Can vertical farms outgrow their cost?

An analysis of the competitive strength of vertical farms in Sweden

Master's thesis in Management and Economics of Innovation

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

Globalisation and urbanisation are creating sustainability challenges in the global food system that require new methods for food production. Over 80 % of fruits and greens consumed in Sweden are imported, accompanied with climate damaging side effects like excess packaging, transportation, storing and cooling. With the introduction of vertical farming (VF), urban agriculture is undergoing a transition towards drastically higher crop yields and increased quality control in order to deliver more sustainable, resilient and safe food production. VF could become a viable alternative to imported greens in Sweden, benefitting both local producers and consumers.

The thesis aims to explore the financial, logistical and environmental prerequisites for successfully implementing VF in Sweden, contributing to a more sustainable agricultural industry. A literature review of business models, industry analysis, sustainability and customer acceptance are used to create a theoretical framework. Data about vertical farming actors is gathered through interviews using a qualitative research method, and two field studies were conducted in Tokyo, Japan. The interview data was analysed with the help of the theories and tools presented in the theoretical framework. Several environmental and social benefits, concerning both the producer and other stakeholders, were identified and point towards more sustainable agricultural practises. Overcoming the economic challenges requires technological improvements to create entry barriers and mitigate bargaining power, development in automatization, and reaching economies of scale. The competitive edge over conventional farming methods comes from the ability to produce crops of consistent quality and quantity year-round in close connection to the consumers.

The study indicates that Sweden is a promising country with the right prerequisites to adopt vertical farming. The effect of implementing vertical farming will be a step forward in reducing the environmental impact of agricultural practises while enabling a consistent production of high-quality crops in urban environments.

Keywords: Vertical farming, urban agriculture, hydroponics, indoor farming, sustainable food production, artificial light, business models

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We would like to express special thanks to the ÅForsk Foundation and Chalmers MasterCard Scholarship for believing in our study and giving us financial aid to conduct company visits in Japan. It helped us gain a wider understanding of vertical farming and the reasons it is being pursued abroad. For this opportunity we are truly grateful. At the same time, we want to thank Japan Plant Factory Association and ESPEC MIC Corporation for sharing their knowledge of hydroponic systems and vertical farming in Japan.

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Adam Dahlberg & Adam Lindén, May 2019

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1 Introduction

This thesis aims to explore the financial, logistical and environmental prerequisites for successfully implementing vertical farming (VF) in Sweden. VF is the practice of growing crops indoors vertically, using artificial lighting, to increase yield per area while controlling all external environmental factors (Ungvarsky, 2016). Vertical farms use hydroponic systems, where soil is replaced by a stabilising growing medium and a nutrient-enriched water solution is circulated through the roots to provide the plants with the necessary nutrients and minerals. Different business models will be evaluated to investigate whether VF can compete with traditional farming in terms of sustainability, quality, and profitability.

1.1 Background

With a rising global population, rapid urbanisation and increased globalisation heavily impacting both the climate and the way we are able to produce food, the need to find an alternative source to traditional farming is growing. A global market has moved local farmers from competing with their neighbours to competing with every other farmer in the world. International competition, an increased demand for organic produce and poor growing conditions has made Sweden increasingly reliant on imported fruits and greens. Over 80 % of fruits and greens consumed in Sweden are being imported. Imported foods are accompanied with many negative side effects like excess packaging, transportation, storing and cooling. Globalisation and urbanisation have created an opportunity and a necessity for cities and urban food actors to improve the food systems. With the introduction of vertical farming techniques, urban agriculture is undergoing a transition towards drastically higher crop yields and increased quality control which can help deliver more sustainable, resilient and safe food production (Lu & Grundy, 2017).

The concept of vertical farming is a novel technique that was developed by Columbia University professor Dickson Despommier in 1999 (Columbia University, 2018). Despommier developed the technique to protect crops from weather related issues like droughts and storms. He quickly realized that there were more benefits to growing indoors: higher productivity, more control and lower environment impact to name a few. Depending on farm height and crop types, some vertical farms have experienced over 100 times the yield of what a traditional farm could produce in the same area. It uses up to 99 % less water and allows for locally grown food in urban environments, decreasing the need for transportation (Kalantari, Mohd Tahir, Akbari Joni, & Fatemi, 2017). If it turns out to be economically justifiable, there are very few downsides to VF since it allows for year-round production, no weather-related crop failure, no use of pesticides or other chemicals, and sustainable food production.

1.2 Problem description

The current value chain of imported greens is characterized by several different steps, resulting in a loss of flavour and nutrients, food-wastage and excessive transportation. FAO (2011) estimates that one third of all food produced globally goes to waste, with most of the losses occurring during distribution, handling, storing and cooling. The differences in the value chain between greens produced in typical agriculture and greens produced in a vertical farm are illustrated in figure 1.

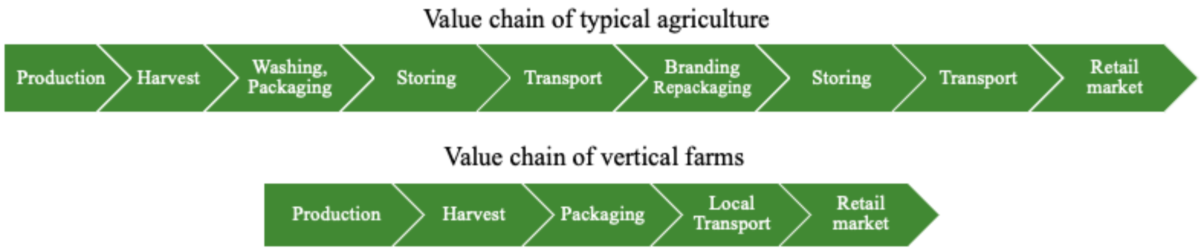

Figure 1. An illustration of the value chain of producing, processing and distributing greens with conventional methods compared to vertical farming.

The typical agriculture value chain contains unnecessary and non-value adding steps like storing, repackaging and transportation from distant locations. A longer value chain means the crops are harvested prematurely and need additional pesticides to stay fresh. Transportation is often associated with large amounts of emissions damaging the environment on top of damaging the produce itself. Moreover, all non-value adding steps are costly and serve no additional benefit to the produce, why removing or reducing the time spent in these steps is highly desirable for any producer.

The shorter value chain enabled by vertical farming eliminates the need of transportation between different processes and distribution is ensured locally. Local distribution makes it easier to deliver crops by more environmentally friendly means of transportation due to the short travel distance, reducing the environmental footprint of food production. The unnecessary and non-value adding processes in the current value chain suggest there is much to be gained for the consumer, producer and environment by eliminating certain steps.

Vertical farming is a relatively new concept in Sweden, and no company has yet reached profitability on a commercial scale. This thesis aims to contribute with a deeper understanding of the advantages and challenges of vertical farming, as well as identifying the prerequisites needed for successful implementation of vertical farming in Sweden.

1.3 Aim and research question

This thesis aims to explore the financial, logistical, and environmental prerequisites for successfully implementing vertical farming in Sweden, contributing to a more sustainable agricultural industry. The aim of the thesis is meant to be achieved by answering the following research questions:

- **How can different stakeholders benefit from vertical farming in Sweden?** To create a sustainable food production system, it is important that every part of the value chain can benefit from cooperation. Commitment from consumers, producers, and suppliers will be necessary for vertical farming to become widely adopted.

- **Which business models exist and how can they be applied to the Swedish market?** Several potential business models need to be evaluated to find one that suits both market and investor needs.

- **Can the business models be both environmentally and financially sustainable while keeping a competitive edge?** To sustain a vertical farming company does not only include supplying consumers with sustainably grown crops at a competitive price point. There needs to be some unique selling point (USP) that wins the consumers over to the new technology. Lower price, higher quality, fresher produce, and lower environmental impact could all be such factors.

1.4 Delimitations

The thesis is limited to hydroponic vertical farming systems despite other alternatives, such as aeroponics[1] and aquaponics[2], are being pursued. The reason being that the biggest actors in Sweden have implemented hydroponic systems which means that there is more available data compared to aeroponics and aquaponics.

The focus will be on business models that involve commercial distribution since it is assumed that these types of vertical farms will have the greatest sustainability impact. Therefore, hydroponic systems for domestic use or office space are not taken into account in the data collection process. Instead, these types of systems are put in relation to vertical farms in the discussion.

Data regarding customer acceptance will be based on the perception of the interviewed vertical farms and secondary research. Interviews with customers would most likely only result in their hypothetical attitude towards vertically farmed produce whereas current actors already have obtained direct feedback from consumers.

1.5 Structure of the thesis

The remainder of this paper is organized as follows: Chapter 2 provides the theoretical framework and explains the different concepts, theories and tools that have been used in

[1] In aeroponic systems the crops' roots extend in air and are periodically misted with nutrient enriched water in an enclosed space

[2] Aquaponics is an ecosystem that incorporates fish into plant farming, which functions as a waste disposal system. The plant's roots are in direct contact with the body of water containing the fish.

the investigation and analysis of vertical farms. Chapter 3 presents the pursued methodology and describes the research design, followed by a description of the interviewee selection process and data collection. The fourth chapter describes the resources and capabilities needed to operate a vertical farm. Chapter 5 describes the market size and the Swedish actors involved in vertical farming. In the sixth chapter, the business models pursued in Sweden are described. In chapter 7, the analysis combines the theoretical models and frameworks with empirical data in order to gain a better understanding of the industry, business models, and challenges and benefits of vertical farming. In chapter 8, the results of the study are explained and discussed through the opinion of the authors. The final chapter concludes the report by summarising the paper and re-states the conclusions drawn from the research.

2 Theoretical framework

The theoretical framework explains the different concepts, theories and tools that have been used in the investigation and analysis of VF. In order to answer the research questions, relevant literature regarding business models, industry analysis, sustainability and customer acceptance have been identified and explained. The first subsection is an elaboration on urban agriculture and its relation to vertical farming.

2.1 Urban agriculture

Urban Agriculture (UA) has been around for thousands of years but has gained increased interest for the last decades. The Food and Agriculture Organization of the United States (FAO) (2001, p.9) define UA as: *"Urban and peri-urban agriculture (UPA) occurs within and surrounding the boundaries of cities throughout the world and includes products from crop and livestock agriculture, fisheries and forestry in the urban and peri-urban area..."* This includes different types of crops and livestock as well as non-food products such as medicinal herbs, ornamental plants and ecological services. Related activities such as production, packaging, processing and marketing are included as part of UA (FAO, 2001). Urban agriculture can take place on roof tops, basements, backyards or any vacant and open spaces in the city. UA is embedded in the urban ecological and economic system, utilizing the local workforce and resources while being in direct connection to the consumers (RUAF Foundation, 2018). It allows for a more sustainable food production, reducing the need for transportation, storage and packaging. UA can lead to fresher produce while creating opportunities for waste management and improved biodiversity. It is a viable option to improve a country's self-sufficiency and secure domestic food production in urban areas at times of supply shortage due to bad harvest or other related consequences.

According to Ellen Macarthur Foundation (2019), outdoor production has the most limited yield when compared to other urban farming techniques. Outdoor production can, however, create socio-environmental benefits by expanding the green spaces in cities, creating cleaner air and reconnecting people with food. With the introduction of vertical farming techniques, urban agriculture is undergoing a transition towards drastically higher crop yields and increased quality control which can help deliver more sustainable, resilient and safe food production (Lu & Grundy, 2017).

2.2 Business Models

An extensive literature review of business models conducted by Zott, Amit and Massa (2011) revealed that there is no clear definition of the business model concept due to its scientific novelty. Teece (2010) describes a business model to be management's perception of how value is created, delivered and captured and subsequently turned into profit. Osterwalder and Pigneur (2010, p.14) describes a business model in a similar manner: "A business model describes the rationale of how an organization creates, delivers, and captures value". Osterwalder and Pigneur (2010) divide this process into nine building blocks which have become known as the Business Model Canvas (BMC), described in greater detail in the following section. To better satisfy customer needs, business model innovation can be a way for companies to create a competitive advantage. However, the model needs to be differentiated from competitors and hard to replicate for new entrants and incumbents in order to sustain that advantage (Teece, 2010). This can be achieved in various ways. Companies can create strong enough relationships with customers, suppliers and other relevant stakeholders that competitors do not have the opportunity to replicate the business model. Another way can be to develop complicated process steps, organizational structures or intellectual property rights (Teece, 2010). However, due to the transparency of business model design it is usually only a matter of time before competitors start imitating new successful business models (Teece, 2010). Therefore, companies have to create a business strategy that helps in sustaining the competitive advantage. Business strategy is dependent on internal and external factors. The external factors are described in greater detail in chapter *2.3 Industry analysis* and *2.4 Macro-environmental analysis*. Internal factors include how a company utilizes its resources and capabilities and is described in greater detail in chapter *4 Technology*. Resources are the productive assets that a company owns, whereas the capabilities are the means by which these resources are utilized (Grant, 2016).

2.2.1 Business Model Canvas

Pölling et al. (2017) state that the Business Model Canvas (BMC) is a useful tool to analyse a vertical farm's performance and organisation and should be adjusted to the specific urban conditions of the city. The BMC was developed by Alexander Osterwalder in 2008 and consists of nine elements that provide a total view of key business drivers (Osterwalder & Pigneur, 2010). It is commonly used by entrepreneurs to evaluate business model innovation since it provides a transparent and focused view while still being flexible for modifications. The BMC is illustrated in figure 2 and will be used in this report as a guideline to evaluate viable business models for vertical farms based on the empirical findings.

