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The Relationship Between Air Transportation and Vertical Farming in Urbanization: The Istanbul Case

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Abstract: Istanbul, historically a cultural and commercial hub due to its strategic location and economic power, has undergone significant transformations in its spatial use and infrastructure needs in recent years, driven by rapid population growth and urbanization. This transformation has been further accelerated by the development of innovative sectors such as air transportation and vertical farming. While air transportation strengthens Istanbul's role in global trade networks, the pressures on space and the environment created by urbanization continue to increase. Vertical farming, on the other hand, offers a viable solution for sustainable food production in limited urban spaces. This study examines the interaction between air transportation and vertical farming in the context of Istanbul's urbanization process. Specifically, the economic contributions of air transportation and the potential of vertical farming to meet the growing food demand will be assessed. Additionally, the synergy between these two sectors in terms of logistics, environmental impacts, and sustainability goals will be discussed. Based on literature reviews, this study, taking into account Istanbul's unique conditions, aims to contribute to both local and global sustainable development goals.

Keywords: Air Transportation, Vertical Farming, Urbanization, Istanbul, Sustainable Agriculture, Urban Food Security, Greenhouse Gas Emissions, Smart Urbanization, Sustainability

JEL Classification: Q1, O1, L93

1. Introduction

Istanbul has historically been a cultural and commercial center due to its strategic location and economic strength. In recent years, however, the rapidly increasing population and dynamic urbanization processes have significantly transformed the city's spatial use and infrastructure needs. This transformation has become more pronounced with the rise of innovative sectors such as air transportation and vertical farming. Air transportation has strengthened Istanbul's central role in global trade and transportation networks, while the growing population and commercial activities accelerate

urbanization, placing significant pressure on land use. On the other hand, vertical farming has emerged as a solution for sustainable food production in limited urban spaces. The relationship between these two dynamics—air transportation and vertical farming—could play a key role in achieving Istanbul's sustainability goals.

This study aims to examine the interaction between air transportation and vertical farming in Istanbul's urbanization process. Specifically, the economic contributions of air transportation to the city's structure and the opportunities offered by vertical farming to meet the increasing food demand will be explored. Furthermore, the ways in which these two sectors can complement each other and create synergy in terms of logistics, environmental impacts, and sustainability objectives will be discussed. Finally, the potential of the relationship between air transportation and vertical farming in terms of urbanization strategies and environmental sustainability will be highlighted through the Istanbul case study.

In this study, the interaction between air transportation and vertical farming, with a focus on the application potential specific to Istanbul, has been examined in detail through a review of existing literature. Given Istanbul's unique urban dynamics and sustainability goals, this research is believed to offer a significant contribution to the field. To shed light on the future, this study's implementation in Istanbul is of great importance for addressing the city's specific challenges and contributing to global sustainability goals.

2. Air Transportation: Definition and Historical Development

Air transportation is a mode of transportation that enables the movement of people and cargo by air. Historically, aircraft were initially developed for military purposes, with Italy becoming the first country to conduct military operations using airships and monoplanes[1] during the Italo-Turkish War of 1911. In 1914, Roland Garros' addition of a machine gun to his aircraft marked a significant turning point in the evolution of military aviation. The following year, Kurt Wintgens achieved the first aerial victory with a fighter aircraft equipped with a machine gun. World War I marked a period when the widespread use of aircraft significantly influenced the course of the war; during this time, France became the leader in aircraft production, producing over 68,000 aircraft.

[1] The term "monoplane" refers to an aircraft with a single main wing layer. It is used to describe an aircraft type characterized by having only one main set of wings. Monoplanes are a common design in modern civil and military aviation.

World War II accelerated the global development of aircraft production and flight-based systems. The war led to the development of various military aircraft, including fighter bombers, strategic bombers, and ground attack aircraft. The invention of radar technology increased the precision of air operations, and the introduction of the Arado Ar 234 in 1942, the first jet-powered bomber, represented a major technological advancement.

In the post-war period, airports were built in many cities, and military aircraft were converted for civilian use. This transformation encouraged both personal and commercial air transportation. Innovative designs such as the Douglas DC-3 facilitated access to aviation for new passengers by offering comfortable and safe flight experiences. The International Civil Aviation Convention, adopted in 1944, aimed to standardize the safety and efficiency of civil flights, supporting the development of safer and more economical airlines operated by major carriers (Spartan College of Aeronautics and Technology, 2021).

