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Faculty of Applied Ecology, Agricultural Sciences, and Biotechnology

UMMEE HANI MITU

Master's Thesis

Vertical Farming- is a Sustainable and Efficient Method for Food Production

Master's degree in applied and Commercial Biotechnology

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Abbreviations

Acronym	Explanation
VF	Vertical Farming
NFT	Nutrient Film Technique
NASA	National Aeronautical and Space Administration
HVAC	Heating, Ventilation, and Air conditioning
LED	Light Emitting Diode
SWOT	Strengths, Weaknesses, Opportunities, Threats
EU	European Union
CEA	Controlled Environment Agriculture

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Abstract

The goal of this thesis is to evaluate the concept of vertical farming methods as sustainable for effective food production and analyse the case of AeroFarms, a leading vertical farming company. In this research, vertical farming's future as a viable food production strategy is investigated. This thesis aims to examine the pros and cons of vertical farming as a possible answer to critical agricultural and environmental problems. This study gives insights into the broader implications of vertical farming by investigating AeroFarms' innovative methods and their influence on sustainability, resource efficiency, and local food production.

The study aims to understand the effects of vertical farming on sustainable food production, efficiency, and profitability. To analyze the benefits, limitations, and opportunities connected with vertical farming and its implementation in the AeroFarms business model, the analysis employs a combination of literature research, value chain analysis, business canvas model, and SWOT analysis.

Finally, this study looks at the environmental impact of each agricultural method, taking into consideration factors like pesticide use, soil deterioration, and carbon emissions. It explores how the regulated environment and pesticide-free methods of Aero Farms lead to a lower environmental effect when compared to traditional farming. The study also assesses the potential benefits of vertical farming in terms of water conservation, soil deterioration reduction, and greenhouse gas emissions reduction.

1. Introduction

As the world's population grows, food insecurity is increasing. In densely populated areas, the tendency of rising urbanization has resulted in food insecurity. More individuals are becoming aware of sustainability measures as dangers like global warming and accessibility problems increase. Prominent scientists have created several solutions that are starting to take root and spread over the world, like soilless food production and vertical farming. (Chatterjee et al., 2020).

Food security and sustainability are two of the most important issues confronting humanity in the twenty-first century. Since the world population is predicted to reach over 10 billion by 2050 and the present agricultural systems are endangered by climate change and resource utilization, there is an urgent need for creative and efficient food production approaches. Vertical farming has emerged as a viable alternative because of its sustainability and scalability (Kalantari et al., 2018).

To produce food in a building that utilises both horizontal and vertical space is what is meant by the term "vertical farming." They involve assessing and managing, and control of the water and nutritional requirements of the plants making this three-dimensional development achievable. (Beacham et al., 2019). As a concept, soil-free vertical farming comes in three distinct flavours.

- Hydroponics.
- Aeroponics.
- Aquaponics.

Water and a nutrient-rich solution containing nutrients frequently necessary for plant development are the main ingredients of hydroponics, a farming system in which water is employed as the major source of nutrient absorption in plants. (e.g., nitrogen, phosphorus) and Hydroponics often necessitates the use of artificial lighting. (Kalantari et al., 2018).

Aeroponics is a plant-growing technology that includes suspending plant roots in a nutrient-rich water mist or aerosol. It is a soilless method of plant growth that is commonly employed in vertical farming and urban agriculture (Peterson & Krueger, 1988).

Integrating fish farming (aquaculture) with hydroponics (growing plants in water) into a single sustainable agricultural system is called aquaponics. As a closed-loop system, aquaponics recycles nutrients from fish waste into plant food while also filtering water for reuse (Al-Kodmany, 2018). This nutrient-rich water is then fed into a hydroponic system, where plants grow in trays or channels filled with a growing material like gravel or clay pellets. The plants absorb nutrients from the water, essentially cleansing it, and then return the clean water to the fish tank (Eck et al., 2019).

Modern technology, including artificial lighting, hydroponic systems, and other cutting-edge methods, have made possible the practice of "vertical farming," in which plants are grown in stacked vertical strata. This farming technology allows for year-round crop production while using much less water and emitting significantly less carbon dioxide than traditional farming methods. It also eliminates the need for product transportation and storage, allowing for more efficient use of urban space and lowering food waste (Chatterjee et al., 2020). Despite the potential benefits of vertical farming, the industry is still in the advance stages and confronts several problems and limitations. High initial costs, energy consumption, and the requirement for specific skills and knowledge are among them. Also, there is a need for major research to fully understand the potential of vertical farming and to address key questions related to its economic, environmental, and social implications (Birkby, 2016).

The purpose of this thesis is to make a profit to the growing body of knowledge on vertical farming by examining a case study of the company aero farm and the potential advantages and limitations of their novel approach to food production. Through an important review of the literature and an examination of case studies, this investigation seeks to shed light on the financial, ecological, and social implications of vertical farming while also pointing the way toward new avenues of study and potential application.

2. Background theory:

2.1 Farming systems:

Vertical farming systems include higher crop yields per square foot, lower land and water requirements, less environmental effect, and increased food security in urban locations. This farming approach provides a long-term solution to meeting the growing demand for fresh produce while avoiding the problems associated with traditional agriculture. This vertical structure makes better use of space and makes crop monitoring and management easier. Plants are frequently cultivated hydroponically or aeroponically, which involves providing nutrient-rich water or a fine mist of nutrients straight to the plant roots without the use of soil (Van Delden et al., 2021).

2.1.1 Hydroponics:

Hydroponics is a kind of farming and gardening that eliminates the need for soil. Plants' roots are submerged in a nutritional solution rich in Sulphur, phosphorus, nitrogen, potassium, calcium, magnesium, and other elements essential to plant growth and development, including zinc, copper, iron, chlorine, boron, molybdenum, and so on (Michael et al., 2021). Continuous monitoring and recirculation of the nutrient solution guarantee that the proper chemical balance is constantly maintained (Pascual et al., 2018). In these systems, plants are grown without inert mediums such as Rockwool, coconut fiber, coir dust, sawdust, gravel, vermiculite, clay rocks, etc. In this context, inert medium refers to a material that does not degrade easily and aids in the supply of nutrients to the plant (Pascual et al., 2018). So far, various types of hydroponics systems have been used to reuse and recycle nutrient solutions and growth mediums. Of all systems, NFT (Nutrient Film Technique) has been used to grow leafy greens and certain other vegetables all over the world, making it the most commercially successful technique (Pascual et al., 2018). Using a water pump, the device circulates water and fertilizer solution into the growth trays. Nutrient solutions flow through the roots and are collected back in the reservoir due to the system’s small tilt. The water cycle is responsible for nutrient circulation.(Pascual et al., 2018).

2.1.2 Aeroponic:

The National Aeronautics and Space Administration's (NASA) interest in plant development in microgravity led to the coining of the term "aeroponics" in the 1990s. Without soil and with just a small amount of water, plants thrive in an air/mist environment (Eldridge et al., 2020). Aeroponics, unlike hydroponics and aquaponics, does not require a solid or liquid medium for plant growth. (Birkby, 2016).

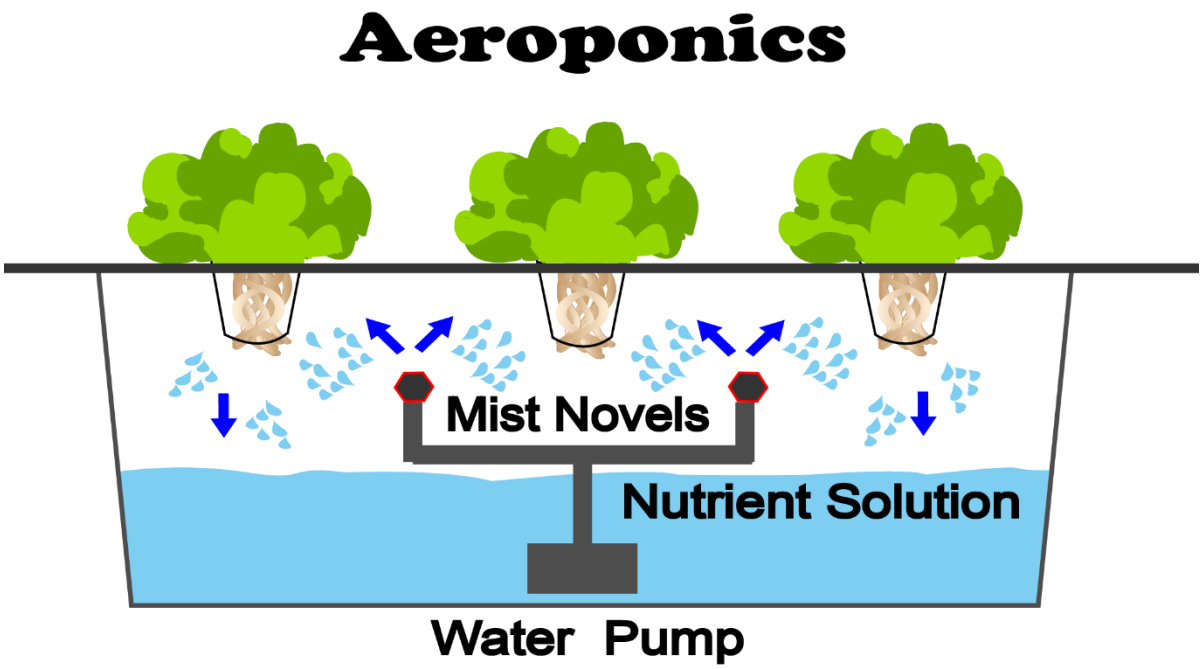

Figure 1 Aeroponic system.