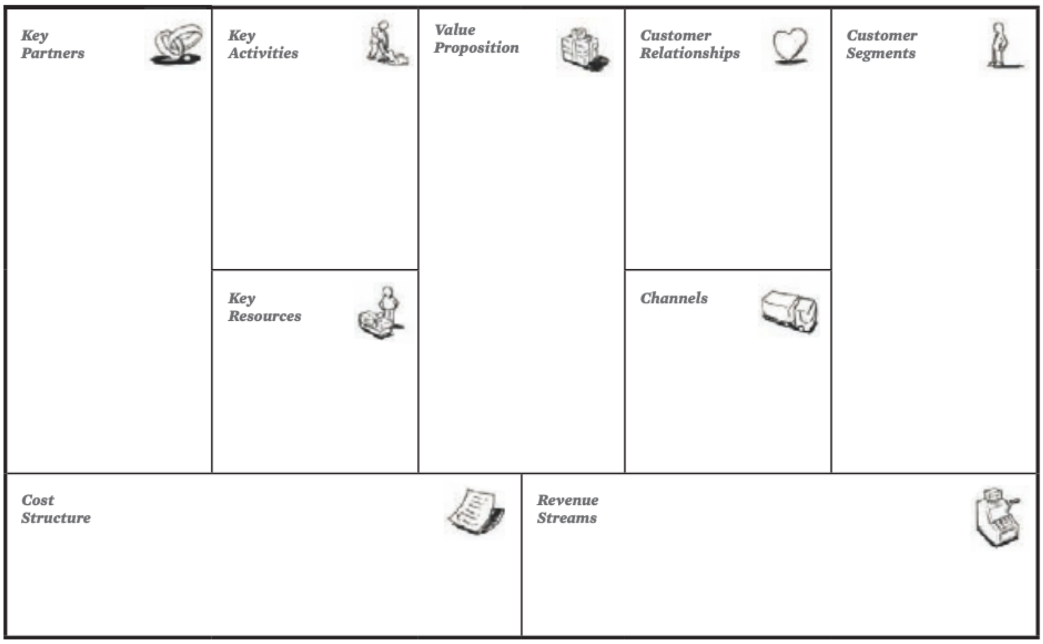

Figure 2. Illustration of how the Business Model Canvas is presented by Osterwalder & Pigneur (2010).

The nine building blocks cover the fundamentals of business: customers, offer, infrastructure and financial viability. A description of each element of the BMC is given in table 1. The descriptions are taken from Osterwalder & Pigneur (2010).

#	Building Block	Description
1	Customer Segments	Defines for whom value is created and who the customers are.
2	Value proposition	Describes the bundle of products and services that create value for a specific Customer Segment.
3	Channels	Describes how the value proposition is communicated, sold and delivered.
4	Customer Relationships	Describes the type of customer relationship a company establishes with each specific customer segment.
5	Revenue Streams	Represents how the business earns revenue.
6	Key Resources	Describes which assets are required to make the business model work.
7	Key Activities	Describes the most important things a company must do to make the business model work.

8	Key Partnerships	Outlines the partners and suppliers that make the business model work.
9	Cost structure	Describes the most important operating costs associated with the business model.

Table 1. Description of each building block of the BMC

2.3 Industry analysis

In order to identify the most suitable business model for vertical farming the external factors affecting the industry have to be identified. The external factors affect the attractiveness of an industry in terms of profitability and can guide in finding a source of competitive advantage (Grant, 2016). These external factors are commonly identified and analysed using Porter's five forces framework (Grant, 2016). Porter (1979) identified five forces that define the competitive landscape of an industry: threat of new entrants, threat of substitute products or services, bargaining power of customers, bargaining power of suppliers, and industry rivalry. Porter (1979) concluded that a firm needs to establish a strategy that is able to cope, adjust and take advantage of these different forces in order to successfully grow and become profitable. Hence, it is relevant to gain an understanding of the forces affecting the agriculture industry to understand whether vertical farming is a viable option to traditional farming methods.

The threat of new entrants to an industry depends to a large extent on six sources of entry barriers. If the barriers are high, the attractiveness to enter the industry is low. Furthermore, if incumbents are known to price cut or use resources to fight new entrants off, new entrants might decide not to enter the industry (Porter, 1979). Determining the barriers to entry is therefore essential to evaluate the potential of VF. The six sources of entry barriers are according to Porter (1979):

1. Economies of scale - is one of the key entry barriers since it forces new entrants to either compete at a cost disadvantage or immediately start large scale operations at a high investment cost.
2. Product differentiation - Brand recognition of incumbents ensures customer loyalty. It forces new entrants to spend a lot of money on brand building and advertising and can make a great entry barrier.
3. Capital requirements - Large initial investments in advertising or R&D can create big enough entry barriers that new entrants are ruled out.
4. Absolute cost advantage - May arise due to learning curves or access to low-cost sources of raw material for example.
5. Access to distribution channels - New entrants have to secure a spot in the existing distribution channel by displacing competitors or creating new distribution channels. A strong distribution network can make it difficult for new firms to enter.

6. Government policy - Governments have the authority to decide which companies are able to enter an industry through policies and legislations and is therefore a very effective barrier to entry.

Buyer and supplier power are determined by the same factors, namely price sensitivity and relative bargaining power. Price sensitivity is based on product differentiation and competition between buyers whereas bargaining power is dependent on switching costs, information and size relative the producer. Threat from substitutes is largely dependent on if there are any available substitute products or services which the customer is willing and able to switch to. The intensity of industry rivalry between established competitors depends on several factors. If many competitors, similar in size and strength, are present, industry rivalry increases. If differentiation is low and industry growth is low, competition is further increased.

2.4 Macro-environmental analysis

As a complementary tool to the industry analysis, a PESTEL analysis is used to identify macro forces which might affect an organisations performance and decision making (Grant, 2016). PESTEL is an acronym for Political, Economic, Social, Technological, Environmental and Legal (Grant, 2016). The following definitions of macro-environmental analysis come from Oxford College of Marketing (n.d.). *Political factors* include government policies affecting an organisation or an industry. These trends might influence the business model (Osterwalder & Pigneur, 2010). *Economic factors* are those affecting the economy, which in turn will affect an organisation. Economic factors could for example be changes in economic growth, interest rates, taxes and employment rates. *Social factors* constitute cultural trends, family demographics and changes in lifestyle or attitudes. *Technological factors* are technological discoveries and development influencing an industry. Such trends can either threaten or improve the developed business model (Osterwalder & Pigneur, 2010). *Environmental factors* consider ecological and the surrounding environmental effects. Corporate Social Responsibility (CSR) has started to become incorporated in business strategies as a response to increased environmental consciousness. Lastly, *legal factors* are the regulations and laws that companies must operate within. Legal aspects include consumer law and employment legislation for example.

2.5 Sustainability

Part of the study is to investigate whether VF can compete with traditional farming in terms of sustainability, which makes it necessary to create common ground for its definition. Academia and enterprises use a variety of different definitions for sustainability (Epstein & Buhovac, 2014). Shaker (2015, p.315) distinguished sustainability from sustainable development by describing sustainability as humanity's goal of reaching ecosystem equilibrium, while sustainable development is the temporal process that leads to this goal. The most cited definition for sustainable development is derived from the Brundtland

Commision (1987, p.41): *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* The remaining section firstly puts this definition into a corporate context and secondly continues by elaborating on what sustainability entails in greater detail.

Dyllick and Hockerts (2002, p.131) state that the corresponding meaning for corporate sustainability is defined as *"meeting the needs of a firm's direct and indirect stakeholders (such as shareholders, employees, clients, pressure groups, communities etc), without compromising its ability to meet the needs of future stakeholders as well*." The goal being to grow and maintain the company's economic, social and environmental capital base. Epstein and Buhovac (2014) state that for businesses this includes how to incorporate and develop environmental protection, economic growth and social progress in their sustainability strategy. A single focus on either of these dimensions is not sufficient in order to create long term sustainability since they are interrelated (Epstein and Buhovac, 2014). Corporate sustainability requires an improvement in stakeholder input and engagement. The challenge for companies is to incorporate CSR while still improving short-term financial performance, which often is the main driver for shareholders (Epstein & Buhovac, 2014). However, the authors further argue that sustainability can be turned into a competitive advantage and create value in the long-term. CSR is therefore relevant to consider when creating a business model for vertical farms. It can increase employees' desire to work for a company and consumers' willingness to buy the available products. Furthermore, it is important to consider the sustainability aspects since government policies require companies to add increasing attention to sustainability and can result in penalties if not undertaken.

In 2015, the United Nations General Assembly released a collection of 17 universal objectives for environmental, economic and social sustainability, called the Sustainable Development Goals (SDG). These objectives and 169 underlying targets are meant to be achieved by the involved actors by 2030 (United Nations, n.d.). One of the targets within the agriculture industry is to ensure sustainable and resilient food production, in order to help maintain ecosystems and improve land and soil quality. If VF can facilitate the process of reaching part of these objectives and targets, while following the directives of corporate sustainability, it can be considered a sustainable business. For the remainder of this report, the definitions of corporate responsibility and sustainable development will be assumed a prerequisite for implementing vertical farming.

2.5.1 Environmental sustainability

The premise for environmental sustainability is that natural resources are finite, and extraction and accumulation of these resources cannot go on forever without consequences. Dyllick and Hockert (2002) argue that in addition to natural resources, ecosystem services such as climate stabilization systems provided by the Amazonas or the Ozone layer, water purification, and soil remediation need to be sustained. The authors further state that while future generations might be able to cope with a lack of some natural resources through innovation, it is unlikely that they will sustain a degrade of these ecosystem services. Dyllick and Hockert (2002, p.133) propose the following definition for ecological sustainability: *"Ecologically sustainable companies use only natural resources that are consumed at a rate below the natural reproduction, or at a rate below the development of substitutes. They do not cause emissions that accumulate in the environment at a rate beyond the capacity of the natural system to absorb and assimilate these emissions. Finally, they do not engage in activity that degrades ecosystem services."*

2.5.2 Economic sustainability

Economic capital represents both financial capital as well as tangible and intangible capital. The proposed definition by Dyllick and Hockert (2002, p.133) is: *"Economically sustainable companies guarantee at any time cash flow sufficient to ensure liquidity while producing a persistent above average return to their shareholders."* For vertical farms to be economically sustainable they need to have a competitive edge that generates a cash flow which ensures liquidity while still generating above average return to their shareholders.

2.5.3 Social sustainability

Social capital can be divided into human capital and societal capital (Dyllick & Hockert, 2002). While the former concerns employee's motivation, loyalty and skills, the latter concerns the quality of public services (infrastructure, educational system, etc.). It is often difficult for companies to meet all stakeholders' expectations, why Dyllick and Hockert (2002) argue that corporations can be regarded as socially sustainable if they can motivate their decisions taken in a trustworthy manner. Dyllick and Hockert's (2002, p.134) proposed definition for social sustainability is hence: *"Socially sustainable companies add value to the communities within which they operate by increasing the human capital of individual partners as well as furthering the societal capital of these communities. They manage social capital in such a way that stakeholders can understand its motivations and can broadly agree with the company's value system."*

2.5.4 Circular economy

The Ellen Macarthur Foundation (2019) state that three things have to be considered when designing a circular economy. Firstly, a circular economy should primarily be designed in such a way that no economic activity results in damage to human health, like malnutrition, or to the ecosystem, such as releasing greenhouse gases into the ecosphere. Secondly, products and materials should be designed in a way that they are durable, reusable, and able to be refurbished and recycled. Biological material should be free from contaminants and hence able to be returned to natural systems. Lastly, in a circular economy only renewable resources should be used in order to support natural regeneration.

Circular economy is a highly relevant concept when addressing VF since it may be a way to disrupt the current linear food production system. The linear approach can be summarized as a "take-make-waste" production system which has focused on high yield crop production through the use of machinery, synthetic fertilisers and pesticides (Ellen

Macarthur Foundation, 2019). The consequences have become an overconsumption of finite resources such as phosphorus, potassium and fossil fuels. Around 30 % of all edible food is wasted worldwide, amounting to 1 trillion USD annually (Ellen Macarthur Foundation, 2019). Most of this food is wasted during production and before consumption (Bhatt et. al., 2018). The pesticides and synthetic fertilisers cause air pollution, destroy natural habitats and water supplies. The linear system has resulted in the agriculture industry being responsible for approximately 25 % of greenhouse gas emission globally when the whole value chain from production to consumption is taken into account (Ellen Macarthur foundation, 2019). 80 % of all food is estimated to be consumed in cities by 2050, meaning food transportation will drastically increase unless the food production systems are improved.

Some existing vertical farms, such as New Jersey based Aerofarms, are already implementing closed loop systems which aim to minimize waste and utilize resources, such as water and nutrients, to their greatest extent.

The Ellen Macarthur Foundation (2019, p.31) highlights five prerequisites for urban farms to become circular. These are:

1. Run on renewable energy
2. Loop water
3. Use nutrient inputs sourced from food by-products
4. Avoid synthetic pesticides
5. Use circular fish feed (for fish production)

If the aim with vertical farming is to create a more sustainable food production system, these challenges have to be considered when designing the business model.

2.6 Customer acceptance

Vertical farming is a novel innovation and has a short history in Sweden. The produce is therefore going to be perceived differently by consumers than conventionally grown produce would. Consumer acceptance related to innovations in the food industry is dependent on the type of innovation (Sajdakowska et al., 2018). Recent innovations in the food industry, such as genetically modified organisms (GMO), have been met with scepticism and it is to some extent unclear what consumers' relation to vertically farmed crops are (Coyle & Ellison, 2017). Coyle & Ellison (2017) conducted a study with 117 participants to evaluate the willingness to pay (WTP) for vertically grown lettuce compared to greenhouse and field grown production. The study concluded that the WTP for vertically grown lettuce was similar to that of greenhouse and field-grown production. However, it was regarded as the least natural option and participants were less likely to purchase vertically grown lettuce. As with most new food technologies, producers and retailers will have to convince the consumer of the benefits with vertically grown food for it to gain wide consumer acceptance (Coyle & Ellison, 2017).

While groceries are generally seen as a consumer good with low price elasticity, the research on organic foods is mixed. Wier et al. (2011) found that consumers are more price sensitive to organic foods because of the low product differentiation compared to conventional foods. On the contrary, Rudholm et al. (2011) found that price elasticity was reduced after organic labels were introduced on store-shelves, suggesting that organic consumers are less price sensitive. Another study found that organic produce is more income elastic than price elastic (Lin, Yen and Huang, 2008). What can be concluded from the studies is that price sensitivity for organic greens largely depends on the values held by the customers.

New technologies are often accompanied with worse quality or higher price, but outperforms in other dimensions such as sustainability, efficiency or speed (Adner and Kapoor, 2011). New technologies also tend to be met with resistance from incumbents and the majority of the population until a proof of concept has been shown (Rogers, 1962). As the new technology gains traction, increased demand leads to more actors, more innovation and reduced price, until the new technology eventually overtakes and surpasses the old (Rogers, 1962).

3 Methodology

This chapter describes the methodology used to reach the aim of this thesis, namely, to explore the financial, logistical and environmental prerequisites for successfully implementing vertical farming in Sweden, contributing to a more sustainable agricultural industry. The research study and methodology are presented below, followed by a description of the interviewee selection process and data collection.

