THE MOST VALUABLE SCENARIO OF

VERTICAL FARMING

BY

COMPARING DIFFERENT BUSINESS PRODUCTION MODELS

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Executive Summary

By 2050, the global population is expected to be close to 10 billion persons. The huge population will bring a huge challenge to prevent a food crisis. Due to industrial development and urbanization, there are a lot of challenges, such as global warming, water shortage, decreased biodiversity, air pollution, to the conventional agriculture system. Vertical farming has been proposed as a feasible solution to release the pressure of food shortages. Vertical farming is defined as a solution to cultivate plants in a climate-controlled environment with dedicated light, nutrients, temperature, and other (energy) supplies (Birkby, 2016; Benke & Tomkins, 2017). By using vertical farms, farmers could produce all year round to supply the food consumption of urban citizens. However, some limitations and data shortages have restricted the development of vertical farming.

This research has adopted a diagnosis and quantitative research design. It mainly focused on understanding better the economic limitation of vertical farming by comparing the costs and benefits of four business production formats. Three critical factors, namely production scale, crop, and location, have been selected as the control factors for the model's combination: We have adopted large scale/ very large scale, microgreens/ lettuce, and Japan/ the U.S. A. as the three pairs of experimental factors that constituted four business models. We plan for microgreens production in the large-scale farms and lettuce production in the very large-scale farms. Thus, based on two different locations, the analysed four business models are (1) large scale/ microgreens/ Japan; (2) very large scale/ lettuce/ Japan; (3) large scale/ microgreens/ U.S.A.; and (4) very large scale/ lettuce/ U.S.A. For each model, we have found one typical commercialized company as an example to relate the calculations with. So, there are four groups of data.

Then, two extra groups of data have been added in the evaluation: one is to compare the value of two different crops production in the same vertical farm; the other is to compare the value of two production levels at the same scale. That adds up to six groups of data. The outcomes suggest the following learning; the most valuable production scale is the large scale; the most valuable crop is microgreens; the most valuable location for lettuce is the U.S.A., while for microgreens it is Japan. We conclude that the most valuable business production model of vertical farming would be the large-scale format producing microgreens in Japan.

From the discussion derived from the calculations of each business model, it seems that mass production can balance the annual depreciation costs and energy costs. Whereas, if the farm's automation facilities are insufficient, mass production will require more labor forces, resulting in high labor costs. Therefore, to make a valuable production

model in the future, the vertical farm is supposed to adopt a highly automatic production method. This is an early public comparison of costs and benefits of four very different business production formats, thus further studies to fine-tune the economics of vertical farms are necessary.

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1. Introduction

This chapter starts with the background information to introduce the development of vertical farming from its origin until now and explain why it is a trending topic. The next section is the problem statement, that describes the current difficulties in the vertical farming industry, which will mainly focus on the commercialized process. Based on the defined problem, the research objective conducted (in 1.3.) is specified, followed by the specification of it into three research questions (1.4). The last section is the research design and research framework that formulates the road map to indicate appropriate steps of research achievement.

1.1 Background information

Due to the growing population and climate change around the world, recently vertical farming has been proposed as a feasible solution to solve the food crisis in the future. However, this concept is not a new idea of urban farming. Since 1999, Prof. Despommier of Columbia University had done the experiment by using the roof garden for food production. It was the initial tentation of vertical farming, which was designed for supplying the food demand of Manhattan (Despommier, 2013). Though the experiment was not a success because of the limited space of the roof garden, it introduced a new assumption of urban farming and finally had the first outline in 2001 (Bian, 2016).

In definition, vertical farming is a solution to cultivate plants in a climate-controlled environment with precise light, nutrients, temperature, and other energy supplies (Birkby, 2016). The plants will be cultivated in the stacked trays within the same footprint. Specific climate control and vertical production ensure high yield and good quality of food (Beacham, Vickers, & Monaghan, 2019; TAKATSUJI, 2010; Touliatos, Dodd, & McAinsh, 2016). Without relying on natural resources, this production model is not only a solution to urban farming but grab new business opportunities and markets around the world (Kalantari, Mohd Tahir, Mahmoudi Lahijani, & Kalantari, 2017).

The global vertical farming market has increased rapidly these years (Vyas, 2018). The VF market report from Patil & Baul (2019) has valued the market size as 2.23 billion dollars in 2018 and is expected to reach 12.77 billion dollars by 2026. The current major players in this market are AeroFarms in the United States, Koninklijke Philips in the Netherlands, Spread in Japan, and Singapore's Sky Greens (Patil & Baul,2019). Since the research group has worked on this project in the early 2000s, Aero Farms adopted a hazing system that can use 95% less water for outdoor production and 40% less water for hydroponics. Advanced technology and professional management made it to be the world's largest "vertical farm", which can produce 130 times more than conventional production (Fortado & Terazono, 2019).

In addition to the United States, Japan has also done much research and the contribution of vertical farming. Dr. Toyoki Kozai, from Chiba University, is known as the "father of modern plant factories." The plant factory is one of the variations of vertical farms. Kozai has defined "PlantFactory with Artificial Light" (PFAL) as a plant production facility consisting of 6 principal components: a thermally insulated and nearly airtight warehouse-like opaque structure; 4 to 20 tiers equipped with hydroponic culture beds and lighting devices such as fluorescent and LED (light-emitting diodes) lamps; air conditioners with air fans; a CO2 supply unit; a nutrient solution supply unit with water pumps, and an environmental control unit (Kozai, 2007). These artificial light source plant factories are characterized by high airtightness, heat preservation, and sanitary level. By producing the crops in such conditions, the product could ensure high quality and cleanness as customers could directly eat it without washing (Kozai, Niu & Takagaki, 2015).

Reasons for the global development of vertical farming relate to good food and resource efficiency. Nowadays, customers prefer to choose the products with added value (Eigenbrod & Gruda, 2015). They can get more than the product itself at the same price (Beacham, Vickers, & Monaghan, 2019). Since vertical farming would not use outdoor resources, it will also contribute to reducing the social impact of changing natural conditions, such as increasing the arable land and using underground water. Thus, some people, who care about environmental issues, are willing to pay this contribution. Furthermore, a stacked farm structure could optimize the room space. It will reduce the land use and balance the energy utilization (Graamans, Baeza, van den Dobbelsteen, Tsafaras, & Stanghellini, 2018; Kalantari, Mohd Tahir, Mahmoudi Lahijani, & Kalantari, 2017). As such, more investors are willing to make benefit from vertical farming, which boosts market growth eventually.

In summary, based on the above information and market development, vertical farming seems to be a feasible solution to food production. However, as a new technical production model, it still has difficulties to overcome. The following section will zoom in on the problems concerning its commercial development

1.2 Problem statement

It seems that after transformation from open-ground agriculture into vertical farming, humans no longer need to concern about climate and exhaustion of arable land. With the indoor climate-controlled environment, people can grow crops throughout the year without concern about the effects of bad weather, drought, or natural disasters (Benke & Tomkins, 2017). At the same time, vertical farming can increase the yield by superimposing planting in the stacked trays with the same footprint. However, there are still many problems with this production method.

Apart from the required dissemination of new production technologies, difficult commercialization is the current problem of this business model. Comparing to conventional agriculture, high start-up cost and energy consumption are the main disadvantages of vertical farming. A circular economy workshop in Germany has calculated that the price of vertical farm products is twice the comparable organic product in the European market (Zeidler, Schubert & Vrakking, 2017). This price gap is primarily due to high capital investments and large energy consumption (Kalantari, Tahir, Joni & Fatemi, 2018). Hence, though vertical farming seems to be a feasible solution to the expected urban food crisis, commercialization difficulty is a main challenge in the global market.

Based on the above statements, the problem staged in this report is how to make more transparent Vertical Farming as a commercial business. It will be investigated and analyzed further.

1.3 Research Objective

According to the problem statement, difficult commercialization is the main problem of vertical farming development among the global market. Thus, this MSc-thesis research aims to provide insight into different cost scenarios of vertical farming and relate them to revenues, to find out the most valueble production format. The value of a business can be calculated in different manners; e.g., for example, by starting with the market share-price valuation. Here we take the accounting method of calculating the total of revenues and costs based on accounting categories. That may help both to make the VF business more transparent, but it will also suggest the commercially most suited production model to invest in.

1.4 Research Questions

This research aims to find out the most valuable business production model of vertical farming based on financials, by comparing and calculating the revenue, costs, and profit of each selected model. Based on this, the following Central Research Question (CRQ) has been formulated:

'By comparing the financials of different business models, what is the most valuable business production model of vertical farming?

As the CRQ is a broad question, several Sub Research Questions (SRQ's) are developed based on the different aspects of it. The following SRQ's will give a thorough answer to the CRQ.

The three sub-research questions are:

1. What is the most valuable production scale of vertical farming?
2. What is the most valuable crop of vertical farming?
3. What is the most valuable location of vertical farming?

1.5 Research design and Research Framework

The research design formulates a road map that indicates appropriate steps to achieve the research objective. It could clearly show the structure of the research plan and the interconnections between each phase. The purpose of this research is to find out the most valuable scenario of vertical farming by calculating the cost and profit of different business models. Hence, a quantitative and diagnosis research design will be adopted for this research.

To answer the main research questions, a preliminary literature study will be conducted for each SRQ. The key knowledge for this research objective is the current VF alternatives, VF crops, VF scales, VF location selection, and relative costs/ wholesale price for those crops. By literature reviewing, feasible business models will be selected for further cost/ profit calculation of this research. The conceptual framework will be spelled out after the preliminary literature review. It will further illustrate the way of selecting and combining different business production models. Below, Figure 1 shows the research framework of this report.

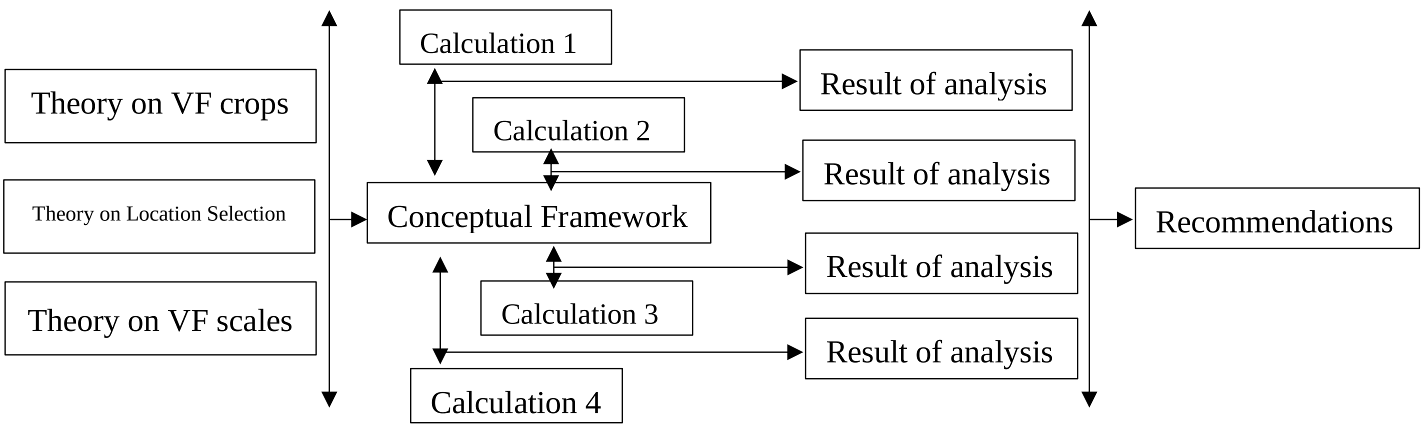


Figure 1. Research Framework.

2. Literature review

Vertical farming is innovative agriculture that has attracted attention in recent years. It is an innovative production method applicable to urban agriculture. As described, the problem statement is to find out the most valuable way of vertical farming production. In the literature study, there will be a thorough explanation that refers to the knowledge about vertical farming.