A simple aeroponic system can be put up in a small amount of area. The tote system is a nice example of a simple aeroponics setup. In this example, holes are drilled into the top of a totes lid, and plants are placed within the lid with their roots dangling in the air. A water pump connected to capped tubing is housed in the tote. There are multiple spray emitters connected to the tube that will spritz nutrient solution onto the plant roots. The pump and sprayer are secured in the tote's bottom, and water is poured into the tote to cover the pump (Sharma et al., 2018).

2.1.3 Aquaponics:

In a closed-loop system, aquaponics (also called RAS, or recirculating aquaculture system) mixes aquaculture with hydroponics. Aquaculture is a wide phrase that may refer to either raising fish or growing plants in water rather than soil. Using aquaculture and hydroponics together is a promising way to produce food sustainably and without harming the environment (Mir et al., 2022). Aquaculture and plant agriculture have a long history together in the world. Native Americans in Mexico were the first to use lake mud as a growing medium while growing their veggies on floating islands. Using wastewater from aquaculture and hydroponic systems to grow herbs and other plants can be a healthy and sustainable practice. The regulation of converting the ichthyotoxic ammonium produced by the fish into nitrate is a significant difficulty for this method, though. Since most commercial projects do not appreciate using an aquaponics component, aquaponics systems are typically used in small-scale projects (Khandaker & Kotzen, 2018). Modern aquaponics is a promising agricultural strategy that combines fish and plant production in a mutually beneficial system. Its resource efficiency, environmental sustainability, and potential for local food production make it a promising future farming alternative (Khandaker & Kotzen, 2018).

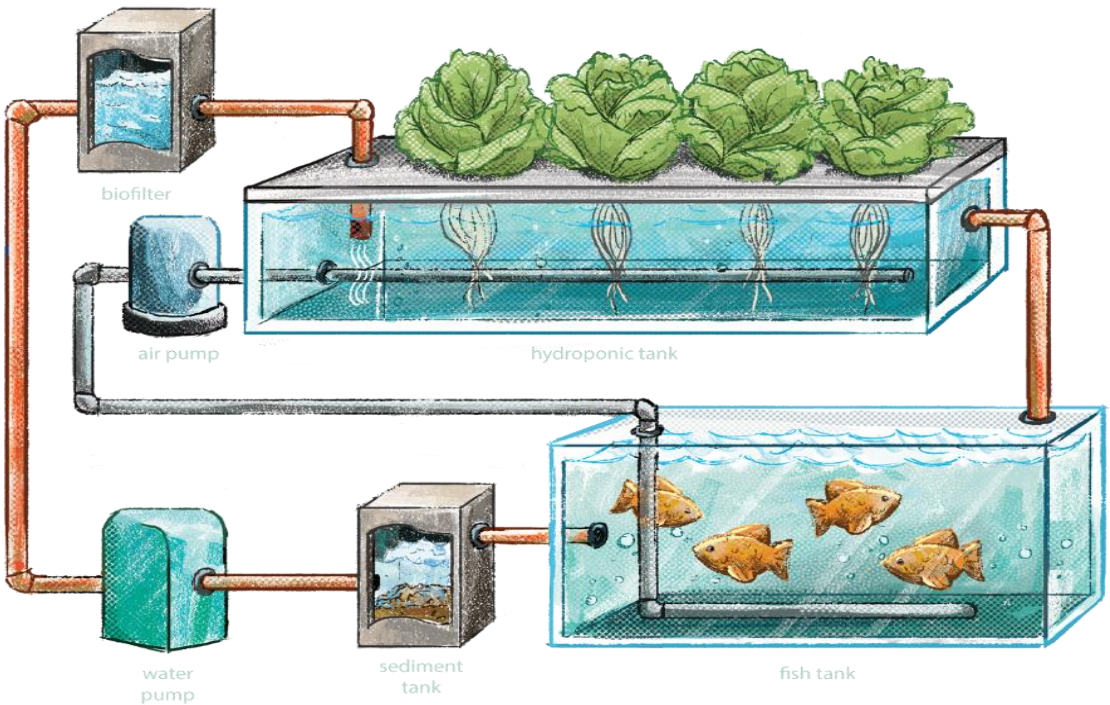

Figure 2 Aquaponic system.

2.1.4 Greenhouse farming:

Greenhouse farming refers to the practice of cultivating plants and vegetables under the protected conditions of a greenhouse. Greenhouse farming is a method that has enabled farmers to raise their yields while simultaneously enhancing the quality of their products. This is accomplished by isolating the plants in miniature ecosystems that provide the optimal circumstances for the plants to flourish and develop into stunning specimens. Additionally, some greenhouses enable growers to cultivate crops throughout the year, resulting in quicker growth and greater harvests (Rubanga et al., 2019). The technique was first used commercially in the 19th century on the international market after being introduced in the 17th century. Your greenhouse has to be like a paradise for your plants, giving them the right amount of light, air circulation, humidity, and temperature. There are various types of greenhouses that are categorized according to the energy and production flow during manufacturing (Rayhana et al., 2020).

2.1.5 Soil-based farming:

Although soil-based farming in vertical rows is still highly common today, soilless agricultural technologies are making remarkable strides. Vertical gardens require a small amount of land, so there is less effort involved in setting up the beds, weeding, watering, fertilizing, and managing diseases and pests (Olfs et al., 2005). It is advantageous to adopt soil-based farming approaches because dirt effectively stores moisture and can provide aeration. With the right fertilization, soil can be utilized repeatedly for several cycles of crops. Most importantly, this approach calls for a high level of expertise in fertilization, field management, and pest management (Ramamurthy et al., 2009).

Figure 3 Soil-based farming.

2.1.6 Sustainability regulations:

There are several regulations and procedures that may be put in place to improve sustainability and reduce pesticide use in vertical farming.

Energy efficiency: Lighting and climate control demand large energy inputs in vertical farming. However, by using energy-efficient technology like LED lighting and high-efficiency HVAC systems, vertical farms are able to reduce their carbon mark and help their sustainability.

Waste reduction: Vertical farmers can also minimize waste and promote sustainability by building composting systems for plant waste and powering their operations with renewable energy sources.

Closed-loop systems: In vertical farming, closed-loop systems recycle and reuse water and nutrients, decreasing waste and the requirement for chemical inputs. By reducing the environmental impact of farming activities, this supports sustainability (Ramamurthy et al., 2009).

Organic certification: Vertical farmers can obtain organic certification from regulatory organizations to verify that their crops are grow without the use of pesticides or fertilizers. Soil and water management, pest and disease prevention, and other ecological considerations

must all be up to par if a farm is to be certified as organic. Vertical Soil and water management, pest and disease prevention, and other components that contribute to environmental sustainability must all meet stringent requirements for organic certification (Van Gerrewey et al., 2022).

2.1.7 Key steps of using Vertical Farming setup:

Depending on the structure of the farm, the vertical farming arrangement may be used in a variety of ways. However, in general, here are some key steps involved in using a vertical farming setup:

Planting: Seeds or seedlings are planted in a grow tray or vertical tower with a growing material such as rock wool or coco coir.

Lighting: Artificial lighting, mainly LED lights, is used to give plants the appropriate light spectrum for photosynthesis.

Climate control: To provide the best possible circumstances for plant growth, the temperature, humidity, and air circulation are all meticulously managed. Constant temperature and humidity may be maintained with the use of HVAC systems, sensors, and automation technology.

Nutrient delivery: Nutrients are provided to plants via a hydroponic or aeroponic system, with a nutrient solution precisely prepared to fit the crop's specific needs.

Pest management: IPM tactics are used to manage pests and illnesses, which may include the use of natural predators, physical barriers, and targeted chemical use.

Harvesting: Once the crops have reached maturity, they are harvested and ready for sale or consumption.

To ensure ideal growing conditions and crop yields, the utilization of a vertical farming structure necessitates continuous administration and monitoring. Modern technology and forward-thinking practices have the potential to make vertical farming the agricultural method of the future.

2.1.8 Sustainable Food Revolution:

As the world's population grows and the climate change has an impact on agricultural production, there is an urgent need to produce food in a sustainable and efficient manner. To find out the nutritional needs of a growing population, we desperately need novel food production methods that boost yields without negatively impacting the environment.

While vertical farming has great potential, there are some problems that must be overcome before it can be considered a viable choice for large-scale food production. High initial capital expenditures, energy consumption, and the requirement for specific expertise and skills to manage the systems are among the hurdles.

As a result, it is important for researchers and innovators to continue inventing novel methods of producing food and addressing these difficulties through collaboration and innovation. This might include creating new technologies to lower energy usage, enhancing crop yields through genetic engineering or environmental component optimization, and figuring out how to reduce the cost of establishing and managing vertical farming systems. Overall, the demand for sustainable and efficient food production will push agricultural innovation and innovative techniques in the future years. We can work for a sustainable and food-secure future by embracing new technology and practices, such as vertical farming, as well as investing in research and development.