Air transportation is defined through four key components: airlines, commercial cargo aircraft, the airspace used for flights, and airports and air traffic management (ATM) facilities. These components create the necessary infrastructure that supports the operations of air transportation.

Although aircraft performance has a decisive impact on the fuel consumption of a particular flight, the operational methods of airlines and, in particular, infrastructure management, have significant effects on overall flight energy efficiency. Airports offer a different energy balance, with potential for using alternative energy sources and achieving a zero-carbon footprint. However, the management of air traffic has a substantial impact on fuel consumption. From an ATM perspective, optimizing the flight paths and flight regimes of operations plays a critical role in reducing energy costs.

In this context, in line with global targets to increase energy efficiency in air transportation, it is important to understand the functions and contributions of four sectors: airlines, aircraft manufacturers, airports, and air navigation service providers. The influence of these sectors on regulatory systems should also be considered, as many operational regulations directly affect energy use and operational efficiency (Benito, 2018).

3. The Role of Air Transportation in Urbanization

Air transportation plays a significant role in the urbanization process by contributing to accessibility, economic growth, globalization, and infrastructure development. The increased accessibility to city centers leads to migration, as people seek better living conditions and job opportunities, while airports stimulate local economies by attracting foreign investment and creating more employment opportunities. Global connections allow cities to become more competitive in international trade and cultural exchanges, while the growth of air transportation necessitates substantial investments in infrastructure.

In the transportation sector, reducing the impacts of climate change presents a challenging goal, especially with the aviation sector, due to the steadily increasing travel activities. This challenge is particularly prominent in large cities, where long-distance travel rates remain high, even though car use tends to be lower in densely populated urban areas. Research suggests that long-distance travel could offset the lower emissions from daily commutes. However, debates persist regarding the factors driving long-distance travel and air travel in urban areas. Some hypotheses suggest a direct relationship between the characteristics of the built environment and long-distance travel, raising questions about whether urbanization and compact city policies contribute to mitigating climate change. Other hypotheses argue that this relationship is spurious and can be better explained by other factors. Empirical support for these explanations is crucial for urban planning. Understanding the determinants of air travel among urban residents is also critical for shedding light on the increasing global aviation emissions (Mattioli, 2021).

Given that these developments bring along environmental issues such as noise pollution and carbon dioxide emissions, it is increasingly important to mitigate these impacts through sustainable methods. Consequently, air transportation requires careful planning and integration to support sustainable and inclusive urban growth.

4. Air Transportation and Smart Urbanization

Air transportation plays a crucial role in the processes of smart urbanization, as it provides fast, efficient, and sustainable transportation solutions that contribute to the economic growth of cities and the development of their digital infrastructures. Smart cities can enhance the efficiency of air transportation infrastructure through data-driven management and optimization strategies. In particular, autonomous air transport systems and digitalized logistics networks not only improve the operational efficiency of

air transportation but also help reduce traffic congestion and minimize environmental impacts. In this context, the integration of air transportation and smart urbanization emerges as a key tool in achieving the sustainable growth objectives of cities. Furthermore, the advancement of air transportation can contribute to the holistic modernization of the transportation infrastructure in smart cities, thus enhancing the quality of life.

The air transportation sector is built on trust. Ensuring the safe transport of passengers and cargo forms the foundation of the industry. According to the International Air Transport Association (IATA), by 2018, the sector had carried 4.1 billion passenger miles and 61.5 million tons of cargo worldwide. The 45 accidents reported in 2017 marked a significant decline compared to previous years, with the accident rate per million miles being 1.08. The maintenance of this safety is largely attributed to engineering standards, regulatory policies, operational processes, and stringent oversight, as well as the collaboration between aircraft and component manufacturers and airlines.

In the context of smart urbanization, security is often associated with privacy and cybersecurity, but these two factors represent only a portion of the elements that contribute to the reliability of cities. The construction of trust is directly linked to the consistent and fair delivery of outcomes that residents and businesses expect. For example, the safety and punctuality of public transport services, the quick response of emergency services, and the effective enforcement of traffic regulations are fundamental elements that reinforce residents' sense of security. In this regard, a multidimensional approach must be developed to enhance the reliability of smart cities (Woodrow, 2021).