In this chapter, section 2.1-2.5 will introduce the theoretical concepts of vertical farming and the knowledge framework to provide relevant knowledge about this topic. Afterward, a conceptual framework in section 2.6 will be spelled out according to the literature study and research objective. To get an overview of vertical farming, section 2.1 will first theoretically introduce the concept of vertical farming, then followed by the description of the advantages and disadvantages of vertical farming. After that, the next two sections will provide insight into multiple aspects involved in vertical farming production. It will explain the main technological production methods, planting spatial arrangement, and typologies respectively. To answer the second RQ, section 2.4 will firstly investigate the most common plants of vertical farming, then followed by a crop selection to choose the most two feasible crops among those. Finally, the last section 2.5 is supposed to introduce the information about location selection of vertical farms.

Search term: Vertical farming, Production methods, Hydroponics, Aeroponics, Aquaponics, Controlled-Environmental Facility, Micro Greens, Lettuce

2.1 Vertical farming

2.1.1 What is vertical farming

In literature, vertical farming is defined as a solution to cultivate plants in a climate-controlled environment with precise control over light, nutrients, temperature, and other energy inputs (Birkby, 2016; Benke & Tomkins, 2017). However, currently, there are many alternatives similar to this concept, such as rooftop farming, greenhouse, plant factory, container farming, and living walls. In order to make a distinction between the concept of vertical farming and those alternatives, it is important to discuss the differences between these alternatives. Hereby, the definitions of each concept are presented below.

Urban rooftop farming: It is a kind of urban farming that cultivates crops or plants on the roof of a building. It includes two variations under this concept: rooftop farming (open air) and rooftop greenhouses (protected). Both systems colonize the rooftops of buildings and conduct to horticulture cultivation through different technologies (Sanyé-Mengual et al., 2015; Buehler & Junge, 2016; Grard et al., 2017).

Greenhouse: It is defined as a structure with walls and roof made mainly of transparent materials to provide a regulated environment for plant cultivation (Van Henten, 1994; Hanan, 1997; van Beveren et al., 2015).

Plant factory: It is defined as a closed growing system that utilizes artificial control of light, temperature, moisture, and carbon dioxide concentrations to ensure a constant crop production all year round (Kim, 2010; Shimizu et al., 2011; Goto, 2012; Kozai, Niu, & Takagaki, 2019).

Container farming: It is defined as a sustainable food production system that can be housed in one intermodal shipping container or multiple shipping containers. The containers are designed as a flexible shape, which is expandable to change based on different crop cultivation. Due to the intermodal design, it is convenient and easy to be transported around the world (Lehman, Stambaugh & Falconer, 2013; Jacobs, 2015).

Living walls: It is defined as an urban green infrastructure that utilizes the vertical surface of the building to grow plants. The living walls will contribute to the sustainable development of the city and environment by creating and modifying a positive environment effect (Sheweka & Magdy, 2011; Hopkins & Goodwin, 2011; Köhler, 2008).

According to the above classification, all the systems: urban rooftop farming, Greenhouse, plant factory, container farming, and living walls are based on sustainability to design the infrastructure. Rooftop farming and living walls both are building combined production systems, which can influence the microclimate inside and outside of the buildings constantly. Container farming is an intermodal cultivation system. It is flexible to be transported around the world and utilized in the greenhouse, plant factory, and vertical farming. Referring to the greenhouse, it mainly uses transparent materials to build the facility to utilize sunlight for plant photosynthesis. It has the closed and semi-closed versions, that can open the rooftop for ventilation. Though the greenhouse could provide a regulated environment for plant production, it is a combination method that integrates artificial control and natural supplements (e.g. influx of daylight and air).

The cultivation system most similar to vertical farming is the Plant factory. Vertical farming and plant factory are fully closed systems that use artificial controls to ensure a specific growing condition to predictably produce all year round. The main difference between the two is that vertical farming contrary to plant factory by definition uses stacked trays (or rotating systems) vertically in one footprint, which will multiply the production area. This implies that the plant factory is the simpler version of vertical farming. Thus, in this research, vertical farming is defined as a closed cultivation system that uses stacked trays to vertically cultivate plants in a fully artificial controlled environment with precise light, nutrients, temperature, and other energy supplies. Although vertical farming comes in different scales and shapes, most of them adopt soilless farming techniques, such as hydroponics, aeroponics, and aquaponics, for nutrient supplying (Birkby, 2016). However, not all techniques are suitable for commercial production. Though aquaponics takes one step further than others, producing plants and fish at the same time, in fact only a few vertical farms use this system due to its complexity.

So far, there are only certain types of plants to be cultivated in vertical farming. Regarding the crop selection, leafy greens, microgreens, strawberry, and some flowers are the main crops, which are feasible to be cultivated in the vertical farm currently. The precise climate control could ensure the quality of crops. When we consider commercialization, those crops are fast-growing that could make a profit in a short production period with all-year-round production (TAKATSUJI, 2010). In the meanwhile, the plants that need a longer growing period are not feasible for commercial production so far. The extra costs are not expected to be compensated by higher revenues.

As mentioned before, vertical farming is realized in different scales and shapes. The size of vertical farming is classified by daily production. Normally, there are four different scales: very large, large, small, and mini/ micro size. Based on the different sizes, there are many alternatives derived from vertical farming, such as balcony production, instore production, etc. However, not all alternatives are suitable for commercial production. For example, the mini/ microscale is designed for customers interested in gardening, or research aims. This research focuses on finding the most valuable business production model of vertical farming. Thus, we choose a B2B business model for which this research compares different production models (cf. Banerjee & Adenaeuer, 2014).

Thus, due to the high investment and energy costs and crop restrictions, there are researchers skeptical of the feasibility of vertical farming's future development (Al-Kodmany, 2018; Allegaert, et al 2020. The following section presents the pros and cons of vertical farming.

2.1.2 Advantages and Disadvantages of Vertical Farming

In this section, there will be an overview of four advantages and three disadvantages of vertical farming. Then, an evaluation will be conducted.

Regarding the aim of vertical farming, high yield production is the first and most important advantage. As the global climate changes and the global population increases, vertical farming seems to be a feasible solution to at least reduce the expected future food crisis. Proponents to VF claim that plants that grow in the stacked trays, what increases the yield within the same footprint area, combined with an all-year-round production instead of a seasonal production (Benke & Tomkins, 2017; Touliatos, Dodd, & McAinsh, 2016). It could be a feasible solution to supply the food demand of urban citizens in the future. Then, the second advantage of vertical farming is environment friendly (Besthorn, 2013). Due to the self-controlled environment, it will save natural resources, such as the arable land and underground water. In the meanwhile, this urban farming will also force less waste emission to the open environment. Thus, deforestation, desertification, and other environmental problems will be improved constantly. The third advantage is the reduction in transportation cost and exhaust gas emission (Al-Kodmany, 2018). Since the vertical farm is located around the urban area, a shortened delivery distance between the farm and supermarket would cut down those negative effects. Finally, the fourth advantage is related to the quality and safety of the products: With precision management of the growing condition, vertical farming products in principle have better quality than conventional production methods. With smart control and a stable climate, plants will have accurate protection during the whole cultivation period (Benke & Tomkins, 2017). Meanwhile, infestations will be eliminated by biological controls instead of pesticides and herbicides (TAKATSUJI, 2010). Hence, based on the above statements, vertical farming is not only having a higher yield than conventional production but ensures better quality products with added value in the environmental aspect (Banerjee & Adenaeuer, 2014).

Though vertical farming seems to be a solution to the urban food crisis, nowadays there are researchers suspicious of its commercial feasibility, which may be combined in three disadvantages of vertical farming (Al-Chalabi, 2015; Allegaert et al, 2020). The first disadvantage is the start-up costs, which claimed to be too high in urban locations (Al-Kodmany, 2018). Despite abandoned warehouse and derelict area could be used as the initial base, the maintenance costs and energy consumption are still the big challenges that should be overcome. The second disadvantage refers to crop selection: the current model of the vertical farm is only suitable to grow high-value, rapid growing, small-footprint, and quick-turnover plants, such as lettuce and microgreens (Cox, 2016). The vertical farm cannot grow all kinds of crops. Finally, the third disadvantage regards the workforce aspect; currently, few companies have enough skilled labors that can conduct commercial production. Thus, to achieve the commercialization of vertical farming, these three problems have to be solved aforehand.

The above argumentations have introduced the pros and cons, the opportunities, and challenges regarding the commercial development of vertical farming. A large survey from the Ministry of Agriculture, Forestry, and Fisheries of Japan has revealed that from 2014 to 2018 the number of profitable vertical farms has increased from 25% to

50%, among 165 facilities (Kozai, 2020). It also investigated the reasons behind unprofitable production. The two main reasons for unprofitable production, are the lack of professional management and too low market prices Thus, professional workforce training and a better marketing strategy may promote the commercial feasibility of vertical farms (cf. Banerjee & Adenaeuer, 2014). Though energy cost and crop limitations are disadvantages of vertical farming, they are not considered to be the main reasons that block the commercialization development of vertical farming.

2.1.3 Different variations of vertical farms

In urban farming, vertical farms are always integrated with buildings. As shown in figure 2, there are two main categories. One is vertically stacked containers on the same horizontal plane (a, b, c, d), and the other is vertical surface planting (e, f) (Beacham, Vickers, & Monaghan, 2019). Those two different spatial arrangements allow for several variations of vertical farms. Thus, urban farmers can choose a specific variation based on the best business model. This subsection will introduce each spatial arrangement with their variations and determine the most feasible one for the scenario study of commercial business models.

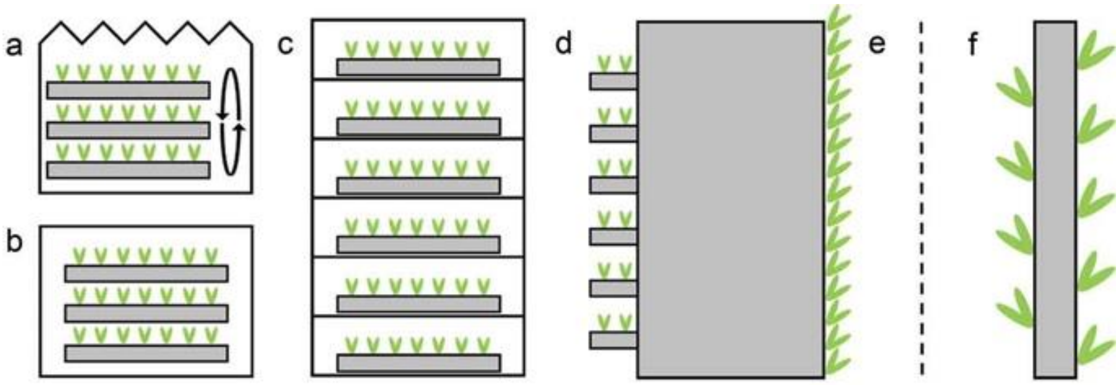


Figure 2. The spatial planting arrangements of vertical farming (Beacham, Vickers, & Monaghan, 2019).

2.1.3.1 Stacked horizontal system of vertical farming

The stacked horizontal system is defined as the containers are vertically stacked in one horizontal plane to increase the production yield. There are four different variations derived from this system.