3.1 Research study

A qualitative research method has been used in the thesis. According to Edmondson and McManus (2017), less maturity in a theoretical area implies a higher likeliness to make use of qualitative research. Lakshman et al. (2000) state that qualitative research is suitable when there are no clear variables that are producing an outcome. Furthermore, the collected data was interpreted and analysed by the authors which makes it more appropriate to make use of a qualitative study. Research methods used in qualitative studies include interviews, observations and interpretations of written material. Easterby-Smith et al. (2015) state that interviews are a good way to gain in-depth information about a topic as they make it possible to gain an understanding about a phenomenon which would be difficult to observe otherwise.

3.2 Research methods

Semi-structured interviews were conducted with all interviewees. In such interviews, the questions are predefined but the order in when they are asked may differ between interviewees (Easterby-Smith et al., 2015). This allows for a more flexible approach to the interview, while still making it possible to compare the interviewees answers (Fallahi, 2018). Interviews were either conducted face-to-face (FTF) at the interviewee's facilities or by telephone, depending on the geographical location of the company. In two instances, five interview questions were sent out by email due to limited availability of the interviewee.

The general interview template can be found in Appendix 1**.** The questions were divided into three main parts: background of the interviewee, background of the company and how the company operated. The aim was to get an understanding of how the companies operated and why they had chosen their respective business models.

When possible, interviews were combined with observations to gain a deeper understanding about the operations. Combining research methods in order to study the same phenomenon is known as triangulation and facilitates data validation (Carter et al., 2014). Observations were conducted at Plantagon, Heliospectra and Kajodlingen. Another aim of the observations was to obtain first-hand experience with vertical farming and verify its performance in practice.

Secondary research was conducted in the cases where the empirical findings from the interviews and observations did not sufficiently explain certain aspects of vertical farming. It was mainly used in combination with data from interviews to develop chapter *4 Technology*. Since vertical farming is a relatively novel concept, obtained information could not always be verified through different sources. This might be a potential weakness in the presented data.

3.3 Interviewee selection process

The aim with the selection process was to interview as many vertical farms in Sweden as possible to gain an understanding about which business models are currently pursued. These vertical farms were identified using online searches, recommendations from interviewees, and the authors' personal network. All companies interviewed are presented in Table 2. Another aim of the selection process was to identify and interview stakeholders from other parts of the value chain such as suppliers (Heliospectra and Castellum) and competitors (Kajodlingen and Spisa). The data gathered was used for the analysis. One vertical farm in Stockholm declined to participate in an interview.

With financial aid from ÅForsk Foundation and Chalmers Mastercard Scholarship, two field studies were conducted in Tokyo, Japan. Two companies working with VF were interviewed and their operations observed to gain deeper insight in their operations and to identify differences and similarities between Japanese and Swedish vertical farms. Japan was selected because of their long history with indoor farming, high number of successful vertical farms, and advanced technology. Vertical farming using artificial lights has been developed since the 1970s in Japan and they were the first to commercialise it which has made them world leaders in the industry (Voronkov, 2019). The two companies, ESPEC MIC Corporation (ESPEC) and Japan Plant Factory Association (JPFA), were chosen for their knowledge in hydroponic indoor farming and from availability in conducting a field visit to their production sites. The field studies were conducted on May 9^{th} and May 10^{th}, 2019 at the respective companies' facilities.

By selecting several actors, both within vertical farming and its relating activities in the food industry, the obtained data could be validated. Abnormalities and contradictory information from interviewees could be detected and questioned in order to ensure the data was truthful and reliable.

Company	Title	Name	Date	Data Collection
FutuFarm	Founder, CEO	Harrie Rademaekers	2019-02-18	Telephone
Plantagon	CEO	Owe Pettersson	2019-02-28	FTF, Observation

Anonymous	Former Head of Operations at VF in Stockholm	Anonymous	2019-02-21	FTF
Kajodlingen	Founders	Anonymous	2019-02-22	FTF, Observation
Castellum	Property Development Manager	Tobias Kristiansson	2019-02-22	FTF
Ljusgårda	Co-founder, CTO	Magnus Crommert	2019-03-01	FTF
Heliospectra	Director of Product Management and Engineering	Karin Dankis	2019-03-28	FTF, Observation
Spread Co., JPN	Public Relations Department	Yurii Voronkov	2019-03-28	Email exchange
Spisa	CEO	Jonna Hansson	2019-04-01	Telephone
Grönska	Co-founder and CFO/CMO	Natalie de Brun Skantz	2019-04-08	Telephone
ESPEC MIC Corporation, JPN	Agri-Bio department representative		2019-05-09	FTF, Observation
Japan Plant Factory Association, JPN	1. Associate Professor 2. Vice President and Director International Relations and Consulting	1. Dr. Satoru Tsukagoshi 2. Eri Hayashi	2019-05-10	FTF, Observation

Table 2. List of interviewees

3.4 Data

This section describes how the research methods were put into practise during the data collection and how the data was subsequently analysed.

Data collection

Every interview started with a short presentation of the interviewers and why the research was conducted. The interview questions did not follow a specific order, but a question template had been prepared to fall back on in case the interview halted and to ensure all relevant topics were covered. The interviewee was given as much time as needed to answer the specific questions. No interview had time constraints. In some cases, follow-up questions were asked which had not been prepared in advance. The received answers were continuously documented in text by both interviewers to ensure that all relevant information was captured. The interviews were not recorded to make the interviewee feel more comfortable and to respect their privacy. Every interview lasted between 30 and 75 minutes.

The first research question, *"How can different stakeholders benefit from vertical farming in Sweden?"* was answered by interviewing different actors in the industry and analysing the interview data from an economic, social, and environmental standpoint. Several interviews were held with different stakeholders in the value chain in order to obtain a holistic view of the industry. Complementing data was collected through secondary research.

In order to answer the second research question, *"What business models exist and how can they be applied to the Swedish market?",* an understanding about the industry, its macro-environment, current business models and required resources and capabilities had to be established. This was accomplished through interviewing various vertical farms, suppliers, and competitors. Focus was put on the motivation for the chosen business models, production, facilities, and which challenges the interviewed companies had identified. This data, in combination with secondary research, built the basis for the empirical findings and was later used in the analysis. The data gathered about the required resources and capabilities needed in vertical farming was presented in a separate section to give the reader an understanding of how vertical farms operate.

The final research question, *"Can the business model be both environmentally and financially sustainable while keeping a competitive edge?",* data on energy and water usage, labour costs, nutrient use and sales- and distribution channels was collected. This was accomplished through interviews in combination with secondary research. To gain an understanding about the financial sustainability of vertical farms, the size of the market was mapped through secondary research.

Data analysis

The collected data was analysed with the help of the theories and tools presented in the theoretical framework. By applying the industry and macro-environmental analysis the external factors affecting the industry could be analysed. To investigate whether VF can compete with traditional farming in terms of sustainability the sustainability benefits and challenges were identified, presented and analysed. The different identified business models were analysed with the help of the elements in the business model canvas. The data on sales- and distribution channels was used in conjunction with the business model analysis to identify the logistical prerequisites for successfully implementing VF in Sweden. By combining the analysis of industry and macro-environmental analysis, sustainability and business model analysis, the concept of vertical farming could be put in relation to traditional farming. Subsequently, the analysis resulted in recommendation for which business model to pursue.

4 Technology

This section contains a description of the resources and capabilities needed to operate a vertical farm. The resources and capabilities differ between vertical farms and the following section is a general description to give the reader an understanding about vertical farming operations. The term vertical farming is a bit vague since production can either be in the form of vertically stacked layers (horizontal planes) or vertical planes, also referred to as towers (Arnold, 2016). Figure 3 visualizes the difference between the farming techniques.

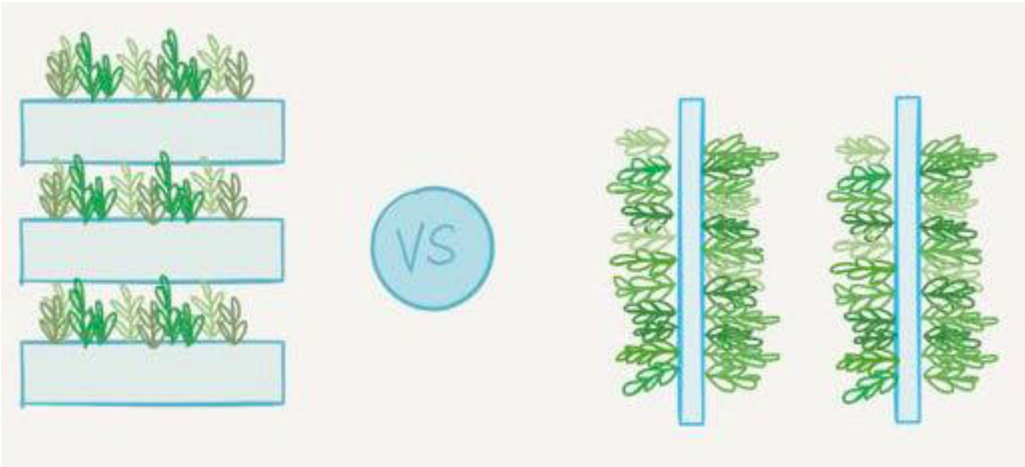

Figure 3. The difference between vertical farming production in vertical layers (left) or vertical planes (right). Illustration borrowed from Arnold (2016)

Production in vertically stacked layers allows for higher crop density by taking advantage of the height of the production facility. More racks stacked vertically leads to higher crop density but increases the difficulty for farmers to supervise the crops. The upper racks, depending on height, can only be accessed with the help of ladders or scissor lifts if the system has not been automated. This method of operation is time consuming and dangerous, which increases labour cost. Supervision includes visual and manual maintenance, pest control and harvesting (Arnold, 2016). Some vertical farms have developed automated systems to solve this issue by automatically bringing the upper levels to the ground floor for supervision, minimizing labour cost (Arnold, 2016). Such systems are costly and expensive to operate but can be a viable option in large scale production due to economies of scale. Vertical planes make it easier for farmers to visually supervise the crops and eliminates the need for scissor lifts, hence decreasing labour cost. The disadvantage being that height is not utilized in the same extent as for vertical layer production.

4.1 Equipment

The uniting factor for all soilless vertical farms is that the crops require light, space, carbon dioxide (CO_2), water and nutrients, which are all associated with some cost (Banerjee & Adenaeuer, 2013). Greenhouses mitigate the energy cost from lights by taking advantage of sunlight but are mostly located in peri-urban areas.

Light

Light is created artificially by light emitting diode (LED) technology. LED-lights are the most energy efficient source of artificial light currently available. They are suitable for crop production due to their low level of thermal radiation and long-life cycle. The most important aspect for its use in vertical farming is the possibility to modify the irradiation output to best suit the crops and lower operating cost. Operating cost can be further decreased by adapting the illumination period of the plants for 12-16 hours a day depending on the type of plant (Banerjee & Adenaeuer, 2013). Research has shown that plants grow best when exposed to red and blue wavelengths, which is why other unnecessary light spectra often are excluded (Greutzmacher, 2018). Developing different irradiation outputs in-house could create competitive advantages.

CO_2

Vertical farms supplement carbon dioxide in order to create the optimal conditions for plant growth and structure (Storey, 2016). Plants turn CO_2 into sugars in order to build plant tissue. If the CO_2 levels in the indoor environment drop below 250 parts per million (ppm), the plants will stop growing. Therefore, it is necessary to keep track of CO_2 levels in the farm and supplement with CO_2 if needed. This can for example be accomplished by releasing bottled CO_2 in the facility or by connecting it with air filters to offices where employees naturally create CO_2 through breathing. Optimal CO_2 levels for crop growth lie around 1200 ppm. (Storey, 2016).

Water

Depending on the vertical farm system, drinking water is automatically circulated repeatedly in a closed loop system, maximizing water usage. At Plantagon's farm, the only water leaving the premises is the water residues left on the plant when it is sold (O Pettersson 2019, personal communcation, 28 February).

Climate control

The temperature, humidity and air circulation need to be monitored and kept at a steady level depending on the crops grown. This is accomplished with the help of monitoring apps and climate control solutions.

Nutrients

Only mineral nutrients are added in vertical farming systems, since these naturally only exist in soil. Nutrient mixes consist of nitrogen, phosphorus and potassium (abbreviated NPK), calcium nitrate and Epsom salt (magnesium sulphate) which different plants require in various amounts (Storey, 2015). Oxygen, hydrogen and carbon is obtained from the air and water. Nutrient levels need to be checked daily through plant-monitoring systems. Vitamins are produced by the plants and are not affected by the growing technique (Hays, 2015). In order to stay sustainable, nutrients should be organic or produced without any negative impact on the climate.

Growing medium
Instead of using soil, vertical farms grow their crop in a variety of sustainably produced media. Ljusgårda use coconut fibre and Plantagon aims to use volcanic gravel (pumice). Futufarm, previously using the Zipfarm technology in their containers, grow in a developed media composed of polyester, made by recycled plastic-bottles (ZipGrow, 2019). The growing media mainly serves the purpose of stabilising the roots and the plant while letting through sufficient amounts of water and oxygen.

4.2 Production methods

This section highlights the different vertical farming techniques that are used today. This report is delimited to focus on hydroponics, but a short description of the most common types of indoor farming are listed below to provide the reader with an understanding of the different techniques.

Hydroponics
The crops are grown in a nutrient-enriched water solution stabilized with the help of a growing medium or plant bed. There are several methods to grow crops hydroponically (Baker and Katsiroubas, 2019). One of the most commonly used methods is the so-called Deep Water Culture (DWC) hydroponic system, where the plant's roots are kept directly in the water solution which facilitates the nutrient uptake compared to if they were to be grown in soil (Former Head of Operations at a Swedish vertical farm 2019, personal communication, 21 February). In vertical planes the nutrient liquid is circulated through the towers.

Aeroponics
The crops' roots extend in air and are periodically misted with nutrient enriched water in an enclosed space (Aerofarms, 2019). This allows for more oxygen uptake for the roots compared to hydroponic system which accelerates nutrient uptake and hence improves growth time (Aessense, 2017). It also uses up to 40 % less water than hydroponic systems (Aerofarms, 2019). However, it is more technically challenging to operate, and the upfront cost are higher than for hydroponic systems (Altervista, 2014).