Air transportation is a key component of globalization, carrying approximately 4 billion passengers and 61 million tons of cargo annually, which is valued at 3.5 trillion USD in global economic activity. In Mexico, the aviation industry represents 3.5% of the country's GDP, and in 2018, it carried 98 million passengers, creating 1.4 million jobs. The International Air Transport Association (IATA) predicts that air transportation will double in the next 20 years. This growth also presents a challenge, as global jet fuel consumption accounts for approximately 2-3% of CO2 emissions. Based on 2005 levels, the goal is to reduce CO2 emissions from air transportation by 50% by 2050 (Vallejo-Blancas, 2022).

5. The Impacts of Air Transportation on Urban Development

The relationship between air transportation and urbanization has garnered increasing attention in recent years, particularly regarding the determinants of transportation emissions and the effects of urban structures. A recent survey revealed that 57.3% of participants had never traveled by air; however, among those who did, a marked positive skew in greenhouse gas emissions was observed. London exhibited the highest values in terms of air travel participation and associated emission levels, while a significant difference between urban and rural areas was not found. Interestingly, it was also found that air travel participation was somewhat higher in rural areas.

According to (Mattioli, 2021), air travel participation and emissions were particularly higher among first-generation immigrants, with ethnic minority groups exhibiting higher emissions compared to 'White Britons'. Additionally, a strong correlation was found between the geographic distribution of social networks and emissions; individuals with better access to major airports had higher emissions. Model analyses showed that air travel participation in London was strongly related to the ease of access to airports and the distribution of social networks. However, it was concluded that air travel participation in London was also influenced by other factors, which require further investigation.

Moreover, a positive relationship was observed between car ownership and air transportation, suggesting that these two modes of transport may interact to influence air travel behavior. These findings challenge the notion that urban planning alone drives increased air travel, instead emphasizing the importance of better access to airports and social networks. The positive relationship between car usage and air transportation also offers opportunities for synergy in sustainable transportation policies. In conclusion, the complexity of the dynamics between air transportation and urbanization highlights the need for further research to better understand these interactions (Mattioli, 2021).

In a broader context, air transportation has significantly shaped urban development worldwide. Airports and air travel have functioned as centers of economic growth, trade, and tourism in major cities, while these infrastructures have increased the integration of cities into global networks, thereby promoting mobility within urban areas. However, the growing demand for air travel has also brought about environmental challenges, such as traffic congestion, air pollution, and greenhouse gas emissions, particularly in large cities. Additionally, easy access to air transportation has accelerated urban growth, resulting in large migrations from rural to urban areas. This phenomenon has

transformed the spatial structure of cities, necessitating the reorganization of infrastructure and transportation policies. As a result, the increasing role of air transportation affects the dynamics of urban development, presenting both economic opportunities and environmental and social challenges.

6. Definition and Importance of Vertical Farming

Vertical farming is a modern agricultural method developed for urban food production, which aims to efficiently produce high quantities of food by utilizing vertical spaces. Unlike traditional agriculture, vertical farming uses water and nutrient solutions instead of soil to facilitate plant growth. Methods such as hydroponics, aeroponics, and aquaponics, which are water-based systems, are typically employed in vertical farming. These systems significantly reduce water usage while enabling higher yields in smaller areas.

Vertical farming holds great potential, particularly in ensuring food security in the context of the growing global population and urbanization. The rapid expansion of cities and the reduction of agricultural land have raised questions about the sustainability of traditional farming methods. Vertical farming encourages local food production within urban areas, thereby increasing the supply of fresh and nutritious food and reducing cities' dependency on external sources. Furthermore, vertical farming offers environmental sustainability benefits, as it not only improves water and energy efficiency but also contributes to the reduction of greenhouse gas emissions. Additionally, vertical farming can support social and economic development in urban areas, as local food production creates job opportunities and increases participation in food systems.

The significance of vertical farming lies not only in ensuring the sustainability of food production but also in helping to reduce the ecological footprint of cities by transforming the urban environment. This innovative method plays an important role in future urban planning and emerges as a strong solution for sustainable urban food production (Abdelfatah, 2023).