As the figure is shown above, the first variation (a) is the multi-level planting design in the glasshouse. Since plants need to get sunlight during the day, all containers have to rotate orderly to ensure the plants in the bottom layer could do photosynthesis as well. Due to limited construction cost and space, this variation is generally considered to be built on the top or side of the building or as a ‘green façade’ (Köhler, 2008). This study will not take this variation into account, because this is variation is not using a fully self-controlled environment. The second variation (b) is a fully closed production environment (CE). The climate is artificially controlled to create a suitable growing condition for crops. According to Takatsuji (2010), it is the same principle of the ‘Plant Factory’ with self-contained controlled environment facilities. Since this method without location and seasonality restriction, it is the most popular one that has been adopted by many companies for commercial production so far (Beacham, Vickers, & Monaghan, 2019). The third variation (c) is called a multi-floor tower. This one is designed for different climate requirements with multiple plants. It could be viewed as different isolated CE vertical farms with containers placed in different chambers. However, due to the complicated design and high investment, currently, there is no economic facility in practice (Mok et al., 2014). This study will therefore not take this variation into account. The last variation is balcony production (d). It is a derived production method from multi-floor towers by using the balconies to grow plants. This approach is more suitable for family size production. It aims at customers who have a personal interest in gardening. Therefore, this system is only suitable to be sold as an integral product as a B2C business model. When taking into consideration the research objective, then variation d cannot be used as the economic production for enterprises (Beacham, Vickers, & Monaghan, 2019).

2.1.3.2 Vertical surface growth system of vertical farming

In literature, this system is to cultivate plants on a vertical surface. In this section, there will introduce two different variations from this system.

As the figure is shown above, the first one is called green walls (e). It is an approach that crops are directly planted on the vertical surface of the buildings without a cover protector (Köhler, 2008). This design is mainly used for decoration rather than food production. Since the crop is directly planted on the building surface, it would get polluted by the urban pollution and hard to harvest. On the other hand, owing to the vertical height, plants cannot abstract balanced nutrient solution and sunlight throughout the surface (Song, Tan, & Tan, 2018). Thus, this variation is not suitable for the companies to do economic production.

The second variation of vertical surface planting uses the cylindrical unit (f) to grow crops. Plants are grown on the surrounding of the vertical cylinders. These vertical cylinders are always placed in a glasshouse or controlled environment facility. An experiment by Touliatos, ey all in 2016 has evaluated the yield of vertical cylinders in comparison with traditional agriculture. It was found that, though there may be an unbalanced distribution of nutrient solution nd light from top to bottom of the cylindrical unit, the cylindrical units still produce more than the traditional production. However, when considering the shape of the cylinder unit, it would be less efficient in the use of space.

According to the above classification, the stacked horizontal system (b) in a controlled environment facility, and cylindrical growth unit (f) would be the feasible solutions of vertical farming for each category. Since the cylindrical growth unit system is usually placed in a controlled environment facility, an investigation is needed into which spatial arrangement is the most suited for vertical farming. Therefore, this study will focus on the stacked horizontal VF-system.

2.2 Technological Production Methods

Based on the technological production methods, there are three different vertical farms: Hydroponics, aeroponics, and aquaponics (Despommier, 2019). The common features are soilless and sustainable production by using an aqua solution to grow and control the physical and chemical parameters (Rajan, Lada, & MacDonald, 2019). During the growing period, the nutrient level would be held at a specific level to optimize plant growth. Since the aqua system in circulation, the solution will be utilized again for further production. Thus, it can save 70% less water than conventional agriculture. Furthermore, the controlled growing condition will reduce the need for fertilizers, herbicides, and pesticides, which would provide a better and safer quality of greens (Benke & Tomkins, 2017).

1. Hydroponics: Hydroponics is the cultivation of crops with nutrient solutions. Comparing to the traditional method, it can reduce water consumption by up to 60-70%. So far, it has been widely applied to thousands of commercial greenhouse and vertical farms around the world (Despommier, 2019).

2. Aeroponics: Aeroponics is a production method that plants can grow without soil. The nutrient solution will be emitted throughout the nozzles to the air. The root system of the plant is directly exposed to the air in a closed container and then take nutrient inside (Birkby, J., 2016). It uses approximately 70% less freshwater than hydroponics (Despommier, 2019). Therefore, this production method becomes more profitable and easier to monitor (Despommier, 2013).

3. Aquaponics: Aquaponics is a production method that links fish farming and vegetable production in a closed system. It makes use of the mineral waste solution from fish to provide the nutrients for the plants (Beckers, 2019). However, this method has very high requirements for equipment, labors, and technology. The operation processes are also complicated throughout the production period. Hence, it is not widely used so far (Giacomantonio, P., 2012).

Based on the above information, the first two methods are easier to manage and operate than aquaponics. In aeroponic cultivation, nutrients and water are sprayed through the nozzles on plants, which improves the efficiency of the nutrient solution. It can reduce freshwater consumption as well. Therefore, in comparison to hydroponics, aeroponics cultivation is cheaper and more and efficient. However, hydroponics is the most widely used production method of vertical farms around the world so far. Hence, taking the research objective into account, one needs to compare the costs of aeroponics and hydroponics, to find out which one is more suitable for vertical farming production.

2.3 Different Structures of Vertical farming

Vertical farming systems can further be classified by the type of infrastructure that houses the system (Benke & Tomkins, 2017). Usually, the structures are mainly divided into two categories: building-based vertical farms, and shipping container vertical farms. Referring to different commercial purposes and construction structures, Vertical Farms are mainly divided into five categories: kitchen farms, indoor artificial climate-controlled farms, plant skyscrapers, zip racks production, and indoor rotating farms. This section specifies these five different facilities to illustrate the current commercial production structures of vertical farming.

Firstly, the kitchen farm usually adopts a small or micro scale of vertical farming. It aims to serve the customers with fresher and tasty food by exhibiting the whole production model within the restaurant. Usually, transparent production and viable manufacturing processes will improve consumer trust, especially in food production. Lokal is a prototype hydroponic farm and salad bar that popped up in London in 2017 has attracted a lot of visitors to explore this new production workshop and taste the nutritious greens.

Secondly, the indoor artificial climate-controlled farm is the most common commercial production facility of vertical farming in the world. Most companies adopt this indoor production model, such as Aerofarm in the U.S. and Spread in Japan. It is mainly used for large scale production with professional management and suitable climate control.

The third type is the plant skyscraper. This production model cultivates crops within the skyscrapers with the hydroponic system and natural sunlight. It aims to combine urban farming and architecture to supply the food demand of citizens by adopting the innovative technical production method. Plantagon, a Sweden company, has conducted a vertical farming project that aims to minimize the need for artificial light by efficiently using the architecture structure to get more natural light inside the building. Though this company bankruptcy in 2019, it has introduced a new idea of vertical farming for minimizing energy costs.

Both the fourth and fifth types of structures are the variations of indoor artificial climate-controlled vertical farming. The fourth one uses the mobile zip shaped racks to vertically cultivate crops with a hydroponic system. The ZipGrow company intends to use wall-mounted modular set up based towers with 2-4 cm planting aperture to grow crops (Sevastiadou et al., 2019). Each base could contain five removable towers, which are 152 cm tall and easy for labor to manage and harvest (Mousa et al., 2019). The fifth indoor rotating farm is a large-scale production model as the planting containers constantly rotating throughout the day in order to minimize energy consumption by utilizing natural sunlight (Benke & Tomkins, 2017). Sky Greens is a Singapore commercial facility based on an A-shaped tower to grow crops with 26 stacked containers (Kalantari, Tahir, Joni, & Fatemi, 2018). This facility only needs a six square meters footprint with 1-ton vegetable production per day, which is ideal for the urban environment (Darcel et al., 2019). Table 1. below will illustrate the above-mentioned facilities.

Table 1. Different vertical farm types (Vyas, 2018).

1. Serving the fresh food where its grown - Lokal ✧ Kitchen garden. ✧ LEDs with stackable trays. ✧ Growing three times faster than the conventional method. ✧ - Making salads using greens grown hydroponically.	
2. Large Scale Vertical farming – Aerofarm ✧ Aeroponic and hydroponic system. ✧ Self-controlled environment. ✧ Smart light, nutrients, data, pest management, substrate, and scaling.	
3. Plantscapers – Plantagon ✧ A building that provides food for residents. ✧ Using a hydroponics system. ✧ No artificial lights. ✧ Rack transport system transport plant boxes from floor to the ceiling.	

<table>
<tr><td>4. Ziprack production – ZipGrow
✧ A variation of smart vertical farms.
✧ Hydroponic system.
✧ Self-controlled environment.
✧ Mobile cultivation racks.</td><td></td></tr>
<tr><td>5. Indoor rotating farm– Sky Greens
✧ Hydraulic-driven vertical farms.
✧ Plant containers rotate throughout the whole day.</td><td></td></tr>
</table>

Although the companies presented as illustrations for the five variations in structure have a different commercial purpose and construction structure, they are mainly using two production methods: aeroponics and hydroponics. Furthermore, the companies also indicate two important business production models: microgreens with small-scale controlled environment facilities, and leafy greens with large-scale controlled environment facilities. This is consistent with the findings of this study.

2.4 Crop Selection

When choosing suitable crops for a vertical farm, there are three factors that should be considered: economic viability, growth cycle, and biological feasibility (Kalantari, Mohd Tahir, Mahmoudi Lahijani, & Kalantari, 2017). Due to specific climate control and smart cultivation management, theoretically, any plants can be cultivated in the vertical farms with a suitable condition. Since the crop productivity of vertical farming is much higher than traditional agriculture, usually it has more than two times higher compared to the conventional production (Kalantari, Tahir, Joni, & Fatemi, 2018). However, to maximum, the production profit, choosing the right crops is very important in this production model.

Regarding the economic viability, even some crops are biological viable to plant in the vertical farm, they are not valuable to make money. To balance the cost and profit on a vertical farm, choosing the crops with relatively lower energy requirements is more economically viable. Some crops need hotter temperature or light than other crops will not be considered. Indeed, 'high' cost is relative to the margin that the farmers can earn from the market. Once the product can grab sufficient profit, no matter how much energy it consumes, it is supposed to produce to meet the marketing demand.

According to the growth cycle, it not only decides the biological growing period but also decides the return of investment. Planting the fast-growing crops allow the farmers to minimize their liability and accelerate the cash flow from the production (Michael, 2017; Frazier, 2017). The short production cycle plant of vertical farming is defined as the crops that can be produced in weeks, normally around six weeks from seed to harvest. Salad greens, herbs, and micro greens are normally considered as the fast-turn crops, which are commonly planted for commercial production (Reddy, 2019; Benke & Tomkins, 2017; Rajan, Lada, & MacDonald, 2019, p. 1404). They can be continuously harvested in a short period to rapidly get a turnover, realise cash flow. Meanwhile, it is also more flexible for producers to arrange the planting schedule based on the marketing demand (Beacham, Vickers, & Monaghan, 2019). Though slow-turn crop normally is more profitable than fast-turns, it may take a higher risk as longer production time and higher energy consumption (Crumpacker, 2018). However, whether to choose fast-turn or slow-turn crops mostly depend on marketing demand.

Biological feasibility refers to the physical growing habits of plants throughout the whole production period in the vertical farm. Due to the physical layout of vertical farming, usually small size plants, which generally 30cm tall or even shorter, are more likely to be planted within the stacked trays (Reddy, 2019). Those plants, such as leafy greens, herbs, or transplants, are also feasible to be cultivated in a high-density condition with low energy requirement and short production cycle. It also fulfilled the year-round marketing demand and high harvestable yield, which could promote the commercialization of vertical farming (Runkle, 2019; Rajan, Lada, & MacDonald, 2019).

Table 2. below indicate ten active vertical farms around the world. The most three common planting crops are leafy vegetables, microgreens, and strawberry. This also proves small size plants are more widely adopted and preferred by the vertical farmers. Though some companies also produce tomato, corn, wheat, and pepper, it depends on the local marketing demand and consumer preferences. Due to the larger plant size and longer growth cycle, normally those plants are not suggested to cultivate for the common production (Beacham, Vickers, & Monaghan, 2019).

Table 2. Ten active vertical farms around the world (Kalantari, Tahir, Joni, & Fatemi, 2018).