Aquaponics
Aquaponics is an ecosystem that incorporates fish into plant farming, which functions as a waste disposal system. The plant's roots are in direct contact with the body of water containing the fish. The plants help purify the water while the fish create waste that cultivates bacteria and functions as a fertilizer for the plants (Sedacca, 2017). The fish play an important role in vertical farms aiming to create a completely circular closed-loop system with no waste.

Greenhouse
Greenhouses provide a sheltered environment for the crops, prolonging the growing season by providing adequate temperature and humidity during both summer and winter. Crops

are sheltered from all forms of weather changes, rodents and insects to reduce the risk of crop failure (MaximumYield Inc., n.d. (a)). Greenhouses utilise the energy from the sun when possible and supplement with lights during the darker season of the year. Vertical farms and greenhouses can be combined, but require mechanical systems moving the planes around to capture the sunlight. Sky Greens in Singapore have combined vertical and greenhouse farming by implementing rotating hydraulic shelves. The rotating shelves reduce energy cost by leveraging natural sunlight and increase farm height without the need of ladders or scissor lifts.

4.3 Production process

Almost any crop can be grown in a VF in theory, but the scope quickly narrows when profitability is introduced into the equation. This has resulted in a focus on growing microgreens, leafy greens, herbs, lettuce, and mushrooms. These alternatives have either a short enough growing cycle or high enough market value to be profitable. Berries and fruits are, to some extent, less profitable to grow since they require pollination. Pollination can be done by hand or by letting bees into the farm which increases labour cost and reduces profitability. There are varieties of berries that are self-pollinating, and some farms have experimented with the viability of berry production.

The process from seed to harvest can be summarized in three steps: germination, transplanting, and harvest. While the early plant development differs between one-seed leaves and two-seed leaves, this is not taken into account for the sake of relevance and simplicity. It is possible to purchase seedlings and transplant them into a VF directly. However, starting production with seeds removes the risk of introducing potential pests and diseases with the seedlings (McKee, 2017). Seeds are also cheaper and easier to transport than seedlings. Seedlings are grown continuously in the VF and replace the harvested plants right away.

Step 1 - Germination
The cultivation of plants starts with seed germination. Seeds are usually placed in a growing medium on a growth tray and start to develop under the right temperature- (above 21 degrees Celsius), moisture- and light conditions (MaximumYield Inc., n.d. (b)). The seeds will start to sprout in a couple of days. The seedlings' roots will have grown sufficiently after two to four weeks depending on the type of plant and can then be transplanted into the vertical farm system.

Step 2 - Transplanting
The seedlings are transplanted from the grow tray to the vertical farm system where the roots adjust to the new growing medium (J Rytterborn 2019, personal communication, 28 February). Depending on if it is an hydroponic or aeroponic system, the roots will be in direct contact, or misted, with the nutrient-enriched water.

Step 3 - Harvest

Depending on the type of plant, the seedlings will grow in size and have matured sufficiently to be harvested after four to eight weeks (Sedacca, 2017). They are packaged at the production facility and transported to the customer.

5 Market description

This chapter describes the Swedish market for fruits and greens and presents the interviewed actors involved in vertical farming. The market description was compiled with the help of the semi-structured interviews and complemented with secondary research.

5.1 The market for fruits and greens

The market for vertically grown food has expanded rapidly in Japan for some years and is currently developing quickly in the USA and Canada. The annual sales growth of vertically grown crops reached 25 % in 2016 and is expected to keep the same growth rate until 2022, when the market is estimated to be worth 5.8 billion USD (PR Newswire, 2017). VF has not yet been especially exploited in Sweden, likely due to the previously high production costs and lack of relevant resources and capabilities. New technologies tend to be accompanied by early challenges while a dominant design and business model emerges. Crossing the chasm of a few early adopters to reaching a majority of the market is a challenge with new innovations, but the technology has developed rapidly over the past years.

Many indicators point towards Sweden being in a susceptible position to adopt vertical farming. Compared to other countries, Sweden has relatively cheap and renewable energy, is health conscious, and favour organic and eco-friendly products. Sweden ranks first in the EU in organic food consumption per capita and gets the highest share of energy from renewable resources (Swedish Institute, 2018). According to Johansson (2016), Swedish consumers are more prone to buy Swedish products despite being more expensive than imported alternatives. Another study in the US, presented in the Ekoweb report on organic food, showed that 44 % of consumers accept a 20 % higher price tag on fruits and greens if they are organic (Ryegård & Ryegård, 2019).

Despite a collective effort towards a greener society, Sweden imports about 80 % of fruits and greens (Johansson, 2016). The increasing demand of organic produce, combined with poor growing conditions due to cold weather, has made Sweden increasingly reliant on imported fruits and greens. A market research on organic foods showed that even though both organic production and the demand for organic food is growing in Sweden, imported fruits and greens are growing at a faster rate and organic farmers are losing market shares (Ryegård & Ryegård, 2018). In the report, several retail buyers also expressed a desire for more locally produced organic, or “swecological”, food. Organic production requires far more land area than conventional farming. As more people move into the cities, large areas of land in urban places are increasingly difficult to find. Vertical farming allows for, increasing the growing area vertically instead of horizontally.

The market in numbers

The Swedish market for organic food is in a stable upward trajectory. Sweden and Denmark are world leaders in market share of organic foods. At 9 % of total sales, the market for organic produce amounted to 28 billion SEK in 2017, a 9.3 % increase from the previous year (Beaumont, 2016). The Ekoweb report on organic food further estimates the market for organic produce to increase by 3 %, or over 1 billion SEK, in Sweden in 2019. The same absolute growth is expected to sustain for a ten-year period, amounting to a total market value of 39 billion SEK in 2028, showing a strong trend for sustainably produced foods.

The market for imported fruits and greens has grown faster than for organic products and totalled 23 billion SEK in 2016, of which 12 billion consisted of fresh produce (Strandberg & Persson, 2017; Johansson, 2016). Imported fruits and greens now make up 16 % of the total import of all food products to Sweden (Strandberg & Persson, 2017). Focusing on greens, figure 4 shows the market value for imported greens between 2014-2016 in Sweden.

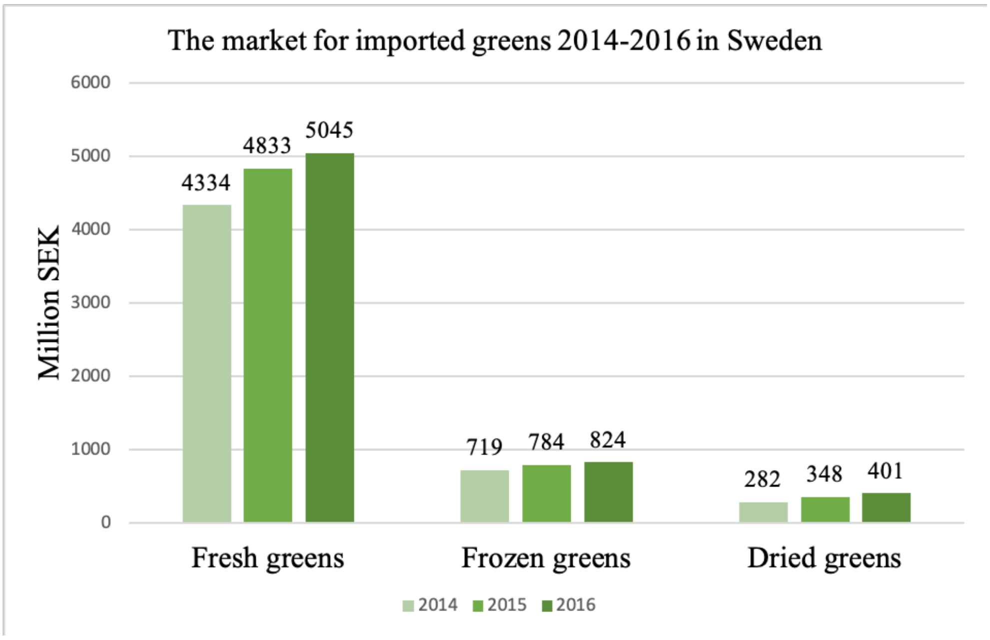

Figure 4. The market for imported greens 2014-2016 based on the findings of Strandberg & Persson (2017)

Sweden is self-sustaining in certain crops for part of the year, but the Nordic climate makes a stable, year-round production difficult. The output of fruits and greens has hovered around 3 billion SEK over the past years. Figure 5 shows the annual production value in Sweden of greens produced on open land and in greenhouses. Of the domestic produce, 38 % consisted of organic products in 2014 (Hafgren-Archeus, 2015). A 100 % increase from the previous year, making Sweden one of the most environmental and health-conscious countries in the world when it comes to food production.

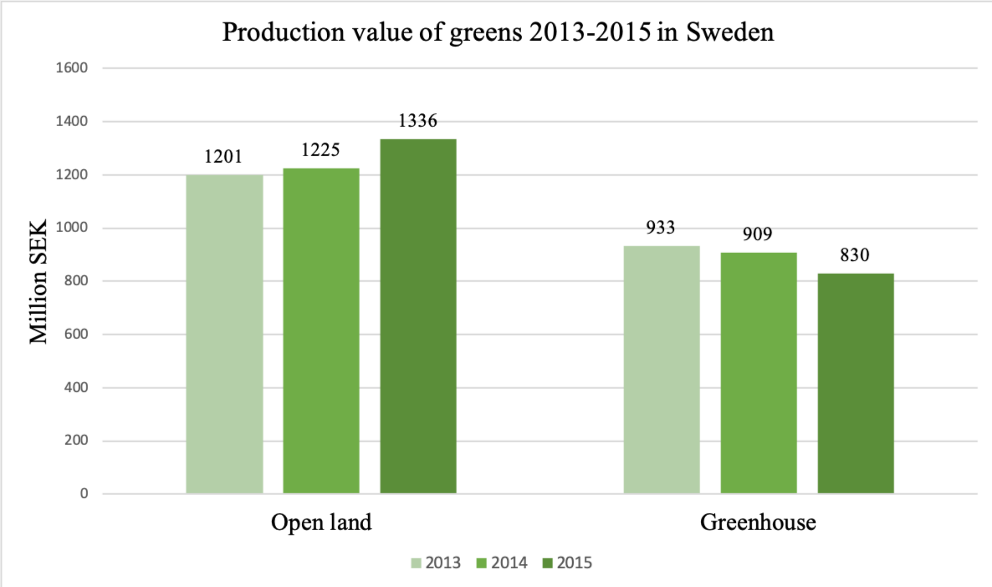

Figure 5. The production value of greens in Sweden between 2013-2015 based on the findings of Johansson (2016)

The serviceable obtainable market (SOM) is restricted to fruits and greens that are economically and practically viable to grow vertically. Most existing vertical farms focus on leafy greens, such as lettuce, microgreens, baby greens and herbs (Kalantari et al., 2017). Microgreens are harvested directly after the sprigs are developed and baby greens are harvested after a shorter growing cycle than done conventionally. The leafy greens are selected because of their relatively short growing cycles, high retail price, and simplicity to grow hydroponically. In 2015, Sweden's import of lettuce was approximately 38.000 tonnes, of which 69 % was imported from Spain, 9 % from Germany and 8 % from the Netherlands (Johansson, 2016).

5.2 The urban farming actors

Appendix II presents a variety of existing operating vertical farms located all over the world. Interviews have been conducted with several Swedish actors and two Japanese actors who are introduced in the following section. The findings are later used in the industry analysis and this chapter serves as a brief introduction and background of the companies.

5.2.1 Plantagon

Plantagon is one of the oldest players in the game and often viewed as pioneers and initiators by industry peers. The urban agriculture company was co-founded by Hans Hassle, a Swedish entrepreneur with focus on CSR, and the Native American people of the Onandaga nation in 2008. Plantagon are visionaries with goals stretching far into the future. A quick glance at their website shows technologically advanced patents for vertical farming, underground farms and blueprints for a skyscraper integrating modern urban agriculture with office spaces. Plantagon had extensive plans for building the skyscraper in Linköping and even broke ground back in 2012. A series of unfortunate events delayed the project and Plantagon eventually ran out of money, filing for bankruptcy in early 2019. The interview was held with Owe Pettersson, CEO of Plantagon between 2016 and 2018, and Joakim Rytterborn, head of R&D at Plantagon, on February 28th, 2019. The interview was held one week after the news of bankruptcy broke, but Pettersson is still hopeful that a restructuring solution can be reached, and that the Linköping project can be pulled through.

"The idea originated from a necessity to increase self-sufficiency of food production in cities," Pettersson explains. "10 billion people are expected to live on this earth in 2050 and 80 % of these people will live in cities where almost no food is produced today. On top of that, 80 % of arable land is already used. That is an equation that does not add up," he continues. Pettersson does however mention that if food wastage was not as high as it currently is, the arable land and food production would be more than sufficient for a planet with 10 billion inhabitants. Plantagon does not only want to become the neighbourhood farmer, but grow food in sustainable, closed loop systems. "Food production should be an integral part of a city's infrastructure, not an imported commodity," says Pettersson.

23 floors below the Plantagon office, a basement that used to serve as a newspaper archive for Dagens Nyheter before digitisation rendered it obsolete has been transformed into a thriving vertical farm. The farm is more of a proof-of-concept for the Linköping project but can produce 200 kg of greens a day at full capacity, explains Rytterborn. The basement is full of vertical towers from ZipGrow, flourishing with different greens and herbs. According to ZipGrow (2019) a fully equipped system of 92 m^2 for local production costs approximately 124,000 USD, which excludes shipping and installation. Rytterborn explains that the closed loop system is connected to the district heating in the building, allowing them to recycle 86 % of all energy used. The production process of greens at Plantagon is thus carbon negative, meaning that the CO_2 emissions from the operations are lower than the plants' consumption of CO_2 during the growing process. Less than 1 % of water consumption compared to conventional farming is required as water is constantly recycled, and everything is free from pesticides and herbicides.

Figure 6. Vertical plane farm system at Plantagon (Source: Authors)

It all sounds good on paper but there are challenges when it comes to profitability. A 4 million SEK investment in growing equipment and another 6 million in district heating solutions has made it a costly endeavour. “Our current production cost lies over 100 SEK per kilogram which is not sustainable at this scale,” explains Pettersson. Much of the margin is also lost through middlemen. ICA, which Plantagon currently supply, often require at least 100 % mark-up margins on their purchase prices, which drastically cuts margins for Plantagon. “The Linköping building is estimated to produce lettuce at 20 SEK per kilogram, which would be extremely profitable. Herbs are sold to consumers at 1,000 SEK per kilogram. Selling directly to end customer would already be very profitable even with the high production costs we have now,” Pettersson continues.