6.1. Applications of Vertical Farming in Cities

When considering urban areas, concerns about the displacement of agricultural land from cities and the increasing distances in distribution raise various issues. Inequalities in food access, unemployment, and rising prices further exacerbate concerns regarding food crises. Urbanization has led to the growth of informal settlements, and this, in turn,

poses a significant threat to food security, as a large portion of the income of individuals living in these areas is spent on food (Matuschke, 2009).

6.2. Vertical Farming Projects in Istanbul

The need for vertical farming in Istanbul arises from a range of factors, including the growing population, decreasing agricultural land, food security concerns, environmental sustainability, transportation and distribution costs, as well as the potential for job creation. The rapidly growing population is increasing food demand, rendering existing agricultural production systems insufficient. Urbanization is leading to a decrease in agricultural land, while vertical farming allows for higher yields in limited spaces. Additionally, local food production can enhance food security in Istanbul while consuming less water and energy, thus reducing environmental impacts. Vertical farming ensures the freshness of food by producing it within the city and facilitates better control over food prices. Finally, these projects have the potential to create new employment opportunities while stimulating the local economy. For these reasons, vertical farming is seen as an important alternative in Istanbul for both increasing food production and addressing various social and economic challenges.

The appeal of employment opportunities in metropolitan areas has led to an increase in unemployment rates alongside population growth. This situation has resulted in significant difficulties for low- and middle-income families in accessing food. The movement of urban agricultural lands out of the city, the reduction of agricultural activities, and the rise in fruit and vegetable imports have contributed to the increase in food prices in large cities. This process, coupled with the reduction in purchasing power, has the potential to deepen the effects of a possible food crisis in Istanbul. Facilitating access to food for low- and middle-income families, encouraging the cultivation of vegetables and fruits, and supporting the sale of surplus products are critical measures to mitigate these negative impacts.

It is noted that 15% of Türkiye's population resides in Istanbul, and with the continuation of current growth trends, this number is expected to reach 19 million by 2020. Although 14.3% of Istanbul is classified as primary agricultural land, the city largely meets its food needs from surrounding regions. According to TURKSTAT data, agricultural areas in Istanbul decreased by 15% between 1997 and 2002, and 2.5% of residential areas were built on critical agricultural zones. This information highlights the challenges a city faces when it cannot meet its food needs, particularly in the context of decreasing agricultural land, increasing population, and growing urbanization. Therefore, urban agricultural

practices must be integrated into urban policy to partially meet urban food needs, create job opportunities, and allow families to grow their own food (Türk, 2017).

Historically, agricultural activities have provided the primary economic support and met basic food needs. Recent legislative changes and the rise of large-scale agricultural enterprises in Türkiye have significantly reduced small-scale farming. This shift, combined with changes in global food policies and competitive pressures, has led many rural farmers to migrate to urban areas in search of better employment, education, and healthcare opportunities.

With the acceleration of urbanization in the 21st century, it has become inevitable to reassess the relationship between cities and agriculture. The looming "food crisis" is increasingly being addressed not only as an economic issue but also in terms of accessibility, a consideration that has gained importance, particularly given the rapid growth of urban populations. Many cities, including Istanbul, are facing difficulties in meeting food demands due to the conversion of agricultural land into construction areas and insufficient urban farming activities.

The scarcity of horizontal spaces for agriculture and the loss of green areas necessitate the exploration of alternative urban farming models. Various architectural typologies, through vertical farming solutions, can strengthen existing ecological frameworks while promoting local food production and reducing energy consumption. This approach not only addresses food security but also provides significant environmental, social, and economic benefits for urban neighborhoods.