Name	Location	Height	Type of building	Products
The Plant Vertical Farm	Chicago	3 story	Existing building in 19th century	A wide variety of edible crops includes an artisanal brewery,

				kombucha brewery, mushroom farm, and bakery, Tilapia
Sky Greens Farms	Singapore	9 m	New	Leafy green vegetables
VertiCrop TM	Vancouver, Canada		Rooftop of existing building	Leafy greens, micro greens, and strawberry
Republic of South Korea VF	South Korea	3 story	New	Leafy green vegetables, almost wheat, and corn
Nuvege plant factory	Japan (Kyoto)	4 story		Leafy green vegetables
Plantlab VF	Den Bosch, the Netherlands	3 story underground	Existing building	Beans, corn, cucumber, tomato, and strawberry
Vertical Harvest plans2	Jackson Wyoming, USA	3 story	New	Tomato, strawberry, lettuce, and micro greens
Planned Vertical Farm	Linkoping, Sweden	17 story	New	Asian leafy green vegetables
Green Sense Farms	Portage, Indiana; Shenzhen, China		New	Micro greens, baby greens, herb, and lettuce
AeroFarms	Newark, New Jersey	9 m	New	Herb and micro greens

The listing in Table 2 shows that microgreens and leafy greens are indeed the most common crops for vertical farms. Especially lettuce is the most popular crop among leafy greens. It is quick and easy to grow in the vertical farm and available in dozens of varieties (Crumpacker, 2018; Reddy, 2019). Based on information from the previous section, usually, microgreens are cultivated in small-scale controlled environment facilities, and leafy greens are often cultivated in large-scale controlled environment facilities. Hence, micro greens and leafy greens usually represent two different business production models. In order to find out the most valuable business model for vertical farming, this study will try to compare the profitability of these two kinds of crops.

2.5 Location Selection

2.5.1 Why Location is Importation

Where to build a vertical farm is a critical question to urban farmers now. Since the urban estate is expensive to start a vertical farm, choosing the right location is an important decision before startup. By choosing the right location, firstly company could minimize the startup investment, which could release its financial liability. The second reason is related to the transportation cost. The company has to balance the costs of estate investment and transportation. In order to grab more profit from this business model, the vertical farm is supposed to build as closer to the local market as possible. Shortening transportation distances could reduce transportation costs and provide fresher food (Michael, 2019). However, the feasible urban area is limited to utilize due to the intensity and cost of central business districts are high. Thus, based on the above argumentations, choosing a suitable location is very important as the first step of the whole business.

2.5.2 Location Selection – Local market consideration

The location selection has to be considered from the following aspects: product, estate, and local purchasing power (Michael, 2019). When choosing the right place for production, it is supposed to think about what kind of products suitable for the local customers and how to promote the products to the local market. Firstly, choosing the right crop is the fundamental step of all startup farmers. Based on the marketing investigation of local demand, the company could find out the most valuable crops of the local market. Then, producers must pick up the feasible crops that could be cultivated in the vertical farm. Based on the on-demand market relationship, the producer can tap into an effective network for promoting the products with local consumers (Michael, 2019).

Secondly, choosing the right estate with sufficient energy supply is very important for plant cultivation. Currently, it is very difficult to find a feasible urban estate for building a vertical farm in the central commercial area. Budgetary consideration is not the only factor that influences estate selection. Besides that, the producer has to estimate and calculate the energy consumption throughout the whole production period (Michael, 2019). Since most vertical farms are self-controlled environment, it needs enough energy to maintain the indoor climate for plant growth. Thus, the estate has to be equipped with facilities to provide a suitable growing condition, such as lighting, pumps, dehumidifiers, fans, etc. An adequate growing condition ensures better quality and shorter production time of crops. Hence, choosing a suitable estate will beneficial for later production within an economically viable budget.

The third aspect is related to the local purchasing power. To achieve commercial feasibility, farmers must choose the right pricing strategy based on local purchasing power. They must propose the food into an appropriate marketing segmentation by branding its value proposition. Look into the pricing strategy, VF food should avoid competing with conventional products. The VF farmers cannot grab enough profit margin when the price is as same as the conventional products (Michael, 2019). Although its production costs are higher than conventional cultivation, the better quality and freshness should be priced accordingly. The targeted customer group would be the people who focus on the fresh taste, better quality, local growing, and healthy lifestyle (Tasgal, 2019). Choosing the right business central district will conduct a better marketing environment to propose the added value of vertical farming products.

Based on the above argumentations, a suitable location is not only focused on minimizing the production cost but make a connection with the local consumers. In order to maximize profit, the producer has to select a suitable location with valuable plants and sufficient energy supplements to ensure product quality. In the meanwhile, an appropriate pricing strategy will accelerate the engagement of the local market.

2.5.3 Location Selection – Farm Scale Consideration

According to the last section, there have introduced three basic rules for location selection as considering the cultivated crops with feasible cultivation conditions to match the local purchasing power in one zone. This section will explain an advanced consideration that refers to the farm's scale. After all, productivity has to match the marketing demand. Normally, for supplying a large demand market, the building-based vertical farm is more appropriate with high yield production. However, nowadays some restaurants or coffee bars would like to serve food with good quality and fresher taste. Besides that, for personal interest, some people prefer to have a balcony/ family size vertical farm as well. Hence, there derived some small and micro-scale vertical farms as well. According to the research objective, this study is only focusing on the commercial objective, which means to compare the profit margin between different vertical farming business production models. Thus, the micro-scale vertical farm, which is only suitable to grow crops in the home, is not in the research scope. The comparison will carry out between the large- and small-scale vertical farms.

Unfortunately, prior literature does not provide such classifications between small and large scales. Most of the literature uses the term “small” and “large” to generally describe the size of companies, however, the lack of scale definition persists. Besides, to formally classify the scales, we first have to define the measurements to be based on. In this research, the daily harvest is used to measure the scales of each firm as suggested by Kozai (2020). This is a standardized measurement to prevent any production difference due to technology or location. Kozai (2020) defined a daily harvest of fewer than 300 plants as the smallest size and a daily harvest of more than 10,000 plants as the largest size. Besides that, there are also papers in Kozai (2020) that claim the lower level of daily harvest as the large-scale production. Based on that, a number of daily harvests that distinguish the small and large scale is necessary. In order to do so, Table 3. summarizes how literature describes each firm with a different daily harvest. It is concluded from the table that a large scale has a daily harvest of fewer than 2600 plants and a very large scale has a daily harvest of more than 2600 plants.

Table 3. Scale descriptions from literature. (Kozai, 2020; Harding, 2020; Hayashi, 2020)

Description	Daily harvest	Scale
It is estimated that a 15-tier PFAL with a floor area of 1 ha needs more than 300 full-time employees if most handling operations are conducted manually.		small
Techno Farm Keihanna was built in Kyoto with a production capacity of 30,000 leaf lettuce heads (120 g per head) daily by Spread Co., Ltd	30,000	large
A plant factory that producing 10,000 leaf lettuce heads daily was built by Mirai Co., Ltd.	10,000	large
Spread Co. constructed the Kameoka Plant, which can produce 21,000 head lettuce per day	21,000	Large
Toru Numagami heads up A-Plus, a startup building a factory in Fukushima prefecture to produce 20,000 lettuces a day.	20,000	Large
One Japanese company Shinnippou Ltd. established its first large-scale plant factory called '808' in 2014, which can produce 10,000 head lettuce per day.	10,000	Large
Shinnippou Ltd. established its second plant factory in 2017 with daily harvests of 10,000 head of leafy lettuce.	10,000	Large
leading large-scale PFAL in Japan with a cultivation capacity of 5200 lettuce heads per day.	5200	large
In large-scale cultivation, such as 218-panel harvests every day	2600	large
plants of two units are harvested daily, and so the total production is 5200 plants per day.	5200	large

For the small-scale cases, we could not find specific numbers concerning the daily harvest. From the case description of a small scale (see table 3), it only described the farm structure and the number of workforces, which are not clear to estimate the daily harvest. To specify the farming scale, the first column in table 3 is not useful to define a small scale as the number of daily harvests is missing. On the other hand, for large-scale cases, there is a huge gap between 2600 and 30000 daily harvest. According to this production gap, a large scale could be split into two classes. Based on the descriptions in Table 3, 2600 to 10,000 daily harvests will be classified as a large scale while the daily harvest larger than 10,000 to 30000 will be classified as very large-scale vertical farming production. Due to this classification, the production comparison will be conducted between a large scale vertical farm and a very large scale vertical farm.

To sum up, productivity determines the farm scale, which is an influential factor in selecting the location.

2.6.4 Location Selection – Financial Consideration

To achieve the commercialization of vertical farming, it is important to find out the most economical way of production. Currently, the high investment of vertical farming is a big problem for its commercialization. Besides the start-up cost, figure 2. illustrates that the costs of energy consumption and workforce are the most important parts of the growing costs (Ijichi, 2018; Takeshima & Joshi, 2019). In the U.S. and European countries, the cost structure is similar, however, the labor costs are higher and hold the main component of production costs. So, minimizing energy consumption and labor costs will save money and accelerate the commercial development of vertical farming.

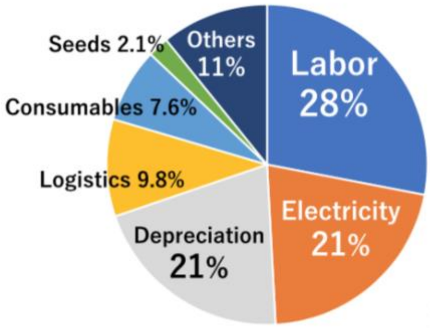


Figure 3. The production cost by components of a vertical farm (Ijichi, 2018).

According to a report from Loman (2018), the labor cost is quite similar between the U.S., and the Netherlands, which is around six times higher than Taiwan and 1.6 times higher than Japan. Table X. below shows labor costs among those regions. From economic consideration, Taiwan would be the lowest labor cost place. However, despite the labor cost in the U.S. is much higher than in Taiwan, the total growing cost per pound is almost the same as the greenhouse production (Tasgal, 2019). That means the VF product has more possibility to be accepted in the U.S. market. Since the current VF company in the Netherlands is mainly building for research and knowledge sharing, in this research it would not be concerned for further analysis (Kozai, 2020; den Besten, 2019).

Regarding the energy costs, lighting consumption that accounts for approximately 70%-80% of the total energy consumption (Graamans et al., 2018; Molin & Martin, 2018). Comparing to other indoor farming, vertical farming usually needs more time (16h – 18h per day) to use artificial light due to insufficient sunlight supply (Massa et al., 2008; Clarkin, 2016). According to Perez (2014), the electrical energy consumption of LEDs for lettuce production is around 17.5 kWh/ kg in the U.S, which is approximately 2.4 times lower than Japan.

Hence, it is hard to decide on the most economic region since both countries have their economic superiority. Then, in the later section, it is supposed to make a profit comparison between the business production model in the U.S. and Japan.

Table 4. Labor cost comparison (Loman,2018).

Region	Hourly labor costs ($) (US Bureau of Labor Statistics, 2013)	Hourly labor costs ($) (The Conference Board, 2016)
USA	35.70	37.70
Japan	35.34	23.60
Taiwan	9.46	9.51
Netherlands	39.62	36.50

2.6.5 Location Selection - Organic Certification Consideration

The last part is about the discussion of organic certification of the vertical farming product. Nowadays, customers are willing to pay a premium price for the products with organic certification. However, whether the vertical farming product can be certificated as organic is controversial between different regions (NCAT IT, 2019).