Whether a reconstructing solution will be reached, and the Linköping skyscraper become a reality is still undecided as of the writing of this report. Plantagon does, however, have the world’s largest patent portfolio in urban agriculture with over 60 patents and possess vast knowledge in the field. They were industry leaders, first-movers, and perhaps ahead of their time, but they paved a path for others to follow.

5.2.2 Ljusgårda

Founded by three childhood friends in Tibro, Sweden in 2017, Ljusgårda is a recent entrant to the industry. The interview was held with Magnus Crommert, head of R&D at Ljusgårda, on March 1st, 2019. After successfully growing basil in a homemade hydroponic system in their garage, Ljusgårda invested in equipment from ZipGrow and lights from Heliospectra to scale up. Ljusgårda moved into an old industrial building in the beginning of 2018. “The building had been unused for a long time, so we got a good price on rent, and after some renovation it was ready to become a vertical farm,” explains Crommert. They use 1,500 m^2 of the building with an option of an additional 7,000 m^2, which they aim to take advantage of by 2021. At the time of the interview, Ljusgårda produced around 1,000 boxes á 65 grams of arugula per week on the 200 m^2 of floor space dedicated to growing greens.

The produce is delivered to and sold by local ICA stores. Crommert says that demand has exceeded their initial expectations. Ljusgårda planned to supply ten stores by the time sales reached the current capacity, but the first three stores exceeded expectations and demand skyrocketed. At the time of the interview, Ljusgårda had higher demand than production capacity from only three stores. When asked why Crommert thinks their arugula has become so popular he is quick to answer, “I believe it is because we can make a ‘recipe’ for how we want it to taste, and then replicate the exact same product every time. The first harvest was too peppery and strong for the Swedish market and was instantly rejected by the purchasers at ICA. After some trial and error, we found a perfect, milder taste to our arugula and since then we have had no complaints of the quality of our produce.”

While Ljusgårda does not have an as technically advanced production facility as Plantagon, with connected district heating and carbon dioxide circulation systems, they do have a functioning business model and a strong demand for their products. Ljusgårda aims to become profitable by 2020 and have a core focus on delivering high-quality greens to retailers. “The first store is the most difficult to make a deal with, after that it becomes a domino effect,” Crommert explains. With plans to produce 1,000 tonnes of greens in 2021, a lot more deals will have to be made, but Crommert is confident. “Our competitive advantage lies in our recipes, which of course are trade secrets,” he explains. By tweaking lights, nutrients and temperature, Crommert aims to find the best tasting version of each crop. A production of 1,000 tonnes would make them market leaders in Sweden in 2019 measures. There are, however, several competitors with similar goals, but Ljusgårda believe competition is what will push the industry forward.

5.2.3 Grönska

After reading an article about vertical farms in Japan, two of the founders of Grönska decided to develop their own small vertical farming system in 2014. Shortly thereafter, the third founder, Natalie de Brun Skantz, joined the team after discovering vertical farming through her master’s thesis on urban farming. De Brun Skantz was interviewed the 8th of April 2019 and has been responsible for finance and marketing since the early stages of the company. Grönska’s own vertical farming equipment has been developed and improved continuously since 2014 and today Grönska consist of a team of nine people.

Grönska have one facility in Hammarbyhöjden and a bigger facility in Huddinge, in the suburbs of Stockholm. The facility in Huddinge has a total area of 900 m^2, including offices, storage spaces and growing area, with a production capacity of 1.4 million plants per year. The system is semi-automated with an aim to further increase automatization with scale and time. “The process does not necessarily need to be completely automated, but the most time-consuming steps are crucial to make as efficient as possible,” explains de Brun Skantz. The produce is packed, sold, and delivered to a variety of retailers in the Stockholm area such as ICA, Coop and Urban Deli. They have chosen to package their greens in environmentally friendly paper bags in accordance with their sustainability-values. The packaging is significantly more costly than plastic alternatives and constitute a large part of operating costs together with energy and salaries. Grönska have considered selling produce directly to the end consumer but distribution challenges and food safety regulations have proved it to be costly and difficult to pursue.

In addition to producing and selling greens, Grönska have developed a small vertical system called GrowOff, which can be used in places like restaurants, supermarkets, or offices. The system has been installed at two supermarkets in Stockholm. It is primarily used as a marketing tool to raise awareness of vertical farming to consumers but should still yield a positive return on investment (ROI).

Unlike many other vertical farms in Sweden, Grönska have developed and improved their own vertical farming system over many years. The founding team included an architect and a craftsman with the right capabilities to build the equipment from the ground up. De Brun Skantz states that they have tested a variety of different technologies, light recipes, and greens, which has given them the knowledge of what works and where the challenges lie. Their system is developed to be as cost and space efficient as possible and suited for their specific needs. “The benefit of developing your own system is that it eventually brings great cost- and knowledge advantages,” explains De Brun Skantz, while acknowledging that it is time consuming and difficult without the right resources and capabilities.

5.2.4 FutuFarm

FutuFarm is another relatively new vertical farming company, founded by Harrie Rademaekers and Anders Nilsson in 2016. The company, based in Halmstad, Sweden, has a slightly different business model than that of Ljusgårda and Plantagon. Futufarm is a system implementer of vertical farming for a number of different stakeholders who want to transition from purchasing greens to producing it themselves. Rademarkers explains in a telephone interview held on February 18th, 2019 that, “We are a food-tech company providing growing system solutions for urban farmers. Food-tech is not only a possibility, but a necessity.”

FutuFarm are partners with the American container-farming company Freight Farms and act as a retailer in northern Europe. At the time of the interview, FutuFarm sold Freight Farms 30 m^2 containers, called the Leafy Green Machine (LGM), equipped with ZipGrow towers and growth supervising technology. It had a growing capacity of 1,000 small heads of lettuce or 45 kg of basil per week (FreightFarms, n.d.). Since the interview, a successor to the container solution was introduced. The new container is called The Greenery and has been completely redesigned with a 70 % increase in growing space. The fully equipped container illustrated in Figure 7 currently costs around 105,000 USD (Freight Farms, n.d.).

Figure 7. The interior of an empty Greenery container, borrowed from FreightFarms (2019)

“We offer a plug and play system,” explains Rademaekers and continues, “You simply connect water and electricity and you are ready to go. The whole operation can be controlled through your phone and requires about 20 hours of work per week to maintain.” Futufarm believe that smaller, local producers are the future of agriculture. It is easier to control a small farm and everything that is produced can be sold at the same place. “A larger vertical farm, producing thousands of tonnes of greens a year cannot possibly sell everything in close proximity to the production facility,” argues Rademaekers.

The Greenery allows anyone to become an urban farmer after only a couple of days of initial training. Rademaekers names companies or institutions with a pre-existing interest in greens as their target audience. It could be used for educational purposes at schools, for retailing at a grocery store, or for increased control and range of produce in a restaurant. One of the first customers is ICA Maxi in Halmstad who placed an LGM on the roof in February 2019. Rademaekers says that the LGM gives ICA the opportunity to offer an almost infinite range of greens that would have been very difficult to purchase and ship to Sweden in small quantities. On top of that, ICA can strengthen their position as a sustainable company, with crops grown in direct connection to the store.

“The LGM is a proven technology with over 220 container farms active around the globe,” says Rademaekers, who continues to explain that the difficulties lie in breaking the current industry structures and standards. With a first container implemented in Halmstad the idea will soon be evaluated and tested in practice and may end up being a common sight in supermarkets across the country.

5.2.5 Kajodlingen

On a pier in the centre of Gothenburg, two urban farmers are producing 2,000 kg of greens a year. They are using a modern version of traditional soil farming, which is not included in the scope of this thesis. However, their business model of hyperlocal production and sales is highly relevant for the urban farmer no matter the growing technique. The interview and visit to Kajodlingen's farm were conducted on February 22nd, 2019. The farmers explain that the idea sprouted from their common interest in sustainable urban agriculture. The business was a result of system criticism to unsustainable growing practices and large amounts of imported food.

Kajodlingen grow leafy greens, root fruits, and fruits in a combination of outdoor and wind-sheltered pallets covering an area of 600 m^2. What is more interesting for the purpose of this report is their hyperlocal business model. "We initially targeted restaurants. They were super interested when they found out they could buy fresh produce and take part in the production planning," explains one of the founders. Due to short planning horizons and weekly menu changes, difficulties with planning and continuity when supplying the restaurant business arose and Kajodlingen later shifted their focus towards the consumers. By selling directly to end user Kajodlingen can keep a higher margin and become profitable in the first year. The produce is now sold through businesses to individuals within walking distance of the farm, meaning the crops can be delivered by bicycle to completely eliminate any negative environmental impact typically associated with transportation. "Logistically it is much easier. We deliver a basket of assorted greens to the front desk once a week and the customers can pick them up after work," explains the founders. A basket is typically a mix of seasonal greens weighing about 1.8 kg and priced at 250 SEK.

Apart from the subscription basket, Kajodlingen offer customers to pick their own greens during the summer season. It has been very appreciated, and many urban residents are interested in seeing how the food is grown according to the founders. Kajodlingen also has an integrated solution with a farm on top of a restaurant. The roof of Clarion Hotel Post in Gothenburg has been transformed into a small rooftop farm that supplies the hotel's restaurants with greens. By using the food waste from the restaurants as fertilizer, Kajodlingen can create an environmentally sustainable and circular system. "The chefs love having a farm on top of their restaurant. They can influence what is grown, find inspiration and try out different microgreens or edible flowers for a high-end dining experience," explain the founders of Kajodlingen.

When asked about vertical farming, the pair behind Kajodlingen say they do not have much experience in the area but believe it would work well. Kajodlingen's farm comes with almost no initial investment cost while a VF is rather costly. A VF can, however, operate 365 days a year. Kajodlingen acknowledges that the weather effects are a disadvantage to the traditional model, which is part of the reason why they use a homemade version of a VF. A few shelves and some lights allow for plant germination indoors during the cold start of the growing season, prolonging the season.

5.2.6 ESPEC MIC Corporation

ESPEC is a Japanese worldwide manufacturer of indoor farming solutions and growing chambers for commercial scale agriculture. They provide vertical farming systems ranging from small-scale to fully automated large-scale production. The interview and visit to ESPEC were conducted with Ayumi Nakama on May 10th, 2019 at their vertical farm VegetaFarm in Haneda, Tokyo. The facility is meant to showcase their technology, but they also sell about 80 kg of lettuce per day from the showroom to local grocery stores. VegetaFarm also have facilities in Osaka, Japan and sell approximately two to three vertical farming systems annually.

According to Nakama, a representative of the Agri-Bio department at ESPEC, VegetaFarm is developing VF systems to better supply the large population with vegetables as arable land has become scarcer. Japan's aging population and rapid urbanisation of young people has decreased the available workforce in the agriculture industry which makes Japan more reliant on automated and efficient food production systems. Similar to Sweden, the growing conditions in Japan make it difficult to grow crop year-round with conventional farming methods. Japan therefore relies on other countries, mainly China and South East Asia, for a steady supply of food. While Swedish vertical farms focus on high value produce such as herbs, the cuisine in Japan keeps the demand for non-native herbs very low. VegetaFarm currently focus on growing frill lettuce because of its short growing cycle and relative simplicity to grow. Other alternatives, such as kale and shiitake mushrooms, are being pursued as well but at a smaller scale.

VegetaFarm have tried to differentiate themselves from competitors by using Deep Sea Water (DSW) in their hydroponic systems. DSW is pumped from 800 meters below sea level and is sterile and naturally rich in minerals. The reason for using DSW for plant growth is that its calcium to magnesium ratio (Ca/Mg) is higher than other water sources which creates a healthier product. This is especially valuable in Japan where a more western diet has led to a lower intake of magnesium. According to a study by Karppanen, Pennanen and Passinen (1978), the Ca/Mg-ratio correlates to increased mortality from ischemic heart disease. Further Japanese studies have shown a similar correlation. Vegetafarm have therefore marketed their crops as "Edible Supplement-Vegetables". Whether the correlation has a causal relationship and introduction of DSW-grown lettuce can affect the occurrence of heart disease is still unproven.

The main costs of VegetaFarms systems are associated with labour, energy and foremost rent. VegetaFarm's showroom production is not profitable, but their main goal is to sell the equipment rather than the crops themselves. One explanation given as to why it is not profitable is that the government decides the market price for their crops, so producers cannot increase prices to increase profits. Another reason being that rents are very high in the bigger cities in Japan, even in the suburbs where VegetaFarm is located. The only way to circumvent the high rent is to locate the facilities outside of the cities, which eliminates some of the benefits of hyperlocal vertical farms.

5.2.7 Japan Plant Factory Association

Japan Plant Factory Association (JPFA) is a non-profit organisation, founded in 2010, by Chiba University with funding from the Ministry of Agriculture, Forestry and Fishery. JPFA collaborates with several leaders in the Japanese agriculture industry to offer sustainable farming solutions, ranging from high-quality and high-yield production systems to ensuring efficient energy usage. At their demonstration facilities at Kashiwanoha Campus at Chiba University, three facilities for growing lettuce with artificial light are being tested in collaboration with different corporations. The interview and visit to JPFA was conducted on May 10th, 2019. The field visit and interview was held by Associate Professor in hydroponic systems, Dr. Satoru Tsukagoshi. Tsukagoshi explained that JPFA investigate and research how different wavelengths of artificial light affect the plants' health, growth, taste and nutritional value. Figure 8 shows the testing racks of a handful of the companies that test their technology at the facilities of JPFA.

Tsukagoshi believes that Swedish actors who want to grow herbs should aim for a hydroponic system which uses either a deep flow technique (DFT) or nutrient film technique (NFT). In a DFT-system the plant roots are in direct contact with the nutrient-enriched water solution. Nutrients are added to the water automatically when the concentration runs lower than a predefined value. In NFT-systems the plants are suspended over a sloping bed and the nutrient-enriched water solution flows from one side to the other. Both these types are easy to set up and monitor. From his experience, aeroponics do not decrease water usage sufficiently to justify the high cost and complexity since the plants still need the same amount of water to grow regardless of hydroponic system.