6.3. Vertical Farming Applications in Istanbul

Vertical farming plays an important role in enhancing local food production and ensuring environmental sustainability in Istanbul. Some examples of vertical farming projects in Istanbul are outlined below:

Urban Agriculture Istanbul: A 1-acre vertical and soilless farming facility, established in the parking lot of a luxury shopping center in Istanbul's Sarıyer district, presents a model for sustainable agriculture within the city. This facility produces fresh vegetables year-round, regardless of weather conditions. Thanks to LED lights and controlled environmental conditions, plants grow rapidly, yielding high productivity, while water consumption is reduced by 95% compared to traditional agriculture. Furthermore, the absence of any pesticides or hormones used in the process ensures that the products are healthy and natural. With the vertical farming method, the production capacity

achieved in just 1 acre is equivalent to that of 315 acres of traditional land. This model reduces fossil fuel consumption associated with transportation by producing food locally within the city, thus decreasing the carbon footprint and supporting environmental sustainability (Grozine Contributor, 2024).

Figure 1. Urban Agriculture Istanbul

Istanbul Closed Vertical Farming Application Center: The Istanbul Closed Vertical Farming Application Center, inaugurated by the Minister of Agriculture and Forestry of the Republic of Türkiye, Prof. Dr. Vahit Kirişci, represents a significant advancement in agricultural technology. Located 30 meters underground in a parking lot in Kağıthane, this facility is the second of its kind in the world. By demonstrating how modern technologies, such as artificial light for photosynthesis and minimal water usage, can revolutionize agricultural practices, the center aims to attract young people to the agricultural sector. The center offers high-efficiency vertical farming, providing up to 40 times greater productivity compared to traditional methods, and by cultivating produce directly in urban areas, it reduces logistical costs and food waste. The first harvest, which included lettuce and herbs, was successfully completed, highlighting the potential of urban farming to supply fresh, pesticide-free food.

Figure 2. Istanbul Closed Vertical Farming Application Center

The project is part of broader efforts to address the challenges posed by climate change and population growth, aiming to create a sustainable food production system in cities. It also emphasizes Türkiye's commitment to innovative, locally developed agricultural technologies (T.C. Tarım ve Orman Bakanlığı, 2022).

The Root Istanbul: The Root Istanbul is a biotechnology-based food production company that designs and constructs turnkey vertical indoor farming factories and facilities using eco-friendly, soilless hydroponic systems. The Root Istanbul project began in 2014 with four engineers, aiming to design effective, low-cost, and hygienic food production systems in soilless hydroponic plant factories. After five years of research and development, the first soilless vertical hydroponic plant factory in Istanbul was launched, with a production capacity of 24,000 units per month. The company continues its research, development, production, and sales activities both domestically and internationally, in collaboration with universities and public institutions. The technology and data-driven turnkey solutions offered by The Root Istanbul are equipped with microclimate-supported indoor environments. Systems such as ozone sterilization, HEPA-filtered air purifiers, and UV filters enable farming in climate-controlled

environments. This allows agricultural activities to be carried out even in urban centers or areas where climate conditions and soil fertility are insufficient. The hygienic production conditions provide protection from organisms that may arise from air, water, or soil, while also enabling production throughout the year. No chemical fertilizers or pest control products are used in this system. The company's indoor vertical farming solutions produce more than 200 different plant varieties, offering a wide range of sales opportunities that cater to various national and regional gastronomic cultures (The Root Istanbul, 2024).

Plant Factory: Plant Factory is dedicated to shaping the future of farming by training the next generation of farmers. Focusing on urban farming, it provides hands-on, interactive education to both young people and adults on the entire cultivation process from seed to harvest. The organization develops environmentally friendly, technologically advanced farming systems to produce healthy and nutritious products. Using vertical farming in urban environments, Plant Factory challenges traditional agriculture by reducing water use by 95% and increasing yield per square meter by 20 times. Its goal is to ensure sustainable year-round production while tracking every step of the product journey from seed to plate. The operating facilities include PF001, PF-GTÜ, and PF002-İstinyePark. Among them, PF001, located on the Asian side of Istanbul, is an R&D and production facility growing a variety of products including leafy greens, strawberries, and tomatoes. PF-GTÜ, located at Gebze Technical University, focuses on developing functional foods with specific nutritional profiles. PF002 İstinyePark, the first commercial facility located in Istanbul's İstinyePark Shopping Center, produces 900,000 units annually, delivering fresh products to local customers (Plant Factory , 2024).

Vertical Farming Training and Workshops: Various universities and agricultural cooperatives in Istanbul organize workshops and training programs to teach vertical farming techniques to individuals and communities. These educational initiatives aim to raise local awareness about agriculture.