Some countries conclude that VF is organic since its production avoids using mineral fertilizers, chemical pesticides, and herbicides, while others are more negative. The organic rule in the U.S., China, and Singapore has organic certified vertical farming production. However, the recent update EU regulation, emphasizes the soil-based principle of organic certification (European Commission, 2019). That principle means that organic production must be cultivated in the living soil or mixed/ fertilized soil condition. Growing in hydroculture or substrates cannot be certificated as organic products (Moore, 2019). Meanwhile, it can neither be certificated as organic in Japan: In Japan, organic production must be grown outdoors in soil conditions (THE JAPAN TIMES, 2018). As a consequence, this denial of an organic certificate may slow down the commercial development of vertical farming in those regions. Currently, though vertical farming has developed for years, it is still a new concept to the local consumers. Most of them even have no idea of this concept. Thus, losing organic certification is losing the market competitive position when compared to conventional production. It is hard to convince people to trust this new business production model and hard to promote the product penetrating the existing market. Hence, the country legislation on organic produce is important for location selection to start the VF business

2.6 Conceptual Framework

The research objective is to find out the most valuable production method of vertical farming. Based on the literature review, the influential factors of value creation have been selected. As mentioned before, there are different structures and variations of vertical farming, which mainly reflect on the building structures, planting spatial arrangement, and technical production methods. In order to compare the value creation of different business models, a uniform setting of vertical farming will be adopted in this report. The most common design of vertical farming is a stacked horizontal structure within a building-based facility and the most common technical production method is hydroponics. This combination will be used as the uniform vertical farming design in this report.

Referring to crop selection and location selection, there are influential factors that should be specified in different business models. Since this report will evaluate the value creation of different business models, it is supposed to compare different combinations of crops, farming scales, and the marketing condition in different regions. Based on the literature review, lettuce and micro greens are the most common and popular crops of vertical farming around the world, no matter what other restrictions. The selected farming design is producing crops in the stacked trays, which structure increases the yield by growing vertically stacked in the same footprint. Thus, using the number of daily harvests of specific crops in a year to define the farming scale is better than the facility size and land area. According to the feasible data collected in the farming scale section, the business models aim at selecting two production levels: the large scale and very large scale, based on the number of daily harvests. Though, around the world, there are many researchers and companies are focusing on the agricultural development of vertical farming and investigating its commercial market, most of them are still in the early stage or used primarily in education and research. To find the commercialized examples, currently, Japan and the U.S. are the most feasible target regions to be used for references as they have more feasible data to be analyzed. Thus, the business model comparison will be conducted to the value creation that varies from different crops, farming scales, and geographic regions.

Due to that distinction, to find out the most valuable scenario of vertical farming, there are four business production models via different combinations of regions, farming scales, and crops as illustrated below. By calculating the cost and profit of each model, the most valuable production method will be found out. Hereby, the four business models are listed below:

Business models:

BM 1: Large scale – Japan – Micro greens

BM 2: Very large scale – Japan – Lettuce

BM 3: Large scale – the U.S. – Micro greens

BM 4: Very large scale – the U.S. – Lettuce

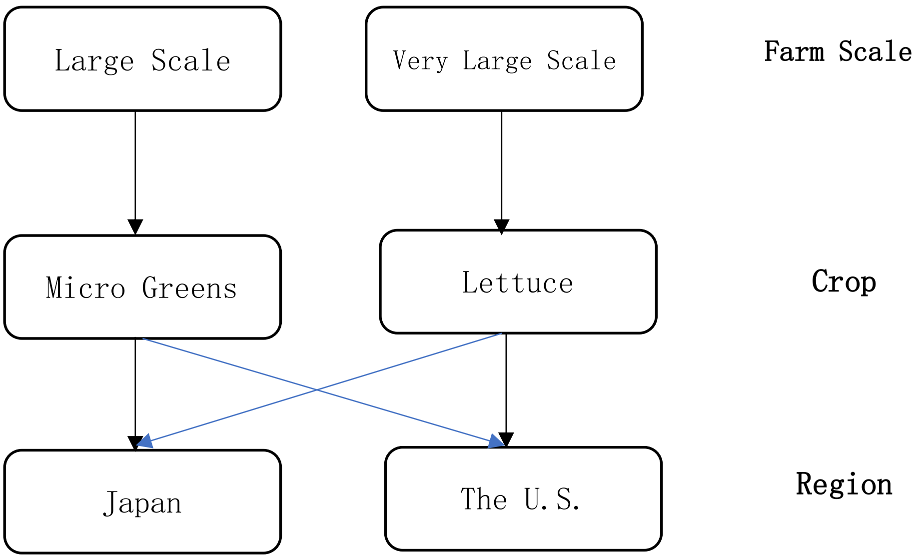


Figure 4. Conceptual framework.

3. Methodology

Previous chapters elaborated on the related information from the literature study and illustrated feasible steps to achieve the research objective. There are four business production models of vertical farming have been selected to do the further selection based on different scales and crops combination. Hence, this chapter will describe the procedure of data collection and analysis. Besides, the validity and reliability are described as well as how the limitations and risks are taken into account.

3.1 Research strategy

In order to find out the most valuable scenario of vertical farming, it needs to calculate the revenue, costs, and profit of each business model. Thus, this study consists of quantitative research. The study calculates the revenue, costs, and profits of four business models. Since all empirical data will be gathered from reports and companies, a desk research strategy suits well. Next to this, the research compares the values of those four business models. This requires using existing data from, secondary research materials for further calculations and analysis.

The research will investigate the market prices of micro greens and lettuces and the costs of equipment, labor, crop energy consumption, etc. The market price will be the local wholesaler price. The market prices and full costs will be illustrated and operationalized in the following section. Next, the calculations of each business production model will be detailed.

From the viewpoint of application, this is an applied research, and objectives follow an exploratory approach. Public research on business models that compares countries, crops, and facility sizes is hardly available. The reference period for this study is retrospective. The researcher, therefore, wants to make clear that the outcome of this research can be considered as a starting point for further research – as an overview of what kind of business production model is the most valuable scenario with consideration of the main cost categories and components. With the business models as an object of research and the exploratory approach, details about the technical parts of vertical farms will not become elaborated upon in this research.

3.2 Calculation Method

This section will introduce the detailed cost information among the whole production period and discuss different cost classification methods as used in prior cases. We will use various accounting cost categories, to arrive at total costs per year. The fixed costs are the equipment cost and building cost. It is assumed that all equipment has been settled down based on the choice of technical production method. The variable costs category comprises labor costs, energy costs, delivery costs, and other operational costs, which are expected to fluctuate based on the production scale, region, and crop.

According to Kozai (2019), costs are mainly divided into two components: initial costs and production costs. Initial cost includes the building cost and facility costs, which include the illumination cost, air management cost, thermal system cost, and water consumption cost. As production cost Kozai (2019) distinguishes between the following cost categories: energy cost, labor cost, depreciation, transportation cost, and other operational costs, which account for 25% to 30%, 25% to 30%, 25% to 35%, 10% to 12% and 8% to 10%, respectively.

A workshop in Germany (Zeidler, Schubert & Vrakking, 2017) has designed a vertical farm, which contains four modules, one packaging module, and three cultivation modules. They assumed each module has the same cost and divided the whole costs into four parts: construction cost, labor cost, core cost, and subsystem costs. The subsystem costs include illumination cost, air management, and thermal cost, nutrient delivery cost, plant health monitoring cost, and horticulture cost.

In addition, agriculture consultant Peter Tasgal has published an article (Tasgal, 2019) about the analysis of cost components about AeroFarms, which is one of the largest vertical farms in America. Tasgal (2019) specified the costs into three components: upfront costs, growing costs, and delivery cost. Upfront costs refer to the building cost, facility cost, and depreciation cost. Growing costs are labor costs and other operational costs.

Based on the above, it is clear that the overall costs would be specified in several cost components. Synthesizing the above classification, in order to make a specific calculation, the cost components in this research are specified as follows: the building cost, equipment costs, energy cost, labor cost, depreciation cost, delivery cost, and other operational costs. The key accounting categories can be gathered under the following variables: turnover; fixed costs, operational costs, and delivery costs. The building cost, equipment cost, and depreciation cost will be categorized as fixed costs. The depreciation method will be the straight depreciation method, which is commonly used by prior literature cases (Tasgal, 2019; Perez, 2014). Regarding the variable turnover in the calculation, it will adopt the wholesale price of each crop in the local market. To avoid seasonal variation, there will use the annual production and consumption to do the calculation.

3.3 Research Materials and Operationalization

The research materials would be quantitative information gathered from people, the media, documents, and literature. The researcher will ask the people who is professional in this research area to inquire about related data. Further data will be collected from related documents, literature, and company reports.

In Table 5. below, key categories from the calculation method are operationalised into several specific cost calculations and revenues components. It is clear to see which costs are involved in the calculation. Those components will be used to search the specific numerical data among different regions as the business production models showed before.

Table 5. Key categories and operationalization.

Categories	Explanation	calculation components	Sources	Information Type
Turnover	Annual marketing sales generated from the vertical farming products	Market price of lettuce; Market price of micro greens; Annual production	Literature study; Company report; Related documents; Professional people in this research area	Numerical data
Fixed Costs	Preparation costs before the production period, and estimated annual depreciation costs	Equipment costs; Building costs; Annual depreciation costs		
Operational Costs	Operational costs during the production period	Labor costs; Energy costs； Other operational costs		
Delivery Costs	Transportation costs between the vertical farm and the purchaser	Transportation costs		

Based on the literature review, Table 6. has specified the percentages of cost components and profit of vertical farming production (Ijichi, 2018). Column A shows percentages of revenue components and column B shows percentages of production cost components. It is clear to see that in both columns the labor cost, energy cost, and depreciation cost are the main components, which add up to around 61% to 70% of the totals. Among the main components, labor cost is the highest component of both columns, with 22% and 26% respectively. Depreciation and electricity costs are each around 20% of each column. The logistic component is the same proportion, 6%, of revenue and cost components. Hence, to minimize the production costs and maximize revenues, it is important to decrease costs from depreciation, labor, and electricity components.

Table 6. Specified percentages of costs and profit components (Ijichi, 2018).

Components	A (%)	B (%)
Depreciation	20	23
Labor	22	26
Electricity	19	21
Logistics	6	6
Others (Tax, Seeds, Supplies, etc.)	21	24
Profit margin	12	-
Total	100	100

However, according to Table 7., the study of Zeidler, Schubert, and Vrakking (2017) proposed a different costs scheme where the importance of labor costs is relatively low, as it only accounts for around 12% of the total costs (856/7204=11.89%). This confirms that this issue needs to be explored in a detailed way.

Table 7. Yearly costs for the baseline scenario in vertical farming 2.0 (Zeidler, Schubert & Vrakking, 2017)

Baseline	Total Cost (K€/year)
Investments	1.818
Water Costs	65
Energy Costs	2.781
CO2 costs	48
Plant Costs	961.1
Labor Cost	856
Total	6.549
Margin	10%
Total with margin	7.204

To further specify those costs and be able to calculate the profit margin of each business production model, Table 8. below shows the detailed information of those composed cost components. Both the marketing price of microgreens and lettuce are based on the average local whole price.

Table 8. Specified calculation method for each selected model.

	BM1 Large scale/ Japan/ Micro greens	BM2 Very large scale/ Japan/ Lettuce	BM3 Large scale/ the U.S./ Micro greens	BM4 Very large scale/ the U.S./ Lettuce

Marketing price of micro greens/ kg				
Marketing price of lettuce/ kg				
Facility size (sq m)				
Building cost				
Equipment cost				
Building cost/ sq m				
Equipment cost/sq m				
Assumption: Depreciation years				
Annual depreciation				
Annual production/ kg				
Annual depreciation/ Annual production				
Total full-time workforce				
Assumed all-in cost/ person				
Total annual people costs				
Total annual people costs / Annual Production				
Annual energy cost				
Annual energy cost/ annual production				
Other growing costs/ Annual Production				
Estimated delivery cost/ kg				
All-in estimated costs/ kg				
Profit margin/ kg				

3.4 Validity and Reliability

Validity

Content validity, "evaluates how well the measures tap the different aspects of the concept as we have defined it" (De Vaus & de Vaus, 2001). Content validity is present, since the measurement instrument used (quantitative calculation), covers the full range of both the concepts. In particular, the conceptual framework consists of 4 business model combinations when taking into consideration important aspects (crop, production scale, and region). However, the online data and numerical information sometimes include estimated or advertised data, instead of factual data. This can affect *content validity*.