Figure 8. Testing rack of LED-technology from different suppliers (Source: Authors)

At one of the showcased facilities for growing lettuce, the growing phase had been designed to be fully automated. A tray of new seedlings was placed on plane which a robot placed in the designated rack in the system. The tray is then supplied with the right amount of water and light for roughly four weeks and later returned to the employee automatically. Today, the growing area is still in direct connection to the transplant- and harvest area. Dr. Satoru Tsukagoshi believes that within a few years it will be possible to disconnect these areas to fully prevent contamination from the employees. Separating the production site from the work site is desirable since contamination leads to all crops having to be discarded and the whole facility cleaned before operations can be resumed.

Eri Hayashi, Vice President and Director International Relations and Consulting at JPFA, was interviewed during the same day. Hayashi mentioned that high income citizens are more concerned with organically grown produce and therefore more likely to purchase vertically farmed crops. Hayashi also mentioned that vertical farms are being pursued by JPFA to ensure more sustainable agricultural practises and to develop new technologies that can be used within the agriculture industry. To advance sustainable agricultural practises in Japan, JPFA collaborate with around 120 companies in different areas of agriculture all across Japan. Academia is involved in several of the projects and Hayashi believes that combining academia and enterprise will lead to a more sustainable future.

Despite Japan's comparably long history of indoor farming, only 30 % of all Japanese vertical farming actors are profitable according to Tsukagoshi. This illustrates the difficulty in reaching financial success even after much R&D, funding and experimentation. There are, however, significant differences in the industry landscape between Japan and Sweden concerning rent- and energy prices, market acceptance and government policies.

5.2.8 Buyers

The buyers of vertically grown crops can be divided into three groups: retailers, restaurants and end consumers. Controlled indoor farming produces crops of high quality and is therefore comparable with organic, high-end products for the buyers.

The vertical farms in Sweden are mostly focused on selling to retailers as shown in Appendix II. The three largest grocery chains in Sweden; ICA, Coop and Axfood, accounted for 86 % of the market in 2018 (Konkurrensverket, 2018). Retailers purchase large quantities at regular intervals, making it easy for the supplier to forecast demand. The B2B-model favours the large-scale farm, which seems to emerge as the most popular business model for vertical farms in Sweden. If the produce shows initial success in the market both the retailer and the VF have the opportunity to quickly scale up. The dominant market share controlled by a few major grocery stores make them an attractive partner for a VF focusing on scale as they have access to almost all consumers country-wide.

Wholesalers and restaurants in Sweden have strong purchasing power. Restaurants often buy wholesale in large quantities and are generally quite price sensitive due to low margins (Founders of Kajodlingen 2019, personal communication, 22 February). However, high-end restaurants also value unique produce of high quality. As experienced by Kajodlingen, constant order changes with short notice makes it difficult to supply high-end restaurants at a large scale. Per Östling mentioned in an interview conducted on 28 February 2019 that there are solutions to be found in the distribution to these restaurants by, for example, combining deliveries of greens with deliveries of fish. Fish is supplied to restaurants several times a week and their delivery system has already been exploited by producers of other foods like meat and cheese. Appendix II shows that some vertical farms in Sweden supply both retailers and restaurants without explicitly omitting any buyers.

Direct sales to the end consumers allow the VF to maximise their margins by cutting out the middlemen. Jonna Hansson mentioned in an interview conducted on 1 April 2019 that ICA bought their crops at 50 % of the retail value 15 years ago. Today, they purchase at the same price as they did 15 years ago while retail prices have increased by 50 %. This means there is a two- or threefold potential in revenue increase for a vertical farm if they sell directly to consumers. The problem lies in reaching customers without a pre-existing distribution network in place. Grönska considered selling crops directly to end consumers but realized that the logistical challenges made it unprofitable. Kajodlingen, who sell directly to consumers, believe that the distribution problem could be mitigated by having several smaller hyperlocal farms in the city. Many small farms are financially problematic for vertical farms, which are reliant on economies of scale due to large initial investment costs. Lufa Farms in Canada is an example of a combined greenhouse and VF that has successfully cut out the middlemen. By partnering with other local food producers, they are delivering tens of thousands of weekly food baskets to a select number of pick-up locations (Lufa Farms, 2019).

5.2.9 Suppliers

The suppliers to urban farms are vendors of growing-equipment, energy, seeds, nutrition, and space. Appendix II shows the equipment used by the Swedish and some international vertical farms. ZipGrow's growing equipment has been identified to be the most commonly used in Sweden. Some vertical farms have designed their own system, either to obtain an initial proof-of-concept or to leverage the advantages of developing their own system.

Producers of LED-lighting solutions are large suppliers to the industry as plenty of light is required for optimal growth. ZipGrow includes lights in their offer but many farms choose other alternatives to increase their growing efficacy. During an interview conducted on 28 February 2019, Owe Pettersson stated that Plantagon implemented water-cooled lights from a Korean supplier in their farm in order to increase growth rate. Ljusgårda chose Heliospectra's lighting solutions for their highly controllable light spectrum and vast indoor-growing experience (M Crommert 2019, personal communication, 1 March). Lighting is often very expensive and a crucial ingredient to a successful VF. A single light bar can cost around 20,000 SEK, which amounted to a total investment of 1,300,000 SEK in lighting for Ljusgårda (Heliospectra, 2018). Due to the vertical farms' high dependency on energy, a separate chapter *5.2.10 Energy market* has been added to briefly explain the energy market in Sweden.

Besides energy prices, renting space makes up a large portion of the cost structure of a VF. An important decision for vertical farms is where to locate their production. Inner-city prices are typically much higher than just a few kilometres outside of the city centre but moving away from the cities contradicts the notion of hyperlocal farming. Many vertical farms in Sweden have handled this problem by targeting otherwise unused spaces. Urban Oasis operate in an underground parking garage, Ljusgårda in an old industrial production facility, and Plantagon in the old archive of Swedish news publisher Dagens Nyheter. Tobias Kristiansson, property development manager at Castellum, explains that at the time of the interview held on February 22nd, 2019, the vacancy in Gothenburg is historically low. However, property developers are always interested in increasing property utilization. Basements and rooftops have often been neglected and unused, but property developers are improving their utilization as space is becoming scarcer in cities. One issue with co-location is that companies increasingly value privacy and security, explains Kristiansson, but adds that digital locks and other solutions could solve this problem.

The final suppliers to the VF industry are vendors of packaging, seeds and nutrients. These products are easily accessible and can be regarded as a commodity. Rademaekers explained in an interview on 18 February 2019 that seeds can be sent across the world in an envelope at the price of just a few dollars. Packaging material can be a small or a significant cost for a VF depending on packaging material. Plastic is very cheap and easily accessible but have a negative impact on the climate. The paper bags used by Grönska or other natural materials are expensive but more sustainable than the typical plastic packaging.

5.2.10 Energy market

A high dependency on consistent lighting implies a high dependency on energy supply and prices. Since 1996, energy is no longer supplied by the government in Sweden with the motivation for privatisation being higher flexibility and lower prices. Consumers are now free to choose supplier and energy source which makes it easy to select a renewable energy source for a VF in order to improve sustainability and reduce environmental impact. The average annual market price on the Swedish energy exchange is illustrated in Figure 9. The graph shows no real trend to where the energy price is going, but research from the Swedish Consumer Energy Markets Bureau (2019a) expects prices and price fluctuations to increase. The fluctuations depend to a great extent on external factors. In 2018, prices were 52 % higher than the previous year due to an unusually hot summer (ibid.). Less wind and rainfall led to higher prices of wind- and water powered energy which make up a large portion of the Swedish energy market.

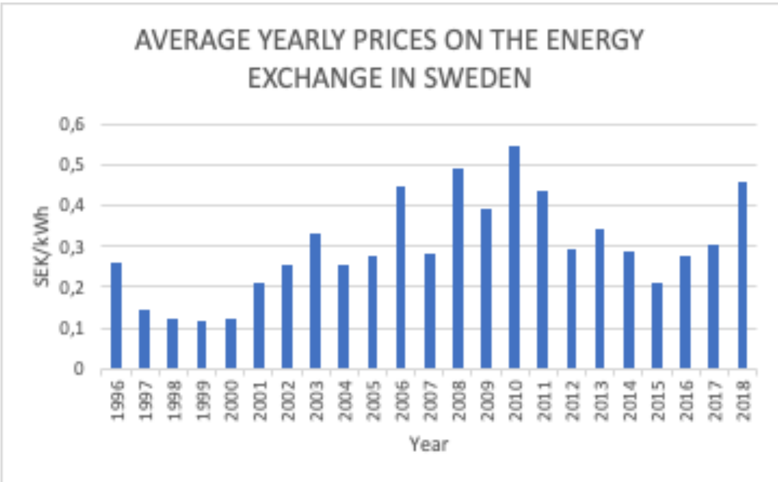

Figure 9. Average yearly prices on the energy exchange in Sweden based on data from the Swedish Energy Markets Bureau (2019a)

While there is no clear trend in energy prices, the trajectory for energy taxes is clearly up. Figure 10 shows energy taxes in Sweden from 1951, and energy tax plus VAT since 1990, in Swedish pennies per kWh (Swedish Energy Markets Bureau, 2019b). A tax above 0,4 SEK/kWh means more than 50 % of the energy prices are made up of taxes on an average year. On top of increasing taxes, Sweden aims to have 100 % renewable energy sources. Renewable energy is highly dependent on the climate, further increasing price fluctuation. Periods of low rainfall, wind and solar energy will cause price spikes and vice versa. As part of the renewable energy transition two nuclear power plants are planned to shut down in 2019 and 2020. Nuclear power is often used to match supply with demand. Closing two power plants is therefore expected to add to both price fluctuations and energy prices (Kristersson, Bohlin & Rosencrantz, 2019).

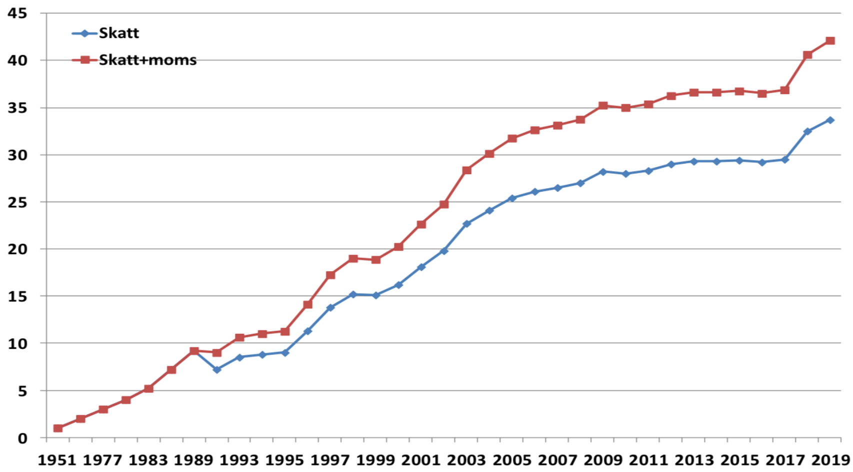

Figure 10. Energy taxes and energy taxes + VAT (moms) in Sweden 1951-2019 based on data from the Swedish Energy Markets Bureau (2019b)

6 Business models

Three main types of business models for vertical farms have been identified from the interviews and empirical data collected: large-scale production and distribution, small-scale production and local distribution, and integrated solutions. There is no established definition of what defines a large- or small-scale vertical farm. In this paper, the term small-scale refers to a production capacity that meets demand in the same city or local area as production. Large-scale refers to production where supply exceeds the local demand and needs to be transported elsewhere in order to be consumed. The term integrated solution means that the crops are sold or consumed at the same place as they are produced, without any need of transportation.

6.1 Large-scale

Large scale production has thus far only been accomplished outside of Sweden where companies such as Plenty, Aerofarm and Spread are market leaders. In Sweden, Plantagon has the most advanced plans to develop a large-scale production facility. Ljusgårda aim to utilize their whole factory of 7000 m^2, but a time frame has not yet been established. Large-scale vertical farms are associated with high initial investment costs in growing equipment, facilities, and supervising technology. The system needs to be automated or semi-automated in order to become profitable which requires technical capabilities and significant investments in research and development. The customers are retailers and restaurants, consistently ordering large quantities at regular intervals. The large output requires an extensive distribution and sales network since many customers are located in other cities. A business model canvas for large-scale vertical farms could include the elements listed in table 3.

#	Building Block	Description
1	Customer Segments	Retailers, Wholesalers, Restaurants
2	Value proposition	Locally grown, high quality, healthy crops at a consistent output
3	Channels	Direct distribution or partnerships with large, pre-planned deliveries
4	Customer Relationships	Partnerships with retail buyers, wholesalers or large restaurants
5	Revenue Streams	Long-term contracts
6	Key Resources	Supervising technology, automatic systems, distribution & sales network, employees, production equipment
7	Key Activities	Monitoring of crops, supply chain management

8	Key Partnerships	Distributors, retailers, restaurants
9	Cost structure	Energy, labour, rent

Table 3. The different elements in a potential business model canvas of large-scale vertical farms

6.2 Small-scale

In Sweden, a variety of actors such as Ljusgårda and Grönska have started with small-scale production and local distribution. The initial investment costs are much lower compared to large-scale vertical farms, and the farm is easier to supervise and operate. Ljusgårda operate without automatization while Grönska have established a semi-automated system. The customers are local retailers, restaurants, or individuals. Distribution is most commonly ensured through deliveries by car or truck but could be distributed through other means of transportation like Kajodlingen's bicycle deliveries or pick-up at the production facility. While the customers of the VF are retailers, all small-scale vertical farms interviewed have established customer relationships through social media. Social media channels are used as a marketing- and educational tool where the production process and company progress are being highlighted. Table 4 shows a potential business model canvas for a small-scale farm.