2.2 The technical solution in vertical farming:

As a way of cultivating food inside, vertical farming is gaining popularity. When using a vertical farming technique, crops are produced in an environment where every aspect affecting their development is strictly controlled. Smart sensors in vertical farms monitor technical characteristics such as temperature, carbon dioxide (CO2), oxygen (O2), lighting, humidity (RH), nutrient content (N), pH (acidity), insect control (IC), watering (W), and harvesting (H). Hydroponic, aeroponic, and aquatic cultivation are often only employed in contained environments. In addition, controlled environment agriculture can make use of cutting-edge sensors and imaging technology, such as thermal imaging and webcams, to measure aspects such as plant growth and temperature. Tomatoes, peppers, melons, and sweet corn, among many others, may now be produced effectively in greenhouses and other enclosed settings, along with other leafy greens, herbs, and microgreens.

2.2.7 Controlled Humidity and Temperature:

The ventilation system and temperature are important components when designing VF. Closely managing the indoor environment allows for optimal plant growth with minimal resource consumption, such as pesticides and water. The HVAC (Heating, Ventilation, and Air Conditioning) system maintains indoor air quality, moisture consistency, and heat and saves energy generated by plants (Van Delden et al., 2021). Locating the facilities close to retailers and consumers reduces transportation costs and overall CO2 emissions. Managing the humidity in these facilities is critical for creating the best day-and-night conditions for maximum yield. In vertical farming, accurate humidity control is critical; too much humidity can cause significant damage to root systems and foliage. This is particularly important in "wet" environments like hydroponics or aquaponics. Too little humidity in the air can cause wilt and leaf drop, as well as slower growth. Plants naturally release moisture due to transpiration once established in the growing phase, which can be difficult to control in a range of projects all over the world (Mir et al., 2022).

2.2.2 Water supply in vertical farming:

Water supply is crucial in vertical farming since plants cultivated in this approach require a controlled environment to maximize development and output. The important and sustainable use of water in vertical farming is critical for cost reduction and resource conservation. Water can be delivered in a vertical farming system using several ways like hydroponics, aeroponics, or aquaponics. Water supply in vertical farming, regardless of technology, must be carefully regulated to avoid water waste and promote optimal plant development (Sanjuan Delmás, 2017). Using a closed-loop water system, in which water is continuously recirculated and reused, is one way to reduce water usage in vertical farming. Because the same nutrient solution is constantly reused, this not only saving water but also reduces the amount of fertilizer required. In modern farms, approximately 70% of water is lost during artificial watering. Evaporation accounts for the majority of irrigation water loss. Water that runs off the farm is also a total waste because it is contaminated with pesticides, salts, and fertilizers. Indoor farms waste less water because all of the aforementioned scenarios can be avoided in plant cultivation (Benke & Tomkins, 2017).

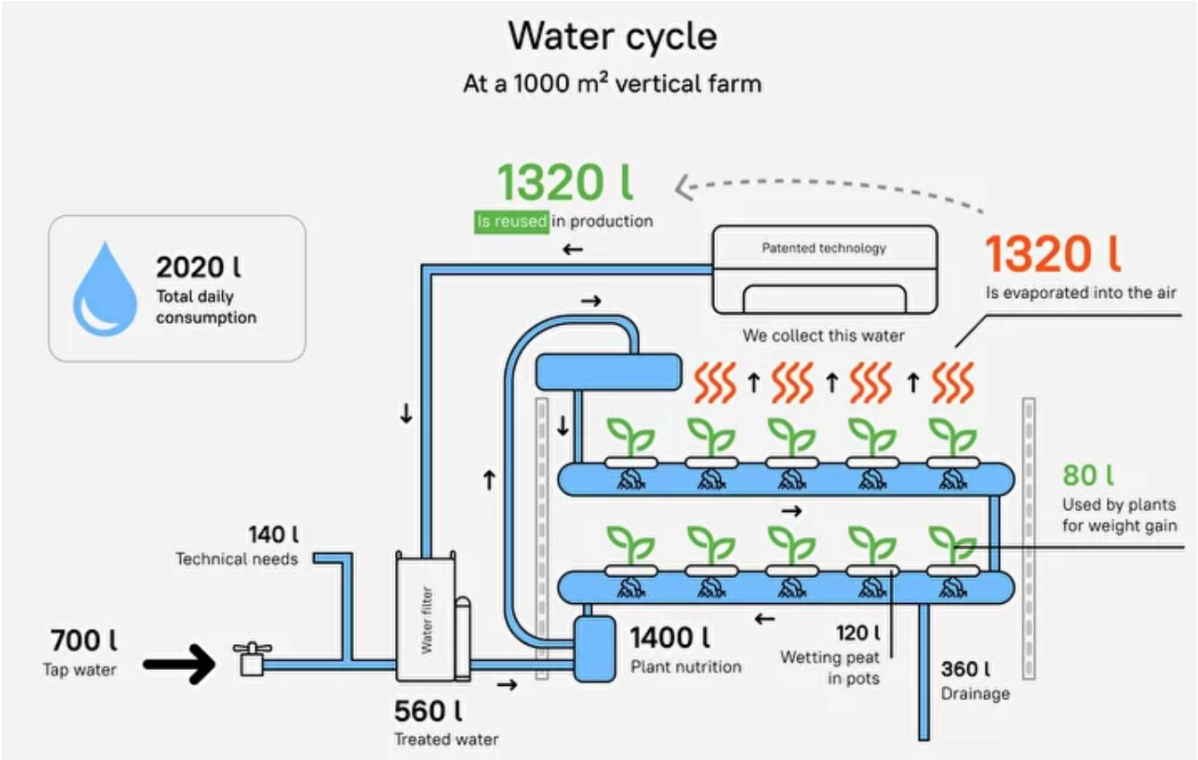

Figure 4 Water supply process in vertical farming.

2.2.3 Lighting:

Farmers can regulate certain important factors that affect how crops develop when they have an indoor vertical farm. Weather elements like humidity, precipitation, and lighting are some of these factors. Regarding lighting, vertical farming lights may provide crops in indoor farms with both nutrition and light. Lighting is an important aspect of visual effects. When starting a farm, you must decide whether to use only artificial light or a combination of artificial and natural light. It can be a make decision for an indoor farm, so proper planning and design of plants and lights is highly recommended. Based on size and cost, many different types of grow lights can be used in an indoor farm. There are a few distinct varieties of grow lights on the market nowadays, each with its own advantages and disadvantages (Ares et al., 2021).

2.2.4 Crop selection:

The choice of crops is particularly crucial in the early stages of a vertical farm. A vertical farm may be used to cultivate almost any crop, but it is crucial to focus on those that thrive in controlled indoor environments. Crop suitability, demand, consumer preference, and market all have a significant impact. Due to the higher production costs of indoor farms, crops that

can be grown in weeks rather than months are preferred in Norway (Garg & Balodi, 2014). Olives, avocados, nuts, and bananas, for example, are difficult to grow indoors. Short production cycles, high harvestable yields, short stature, year-round demand, limited labor, perishable, high value, value-added, and other requirements should be considered. Furthermore, plants that grow no taller than In direct proportion to how long it takes crops to mature, the price of electricity for heating and lighting increases. by 30cm, have low light requirements and can stand close together are best suited (Ares et al., 2021). Value per harvest or value per tray/tower should be calculated for each crop. Commonly cultivated produce in vertical farms includes salad greens like lettuce, rocket, and other varieties. The majority (57%) of indoor farms grow vegetables, including leafy greens, herbs, microgreens, and other similar crops (Santini et al., 2021). The process includes calculating the crop in each tower, determining the selling price, and deducting all associated input costs, such as energy consumption, seeds, labor, and maintenance (Rajan et al., 2019).

2.3 Vertical Farming vs. Greenhouse Farming:

Farming has traditionally been an outdoor activity, but interest in indoor farming techniques is growing due to the numerous advantages. Vertical farms have stacked layers and rely on artificial light, whereas greenhouses rely on sunlight, and plants are grown on a horizontal plane (Kalantari, Tahir, Joni, & Fatemi, 2018). A greenhouse is best suited for rural or suburban areas, whereas vertical farms can be operated in city areas because they take up less land space. Profitability is the primary consideration when deciding between greenhouse farming and vertical farming. Many people believe that vertical farms are less efficient than greenhouses because of the need for artificial lighting, which is a significant expense. The usage of illumination, however, has been proven in a number of studies to not necessarily be a financial drain. Growing lettuce on a vertical farm can be more profitable than growing lettuce in a greenhouse, according to a 2018 study titled "Comparing the Profitability of a Greenhouse to a Vertical Farm in Quebec" (Rajan et al., 2019). Increased yield per square meter and centralized distribution were two critical factors in profitability. Despite the fact that vertical farms have a higher cost structure than lighting and heat, large production capability per square area is a great benefit.

2.4 Fruit and Vegetable Sector in the EU:

Fruits and vegetables are significant agricultural products in the European Union (EU), making up over 14% of all agricultural output in the EU in 2018. In 2016, approximately 823000 farms in the EU cultivated fresh vegetables, with half of these farms located in three member countries. Spain (16.6%), Italy (11.2%), and Romania (11.0%) are the top three countries (Van Delden et al., 2021). People in Europe are less accepting of innovative forms of urban agriculture than they are of conventional and traditional products. As a result, the term "farm" rather than "factory" is used by consumers. European urban farms (especially vertical farms) are little in number and scale despite the continent's rising urbanization. The expansion of this industry in the European world is primarily due to the concurrent drop in LED lighting costs. Furthermore, consumer demand for healthy, fresh, and locally available products may contribute to the industry's growth. Nonetheless, environmental Vertical farms' sustainability, cost-effectiveness, and scalability are still unknown. Evidence suggests that the initial investment in a vertical farm might be as much as 10 times that of a cutting-edge greenhouse (Avgoustaki & Xydis, 2020).