Construct validity, according to De Vaus & de Vaus (2001), "relies on seeing how well the results we obtain when using the measure fit with theoretical expectations." This type of validity is present in this research since the outcome of the calculation measures what they claim to be measuring. To make sure that the terms used within the data search are clear for the calculation, explanations and examples are added.

Reliability

"*Reliability* means that the indicator consistently comes up with the same measurement" (De Vaus & de Vaus, 2001). In order to retrieve useful data, it has to search the concrete data from multiple sources to pick the common information or adopt an average number. Due to this data collection method, the sample might not completely represent the whole production costs without the inclusion of many miscellaneous expenses. By that, it is meant that if the full costs included or investigate other regions with different crops, the result would be varied from this research. This is reflected in the previous sections where multiple prior studies showed contrasting results in different scenarios.

3.5 Limitations and Risks

While conducting this research, several limitations and risks should be taken into account. This paragraph will give an overview of them and how the researcher tries to keep them as low as possible.

Firstly, this research meets limited databases. Since vertical farming is still a new business model so far, only a few companies have achieved commercial production around the world. Among those companies, only a few of them that willing to share their data with the publications. Finally, much of that data is very technical, not very informative for our study. Thus, access to data can be a risk of this research.

Secondly, data accuracy can be another risk that would influence research reliability. Due to the research method, the research will only use secondary data from online information, articles, and professional researchers. It will not obtain the first data via observation or marketing investigation. Thus, the data accuracy would be influenced and cannot get updated in time.

Thirdly, it was chosen is to use the quantitative research method. For this, methods of quality input could be a risk. To conduct useful and good quality data out of searching, it is important that relative information could be matched with those key concepts. To create a clear numerical data list, the component items have been explained and illustrated before.

4. Results

This section presents the collected data according to the list from Table X. The four subsections present the data and calculations regarding the four business models respectively. Each section ends with a discussion and finally, it is clear to show which one is more valuable for commercial production.

All costs are used in form of an annuity. In order to control the consistency of the calculation unit, in this calculation, the kilogram is used as the calculation unit for annual production. Regarding the calculation of the labor force, only the number of full-time employees is considered as the part-time workforce is too fluctuant to calculate. The depreciation used in this calculation is straight depreciation with a period of 15 years.

All data in the four business models are derived from four different commercialized vertical farming companies, in Japan and the U.S., based on the scale and cultivated crop requirements. Mira plant factory and Kameoka plant factory are two famous Japanese vertical farming companies. Both of them have achieved commercial production several years ago. According to the scale definition of vertical farming, the Mira plant factory will represent the large-scale Japanese plant factory (BM1) and Kameoka as the very large one (BM2). Referring to the large-scale American vertical farm, there are two companies, Plenty vertical farming and Green Spirit Farm (BM3), that have been selected to do the comparison. Though both of them belong to the large scale, they are still differing to two size facilities with large differences in the collected data. AeroFarms is a huge commercialized vertical farming company in the U.S. for years. Based on its daily production, AeroFarms has been adopted as the very large scale vertical farm to calculate the revenue, costs, and profit in the fourth business model.

Note: The exchange rate in the following sections is 1 yen equal to 0.0094 dollars.

4.1 BM 1: Large scale – Japan – Micro greens

Since there is no feasible public data of Japanese microgreens plant factories, for large scale vertical farms in Japan, data is collected from Perez (2014) on the Mira plant factory, which is built by the vertical farming company Mirai. This vertical farm is a lettuce production farm. In order to investigate and compare microgreens and lettuce production, there will be a transfer rate between lettuce and microgreens production based on their seeding intensity.

The seeding intensity of microgreens varies from 2.15 to 3.09 seeds/ cm^2 (Jones-Baumgardt et al., 2019). For lettuce production, the plant intensity is 20 mm between the rows and also between the plants (Ishii et al., 2000). Thus, it is 4 cm^2/ seed. According to the seeding density, the planting transfer rate between lettuce and microgreens is 1 lettuce equal to around 10 microgreens.

The following calculation assumes to use the same building and facilities to plant lettuce and microgreens. On these costs components, there is no clear information on the cost differences related to the two crops. So, the costs are assumed the same for these two crops. By using the transfer rate, it is clear to see how much microgreens can be produced by the same facility and how much profit can be gained in the end.

Marketing price of micro greens/ kg:
The wholesale price of microgreens is around 30 to 50 dollars per pound, which is around 65 to 110 dollars per kilogram (Treadwell et al., 2016). So, the average wholesale price is around 88 dollars per kilogram.

Building costs:
The building cost for new construction is around 180 M yen, 1,690,803 dollars (Perez, 2014).

Building cost/ sq m
According to Kozai, Ohyama, & Chun (2006), a well-equipped glasshouse cost 400 dollars per square meter. A 10-fold production capacity closed plant factory is roughly equal to or lower than 32,0000 dollars per square meter building cost.

Equipment costs:
The equipment costs include the NFT system, irrigation system, lighting system, and others, which account for 300 M yen, 2,818,005 dollars (Perez, 2014).

Facility size:
The building size is 1300 square meters including office space, a packing area, a storage room, and a cold storage and production area (1100 m^2) (Perez, 2014).

Assumption: Depreciation years:
The depreciation period divides three categories: 7 years for production systems, 15 years for the other equipment, and 20 years for the building (Perez, 2014).

Annual depreciation
The annual depreciation of the whole facility cost 59.2 M yen, 558,572.72 dollars (Perez, 2014).

Annual production/ kg

Lettuce: The daily production is around 10,000 heads of lettuce per day (Kozai, Fujiwara, & Runkle, 2016) One head of lettuce weight 80 grams. Thus, one-day production weight 10,000*80*0.001=800 kg

- Annual production: 800 * 365= 292,000 kg

Microgreens: The daily production would be 10,000 * 10 = 100,000 plants. According to Jones-Baumgardt et al., (2019), the plant size is 8 grams of kale, 10 grams of cabbage, and 4 grams of arugula. Hereby, we adopt an average size of 7.5 grams of microgreens.

- Annual production: 100,000 * 0.0075 * 365 = 273,275 kg

Annual production/ Cultivation area

The cultivation area of the Mira plant factory is around 4536 sq m (Perez, 2014).

- Lettuce: 292,000/ 4536 = 64.37 kg/ sq m

- Microgreens: 273,275/ 4536 = 60.35kg/ sq m

Annual depreciation/ Annual production

- Lettuce: 558,572.72/ 292,000 = $1.91/ kg

- Microgreens: 558,572.72/ 273,275 = $2.04/ kg

Total full-time workforce:

There are two full-time workers in this plant factory (Perez, 2014).

Assumed all-in cost/ person:

According to Salary Explorer (2020), the average annual salary for a person working in gardening/ farming/ fishing make in Japan is around 3,720,000 yen.

Total annual people costs:

The annual cost of the workforce is 7,440,000 yen, 69,936 dollars.

Total annual people costs / Annual Production

- Lettuce: 69,936/ 292,000 = $0.24/ kg

- Microgreens: 69,936/ 273,275 = $0.26/ kg

Annual energy costs:

The annual energy costs are 72.6M yen ($681,957.21) including the power use and water use (Perez, 2014).

Annual energy costs/ annual production

- Lettuce: 681,957.21/ 292,000 = $2.34/ kg

- Microgreens: 681,957.21/ 273,275 = $2.50/ kg

Other growing costs/ Annual Production:

The packing materials, seeds, light bulbs, fertilizers, chemicals, and other operational costs are combined into this category. The annual other growing costs are 64.6M yen (Perez, 2014) ($606810.41).

- Lettuce: 606,810.41/ 292,000 = $2.08/ kg

- Microgreens: 606,810.41/ 273,275 = $2.22/ kg

Estimated delivery cost/ kg

The annual delivery cost is 6.0M yen, 56360.10 dollars (Perez, 2014).

- Lettuce: 56,360.10/ 292,000 = $0.19/ kg

- Microgreens: 56,360.10/ 273,275 = $0.21/ kg

All-in estimated costs/ kg

All-in estimated costs = Annual depreciation costs/kg + people costs/kg + energy costs/kg + other costs/kg + delivery costs/ kg

- Lettuce: $1.91/ kg + $0.24/ kg + $2.34/ kg + $2.08/ kg + $0.19/ kg = $6.76/ kg

- Microgreens: $2.04/ kg + $0.26/ kg + $2.50/ kg + $2.22/ kg + $0.21/ kg = $7.23/ kg

Profit margin/ kg

- Lettuce: $10.63/ kg - $6.76/ kg = $3.87/ kg

- Microgreens: $88/ kg – $7.23/ kg = $80.77/ kg

4.2 BM 2: Very large scale – Japan – Lettuce

As mentioned before, a very large scale refers to the farms which have a daily harvest of 10,000 to 30000 plants. Kameoka is one of the biggest vertical farms in Japan that produces 21,000 heads of lettuce per day. Thus, for a very large scale vertical farm Kameoka has been chosen as the example for data collection and calculation.

Marketing price of lettuce/ kg:
We expect that sales price and weight are independent of the VF-unit scale. According to Kozai (2018), the wholesale price of lettuce is $0.85 per head. One head of lettuce generally weighs 80 grams. Thus, the marketing wholesale price of lettuce in Japan:

- (1000/80) * 0.85 = $10.63/ kg

Facility size:
One Japanese vertical farming company, Spread Co. has built a plant factory called Kameoka, which could produce 21,000 heads of lettuce per day with 4780 m^2 land area, which converts to the square foot is 51,432.8 sq (Hayashi, 2020).

Building costs:
The initial investment of land and structures cost 612 million yen and the construction of the facility cost is 1046 million yen (Kozai, Niu, & Takagaki, 2016). Thus, the total costs are 612 + 1046= 1,658 million yen. (15,585,200 dollars)

Building cost/ sq m
- 15,585,200/ 4870 = $3260.50/ m^2

Equipment costs:
The infrastructure costs are 6 million yen (56,400 dollars), including electricity equipment and others (Kozai, Niu, & Takagaki, 2016).

Equipment cost/sq m
- 56,400/ 4870 = $11.80/ m^2

Assumption: Depreciation years:
Regarding the lifespan of facility and equipment, this research adopts a straight-line depreciation method for both of them. An article from Uraisami (2018) states that the value of VF-buildings will depreciate to zero in 50 years, 15 years for the electricity equipment, and 7 years for the other facilities.

Annual depreciation
- 15,585,200/ 50 = $311,704

- 56,400/ 15 = $3760

- Total: $311,704 + $3769 = $315,464

Annual production/ kg

The daily production is 21,000 heads of lettuce (Hayashi, 2020).

- annual production: 21,000*365= 7,665,000 heads of lettuce

One head of lettuce weighs around 80 grams.

- annual production/ kg: 7,665,000*80*0.001=613,200kg

Annual production/ Cultivation area

The cultivation area is 25,200 sq m (Hayashi, 2020).

- 613,200/ 25,200 = 24.33 kg/ sq m

Annual depreciation/ Annual production

- 315,464/ 613,200 = $0.51/ kg

Total full-time workforce:

According to Hayashi (2016), there are 50 people who work for the Kameoka plant factory.

Assumed all-in cost/ person:

According to Salary Explorer (2020), the average annual salary for a person working in gardening/ farming/ fishing make in Japan is around 3,720,000 yen.

Total annual people costs

- 3,720,000 * 50 = 186,000,000 yen

Total annual people costs / Annual Production

- 186,000,000 yen/ 613,200 = 303.33 yen/ kg = $2.85/ kg

Annual energy costs:

Electricity consumption for producing one butterhead lettuce from a seed is around 25 JPY in Japan (Kozai, 2013).