#	Building Block	Description
1	Customer Segments	Retailers, restaurants, end consumers
2	Value proposition	Locally grown, high quality, healthy crops at a consistent output
3	Channels	Direct distribution or direct sales of smaller quantities
4	Customer Relationships	Partnerships with retail buyers and restaurants, social media to connect with customers
5	Revenue Streams	Per delivery
6	Key Resources	Employees, supervising technology, production equipment
7	Key Activities	Production management and supervision, marketing and sales
8	Key Partnerships	LED-light suppliers, retailers, restaurant, system suppliers
9	Cost structure	Energy, labour, rent

Table 4. The different elements in a potential business model canvas of small-scale vertical farms

6.3 Integrated solution

Vertical farms offering an integrated solution provide full-service solutions for their customers, including all necessary equipment, technology, and training. In this business model, the value proposition is shifted from selling crops to providing easy-to-use solutions for the customers to grow their own crops. An integrated solution has been adopted by grocery stores and restaurants in Sweden who want to expand their product range or experiment with new produce. Internationally the integrated solution has been used by entrepreneurs, schools, hotels, and farmers aiming to prolong the growing season. The key resources for integrated solution providers are the support systems, supervising technology, and training programs. The farm needs to be easy to set up and operate in order for inexperienced people to be able to run it successfully. Table 5 shows what a business model canvas for integrated solution providers could look like.

#	Building Block	Description
1	Customer Segments	Retailers, restaurants, farmers, entrepreneurs, schools
2	Value proposition	Complete ready-to-use vertical farming solution
3	Channels	Direct distribution
4	Customer Relationships	Education and training, sales representatives, continuous support
5	Revenue Streams	Payment per system, recurring payments for software
6	Key Resources	Supervising technology, support systems, employees
7	Key Activities	Training, marketing and sales
8	Key Partnerships	With all customers
9	Cost structure	Buying or producing integrated VF

Table 5. The different elements in a potential business model canvas of integrated-solution providers

7 Analysis

The analysis combines the theoretical models and frameworks with empirical data in order to gain a better understanding of the industry, business models, and challenges and benefits of vertical farming.

7.1 Industry analysis

The chapter includes an industry analysis based on the five forces introduced by Porter: threat of new entrants and substitutes, the bargaining power of suppliers and buyers, and the competitive rivalry in the industry. The analysis is made with data gathered from interviews conducted with urban farming companies in Sweden in order to assess the industry landscape. The list of interviewees can be found in section *3.3 Interviewee selection process.*

7.1.1 Threat of new entrants

An industry with extraordinary profitability will attract new entrants, eventually driving the profitability to a minimum level to keep the industry going. It is therefore important for incumbent firms to take advantage of entry barriers.

Owe Pettersson mentioned in an interview held on 28 February 2019 that when Plantagon started in 2008, they were the only actor on the Swedish market and one of the first-movers in the world. There was no competition or barriers to entry for anyone possessing the right resources and capabilities. Since then, a number of urban farming companies have been founded in Sweden but are yet to reach profitability. Globally, however, some vertical farms have reached large-scale success, mainly in Japan, Canada, and USA.

Rademarkers (2019) brings up an important point on scalability in regard to entry barriers. The container farm provided by Futufarm and Freight Farms are sold as full-service solutions. The fully equipped container solution provides a person with no prior experience in vertical farming with enough knowledge to operate a farm after only a couple of days of training. Such an easy-to-use solution removes entry barriers to an industry traditionally associated with high barriers to entry. A conventional farm is difficult to set up, requires expertise, and is less likely to quickly respond to competition in the local area. On the other hand, competition from other VF-solutions can be expected to quickly increase if the success of one VF shows great profitability in an area. The scalability of vertical farms favours the market leaders who can expand their business as necessary, while companies struggling with profitability risk getting left behind as they cannot compete with the lower price large-scale farms can achieve through economies of scale.

Economies of scale is an important barrier to entry as it mitigates the impact of large initial capital requirements on firm profitability. A vertical farm incurs a lot of upfront costs in equipment, lights, and space. The operating costs are comparably low and mostly affected by salaries and energy. Increasing the scale of production early in the industry life cycle is thus a way for incumbents to scare off new entrants who are facing even larger investment costs to catch up. However, De Brun Skantz and Crommert explained that access to investors is in a good state because that the risk propensity in food-tech is very high (N De Brun Skantz 2019, personal communication, 8 April; M Crommert 2019, personal communication, 1 March). Pettersson provided contradictory information in claiming that finding investors for a new technology with a short track record is one of the biggest challenges of starting a VF (O Pettersson 2019, personal communication, 28 February). Access to investors depends on many factors, but the amount of newly founded vertical farming companies in Sweden that have taken in capital from outside investors suggests capital requirement is not the biggest issue for vertical farms. Therefore, if funding is secured and until incumbents have too strong pricing power due to scale, a full-service solution like the one offered by Futufarm can provide a new entrant with an easy and accessible way to quickly enter the market.

A smaller farm, like the container solution, will require fewer middlemen or better access to distribution channels in order to be profitable. As experienced by Plantagon, Ljusgårda and Spisa, retailers often require a purchasing price at least 50 % lower than the final retail price, eroding much of the margin for the producer. New entrants who do not possess the capital required to compete on price through economies of scale can enter the market if they have access to efficient distribution channels. An example of this strategy was employed by ICA Maxi in Halmstad who purchased a container farm operating in direct connection to the store where the produce will be sold (H Rademaekers 2019, personal communication, 18 February). Such a strategy increases profitability for the producer and lowers the barriers to entry for the industry as supermarkets can become self-sufficient in certain greens.

When production becomes connected to distribution it opens up the possibility for product differentiation and brand recognition. Crops can be produced in the grocery store and branded as their own to create a recognition factor for the customers, making it more difficult for new entrants to compete. A product differentiation advantage is facilitated with highly controlled indoor farming according to Crommert, who tweaked his arugula recipe to a mild flavour unique to Ljusgårda (M Crommert 2019, personal communication, 28 February). The ability to create unique flavour profiles of the same produce could create barriers to entry for unknown producers. There are, however, currently not enough vertical farms operating in Sweden to assess whether brand name, special flavours, and marketing will have a large enough impact to keep competitors away.

The threat of new entrants depends on the type of business model that will be adopted and what ends up being the industry standard. If store-connected farms become popular, the threat of new entrants from external companies is quite low as the Swedish retail market for groceries is more or less an oligopoly. These large retailers can decide to implement connected solutions for all their stores and have full control of the retail market. This business model would make large-scale farms less attractive as much of the market would already be supplied by a few retailers. If economies of scale turns out to be the winning strategy, new entrants are likely to keep increasing until a few major firms have emerged as winners and created enough barriers to entry to keep smaller actors at bay.

In conclusion, it is difficult to predict how the competitive landscape of a new industry will end up. As shown in Appendix II, most of the larger urban farming companies in Sweden have been founded in the past few years. Vertical farming is still in the very early stages of the industry life cycle. Figure 11 illustrated how the number of firms changes over time in an industry. Until the industry reaches maturity, it can be assumed that new entrants will keep arising at a high pace until the industry has matured.

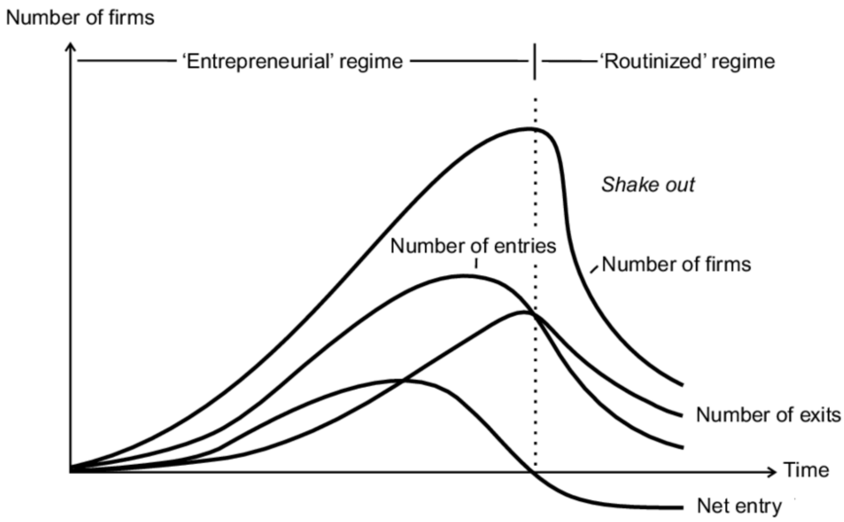

Figure 11. Number of firms over time as illustrated by Fritsch (2013)

7.1.2 Threat of substitutes

The threat of substitutes is not particularly relevant at this point of time in the industry life cycle. Vertical farms are the substitutes to traditional farms. Different techniques compete to grab a share of the new industry but none of the interviewees could identify a specific threat from substitutes. The largest threat is that consumers do not adopt the new food-tech innovations and keep purchasing imported greens. There is always a risk that a new and better technique evolves, but no such threat has been identified at the time of writing this report.

7.1.3 Suppliers' bargaining power

ZipGrow seems to be the largest supplier of growing equipment, indicating that they have a high degree of bargaining power. Many companies are dependent on ZipGrow's equipment and expertise, placing them in a strong position in the industry until competitors emerge. ZipGrow towers can be both leased and purchased. Leasing gives the VF more flexibility and power to scale up or down and to evaluate the business model without binding a lot of capital. Some companies use ZipGrow, or other equipment suppliers, while developing their own systems. Developing a system in-house is costly and time consuming but can give additional technological moats and removes the bargaining power of at least one supplier. Grönska was able to develop their own system since they had an architect and an experienced craftsman in the founding team. These capabilities have made them less reliant on suppliers and they have the potential to offer their own system to future vertical farmers.

Lighting vendors, like Heliospectra, are suppliers to commercial greenhouses, cannabis farms and horticulture producers. These producers order large quantities worth millions of SEK. Such quantities mean a small VF, lacking the purchasing size of a commercial greenhouse, is not in a strong bargaining position. Smaller producers are instead left with the difficult task of balancing the trade-off between price and quality. Large-scale vertical farms will have stronger purchasing power, but no farm in Sweden is comparably large to the lighting vendors' other customers yet.

The high energy consumption associated with the lighting solutions makes energy prices important for the financial success of a VF. While the market has become privatised, energy prices have not dropped, despite consumers theoretically being in a stronger position to bargain. The flexibility has increased but the price largely depends on output and taxes, neither of which a consumer has significant power to negotiate.

The price of space in cities is generally a result of an auction where the highest bidder sets the price. This model leads to high prices where demand is high and can be a problem for a centrally located VF. However, price follows demand both ways and renting unused and unwanted spaces is a way for vertical farms to increase their bargaining power. These unwanted spaces can be transformed into a green landscape of fresh produce at a low price, while still creating value for the property owner who may otherwise fail to find a suitable tenant. There is an inverse correlation between a facility's usability and a tenant's bargaining power. Since vertical farms can use almost any type of building with enough space to fit the farming equipment, they are in a strong position to obtain a beneficial contract. This has been proven a successful concept by most of the vertical farms in Sweden. The VF solutions provider Grönt Under even advertise the business model of unused spaces in a quote on their website, "In unused cellar rooms and empty concrete spaces, we let the green duvets of hydroponically grown micro-green, vegetables and herbs grow." (Grönt Under, 2019).

The suppliers of miscellaneous products to the VF industry constitute a relatively small amount of the firms' costs. Vendors of commodity products, like seeds and nutrients, can be found all over the world and switching costs for a VF are low. According to all interviewees, the ingredients that eventually become the final product make up an almost irrelevant cost in the bigger picture. Low switching costs and an abundance of supply leads to low bargaining power for the suppliers. Commodity products are often accompanied by low margins and competitive pricing.

Overall, the suppliers' bargaining power is moderate. The bargaining power from suppliers of equipment and lighting solutions is high, while it is lower for property owners of unwanted space and miscellaneous vendors. The high degree of bargaining power from equipment suppliers is mitigated by many companies by creating their own solutions, tailored to their needs.

7.1.4 Buyers' bargaining power

As vertical farms use no herbicides or pesticides and provide a high-end product, the crops are compared to high-end organic crops in the analysis. The inconsistent data on customer acceptance and WTP for organic products illustrates the challenges in predicting how vertically farmed greens will be received in the market. Studies on price elasticity for organic produce showed contradicting results, but actors like Ljusgårda and Grönska have experienced high customer acceptance in Sweden and a WTP similar to comparable organic products. In conclusion, price is important when it comes to commodity products such as foods, but exactly how important is difficult to say. Consumers generally do not have a preferred brand of greens as the supply varies with seasons and local factors in the producing countries. Low customer loyalty means there is no lock-in effect and customers are quick to switch brands if presented with a better option. The consumers of greens therefore have low switching costs and indirectly a high bargaining power as they make up the demand forming the basis of retailers' purchasing decisions.

The majority of revenues for vertical farms in Sweden currently come from grocery stores who have a notoriously high bargaining power. ICA, with a market share of over 50 %, gives a producer access to over half the Swedish market and are in a very strong position to negotiate. The large market shares of Swedish retailers leave little room for producer bargaining power. VF companies can partly mitigate their negotiation disadvantage by offering strong product differentiation. A vertical farm can offer local production of crops at a consistent rate throughout the year. Traditional farming only allows for production of certain crops for part of the year, leaving a gap in the market during the darker months. If there are no other alternatives to local produce, vertical farms should, in theory, have a stronger bargaining position. Hansson stated that retailers are requesting more Swedish produce than ever (J Hansson 2019, personal communication, 1 April). Meanwhile, the share of import is increasing. Ljusgårda focused on matching the price of equivalent products and have sold three times more than forecasted in their first three locations. They currently have more orders than production capacity, implying that there is a market potential for vertical farms despite the low bargaining power.

In conclusion, the bargaining power of buyers is quite high. This is also true for conventional farming and does not exclusively affect urban farms. To mitigate the problem, the urban farms interviewed in this study have focused on high-margin products with a high price per kilo. Microgreens, herbs and leafy greens all qualify into this category. A strategy of producing after price instead of pricing after production is necessary in order to compete in a highly competitive and mature market. Product differentiation and consistent supply of local produce will further facilitate beneficial contracts with retailers.

7.1.5 Competition

As globalization connects the world, farming has become a fiercely competitive industry. The global market favours low-labour countries with advantageous growing conditions, making it increasingly more difficult to survive as a Swedish farmer where labour-costs are high and growing conditions poor. In 2011, subsidies constituted almost half of Swedish farmers' factor income (Ander, 2013). Between 2010 and 2015, 1.6 billion euros were granted to agricultural activities in Sweden annually (Nyhetssajten Europaportalen, 2019). This is a strong indication that the agriculture industry as a whole is characterized by highly competitive rivalry and low profitability.