2.5 Current state research based on a case study of AeroFarms company:

Vertical farming has risen in popularity and investment in recent years, with a growing amount of research investigating its potential benefits and drawbacks. Studies comparing the yields and profits of different vertical farming systems to those of conventional farming have been conducted, with an feature on the economic feasibility of vertical farming. Vertical farming has also been studied for its ability to deliver fresh produce to urban areas while reducing transportation costs and environmental effects.

A company has been chosen. This case study of AeroFarms is presented to illustrate the success and benefits of implementing sustainable vertical farming techniques for food production. This company is an award-winning vertical farming startup dedicated to tackling agriculture's most difficult problems by growing genuine food for enhanced flavor. Ed Harwood, a former professor at Cornell University's School of Agriculture, founded Aero Farms in 2004 and is responsible for the company's innovative low-waste, high-yield farming technique. Instead of using gallons upon gallons of water to cultivate plants, the AeroFarms technology sprays plants with a nutrient-rich mist, making aeroponics both soilless and

sunless. Established in 2004, AeroFarms now has more than 200 retail locations throughout the Northeast, including Whole Foods, where its products may be bought. It has one vertical farm up and running in New Jersey, and it wants to grow (Goodman & Minner, 2019). Abu Dhabi will soon be the biggest vertical farm in the world, according to construction efforts by AeroFarms. Using a somewhat different technique than the company's past construction sites, AeroFarms plans to utilize the cash obtained to establish 16 new farms, in addition to the farms in Abu Dhabi and Danville that were previously disclosed. LEDs are used to mimic sunlight, and the intensity of the lights is changed as the plants develop (Birkby, 2016). Since 2019, AeroFarms has been extending its retail line of leafy greens. AeroFarms continues to expand its primary product line in response to user demand. Micro Arugula, Micro Broccoli, Micro Kale, and Micro Rainbow Mix were introduced in addition to Baby Bok Choy-The New Spinach in July 2021. Clearly, things are heating up at the organization. AeroFarms needs to increase operational and energy efficiency, diversify into new goods, and move to the next level, all of which will be made possible by the public market offering and the funds raised (for the time being, berries), and maintaining its social impact. The vertical farming business, which is already a significant element of the food supply chain, is on the verge of exploding. World Wildlife Fund 2020 estimates that indoor farming will generate $3 billion worldwide by 2024, an increase of over 24 percent annually from 2018 until that year. Future vertical farming competitors will learn from Aero Farms' successes and failures over the next several years (Oldani, 2021).

2.6 Aim of the study:

The aim of the study on vertical farming's economic viability is to analyze the cost-effectiveness of various vertical farming systems and compare their productivity and profitability to traditional farming methods. The goal is to evaluate whether vertical farming is a financially viable method of food production, as well as identify potential factors influencing its capacity for growth and popularity. The study's goal is to give insights to farmers, legislators, and investors in the area, as well as to add to the increasing body of information on the economic implications of vertical farming.

Research question:

1. What are the primary strengths, weaknesses, opportunities, and risks connected with AeroFarms' business model, and how can the company use them to achieve market-wide sustainable growth and profitability?
2. How do AeroFarms' market analysis and understanding of customer preferences impact its business model and product offerings, and how can the company keep ahead of developing market demands to maintain its strategic edge?
3. How does AeroFarms' value chain affect its cost structure and profitability, and what efforts can the company take to optimize and improve its value chain?
4. What are the main costs of AeroFarms' business model, and how does the company manage its cost structure to ensure profitability?
5. How does AeroFarms' business plan compare to typical greenhouse and traditional farming methods, and what benefits does this give in terms of sustainability, efficiency, and profitability?

3. Methods

To collect data and information, we used secondary and tertiary data that were used. The use of secondary resources was invaluable in establishing context and learning more about this subject. The author's research statistics were also given. We were able to know more about the company's components, market trends, etc., thanks to the tertiary data.

3.1 Data collection:

Secondary data: This was information that had already been gathered from many sources, such as academic papers, reviews, government, and business websites, etc. Several online data sources were studied to collect the statistical data and information. Secondary sources were added documents like review articles, case studies, research articles, books, reports, etc. The search terms vertical farming, vertical farming technologies, urban agriculture, soil-based farming, water-based farming, and various other words like farm, local, etc., were used in combination. In addition to Google Scholar and NCBI's own search engine, researchers also utilized Science Direct, Springer Link, ACADEMIA, ResearchGate, and other similar platforms. Oria, a database search engine made accessible by Hogskolen I Inlander, was used to locate books, eBooks, journals, and theses pertinent to the issue.

Tertiary data: This included basically the company business information, which is connected to the case study. These helped us to get ideas about the market position and possibilities for vertical farming, market strategy, etc.

3.2 : Data analysis:

Various analyses, such as the SWOT analysis, Market analysis, Business canvas model, Value chain analysis, etc., were applied both outside and internally to all the data acquired in relation to the organization.

3.2.1 SWOT analysis:

Considering a company's strengths, weaknesses, opportunities, and threats (abbreviated as "SWOT") is crucial to developing a sound strategic strategy. Christodoulou and Cullinane (2019) state that since its inception in the 1960s, SWOT analysis has been widely recognized as a critical method for developing the policies and practices essential to strategic thinking.

This resource gives us insight into the many internal and external factors that have an impact on our business and product. SWOT analysis helps us decide how to proceed by identifying the positive and negative variables. There is an opportunity for improvement based on this table.

This illustrates the SWOT components, where a company's competitive advantages come from its strengths, which include things like its patents, brand reputation, innovative product, skilled workforce, and strong financial resources. On the other side, weaknesses are elements that work against a company's strengths (for example, poor leadership, a small, uncompetitive workforce, and insufficient money). Both of these are internal company considerations that have a great deal of sway.

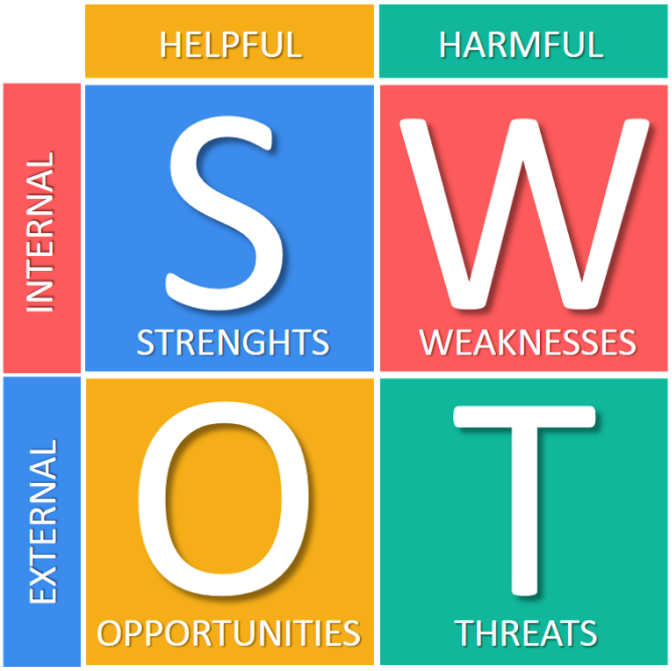

Figure 5 Table showing the components of SWOT, where strength and weakness are the internal factors and the opportunities and threats are the external factors.

Opportunities and threats are external elements that may have a favorable impact on the company's performance or may cause problems in the future.

3.2.2 Market analysis:

A market analysis is an in-depth study of the consumer demographics and competitive environment of the sector in which your business operates. This research gives you a good idea of how well your brand and items will do when they hit the market. Both quantitative and qualitative information is included in the market analysis. This includes things like the actual size of the market you want to service, the prices at which customers are prepared to buy, and projected profits.

Figure 6 Market analysis.

Companies do market analyses to have a better understanding of that market. It provides an overview of the nature of the market and its projected development. That way, businesses may learn about the market as a whole—its size, its growth rate, its profitability, its target demographic, and so on. A stock trader, for instance, may do research on many markets at once.

3.2.3 Business canvas model:

A business model canvas is a single-page template or graphic representation of a business model that outlines a company's major strategic variables, such as customers, revenue sources, product or service offerings, and aims and purposes. It is a method for helping business owners

and managers in developing, evaluating, and improving their business models and strategies. It consists of nine building components that cover both the front and back end of the business.

Figure 7Business model

Nothing surpasses the business model canvas for a thorough overview of the many tactical factors involved in bringing a product to market. This tool's most crucial use is in explaining the key organizational components of a company, but it may also be effectively used for goods. The specific ingredients may differ; however, the following are some of the most common:

- **Customer segments:** Who exactly are the people who will buy this product?
- **Product value propositions:** combine the product's positioning and benefits together, emphasizing the unique, useful, and necessary features.
- **Revenue streams**: How will this product generate revenue for the firm?
- **Channels of distribution**—How will the product be sold or distributed?
- **Customer relationships:** What is the new customer success and support strategy?
- **Key partners:** What other companies or persons are involved in the development and go-to-market strategy?
- **Key activities:** What must occur internally in order for this product to be released?
- **Key resources:** What people, materials, and budget are needed to carry this off?

- **Cost structure:** How much will it cost to create this product, mass produce it, distribute it, and service it?