Private Sector Projects and Initiatives: Several private companies are establishing vertical farming systems in Istanbul to provide fresh produce, which is then sold through restaurants or markets.

7. The Relationship Between Air Transport and Vertical Farming

The relationship between air transport and vertical farming is becoming increasingly important in addressing urban food production challenges and improving supply chain efficiency. Several key points that illustrate this connection are as follows:

7.1. Fresh Produce Delivery

Air transport facilitates the rapid delivery of fresh produce from vertical farms to urban consumers. Given the perishable nature of many agricultural products, the ability to quickly transport these goods minimizes spoilage and ensures they reach the market in optimal condition. The connection between air transport and vertical farming provides a solution that shortens supply chains, reduces environmental impacts, and ensures efficient delivery of fresh products within urban areas. Urban farming plays a key role in the production of perishable goods, particularly leafy greens, fresh dairy, and poultry products, which are often locally produced, sold, or distributed through bartering. This approach increases urban residents' access to fresh, healthy, and affordable food while simultaneously reducing energy consumption and greenhouse gas emissions by shortening transportation distances. By providing fresh food closer to production points, cities can reduce their ecological footprint and contribute to the sustainability of urban food systems. Furthermore, vertical farming allows for the development of synergistic processes between industry and agriculture; for instance, waste heat, cooling water, or CO2 from industrial processes can be efficiently used in greenhouse production. In this way, a circular relationship between food production, energy, and resource management is established, reducing environmental impacts while also benefiting local economies (Zeeuw, 2011).

7.2. Global Supply Chains

Vertical farms can operate in various locations, and air transport enables them to become part of a broader global supply chain. This allows vertical farms to access international markets and supply local products to consumers demanding sustainably grown fresh food, irrespective of geographical barriers. Vertical farms can leverage air transport to reach distant markets, thereby expanding their consumer base beyond local regions. This global reach allows urban farmers to deliver fresh products to high-demand city centers, contributing to food security and economic resilience.

7.3. Reduced Transportation Costs

While air transport can be expensive, the high value and low weight of fresh produce make it economically viable for certain goods. As vertical farming technologies advance

and production costs decrease, the overall economics of air transport may become more favorable for urban food distribution. According to the United Nations Food and Agriculture Organization's Global Food Crisis Action Framework (FAO, 2008), promoting urban food production can shorten food transportation distances, reducing energy consumption and greenhouse gas emissions. In industrialized countries, the transportation process from farm to table consumes four times more energy than the production process itself. The same trend is rapidly expanding in developing countries. Producing food closer to cities can minimize energy usage and reduce the ecological footprint of cities. This, in turn, lowers transportation costs for local food production and makes the food supply chain more efficient (Heinberg, 2009).

7.4. Enhanced Food Security

Air transport can help maintain food security by enabling rapid responses to supply shortages. Vertical farms can produce food closer to urban centers and, through efficient air transport, quickly distribute excess production to areas in need. Food security is expected to become an increasingly important issue in the coming years. Demographic forecasts suggest that urban populations will grow rapidly, while agricultural experts warn that food supply will struggle to meet rising demand due to the shrinking availability of agricultural land (Al-Kodmany, 2018). The United Nations (UN) forecasts that the global population will increase by 40% by 2050, reaching 9 billion, with 80% of this population living in cities. This implies that food demand must rise by 70%. Rising oil prices, along with diminishing water, energy, and agricultural resources, will further increase food prices, and farmers expect food costs to continue rising. The expansion of suburban areas leads to further loss of agricultural land, while urban farming faces challenges due to land scarcity and high costs. Thus, finding solutions to the global food security crisis is of utmost importance (The United Nations, 2017).

7.5. Urban Resilience

As cities face challenges related to climate change and population growth, the integration of vertical farming with air transport can enhance urban resilience. It allows cities to diversify their food sources and reduce their dependence on distant agricultural areas vulnerable to environmental factors. Urban agriculture (UA) can increase a city's capacity to adapt to environmental challenges and climate change. The World Meteorological Organization (WMO) emphasizes the need for more urban farming to combat climate change and make cities more resilient. Urban agriculture and urban forestry benefit cities by improving microclimates and helping them adapt to climate change. These green spaces can mitigate the impacts of climate change, such as water storage and the absorption of excessive rainfall (Tidball, 2006).