- 25 * 7,665,000 = 191,625,000 yen = $1,808,048.94

Annual energy costs/ annual production

- 1,808,048.94/ 613,200 = $2.95/ kg

Other growing costs/ Annual Production:

There is no exact number of this cost component in the literature. However, according to the cost ratio, other growing costs (packing, supplies, material, seed, manure, etc.) take 14% of the total production cost. The energy cost is 27% of the total cost. Thus, based on this proportion and the above calculation, other growing costs:

- 2.95/ 27% * 14% = $1.53/ kg

Estimated delivery cost/ kg

The delivery cost is around 10% of the total production cost.

- 2.95/ 27% * 10% = $1.09/ kg

All-in estimated costs/ kg

All-in estimated costs = Annual depreciation costs/kg + people costs/kg + energy costs/kg + other costs/kg + delivery costs/ kg

- $0.51/kg + $2.85/ kg + $2.95/ kg + $1.53/ kg + $1.09/ kg = $8.93/ kg

Profit margin/ kg

- $10.63/ kg – $8.93/ kg = $1.70/ kg

4.3 BM 3: Large scale - the U.S. – Micro greens

For large scale vertical farm in the U.S., two vertical farms, Plenty and Green Spirit Farm, have been chosen as the examples for data collection and calculation. Thus, it is also possible to make a comparison and an evaluation between the two farms.

Marketing price of micro greens/ kg:

According to Aaron Marquis (2020), the USA marketing price of microgreens is $25 to 40 per pound. So, the average wholesale price is around 72.75 dollars per kilogram.

Building and equipment costs:

- Plenty vertical farm: According to Loman (2018), the investment of the startup cost is $200 million financed by Softbank.

- Green Spirit Farm: According to Zimmerman (2016), the investment of startups is $4,600,000.

Facility size:

- Plenty vertical farm: The facility size is 100,000 square feet (9290.3 sq m) indoor farm (Garfield, 2017).

- Green Spirit Farm: The facility size of Green Spirit Farm is 42,000 sq ft, 3901.93 sq m (Zimmerman, 2016).

Building and equipment cost/ sq m

- Plenty vertical farm: $200,000,000/ 9290.3 = $21527.83/ sq m

- Green Spirit Farm: $4,600,000/ 3901.93 = $1178.90/ sq m

Assumption: Depreciation years:

According to Tasgal (2019), both commercial greenhouse and vertical farms in the U.S. are assumed to adopt a 15- year straight-line depreciation with non-residual value.

Annual depreciation cost of equipment and building

- Plenty vertical farm: 200,000,000/ 15 = $13,333,333.33

- Green Spirit Farm: $4,600,000/ 15 = $306,666.67

Annual production/ kg

- Plenty vertical farm: The annual production is around 4.5 million pounds of baby greens annually (Garfield, 2017). (2,041,166 kg)

- Green Spirit Farm: The production per month is around 5,000 pounds. Thus, the annual production is 5,000*12 = 60,000 pounds (Zimmerman, 2016). (27,215.54 kg)

Annual depreciation/ Annual production

- Plenty vertical farm: 13,333,333.33/ 2,041,166 = $6.53/ kg

- Green Spirit Farm: $306,666.67/ 27,215.54 = $11.27/ kg

Total full-time workforce:

- Plenty vertical farm: According to Haggerty (2019), Plenty vertical farm could create 50 local jobs.

- Green Spirit Farm: The labor force of Green Spirit Farm 11 employees (Zimmerman, 2016).

Assumed all-in cost/ person:

Assumed all-in cost per person is $40,000 per year (Tasgal, 2019)

Total annual people costs

- Plenty vertical farm: 50 * 40,000 = $2,000,000

- Green Spirit Farm: 11 * 40,000 = $440,000

Total annual people costs / Annual Production

- Plenty vertical farm: 2,000,000/ 2,041,166 = $0.98/ kg

- Green Spirit Farm: 440,000/ 27,215.54 = $16.17/ kg

Annual energy costs:

The energy costs for a 30,000 sq ft vertical farm is around $216,000 annually (Holt, 2018). Thus, for a 100,000 sq ft Plenty vertical farm, it would be around three times of $216,000.

- Plenty vertical farm: 216,000/ 30,000 * 100,000 = $720,000

- Green Spirit Farm: 216,000/ 30,000 * 42,000 = $302,400

Annual energy costs/ annual production

- Plenty vertical farm: 720,000/ 2,041,166 = $0.35/ kg

- Green Spirit Farm: 302,400/ 27,215.54 = $11.11/ kg

Other growing costs/ Annual Production:

Assumption: The other growing costs are the same as the very large-scale vertical farm with lettuce production.

- The all-in growing costs per pound are $0.42, which converts to kilogram is $0.92/ kg (Tasgal, 2019).

Estimated delivery cost/ kg

Assumption: The delivery costs are the same as the very large-scale vertical farm with lettuce production.

- Transportation cost per pound is $0.20, which converts to kilogram is $0.44/ kg (Tasgal, 2019).

All-in estimated costs/ kg

All-in estimated costs = Annual depreciation costs/kg + people costs/kg + energy costs/kg + other costs/kg + delivery costs/ kg

- Plenty vertical farm = $6.53/ kg + $0.98/ kg + $0.35/ kg + $0.92/ kg + $0.44/ kg = $9.22/ kg

- Green Spirit Farm = $11.27/ kg + $16.17/ kg +$11.11/ kg + $0.92/ kg +$ 0.44/ kg = $39.91/ kg

Profit margin/ kg

- Plenty vertical farm: $72.75/ kg – $9.22/ kg = $63.53/ kg

- Green Spirit Farm: $72.75 / kg – $39.91/ kg = $32.84/ kg

4.4 BM 4: Very Large scale – the U.S. – Lettuce

For very large scale vertical farm in the U.S., AeroFarms as one of the biggest vertical farming has been chosen as the example for data collection and calculation.

Marketing price of lettuce/ kg:

According to Baras (2018), the wholesale price of large hydroponic lettuce growers is around $0.90 per head. One head of lettuce generally weighs 80 grams. Thus, the marketing wholesale price of lettuce in the U.S.:

- (1000/80) * 0.90 = $11.25/ kg

Building costs and Equipment costs

According to the report from Tasgal (2019), the building costs and equipment costs are combined into the upfront costs: 39 million dollars.

Facility size:

AeroFarms is one of the biggest vertical farms in the U.S. and according to a report from Tasgal (2019), its facility size is 69,000 (sq ft) or 6410 (sq m).

Building cost/ sq m & Equipment cost/sq m:

- 39,000,000/ 6410= $ 6,084.24/ sq m

Assumption: Depreciation years:

The depreciation year is 15 (Tasgal, 2019).

The depreciation method adopts a straight-line depreciation, with no residue value in the end.

Annual depreciation:

The annual depreciation cost is $2,600,000 (Tasgal, 2019).

Annual production/ kg

According to the report of Tasgal (2019), the annual production of AeroFarms is 2,000,000 pounds, which converts to 907,185kg per year.

Annual depreciation/ Annual production:
2,600,000/ 907,875= $ 2.87/ kg

Total full-time workforce:
The total full-time labors are 58 of AeroFarms (Tasgal, 2019).

Assumed all-in cost/ person:
Assumed all-in cost per person is $40,000 per year (Tasgal, 2019).

Total annual people costs:
- 58* 40,000= $2,320,000

Total annual people costs / Annual Production:
- 2,320,000/ 907,185= $2.56/ kg

Annual energy costs and other growing costs:
These two costs are combined into the all-in growing costs in Tasgal's report. He claimed although the energy consumption would cost a lot of vertical farms, the location costs or facility costs would balance the power costs.

Annual energy costs & Other growing costs/ Annual Production:
The all-in growing costs per pound are $0.42, which converts to kilogram is $0.92/ kg.

Estimated delivery cost/ kg
Transportation cost per pound is $0.20, which converts to kilogram is $0.44/ kg.

All-in estimated costs/ kg
All-in estimated costs = Annual depreciation costs/kg + people costs/kg + energy costs/kg + other costs/kg + delivery costs/ kg

- $2.87/ kg + $2.56/ kg + $0.92/ kg + $0.44/ kg = $6.79/ kg.

Profit margin/ kg
- $11.25/ kg – $6.79/ kg = $4.46/ kg

5. Conclusion and Discussion

This section outlines the overall conclusion of this research. According to the calculations from chapter 4, we could answer the main research question: ‘What is the most valuable vertical farming production model by comparing different business models?’. The chapter is split into four sections. The first three sections will discuss and explain the results based on the three sub research questions. Then, section 5.4 will do an extra discussion of the comparison between two vertical farming companies in the same production scale. To end, a comprehensive conclusion will be drawn out.

5.1 What is the most valuable production scale of vertical farming?

When the crop and location are the same, large scale production is more valuable than very a large scale of vertical farming. As model 3 and 4 are two scenarios with different crop types and farm scales, they cannot be used to analyze the difference. Hence, the following discussion would choose business model 1 and 2 as the study group to do the comparison.

By comparing the profit margin from each group, it presents that BM1 is more profitable than BM2. Since we used the same wholesaler price of lettuce, the cost difference between those two production models is important. According to the calculations in the preceding chapter, the main cost differences are three cost components: annual depreciation/ annual production, annual labor cost/ annual production, and annual logistic cost/ annual production. We will reflect on each of these three components.

Annual depreciation/ annual production: Though the annual depreciation cost of business model 1 is around two times of business model 2, after using production per kilogram as the unit of analysis, the number for model 1 becomes around four times higher, as the depreciation years are almost the same for the two production models. The increased number is due to the mass production of business model 2, as its annual production volume is two times of business model 1. So, in this condition, mass production benefits business model 2.

‘Annual labor cost/ annual production’ and ‘Annual logistic cost/ annual production’: These two cost components are reversed conditions as mass production results in higher costs. Due to the very large production scale of business model 2, the farm needs more labor forces to manage the production and distribute the products. It will result in high labor costs and transportation costs. The increased range of these two cost components is very high as these two for business model 2 is 12 times and 6 times the scores for business model 1.

5.2 What is the most valuable crop of vertical farming?

When the production scale and location are the same, microgreens are more valuable than lettuce. The following paragraph uses the business model 1 as an example to present the discussion of using the same plant factory to plant those two different crops.

The production volume is quite similar to microgreens and lettuce. Hence, the overall costs are also very close to each other as using the same plant factory of assumption. In this case, only the wholesaler price determined the difference between the two crops' profit margin. The wholesale price of microgreens per kilogram in Japan is quite higher than lettuce (8 times) when the all-in costs are close. One may thus conclude that microgreens production is significantly more valuable than lettuce production.

5.3 What is the most valuable location of vertical farming?

When the crop and production scale are the same, there are two different conclusions based on two crops. For lettuce, based on the profit margin, the U.S. market is more valuable than the Japanese. In contrast, microgreens are more valuable in the Japanese market rather than in the U.S. The following discussion will present the reasons for each situation.

Lettuce

Both business model 2 and 4 are the very large-scale vertical farms of lettuce production. The wholesale price in Japan (10.63 dollars/ kg) is similar to the U.S. (11.25 dollars/ kg). However, comparing the profit margin, the U.S. is around 2.5 times more in Japan (4.46/1.70=2.62). The main differences in the costs of these two locations are the depreciation cost/ production and energy cost. In Japan, the depreciation year of the building and facilities is usually longer than the U.S. Thus, when the production scale and production volume are similar between the two models, Japanese depreciation cost/ production is quite lower than the U.S.

Concerning the energy costs, Tasgal (2019) states that the energy costs will be balanced by the facility and building location. So, there is no specific number of energy cost in his report. This resulted in around three dollars difference between the two models as the energy cost/ production in Japan is 2.95 dollars per kilogram. Due to the profit difference between the two models' is 4.47 – 1.69 = 2.78 dollars per kilogram, the energy cost could be an interesting point for further investigation.

Another interesting point is that production volume and labor costs in Japan are lower than in the U.S., while the annual transportation cost/ production is higher in Japan than in the U.S.A This be caused by the differences in transportation tax, transportation distance, energy type, etc.