3.2.4 Value chain analysis:

A value chain analysis is the process of studying and evaluating the processes that convert inputs into outputs for a product or service. This approach can assist companies in improving manufacturing procedures, making better-informed business decisions, and creating a competitive advantage by identifying the most important and beneficial activities for customers. The value represents the actual client needs that the company intends to meet. A clear value proposition that solves an existing need for the consumer is critical for the company's commercial success. The following are some key questions for determining value:

1. What crops do customers prefer?

2. How much do the buyers wish to spend?

3. How would they like it delivered?

4. What is their desired price for the product?

Indoor farms should be able to produce crops that can readily be produced in outdoor farms if they are to be a viable alternative to conventional farming.

Value proposition:

A value proposition is a claim made to potential customers that outlines the many ways in which the product or service they are considering will improve their lives. It is a brief explanation of why buyers should choose one product or company over another. The value proposition emphasizes the unique benefits that a customer will obtain from using a product or engaging with a company. It emphasizes the problem or need that the product or service addresses, the benefits it delivers, and the reasons why it is preferable to market alternatives.

A strong value proposition should effectively communicate the following elements:

Target market: Clearly identify the specific group of customers for whom the product or service is designed.

Problem or need: Describe the target market's pain points or challenges and explain how the product or service addresses those issues.

Benefits: Highlight the key benefits and advantages that the product or service offers to customers.

Differentiation: Clearly describe what distinguishes your product or service from competition. This could include distinguishing features, innovative technology, superior quality, exceptional customer service, or any other distinguishing attribute.

Proof or evidence: Provide evidence, case studies, or data to back up the value proposition's statements. This contributes to the reputation and confidence of potential customers.

Effective marketing and sales operations require a well-crafted value proposition. It explains to customers why they should choose a specific product or service, and it distinguishes the offering from competitors in the market.

4. Results and Discussion:

This study was to evaluate the effectiveness of various business tools used in sustainable agriculture, with a particular emphasis on their impact on economic sustainability and profitability. In order to do this, analysis of a case study of AeroFarms to collect data on how they used business skills, including financial planning, risk management, and marketing strategies.

Business tool analysis:

4.1 SWOT analysis:

The AeroFarms served as a case study for a SWOT analysis of the internal and external elements influencing the success of Vertical Farming. The strengths, weaknesses, opportunities, and dangers are listed in the table below:

Table 1 SWOT analysis for AeroFarms company.

Strengths	**Weaknesses**
• Innovative technology and sustainable practices. Using LED light, less use of water and energy. • Focused on sustainability and social responsibility. • Capability to produce high-quality, fresh produce in any place all year. • Capability to operate in urban places when traditional agriculture has limited space. • Reduced water consumption and pesticide-free vegetables make it a safer and healthier option for customers.	• High initial investment cost. • Dependence on electricity. • High initial investment costs and continuing operating expenses. • Scalability is limited when compared to traditional farming methods.
Opportunities	**Threats**
• Growing demand for sustainable agriculture. • Expansion into new markets. • Collaborations and partnerships with retail chains, restaurants, and food sector stakeholders. • Increasing investment in vertical farming and related technologies to meet rising demand for locally sourced, sustainable food.	• Market Competition with more companies who enter the new market, • Supply chain disruption. (Raw material shortages, equipment or technologies failures, transportation, and logistics disruptions, regulatory changes, cybersecurity threats.) • Changing customer preference.

Internal factors:

Internal factors include the company's designed strengths and limitations. A company has complete control over internal factors, allowing it to develop strategic plans to capitalize on strengths and solve problems.

- **Strength:** When analyzing the available resources and the designed VF's capabilities, the company's strengths come out as being highly effective, high quality (such as organic nature, taste, durability, and buyer-supplier relationships), close-knit, food safety, highly skilled employees, innovative, and customer-focused. It is a strong brand with innovative technology due to the mentioned qualities.
- **Weaknesses:** However, there are other challenges in the company that prevent it from performing well. Weaknesses are areas where the company needs to improve in order to succeed. The variety of products carried by the company is referred to as the product mix's variety such leafy greens, herbs, and microgreens, for example, are the main crops chosen for production in the case of AeroFarms, although there is a wide range of crops that cannot or will be difficult to grow in a vertical farm. People's lives cannot be sustained simply through the consumption of such things. The higher selling price of the product is caused by the higher original investment and higher farm operating costs.

External factors:

External factors are opportunities and threats that exist outside of a company. A company can affect such things, but it cannot completely control them.

- **Opportunities:** This section includes all external elements that provide a company with a competitive advantage. From a sustainable perspective, it is essential to consider what the vertical farm achieves for the environment and actual sustainability. If input resources are not wasted, a vertical farm can become a circular economy. Compared to traditional farming, circular economy solutions in this project include water and fertilizer recycling, effective water management, and renewable energy. Furthermore, the best feature of a vertical farm is year-round production in a highly controlled environment.
- **Threats:** AeroFarms, a market competitor in vertical farming, is facing five major challenges that could impact its success. As vertical farming becomes more

widespread, one big issue is increased competition in the market. The growing popularity of the industry attracts new entrants and motivates existing competitors to expand their operations, thereby placing AeroFarms' market share and profitability under strain. Furthermore, the rapid improvement of technology threatens AeroFarms' competitive position. AeroFarms may experience challenges in maintaining its technological advantage and operational efficiency if competitors or new market entrants adopt more advanced or cost-effective technologies. Supply chain disruption, such as the availability of vital inputs, or external reasons, such as extreme weather occurrences, trade restrictions, or worldwide pandemics, can also endanger the company's operations. In a capital-intensive business, it is also critical to manage costs and set competitive pricing while covering expenses. Energy price fluctuations, growing labor costs, and increased spending for maintenance and technology improvements can all have an impact on AeroFarms' cost structure. Furthermore, regulatory compliance, customer approval, and consumer perception of vertical farming methods and produce can all have an impact on demand and market growth. AeroFarms can focus on continual innovation, strategic alliances, brand equity creation, and actively interacting with consumers to resolve any concerns or misconceptions to mitigate these dangers. Maintaining a resilient supply chain, analyzing market trends, and successfully controlling costs will also be critical for sustaining growth and profitability in the face of possible risks.

The SWOT analysis conducted on AeroFarms highlights the company's advantages, disadvantages, opportunities, and threats. AeroFarms' strengths include technological know-how, vertical farming experience, and the capacity to optimize resource efficiency. The company's weaknesses may be the initial significant capital investment required and potential consumer acceptability issues. AeroFarms, on the other hand, operates in a market with considerable potential, such as rising demand for sustainable agriculture, urban farming, and locally produced produce. To capitalize on these chances, the organization can use its strengths. AeroFarms is also threatened by possible competition, regulatory limits, and market swings. Understanding these characteristics enables AeroFarms to devise tactics to counteract weaknesses and threats while maximizing strengths and opportunities.

AeroFarms may utilize their capabilities to achieve market-wide sustainable growth and profitability by:

1. **Expanding Market Reach:** AeroFarms can improve sales by strengthening connections with local retailers, restaurants, and distribution networks. This involves looking into direct-to-consumer approaches, internet sales platforms, and collaborations with food stores.
2. **Research and Development:** Continuous investment in research and development can help AeroFarms improve their growing techniques, crop varieties, and automation processes. This will increase output, lower costs, and keep vertical farming at the forefront of innovation.
3. **Sustainable Branding:** AeroFarms can establish a strong brand identity focusing on protecting the environment, health, and social responsibility by capitalizing on their sustainable farming processes. Communicating their unique value proposition and commitment to sustainable agriculture will appeal to environmentally conscious shoppers.
4. **Efficiency and Cost Optimizing:** AeroFarms should work on optimizing their operations, including energy use, supply chain management, and manufacturing processes. Advanced technology, machine learning algorithms, and data-driven decision-making can improve efficiency, eliminate waste, and minimize prices.

AeroFarms can utilize their strengths and opportunities while reducing their weaknesses and risks to achieve long-term growth and profitability. The company can spend on research and development to increase crop diversity while lowering energy expenses. They might also concentrate on extending their operations in emerging markets and forming collaborative partnerships with other food industry stakeholders. AeroFarms may achieve long-term growth and profitability in the vertical farming industry by expanding their product offerings, maintaining a strong brand reputation, and remaining responsive to changing market demands.

4.2 Market analysis:

AeroFarms' market research and awareness of customer preferences are important for the development of its business model and product offers. AeroFarms may build customized strategies to produce value-added products and maintain a competitive edge by understanding

market trends and customer wants. These factors have the following effects on the company's operations:

1. **Business model development:**

- **Target Market Identification:** Market analysis helps AeroFarms in identifying certain customers with the highest demand for their products. AeroFarms may target groups of customers depending on their tastes, lifestyles, or nutritional requirements. This can include health-conscious people, people living in cities looking for locally sourced food, or customers interested in ecologically friendly and sustainable items. This helps the company to efficiently adjust its business strategy to fit the needs of these target markets.
- **Value Proposition:** By understanding consumer preferences, AeroFarms can create a compelling value proposition that meets their needs. AeroFarms value proposition focuses on the important characteristics that identify the company and its offers in the agricultural marketplace. These factors show the unique benefit that AeroFarms provides to its customers and stakeholders. The main value propositions of this company are sustainable and resources efficient farming, year-round supply of fresh produce, locally sourced production, enhanced flavor, nutrition and quality, innovation, technological expertise, etc. Retail consumers, restaurants, food service providers, and specialty markets are among AeroFarms' end users. Retail customers who buy AeroFarms products in grocery stores or on online platforms value freshness, taste, nutritional value, and sustainability. Restaurants and food service providers demand premium ingredients and unusual produce types, as well as consistent quality, flavor, and reliability in the supply chain. Organic certifications, traceability, and food safety may be preferred by specialty markets such as health-conscious customers and organic food lovers. Customers at AeroFarms demand fresh and tasty vegetables with a focus on sustainability, health, and nutrition. They like how the company's farming methods are pesticide-free, locally sourced, and environmentally friendly. Customers who want to know the origin and production processes of the food they eat value transparency and traceability. AeroFarms may effectively position and promote their products to satisfy the needs of their target customer groups by recognizing and catering to specific customer preferences, allowing them to maintain a competitive advantage in the market.

