, supporting soil health and the fertility necessary for plant growth. Through this holistic approach, vertical farming is not only an innovative solution for food security but also an important pillar in maintaining ecological integrity and environmental sustainability.

4. Economic Aspects of Vertical Farming

Economic aspects in the context of vertical farming play a crucial role, especially in the financial sustainability of agricultural operations. Initial investment is an important factor to consider in adopting vertical farming. Although the technology required to set up a vertical farming facility can be expensive, this investment is often offset by the long-term efficiency and potential economic benefits. With higher production scales and optimal land use efficiency, vertical farming can create a financially sustainable business model. The importance of financial sustainability is also closely related to the growing research and development of vertical farming technology, which can optimize production processes and reduce overall operational costs.

Market potential and economic benefits are additional attractions of vertical farming. The growing demand for sustainable and organic agricultural products provides an opportunity for vertical farms to enter a growing market. Consumers who are increasingly concerned about sustainability and health aspects can become a strong customer base for vertical farming products. By providing clean, safe, and

sustainable food options, vertical farming can create a competitive advantage that can be valued in the global marketplace. Therefore, the economic aspects of vertical farming not only involve the financial sustainability of the farming operation itself but also integrate broad market considerations to create a positive economic impact on the agricultural industry as a whole.

Social impact and community welfare are other important dimensions of vertical farming. Local job creation is one positive aspect that can have a direct impact on the local economy. Vertical farming, especially if integrated into an urban context, can provide employment opportunities for local people, from agricultural technicians to processing factory workers. This can help reduce unemployment rates and improve the economic well-being of communities. Apart from that, food access for urban communities is also an important focus in the social impact of vertical farming. By producing food close to consumer centers, vertical farming can provide urban residents with easier and faster access to fresh agricultural products. This not only contributes to economic prosperity but also promotes healthier and more sustainable food choices in dense urban environments. As a holistic agricultural solution, vertical farming can play a major role in creating a positive impact not only from an economic perspective but also from a social perspective and community welfare.

Apart from the economic aspect, the social impact of vertical farming can involve active community participation and involvement in the food production process. This participatory approach can create closer relationships between producers and consumers, increase awareness of food origins, and give consumers a sense of ownership over their food production. Education and training programs for local communities, especially for those directly involved in vertical farming, can provide new knowledge and skills, increase community economic capacity, and create opportunities for career growth in the agricultural sector.

Apart from that, positive social impacts can also be seen in increasing the welfare of urban communities that can access quality food through vertical farming. Vertical farming can play a role as an initiative in overcoming the issue of unequal food access, especially in urban areas with dense populations. By providing easier and more affordable access to agricultural products, vertical farming can help reduce disparities in food access and make a positive contribution to community nutrition. In this way, vertical farming is not only a motor for the local economy but also an agent of social change that has a positive impact on prosperity and equality in urban communities.

5. Challenges and Opportunities for Implementing Vertical Farming

Challenges in implementing vertical farming involve several critical factors, including aspects of applicable agricultural regulations and policies. Regulations that have not yet been fully adapted to support vertical farming can be a major obstacle to the development and growth of this industry. A clear and supportive regulatory framework is needed to ensure the sustainability of vertical farming operations. This includes regulations regarding land use, food safety, and environmental standards.

Alignment between regulations and policies with the special needs and characteristics of vertical farming is essential so that its implementation can be effective.

Apart from regulations, another challenge is the suitability of vertical farming technology to the local environment where its implementation is planned. Local climate and infrastructure characteristics can influence the efficiency and sustainability of vertical farming operations. Therefore, adapting technologies to take these differences into account, including the integration of renewable energy systems or structural design modifications, is a crucial step in overcoming these challenges. It is necessary to create synergy between vertical farming technology and the local environmental context so that its implementation can achieve optimal and sustainable results.

Meanwhile, there are development and scalability opportunities that can support the growth of vertical farming. Innovation in vertical farming system design is key to increasing production efficiency and overcoming specific environmental challenges. The development of technologies that are more efficient, cost-effective, and easy to adopt will open up new opportunities for vertical farming to become more economically attractive. Stakeholder engagement, including support from governments, research institutions, and the private sector, is also an important opportunity. Close collaboration between all parties can produce faster innovation and support the development of vertical farming as a more integrated and sustainable solution for supporting global food security. By understanding these challenges and embracing these opportunities, the implementation of vertical farming can be one of the innovative answers that lead the change towards a more efficient and sustainable agricultural system.

E. CONCLUSION

Vertical farming is emerging as a promising innovative solution to address global food security challenges. In exploring critical aspects such as ecology, economy, and social, vertical farming shows great potential to provide positive impacts. With its high land use efficiency, adaptability to urban environments, and integration of advanced technology, vertical farming can solve several major problems in food production, especially amidst rapid global population growth and ever-expanding urbanization. However, the implementation of vertical farming is not without challenges that need to be overcome. There is a need for a supportive regulatory and policy framework, as well as adapting technology to local environmental characteristics. In facing these challenges, there is a great opportunity for innovation in vertical farming system design and the active involvement of various stakeholders. By strengthening collaboration between governments, research institutions, the private sector, and society, vertical farming can become a major force in achieving sustainable global food security. In this context, the conclusion confirms that vertical farming is not only an alternative but also a significant step forward towards positive transformation in the global agricultural sector.

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