Microgreens

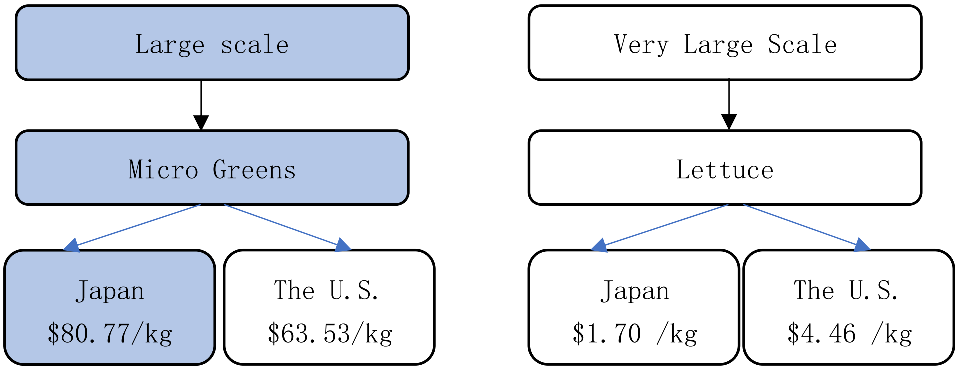
The main reason that makes the microgreens more valuable in Japan than the U.S. is the wholesale price. Both business model 1 and 3 are the large-scale vertical farm of microgreens production. According to the calculations, both countries have different pros and cons. The most important cost term of the U.S. is the depreciation cost/ production, which accounts for 70% of the all-in cost. It is around 3 times of Japan. Another con of the U.S. is the labor cost, which is around 4 times of Japan. Despite these two cost components are much higher than Japan, the energy cost and other growing costs are much lower. Hence, at the end of the all-in costs of the two regions, there is only two euros difference.

5.4 Extra Discussion: Plenty & Greens Spirit Farms Comparison

Plenty and Greens Spirit Farms both are large production vertical farms in the U.S. Normally, even at the same production scale, there are still different scores between companies based on their daily production. No matter the investment, facility size, annual production, or labor force, Greens Spirit Farms is a relatively small vertical farming company than Plenty. In the meanwhile, each cost term of Greens Spirit Farms is higher than Plenty. Thus, based on this simple comparison, for the same production scale, it is better to build a relatively larger farm for cost-saving.

5.5. Comprehensive Conclusion

In summary, based on the above discussion and explanation, the most valuable production scale is the large scale; the most valuable crop is microgreens; the most valuable location: lettuce (the U.S.), microgreens (Japan). Hence, based on this result, the most valuable combined business model of vertical farming is: ‘Large scale – Microgreens – Japan’, business model 1.



6. Recommendations and Reflection

This section will start with the recommendations for further research from four aspects: technical improvement, sales network, consistent marketing turnover, and potential crop selection. The fifth section will state the learnings from the Business Administration Sheets on Plant Factory, which is a real business case that conducted by Kaz Uraisami, one of the Directors of NPO Japan Plant Factory.

1. Automation

Technology is advancing at a rapid pace. With the help of big data and artificial intelligence, firms are able to run the vertical farming system in a fully automatic way. Although it requires more initial fixed costs of building and equipment, the substantial labor costs and maintenance costs in the long-term are much lower compared to the traditional production method. The ultimate goal is, therefore, to figure out the balance between automation/ partial automation and labor costs, which differs for each firm.

2. Multiple diverse sales channels

As of now, the major players in the vertical farming industry have their sales channels with large store chains, restaurants, and wholesales. However, due to the nature of vertical farming, the price will not be attractive in a foreseeable future. Therefore, large scale firms should narrow down their target groups and focus on high wealth and environment-friendly customers. These customers are willing to pay the premium that vertical farming asks and the benefits the vertical farming produces for the environment. It can be sold in a fixed quantity and delivered straight to the door.

3. Long-term fixed transactions

Regarding sales, first of all, after confirming the production volume by stably achieving a high yield, it is important to have the ability to “sell out” the crops that have been produced. But for that purpose, it is important to have multiple diverse sales channels. At retail stores such as supermarkets, it is difficult to make a contract to fix the transaction volume. Long-term transactions that fix the transaction volume are common in transactions for meals and restaurants, but prices tend to be low. For stable management, long-term fixed transactions are attractive, and the transaction prices for meals and restaurants are sufficiently profitable. It can be dealt with by devising the manufacturing cost to match.

4. More valuable crop types

In Singapore, most of the strawberry consumptions are imported from other countries, as the climate is not suitable for this kind of fruit. However, with vertical farming, strawberry production can be done in Singapore. The price is not particularly lower than the imported ones, but the quality and freshness are way better. Followed by the example, the crop production types should be adapted to local conditions and habits. Some vegetables and fruits have a significantly higher value in certain locations due to climate and eating habits, firms should take them into considerations to maximize their profits.

5. Learnings from Business Administration Sheet (BAS) on Plant Factory

Having executed the business model calculations, the research was able to relate the results with a not to be disclosed Business Administration sheet (Uraisami, 2020) This sheet presents a five-year operation plan of a Japanese plant factory with numerous detailed operational data. This sheet was very helpful to get overall operational elements and involved components throughout the whole production process. Reflecting on the sheets, there are five points that are very important for further research and business study of vertical farming.

First of all, the business plan is divided into five parts: production& sales, cultivation systems, lighting, labor, and consumable. Those five parts construct the whole production and sales processes. The research could also use this cost framework and format for more specific data collection and analysis.

Secondly, lighting is the most important cost component among energy consumption, all other energy consumptions are classified into the consumables. The photoperiod, light type, and lighting capacity could be evaluated and improved to the lighting efficiency during the cultivation period. Meanwhile, according to the data from costs versus sales, lighting cost takes around 50% of the total sales. Thus, in order to reduce total cost, lighting is the most important part that should be considered in future research and business production.

The third point concerns the labor cost. According to the sheet, labor cost has been split into several components based on different cultivation periods. The initial cultivation period, 'gemination + 1st stage seedling', is the most relaxed period which uses only 1 second/ stock as labor time. Then, from the second stage seedling to the end of transplanting, every stage uses 3 seconds/ stock, which makes 9 seconds/ stock in total. Cropping and shipping are the highest labor cost components, which require the most labor time of 26 seconds/ stock (each 13 seconds/ stock). Thus, it also calls back to our first recommendation: using automation instead of the labor force.

Fourthly, there is a huge difference between target operation and standard operation in the term ‘Fresh weight per pack’. From the excel, we can see that the fresh weight decreased from 200g to 90g. The loss will influence product quality and marketing price. Hence, further research could devote to study how to improve the fresh weight loss condition as lower as possible.

The fifth one is about investment. The sheet adopted a straight-line depreciation with no residual value in the end. The depreciation period is the same as business model 2 in this report. According to the sheet, the initial investment is 3,183,400 dollars and the payback period is eight years. It is quite a long time for a company to get paid back. That is also one of the reasons that many firms are taking a wait-and-see attitude to the business of vertical farming.

To end, future research and marketing study could consider the above perspectives for further devoted research points. As argued in this chapter, the main improvements will be efficiency, new technologies, quality control, and automation.

6. Reflection

This is a self-reflection section of the thesis writing. The topic started in November 2019 and used almost one year to finish it. I have never imaged that I would need to use one year to finish it. Looking back to the entire period, I have encountered several difficulties and challenges throughout the writing period.

It was not easy to start from the beginning, but I still managed to formulate a research question and conduct the literature review. The first challenge arose from defining the scale definition, which I need to specify it in order to collect corresponding data. Initially, I have used “small” and “large” to describe the farm scale. However, the study is lack of formal explanations of defining these two scales. Unfortunately, no prior studies have indicated such definitions, where they usually describe the size of farms by using the words “small”, “large”, and “one of the largest” etc. When I was desperate in finding and formulating the scale definition, Prof. Wubben gave me a suggestion that we should just leave “small” and continue with “large” and “very large”. The problem is then solved, and I learned that sometimes I need to be more flexible and think out loud to find a way out of difficulty.

Moreover, the extended time used in completing the thesis was mostly due to insufficient communication. Sometimes I wanted to first write out my idea, then send it to my supervisor to receive feedback. I was often afraid to deliver incomplete work, which makes me write before asking for suggestions from my supervisor. This makes the writing procedure longer as I always tried to figure out the problems by myself, whereas discussing with supervisors would be more efficient. Though I think independence is a good asset, I should learn to ask and discuss it with others when it is necessary.

Last but not least, I was not able to answer all questions and comments from my supervisor. There were some problems from the technical aspect and data collection that bothered me a lot from the beginning, though I cannot find proper solutions or explanations for them. For example, in the real world, farms usually employ both permanent and temporary labor force. However, in most of the literature, no one has specified the composition of the labor force. When stating “50 working people” in the paper, I assume it to be 50 permanent labor force, but it may differ a lot from the reality, which makes my data look vague. Another example is the composition of different types of costs. As different literature adopted various terminologies and calculation methods, I tried to standardize each type of cost, but I cannot find the specifications of each item. These kinds of questions are difficult to estimate and to guestimate. To solve them, a deeper understanding of the industry and comprehensive qualitative research are required.

Fortunately, at the same time, I have also gained more knowledge of vertical farming and improved the abilities of problem-solving, data collection, communication skills, and critical thinking. Though I know it may not be perfect, as there are still many questions remained, I have challenged myself and finalized the thesis in the end.

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Appendix

Table 9. Specified calculation result for 4 business models. ($)

	BM1		BM2	BM3		BM4
	Large scale/ Japan/ Micro greens	Large scale/ Japan/ Lettuce (Mira)	Very large scale/ Japan/ lettuce (Kameoka)	Large scale/ the U.S./ Microgreens (Plenty)	Large scale/ the U.S./ Microgreens (Green Sprit Farm)	Very large scale/ the U.S./ lettuce (AeroFarms)
Wholesale price of micro greens/pound	30 - 50			25 - 40		
Wholesale price of lettuce/head (80g per head)		0.85	0.85			0.90
Wholesaler price of micro greens/ kg	88			72.75		
Wholesaler price of Lettuce/ kg		10.63	10.63			11.25
Facility size (sq m)	1,300		4,780	9290.3	3901.93	6410
Building cost	1,690,803		15,585,200			
Equipment cost	2,818,005		56,400			
total building-related investments	4,508,808		15,641,600	200,000,000	4,000,000	39,000,000
Building cost/ sq m	1300.62		3260.50			
Equipment cost/ sq m	2167.70		11.80			
total investment /sq m	3468.31		3272.30	21527.83	1025.13	6084.24
Assumption: Depreciation years	production system(7), equipment(15), building(20)		building(50), electricity equipment(15), others(7)	15	15	15
Annual depreciation	558572.72		315464	13333333.33	266666.67	2,600,000
Annual production/ kg	273,275	292,000	613,200	2,041,166	27,215.54	907,185
depreciation costs / kg of production	2.04	1.91	0.51	6.53	9.80	2.87
Total full-time workforce	2		50	50	11	58
All-in cost/ person	34,968		34,968	40,000		
Total annual labor costs	69936		1748400	2000000	440000	2320000
Total annual labor costs/ kg of production	0.26	0.24	2.85	0.98	16.17	2.56
Annual energy cost	681,957.21		1,808,048.94	720,000	302,400	??
Annual energy cost/ kg production	2.50	2.34	2.95	0.35	11.11	??
Annual other growing costs (such as mate	606,810.41					
annual other growing costs/kg productior	2.22	2.08	1.53	0.92	0.92	0.92
annual estimated logistics cost	56360.10					
annual lostistics cost/ Annual production	0.21	0.19	1.09	0.44	0.44	0.44
All-in costs/ kg	7.22	6.76	8.93	9.22	38.44	6.78
Profit margin/ kg	80.78	3.87	1.69	63.53	34.31	4.47
profits per location per year	22074563.56	1128863.56	1036753.06	129665507.4	933850.7339	4052059.65