2. **Product offerings:**

- **Product Development:** AeroFarms' market research shows growing trends, preferences, and needs. This information enables companies to create novel products that know the needs of their customers, such as unique varieties of leafy greens or specialty crops. They can also change cultivation practices to improve flavor, nutritional content, or other customer-requested characteristics.
- **Customization and differentiation:** AeroFarms can customize its product offerings for specific market segments by learning customer preferences. This could include providing organic options, unique flavor profiles, or package designs that are appealing to target customers.

AeroFarms can use the following techniques to sustain its strategic advantage and keep ahead of evolving market demands:

1. **Continuous Market Research:** AeroFarms should monitor the market, keeping up with changing trends, preferences, and rising customer demands. Surveys, focus groups, social media monitoring, and partnership with market research companies can all help with this.
2. **Collaboration and Partnerships:** By collaborating with retail chains, restaurants, and other food sector stakeholders, to acquire access to their existing distribution network or customer base in the beachhead sector. This collaboration can assist the company in more effectively establishing a foothold and expanding its reach. Collaborations of this type can provide knowledge on product performance, customer preferences, and future market trends. While collaboration and partnership can be successful strategies for entering and growing into new markets, the term "beachhead market" refers to the initial target market or geographic location in which a company focuses on creating a strong presence before going further.
3. **Innovation and technology adoption:** AeroFarms should spend on research and development to develop new growing techniques, crops, and product lines. They may enhance production, quality, and sustainability by employing cutting-edge technology, connecting with market expectations for modern agricultural techniques.
4. **Customer Participation:** Involving customers actively through their main source of information on customer preferences is market research, surveys, social media monitoring, customer feedback and surveys, sales, and transaction data, website

analytics, competitor analysis, etc., can provide significant insights into their preferences, complaints, and suggestions.

5. **Strategic Collaborations with Research Organizations:** AeroFarms can gain access to the most recent research and advances by collaborating with research organizations and universities specializing in agriculture and food sciences.

The leafy greens market is AeroFarms' beachhead market. They began by planting and distributing a range of leafy greens, such as lettuce, kale, and spinach. They have established a significant presence and success in this market area because of their vertical farming technology and controlled environment solutions.

Following that, AeroFarms went beyond leafy greens to target the market for herbs and microgreens. They've improved their skills in cultivating herbs like basil, mint, and cilantro, as well as microgreens like arugula and radish. Because of their flavor, nutritional value, and versatility in culinary applications, these specialty crops have grown in popularity. AeroFarms began with the leafy greens market as their beachhead market, then moved on to the herbs and microgreens markets for additional growth and diversification. AeroFarms may continuously change its business strategy and product offerings by employing market analysis, recognizing customer preferences, and remaining linked to changing market demands. This proactive approach allows the organization to maintain a strategic advantage while also focusing on developing opportunities in the vertical farming market.

4.3 Business canvas model of AeroFarms company:

Table 2 Business canvas model of AeroFarms company.

<table>
<tr>
<td rowspan="2">Key Partners:

• Suppliers of raw materials.
• Research institutions and universities.
• Distributors and retailers.
• Investors.</td>
<td>Key Activities:

• Marketing and promoting products.
• Finding and improving raw materials and inputs.
• Improving technologies and data analytics.
• Providing after-sales services and support.</td>
<td rowspan="2">Value Propositions:

• Sustainable and efficient food production.
• Fresher and more nutritious produce.
• Reduced transportation costs and co2 emissions.
• Crop yields of high quality and consistency.</td>
<td>Customer Relationships:

• Developing strong customer relationships through excellent marketing and customer service
• Value-added services such as product customization and after-sales support are available.</td>
<td rowspan="2">Customer Segments:

• Retailers and distributors.
• Restaurants and food services providers.
• Customers who promote health and sustainability.</td>
</tr>
<tr>
<td>Key Resources:

• Exclusive technology and data analytics.
• Expert labor and management team.
• Ingredients and raw materials.</td>
<td>Channels:

• Sales are made directly through e-commerce platforms and the company website.
• Partnerships in retail and distribution
• Restaurant and food service collaborations.</td>
</tr>
<tr>
<td colspan="3">Cost Structure:

• Costs of research and development.
• Costs of raw materials and inputs.
• Labor and management expenses.
• Costs of energy and infrastructure.

Marketing and sales expenses.</td>
<td colspan="2">Revenue Streams:

• Produce sales to retailers, distributors, and consumers.</td>
</tr>
</table>

AeroFarms' business canvas model highlights essential factors such as its product proposition, customer segmentation, channels, income streams, and cost structure. AeroFarms has a unique business canvas concept centered on vertical farming and sustainable agriculture. The value proposition of the company is its capacity to supply fresh, locally farmed vegetables while utilizing modern technologies and resource-efficient procedures. AeroFarms has identified important customer segments such as merchants, food service providers, and consumers looking for high-quality, nutrient-rich, and sustainably produced crops. By providing a

continuous supply of year-round goods customized to individual market demands, the company maintains strong relationships with customers. AeroFarms employs cutting-edge technology such as vertical stacking, LED lighting, and aeroponic/hydroponic systems to maximize space utilization, manage growing conditions, and reduce resource usage. This allows the organization to offer reasonable pricing while delivering consistent, high-quality harvests that exceed strict food safety regulations. AeroFarms' primary revenue sources are the sales of vegetables to retail partners and food service providers. AeroFarms highlights the importance of transparency, traceability, and sustainability methods in its branding and marketing activities by offering a direct link between consumers and their locally grown food. In addition, the corporation forms partnerships with organizations and institutions to promote research, community participation, and educational programs, strengthening its brand recognition and social effect. Crop production, research and development, technology breakthroughs, and supply chain management are among AeroFarms' key activities. The organization prioritizes constant innovation in order to increase yield, lower manufacturing costs, and improve resource efficiency. AeroFarms also focuses on operational excellence, which ensures strong supply chain logistics, efficient operations, and adherence to standards and laws. AeroFarms relies on collaborative relationships to get critical resources such as financing, technology providers, and distribution networks. These ties are nurtured by the company to maintain a consistent supply of inputs, access to knowledge, and market reach. Capital expenditures for infrastructure setup, operational costs for energy, labor, and raw materials, as well as ongoing R&D investments, are all cost structure factors. Overall, AeroFarms' business canvas model demonstrates a sustainable and based-on-technology approach to agriculture, allowing the company to offer fresh fruit, cultivate strong customer relationships, and promote a good social and environmental impact. AeroFarms intends to maintain its market leadership and drive the rise of vertical farming as a viable and sustainable solution for the future of food production by leveraging innovation, collaborations, and efficient operations.

Vertical farming, a capital-intensive and technology-driven industry, is key to AeroFarms' business model. The following are the primary costs connected with this business model:

1. **Infrastructure and Facility Costs:** Building indoor farming facilities demands a considerable upfront investment in vertical farming. Acquiring or leasing property, constructing or retrofitting buildings, and installing vertical growing systems, climate control systems, and lighting infrastructure are all part of the costs. AeroFarms reduces

these costs by optimizing facilities for optimum space usage, leveraging economies of scale through larger production facilities, and applying automation and smart technologies to lower labor requirements.

2. **Energy Costs:** Artificial lighting, climate control systems, and other energy-intensive equipment are required for indoor farming. AeroFarms reduces energy expenses by installing energy-efficient LED lighting systems, employing renewable energy sources whenever possible, and constantly researching innovative solutions to lower overall energy consumption.
3. **Operational costs:** Labor, raw materials, seeds, fertilizers, packaging materials, and other inputs required for the growth process are all included in operational costs. AeroFarms manages operational costs through automation and innovative technology, which reduces the need for labor. Additionally, streamlining the raw material procurement process and securing beneficial contracts with suppliers can help in cost reduction.
4. **Costs of Research and Development:** AeroFarms invests in research and development to improve growing processes, optimize crop yields, and develop new varieties. Managing these costs involves focusing on research activities, cooperating with academic institutions or research groups, and using government grants or subsidies where possible.
5. **Promoting and distribution expenses:** AeroFarms incurs expenses associated with promoting its products, increasing brand awareness, and extending distribution networks. The company handles these costs by implementing focused marketing techniques, leveraging digital platforms and social media, and forming partnerships with retailers, restaurants, or food service providers to maximize distribution and lower associated expenses.