7.6. Sustainability Outcomes

The integration of air transport with vertical farming promotes sustainability by enabling local production that reduces dependence on extensive supply chains. By shortening transportation distances for fresh produce, urban farms can lower their carbon footprint compared to traditional agricultural practices involving long-distance trucking. Vertical farming is an advanced approach to efficient food production on limited and expensive land. Similar to the logic behind high-rise buildings, this model combines food production, waste management, and other ecosystem functions to create compact, self-sustaining systems. Vertical farms can conserve water and energy, provide year-round production regardless of weather conditions, and increase overall productivity, all while reducing pollution and greenhouse gas emissions. By shortening travel distances between food production sites and markets, transportation costs are minimized. These systems can create new employment opportunities, contribute to local economies, and strengthen food security and economic well-being. As a result, vertical farming is supported by organizations and initiatives focused on environmental protection and promoting local food production (Al-Kodmany, 2018).

7.7. Flexibility and Sensitivity

Vertical farming offers a flexible and resilient model for food production, providing resistance to environmental threats. Agriculture in closed environments is less affected by external factors such as climate change, pest infestations, and water scarcity, leading to healthier and more sustainable production. Moreover, since vertical farms are not dependent on weather conditions, they allow for high yields throughout the year, overcoming seasonal challenges and increasing flexibility in food production. This flexibility strengthens both food security and economic stability. Governments and the private sector in various regions of the world are supporting vertical farming as a means to contribute to the long-term sustainability of cities (Al-Kodmany, 2018).

Air transport enables vertical farms to quickly respond to fluctuations in market demand. This adaptability is crucial in urban environments, where consumer preferences can change rapidly. Research highlights that agile supply chains, facilitated by air transport, can better align with the dynamic nature of urban food markets.

7.8. Innovative Business Models

Companies are increasingly exploring innovative business models, such as subscription services for direct-to-consumer delivery, to create synergies between vertical farming and air transport. This approach can streamline logistics and improve the accessibility of fresh products.

In summary, the interaction between air transport and vertical farming presents opportunities to improve urban food systems, increase sustainability, and address the challenges of food distribution in metropolitan areas. As both sectors continue to develop, collaborations may lead to more efficient and resilient urban farming solutions. Ultimately, air transport significantly impacts the operational dynamics of vertical farming by enhancing the speed and efficiency of food distribution, expanding market access, and promoting sustainability. As both sectors evolve, their interaction may bring innovative solutions to urban food challenges.

8. Conclusions and Recommendations

The rapidly growing population and intense urbanization process in Istanbul have created significant pressures on the city's infrastructure and living spaces. In this context, the relationship between air transport and vertical farming presents a crucial opportunity in achieving the city's sustainability goals. Istanbul's air transport infrastructure not only positions the city as a global trade hub but also stimulates economic growth. However, these developments also bring challenges, such as spatial congestion, traffic density, and environmental impacts, which are inherent in urbanization. In this regard, vertical farming stands out due to its potential for efficient food production in the limited urban spaces. Air transport, on the other hand, can facilitate the rapid distribution of vertical farming products, shorten the food supply chain within the city, and reduce logistical costs.

Vertical farming provides solutions to city-specific environmental challenges while also promoting a local and sustainable approach to food production. This becomes particularly relevant in large and densely populated cities like Istanbul, where the shrinking of agricultural land and food security concerns pose significant challenges. Given the environmental impacts of air transport, the potential for vertical farming to create a city structure based on local production and occupying less space could contribute positively to Istanbul's sustainability goals.

In conclusion, the integration of air transport and vertical farming in Istanbul can support both economic growth and environmental sustainability in the city. Urban planning, urbanization strategies, and logistics infrastructure policies that effectively integrate these two sectors will not only enhance the quality of life in the city but also reduce its environmental footprint. The Istanbul example demonstrates that effectively managing the relationship between air transport and vertical farming can create an important

model for sustainable development and efficient land use in urban environments. In the future, the synergistic development of these two sectors could contribute to making Istanbul a greener, more efficient, and more livable city on the global stage.

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