4.4 Value chain analysis:

AeroFarms is a vertical farming company that grows leafy greens and herbs in a controlled environment using innovative indoor farming techniques. The value chain of a company refers to a chain of activities and processes involved in generating and distributing items to customers. AeroFarms' cost structure and profitability can be considerably influenced by the value chain. Here's an overview of how the value chain influences these factors and what the company can do to improve it:

1. **Input purchasing goods:** AeroFarms must obtain a variety of inputs, such as seeds, fertilizers, water, lighting systems, and automation equipment. Optimizing the purchasing procedure by forming strong relationships with suppliers, establishing attractive contracts, and ensuring the quality and dependability of inputs can all assist to cut costs and increase profitability.
2. **Growing Operations:** AeroFarms' primary business is the cultivation of plants in vertical farming systems. Efficiency in managing resources like energy, water, and nutrients may have a significant effect on overall expenditures. Using modern technology and automation to maximize resource use, eliminate waste, and boost production can result in cost savings and enhanced profitability.
3. **Harvesting and packaging:** Once the plants are mature, they must be harvested and packaged. Using automated systems, optimizing worker usage, and applying efficient packaging processes can assist in cutting costs and enhancing overall profitability.

4. **Distribution and Logistics:** AeroFarms must ensure that its products are delivered to customers in a timely and effective manner. Evaluating and optimizing the distribution network, transportation techniques, and storage facilities can assist in lowering transportation costs and increasing customer satisfaction.

5. **Marketing and sales:** Marketing and sales strategies must be effective in order to generate demand and maximize revenue. AeroFarms can concentrate on increasing brand awareness, extending its customer base, and reaching a larger audience using technology platforms. Creating partnerships with merchants, restaurants, or food service providers can also improve market access and profitability.

AeroFarms can consider the following activities to optimize and improve its value chain:

- **Research and Development:** Investing in research and development to improve growing techniques, develop new plant types, and improve automation technology can result in higher yields, lower costs, and increased profitability.
- **Data Analytics and Technology:** Using data analytics and advanced technologies such as artificial intelligence and machine learning to optimize operations, resource allocation, and decision-making can yield useful insights. These techniques can assist in identifying patterns, forecasting demand, and improving overall efficiency.
- **Supply chain collaboration:** Collaboration with suppliers, distributors, and other value chain partners can result in cost savings, increased coordination, and better inventory management. Strong relationships and collaborative planning processes can help to optimize the entire supply chain.
- **Sustainable Practices:** Emphasizing sustainability throughout the value chain can result in cost savings and increased profitability. Implementing renewable energy sources, lowering water consumption, and limiting trash, for example, can contribute to cost savings and improve the company's reputation among environmentally sensitive customers.

AeroFarms' value chain analysis illustrates how the company's actions, from procurement to distribution, contribute to its cost structure and overall profitability. AeroFarms' cost structure can be optimized by strategically controlling inputs such as seeds, nutrients, and automation equipment. Furthermore, the organization can increase profitability through effective growing operations, harvesting, packaging, and distribution processes. AeroFarms can find areas for cost reduction, efficiency improvement, and value generation by constantly evaluating and optimizing its value chain.

4.5 AeroFarms business plan compared to typical greenhouse and traditional farming methods:

AeroFarms' business model differentiates greatly from typical greenhouse and farming methods, providing various advantages in terms of sustainability, efficiency, and profitability. Here is a comparison of AeroFarms' business model to traditional farming methods:

- **Resource Efficiency:** AeroFarms' vertical farming technique maximizes resource efficiency when compared to typical agricultural methods. Vertical farming takes up over 90% less land while harvesting 80% more per unit area. Traditional farming requires a large amount of land, consumes a lot of water, and is affected by weather. The Columbia University Earth Institute estimates that compared to conventional farming, vertical farming uses 70% to 95% less water. Vertical farms consume an average of 38.8 kWh per kg of output, substantially more than typical greenhouses, which use an average of 5.4 kWh per kg, according to the 2021 Global CEA Census Report. This is true both for electricity needs and energy use in general. Aero Farms, on the other hand, uses vertical space in indoor facilities, employing innovative technologies to precisely manage lighting, water, and nutrient inputs. This focused resource utilization saves water, eliminates the need for pesticides, and optimizes energy consumption. The regulated environment reduces losses caused by weather changes, pests, and illnesses, resulting in increased crop yields and less waste.
- **Land Utilization:** Vertical farming by AeroFarms enables agriculture in metropolitan areas or regions with little arable land. AeroFarms can increase output within a smaller footprint than traditional farming, which requires large land resources, by leveraging vertical space. This technique expands agricultural prospects in densely populated areas while lowering transportation distances and carbon emissions connected with food distribution (Singh & Das, 2018).
- **Year-Round Production:** AeroFarms' indoor farming model allows for year-round production regardless of the weather. Traditional agricultural methods are usually restricted to specific growth seasons and necessitate crop rotation and fallow periods. The controlled atmosphere and optimum growth conditions at AeroFarms enable a continuous harvest, boosting supply chain stability and meeting consumer demand all year. More food can be produced each year in a much less area than on a traditional farm because of CEA technology's shorter growing cycles and quicker harvests. One of the best-producing farms produces 350 times more food per area than a regular farm.
- **Environmental Sustainability:** AeroFarms' business approach matches sustainability aims by lowering agriculture's environmental effect. The regulated environment reduces water use by up to 99 percent less water than traditional farms, decreases 90 percent reliance on synthetic fertilizers and pesticides, and eliminates the discharge of these compounds into ecosystems. Vertical farms' proximity to metropolitan areas also

minimizes the carbon footprint associated with transportation and food miles, helping to lower greenhouse gas emissions.

- **Crop Diversity and Nutritional Value:** AeroFarms' method of vertical farming makes it possible to grow many different plants, including microgreens, herbs, and leafy greens. This variety broadens consumers' dietary options and supports a balanced diet. Furthermore, AeroFarms can adjust growing conditions to improve crop nutritional content, such as increasing vitamin and antioxidant levels, resulting in good quality and yield.
- **Predictability and Consistency:** The controlled environment provided by AeroFarms provides predictable and consistent crop growth, quality, and yield. Traditional farming is vulnerable to external influences such as weather, which can result in crop failures or decreased yields. AeroFarms' strategy mitigates the inherent risks connected with external causes, ensuring year-round product supply and quality.
- **Scalability and Efficiency:** AeroFarms' vertical farming technology is very scalable and may be replicated in a variety of locations across the world. AeroFarms optimizes productivity per square foot by leveraging vertical space, resulting in higher yields when compared to standard farming methods. This scalability and efficiency can lead to cost savings, economies of scale, and enhanced profitability.

The approach and technology utilized for crop production distinguish AeroFarms, a vertical farming company, from traditional farmers or greenhouse farmers. Here are some important distinctions: AeroFarms specializes in indoor vertical farming, where crops are cultivated in stacked layers or trays under regulated conditions. Lighting, temperature, humidity, and nutrient delivery are all meticulously managed. Traditional farmers normally cultivate their crops outside, whereas greenhouse farmers cultivate their crops inside covered structures that allow some control over the growing environment. Compared to traditional farming, AeroFarms' business model requires less land. AeroFarms can produce larger yields in a smaller footprint by adopting vertical farming techniques. Traditional farmers normally require more acreage for crop production, whereas greenhouse farmers lie halfway in the middle because they employ covered structures that require less land than open-field farming.

4.6 Advantages and disadvantages of vertical farming of AeroFarms company:

Advantages of vertical farming in Aerofarms:

Year-round production: Vertical farming enables AeroFarms to grow crops continuously throughout the year, regardless of seasonal differences or climate conditions. This ensures a consistent and reliable supply of fresh products to fulfill market demand.

Increased Crop Yield: Vertical farming increases productivity per square foot by making more efficient use of available growing areas by stacking individual crop layers. AeroFarms can improve their operational productivity and efficiency.

Reduced Land Requirement: Vertical farming requires less land than regular agriculture. AeroFarms can set up shops in cities or locations with little arable land, allowing crops to be grown closer to consumer markets. This lowers transportation expenses while also ensuring fresher produce.

Water Conservation: When compared to traditional soil-based farming, AeroFarms' vertical farming methods use much less water. Closed-loop hydroponic systems recirculate water, reducing waste and increasing the water efficiency of vertical farming.

No Pesticide Use: Pesticides are not used in vertical farms since the regulated environment eliminates the need for pesticides and decreases the risk of pests and diseases. AeroFarms can offer pesticide-free, organic-like vegetables, which will appeal to health-conscious consumers.

Enhanced Sustainability: Vertical farming improves sustainability by reducing the need for synthetic fertilizers, conserving water resources, and lowering carbon emissions related to transportation. AeroFarms' environmentally friendly food production processes are in line with rising customer demand.

Disadvantages of vertical farming in AeroFarms:

High Initial Investment: Setting up a vertical farm necessitates a significant initial investment in infrastructure, lighting systems, heating and ventilation systems, and modern technologies. AeroFarms need significant capital to establish and operate its vertical farming companies.

Energy Consumption: Vertical farming relies on artificial lighting and climate control systems, both of which require a lot of energy. AeroFarms must manage and optimize their energy usage to keep operational costs under control and profitability intact.

Limited Crop Variety: AeroFarms' vertical farming systems are best suited for leafy greens, herbs, and some vegetables. Growing crops with bigger structures, such as fruits or root vegetables, may be difficult in the limited space of vertical farms.

Technological Dependence: AeroFarms' performance is strongly dependent on the effective operation of technology-driven systems such as lighting, irrigation, and environmental controls. Any equipment failure or technical issue can disrupt operations and influence crop yield.

Skilled employees Required: Operating a vertical farm necessitates a skilled employee with modern agricultural techniques, technology, and plant biology understanding. AeroFarms must find and train staff with the required skills, which might be difficult in some cases.

Market Acceptance and Price Competitiveness: Because of the initial investment and operating costs, vertical farming products may be more expensive than conventionally grown vegetables. To secure market acceptance and justify pricing, AeroFarms must educate consumers about the value proposition and benefits of the goods.

4.7 Sustainable solutions: AeroFarms and the benefits of vertical farming.

According to the AeroFarms case study, vertical farming has various potential benefits in terms of water conservation, soil deterioration reduction, and greenhouse gas emissions reduction. The following are the important findings:

1. **Water Conservation:** When compared to traditional farming methods, AeroFarms' vertical farming systems offer considerable water conservation benefits: AeroFarms uses a controlled environment in which water is recycled efficiently within the system, resulting in a significant reduction in water usage when compared to conventional agriculture. Vertical farming's precision irrigation systems allow for a focused water supply to plants, reducing water waste due to evaporation or waste. AeroFarms'

hydroponic and aeroponic systems enable accurate fertilizer delivery while conserving water and minimizing nutrient leaching.

2. **Reduced Soil Deterioration:** Vertical farming can reduce the soil deterioration concerns associated with traditional farming: AeroFarms uses soilless growing mediums such as nutrient-rich liquids or inert substrates instead of soil. This reduces the possibility of soil erosion and deterioration caused by intensive farming techniques. Vertical farming eliminates the demand for chemical fertilizers and pesticides by eliminating the requirement for soil, protecting soil health, and reducing pollution.
3. **Reduced Greenhouse Gas Emissions:** Reduced greenhouse gas emissions from agriculture might be achieved via the adoption of vertical farming techniques like those developed by AeroFarms. AeroFarms' indoor farming technology has precisely regulated conditions in terms of temperature, humidity, and carbon dioxide concentration. When compared to traditional agricultural practices, this optimization reduces the energy required to maintain acceptable growing conditions, resulting in lower greenhouse gas emissions. Pesticides and synthetic fertilizers, which are significant drivers of greenhouse gas emissions, are eliminated in vertical farming systems, resulting in lower carbon emissions.

   These potential benefits demonstrate how vertical farming, exemplified by AeroFarms, can contribute to sustainable agriculture by conserving water resources, preserving soil health, and reducing greenhouse gas emissions. By implementing innovative technologies and practices, AeroFarms showcases the potential for vertical farming to address critical environmental challenges associated with traditional farming methods while ensuring a reliable and sustainable supply of fresh produce.

4.8 Future scope for market possibilities:

AeroFarms companies to grow their new market value. They need to focus on some key elements such as market segmentation, product differentiation, strategic partnership, new product item introduction, etc. Market segmentation is identifying specialized customers and developing products and marketing methods to their individual demands. Focusing on urban areas with limited access to fresh food, health-conscious consumers, high-end restaurants looking for specialty crops, or locations with a strong emphasis on sustainability could be examples of this. Offer uncommon crop variations, such as uncommon herbs, exotic

microgreens, locally suited plant species, different types of flowers, etc. In comparison to traditional farming methods, emphasize the higher quality, freshness, and flavor of AeroFarms products. What new items like flowers such as roses, orchids, lilies, tulips, and other exotic blossoms can make a profit for their market value. These types of flowers can grow in mist systems utilized by AeroFarms or vertical farms. While most AeroFarms specialize in leafy greens and herbs due to their high yield and quick growth cycles, several companies have successfully experimented with growing flowers utilizing mist systems. Mist systems, such as aeroponics, distribute a fine mist of water and nutrients straight to the plant's roots, creating a controlled environment for plant growth (Fascella & Zizzo, 2006). When compared to traditional soil-based farming, this technology enables more efficient water and nutrient absorption while using less water. It is critical to optimize environmental parameters such as temperature, humidity, light intensity, and nutrient levels while growing flowers such as roses in a mist system. Roses have unique growth requirements, including appropriate light, proper air circulation, and the proper nutrient balance. AeroFarms companies are interested in cultivating flowers would need to modify their mist systems and environmental controls to fit the unique requirements of flower crops. This may entail fine-tuning misting conditions, nutrient formulas, and lighting schedules in order to produce a perfect growing environment for roses and other flower species. Growing flowers in an AeroFarms system requires careful consideration of market demand, economics, and feasibility. Thorough research, consultation with floriculture specialists, and small-scale trials can assist in establishing the practicality and potential success of cultivating flowers in a mist system as part of an AeroFarms company's activities (Christie & Nichols, 2003). And there are some key elements for promoting new items on the market and how to make a profit from their:

- **Market Research and Demand Analysis:** Conduct extensive market research to understand flower demand in your target market. Determine whether flowers are in high demand or have a niche market appeal. To estimate the potential profitability of growing flowers in AeroFarms, analyze consumer preferences, trends, and pricing dynamics.
- **Grow High-Value Flower Varieties:** Choose flower varieties that have a high market value and appeal. Concentrate on flowers used for special occasions, events, or floral arrangements. Roses, orchids, lilies, tulips, and other exotic blossoms could be included. AeroFarms company can command better pricing and boost profit margins by cultivating premium and sought-after flower types.

- **Customization and Specialty Orders:** Provide choices for customization and respond to special consumer needs. Allow for color differences, unusual flower species, and personalized arrangements. Collaborate with event planners, wedding coordinators, and florists to execute special orders and suit their unique requirements. This can open up prospects for premium pricing and volume sales, resulting in higher profits.
- **Direct-to-Consumer Sales:** To increase profit margins, investigate direct-to-consumer sales methods. Create an online platform or e-commerce site where people may buy flowers directly from AeroFarms. This eliminates intermediaries, allowing businesses to collect a higher share of the sale price. To increase customer satisfaction and encourage repeat business, provide simple delivery options.
- **Collaborate with Florists and stores:** Form relationships with local florists, floral designers, and flower stores. AeroFarms can provide customers with fresh, locally cultivated flowers. This can result in repeat orders, bulk sales, and long-term contracts, assuring a continuous revenue stream and profitable business connections.
- **Value-Added Products:** To diversify revenue sources, look at value-added products related to flowers. Creating supplementary products such as floral arrangements, bouquets, wreaths, or potpourri could fall under this category. AeroFarms companies can increase profit margins and accommodate customers searching for ready-to-use floral items by delivering these value-added products.
- **Branding and Marketing:** Invest in good branding and marketing methods to differentiate flower products and establish a strong brand image. Highlight the distinguishing characteristics of locally grown flowers, such as freshness, sustainability, or a lesser carbon footprint. To raise awareness and demand for the flowers, use social media, targeted advertising, and collaborations with wedding planners or event organizers.
- **Seasonal and Special Event Promotions:** Use seasonal and special event promotions to increase sales and profitability. During holidays, weddings, Valentine's Day, Mother's Day, and other flower-centric occasions provide promotions, discounts, or limited-time bargains. This can attract customers and stimulate repeat purchases, resulting in increased profitability during peak seasons.
- **Efficient Operations and Cost Management:** Improve profitability by optimizing operational efficiency and cost management. To cut costs, constantly analyze and streamline growing procedures, resource utilization, and labor management. Invest in

energy-saving technologies, automation, and process optimization to increase yields while reducing waste.

- **Customer Satisfaction and Retention:** Put the customer first and focus on long-term partnerships. Provide outstanding customer service, maintain constant product quality, and respond quickly to complaints or queries. Loyalty programs, customized offers, and referral incentives can all be used to increase client loyalty. Customers who are satisfied are more likely to become repeat purchases, resulting in long-term profitability.

Aero Farm companies can capitalize on the profitability of growing flowers in AeroFarms by applying these strategies. Companies can develop a profitable and sustainable business model in the flower market by cultivating high-value flower types, targeting specific market areas, and improving operations.

AeroFarms may improve strategic decision-making, increase operational efficiency, and seek expansion possibilities by harnessing these data. The company may concentrate on ongoing value chain improvement, match its activities with its value proposition, and efficiently handle market challenges. Overall, these studies help to provide a full knowledge of AeroFarms' business model and a path for long-term success in the vertical farming market.

5. Conclusion

In conclusion, this research has provided essential knowledge into the economic viability of vertical farming as a food production strategy. By analyzing the relative efficiency and profitability of numerous vertical farming systems in comparison to more conventional approaches, we were able to get a thorough knowledge of the potential advantages and limits of this novel approach to food production.

The findings suggest that vertical farming has the potential to be a lucrative and efficient alternative to conventional farming techniques, especially in congested metropolitan locations where land is expensive. Vertical farms use advanced technology and new approaches to grow crops in controlled indoor conditions, utilizing substantially less water and land than traditional farming methods. This can result in improved yields, lower costs, and increased profitability for farmers. It is necessary to highlight, however, that the economic sustainability of vertical farming is dependent on several factors, including the cost of electricity, labor, and capital, as well as demand for locally grown produce and the availability of government subsidies and incentives. Furthermore, there are still issues to be solved, such as the high initial costs of establishing a vertical farm and the continuing maintenance and optimization required.

While these obstacles exist, the study's results suggest that vertical farming might become more important in the future of food production, especially in urban areas where space is limited and conventional farming techniques may not be feasible. We can work for a sustainable and resilient food system for the future by continuing to invest in research and development and solving the industry's economic and technological difficulties.

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