The intense rivalry, aggressive price-cuts subsidised by the authorities, and low product differentiation has made farming a tough industry to enter. Vertical farms try to disrupt the industry by having a niche focus on high-quality, environmentally friendly, locally produced greens in order to narrow the scope of competition. If transportation distance is taken into account, the only real comparable competitors are local producers of organic crops. The increasing demand for organic and locally produced crops has created a spike in urban farming companies over the past years. Sweden is considered as a promising country for the development of vertical farming because of the prevailing environmental- and health consciousness in the country.

In conclusion, the threat of competition on a broad scale is very high. However, the threat of competition in the targeted hyperlocal market segment is currently quite low as there are no other alternatives to locally produced crops in Sweden for large parts of the year. While the number of vertical farms in Sweden is steadily growing, no farm has reached a significant size to where it hinders competitors to enter. When Ljusgårda launched their arugula in three ICA-stores, the customers' demand for arugula increased from what ICA had forecasted without reducing demand for other leafy greens. The current demand for local produce can therefore be assumed to be higher than the current supply, suggesting there is an opening in the market for vertical farms.

Furthermore, vertical farms show strong competitive advantages in distribution, food-wastage, crop variation, health, taste and environmental impact. If vertical farms turn out to become economically sustainable the competitive rivalry is expected to quickly increase as the current actors scale up and new firms enter. Until then, competitive pressure remains high in the general market for greens, but low in the high-end, locally produced, organic market for greens. How much these two markets overlap is difficult to estimate and depends on the consumers' view on food and new technology. The interview data suggests there is room for the total serviceable market to increase with the introduction of vertical farms before the segment of local production will need to compete with the market for imported greens.

7.2 Sustainability analysis

The environmental and social sustainability benefits of implementing vertical farming in Sweden are listed below. This is followed by the economic benefits as well as economic challenges that have to be overcome in order to compete on profitability with conventional farming. Table 6 summarises the key sustainability benefits identified through interviews with urban agriculture actors and secondary research.

Benefit	Economic	Social	Environmental
Reduced transportation	Reduced cost for washing, packaging, repackaging, and transporting. Reduced waste due to transport and handling	Improving air quality, product quality, and nutritional value	Reducing CO_2 emissions, air pollution, noise. Reduced waste
Reduced water usage	Reduced cost	Not compromising water resources	Not compromising water resources, no overfertilization of rivers
Reduced use of fertilizers, pesticides	Reduced cost	Increased consumer health	Reduced environmental impact
Improved productivity	Greater yields per area, higher scalability	Reduced repetitive and uncreative work, increased amount of urban jobs	Decreased need of land use
Food production not being weather dependent	Easier forecasting, economic loss due to wastage prevented, seasonality removed	Food supply secured during all conditions	Bad harvest due to climate change prevented, less import needed during winter
Use of renewable energy	N/A	Improved air quality, less noise	Reducing CO_2 emission, air pollution

Table 6. A summary of the key sustainability benefits of vertical farming

7.2.1 Environmental

While vertical farming is not a solution to all environmental problems, it can compete with traditional farming in many aspects. Despommier (2010) believes that the VF can be part of a solution to many existing environmental problems. Vertical farms make it possible to use resources that do not cause emissions and does not degrade ecosystem services. Vertical farming can operate with more ecological responsibility and with a lower carbon footprint than the agriculture industry does today. To fully capture the environmental benefits of vertical farming, the farms should aim to follow the guidelines of a circular economy presented by the Ellen Macarthur Foundation (2019) of using renewable energy, looping water, using sustainable nutrients, and avoiding synthetic pesticides. Looping water is inherent to hydroponic systems and renewable energy has been mentioned as a prerequisite for vertical farms to produce crops sustainably. Furthermore, pesticides are avoided completely due to a closed environment. The remaining prerequisite for a circular system is to use nutrients from food by-products which cannot be controlled in this study due to the Swedish farms' keeping their nutrient solutions a trade secret. However, most farms interviewed stated that the nutrients were produced sustainably. It is therefore concluded that the systems of vertical farms in Sweden are circular to a high degree. The remainder of the chapter lists the environmental benefits of implementing VF in Sweden, assuming the guidelines of a circular system has been followed:

Carbon footprint. One of the biggest advantages to vertical farming is the opportunity to locate it in the city centres which in turn leads to a number of positive outcomes. As urbanisation takes place, more local production becomes a necessary part of the transition to revolutionize the food industry. Local production is a necessary step towards a sustainable society through reducing transportation. The demand for local produce already exists and it lies in every person's best interest to remove the non-value adding steps of the food value chain. In America, 20 % of all fossil fuels consumed annually go to agriculture (Besthorn, 2013). Most of it is consumed by transporting or storing, but a large part comes from the heavy machinery used in ploughing, seeding and harvesting (Kalantari et al., 2017). Growing food in the cities will greatly reduce the need for transporting and storing fresh produce. Additionally, using renewable energy sources can make a vertical farm carbon neutral, or even carbon negative as in the case with Plantagon. Sweden, with a large amount of renewable energy and relatively low energy prices, is thus a favourable country for a VF in regards of energy consumption.

Reduced food waste. Removing steps in the value chain can help combat the growing problem of food wastage occurring in every step. According to FAO (2011), fruits and greens are the category of food with the highest degree of waste products with 40-50 % of global produce never being consumed. Local production assures less time in storage and transportation, the two activities where most of the spoilage occurs. Local production can also better match supply with varying demand for different foods, further reducing food waste due to unused or unsold greens.

The FAO report (2011) further states that too much focus on food appearance in industrialized countries is an important factor in why so many fruits and greens are discarded by supermarkets. This argument heavily favours highly controlled indoor farming, as the crops can be mass-produced with very little variation in both looks and taste.

Water. Worldwide, the agriculture industry uses approximately 70 % of all freshwater consumed annually (Khokhar, 2017). The high water-usage can be detrimental to areas of low natural water reserves. With vertical farming, water usage can be reduced by up to 99 % compared to conventional agriculture practises (ibid.). Circulating the water gives the plants the exact amount they need with no water leaves the premises which could cause eutrophication in rivers or contaminate the local ecosystem.

Land use. As the demand for food has increased along with the population, the quest to find arable land has become more difficult. Arable land is scarce and when new land that favours food production is found, the existing ecosystem often gets destroyed. Kalantari et al. (2017) found that vertical farming could increase crop yield by up to 100 times depending on the crops grown and farm height. This would reduce the need to find more farmland and can allow the natural ecosystem to recover.

Resilience. The layering of separate growing spaces creates further advantages for a VF: crops can be grown year-round, several different crops can be grown simultaneously, and there is no need for crop rotation as there is no soil. Growing indoors removes the risk of external, uncontrollable factors like climate change, weather issues and natural disasters. Seasonality effects are also removed, and strawberries could be grown in the middle of the winter in Sweden.

Pesticides. The closed environment of vertical farms prevents germs and pests from damaging the produce which eliminates the need of using pesticides. None of the companies interviewed used any pesticides or herbicides. They instead used protective gear for employees and an airlock-door to enter.

7.2.2 Social

Vertical farms could result in a number of social benefits that would add further value to the surrounding communities. The identified human and societal capital gains are the following:

Health. Crops grown indoors can potentially be more nutritious and healthier for people to consume. The highly controllable growing conditions allows for growing precision, maximizing its nutritional value and harvesting at peak growing cycle. Pesticide and herbicide use can be removed due to the closed space, creating a healthier, better tasting product. The lack of transportation, storing and cooling could even create a more nutritious product. Greens that have to ripen during transit are harvested prematurely and cannot take advantage of the full nutritional development of the crop. Additionally, nutrients can degrade during the storage process. Eaves and Eaves (2017) discovered that if spinach is stored cooled for eight days, it has lost 47 % of its folate, a B-vitamin needed for DNA synthesis.

Cleaner air. A VF can even be used as a 'city lung' where the plants grown there can use their natural ability to soak up carbon dioxide to clean the air. Plantagon, for example, use carbon dioxide from the air of offices located in the same building and in return provide more oxygen to the office spaces (O Pettersson 2019, personal communication, 28 February).

Local businesses. Locating food production in city centres is expected to increase economic growth for the area (Specht et al., 2014). Locating production closer to the consumers can reduce transaction costs, facilitate collaborations and will lead to new jobs. Currently, farmers are run by the older generation in Europe, and few young farmers want to continue growing their family farms in favour of moving into the cities and securing a degree (European Commission, 2017). Less than 6 % of farmers in the EU are younger than 35, while over 31 % are older than 65, and young farmers are often constrained by land or credit access (ibid.). Vertical farms could provide young farmers with the opportunity to run a centrally located farm while pursuing their degrees. People who are not farmers can quickly be taught the skills required to work at a VF. Job opportunities include surveillance, managing the crops, harvesting, energy management and waste management (Kalantari et al., 2017).

Safer farming. Vertical farms can be much safer than a conventional farm by eliminating the need of heavy machinery, as the usage of such machines is always a hazardous activity accompanied with high risks of injury. The challenge for vertical farms lies in creating easy-to-use equipment. The height of the farm can lead to worse ergonomics and higher risk of injury while creating bottlenecks through the use of ladders or scissor lifts. Most vertical farms in Sweden are circumventing this issue by using lower height farms. Internationally, the solution for large-scale farms has been automated shelves which the Swedish firms plan for as production volume increases.

Education. Growing the food where it is consumed can serve as an educational tool. Specht et al. (2014) sees a VF as the link between producer and consumer, suggesting that a partnership with farms and schools can help young individuals understand where food comes from and what makes it healthy. Farm and school partnerships have already been initiated in several places, including New Jersey, where Hopewell Elementary School has implemented a farm-to-cafeteria program (Hopewell Elementary School, 2018). Another example is Science Barge greenhouse which combines a greenhouse with educational purposes and is open to the public year-round (Specht et al., 2014). In Sweden, Kajodlingen have offered self-harvest days during summer which has been educational for, and appreciated by, city dwellers.

7.2.3 Economical

For vertical farms to be economically sustainable they need to have a competitive edge that generates a cash flow which ensures liquidity while still generating above average return to their shareholders. There is no definite answer to whether this can hold true in Sweden as the industry is in its infancy. While there are obvious environmental and social benefits to vertical farming, the economic sustainability has been the restraining factor to why vertical farms have not become successful sooner. The challenge for the vertical farms is to overcome the costs listed below through a combination of increasing sales and lowering expenses. Increasing sales requires market adoption and market acceptance of the new technology, while reducing costs largely depends on technological advancement.

Investment. Due to the high initial investment cost associated with vertical farming, a reasonable payback time needs to be achieved. The high upfront costs have been mitigated by taking in outside investors in order to survive the first few years. While no VF in Sweden is yet profitable at a large scale, a few expect to reach profitability soon with a calculated payback period of around five years. The high investment costs are combated by in-house development, the use of unwanted space, and by leveraging existing distribution systems.

Energy. Since vertical farms use artificial lightning to grow produce, energy costs are high and make up a large part of the operating cost (Kalantari et al., 2017). The use of LED technology has made it possible to lower energy consumption and is a better alternative to conventional High-Pressure Sodium (HPS) technology, often used in greenhouses. The technology for LED-lights is assumed to continue falling while renewable energy sources, like solar power, is expected to improve in quality and reduce in cost. A margin of safety will be necessary for energy price fluctuations from external factors like government taxation or weather effects.

Alternatives for leveraging the sunlight in a combined greenhouse and VF has been considered but not yet deployed in Sweden. Another solution to mitigate energy cost is to use district heating in order to recycle the heat produced in the growing process. The technique of district heating is already well established in Sweden, where excess heat from the cooling of ice rinks or public baths generate heat for households located nearby (Mattsson, 2019). A district heating solution could be used to heat apartments or offices located in the same building as a VF, drastically reducing their energy costs. Sharing resources with other property owners can provide an opportunity to recycle water, energy and heat while reducing costs for the VF. Safikhani et al. (2014) argue that a VF can significantly lower the energy bill for the rest of the building due to the excess heat produced in the lighting and growing process. The theory has been supported by its successful deployment by Plantagon.

Labour. Labour costs are another large expense item for vertical farms. In order to increase profitability, vertical farms have to develop semi-automated or wholly automated systems. As explained by Grönska, automating the most time-consuming processes in the production chain solves most of the problem. Automatization is, however, costly and time consuming and needs to be supported by a high production capacity (J Hansson 2019, personal communication, 1 April).

Rent. The price of land in city centres tends to be significantly higher than outside the city where conventional farms are located. Most farms in Sweden have solved the problem by using unwanted space. This requires vacant facilities, which are at an all-time low in Gothenburg (T Kristiansson 2019, personal communication, 28 February). Rent prices and availability vary greatly between cities and countries, why a general solution cannot be given. So far, the few existing VF companies in Sweden have been able to secure beneficial contracts. As the industry grows, there is a risk that space becomes scarcer and the farms will have to move further away from the city centres. An alternative solution is to integrate a VF into a symbiotic relationship in an existing building. Such a relationship has been utilized by Plantagon who cleaned the office air while reducing energy costs for the building through district heating.

Crop supply. The challenge is to produce cost-competitive crops that can compete with similar products, or to produce products of higher quality which customers are willing to pay a premium price for. Not all crops are suitable for VF. Some have long growing cycles; others do not thrive in indoor climates or induce too many costs to contribute with a positive ROI. Crops need to be evaluated and compared over a number of factors and measured against customer demand. Identified elements that influence crop viability are growing cycles, retail price, variable growing costs, quality of produce, risk of crop failure and production capacity per area. The existing vertical farms have landed in producing herbs, leafy greens, and microgreens due to fulfilling these criteria. Many farms are, however, experimenting with other crops like fruits, berries, and mushrooms. The crop range is expected to increase as R&D investments are capitalised.

Consumer acceptance. In order to create economic growth, consumers have to be willing to purchase vertically grown greens. According to De Brun Skantz at Grönska, consumers showed surprising willingness to pay for vertically grown greens, which could be explained by Swedish consumers environmental consciousness and willingness to try new things (N De Brun Skantz 2019, personal communication, 8 April). De Brun Skantz statement is supported by Johansson (2016), who found that Swedish consumers are more prone to buy Swedish produce despite being more expensive than imported alternatives. However, some customers do not completely understand the innovation of vertical farming and VF actors have to continuously increase consumer awareness about vertical farming and its benefits.

Cost reduction. Despite the mentioned challenges to obtain economical sustainability, there are a number of cost reduction benefits associated with vertical farms. Reduced need for transportation, water, fertilizers and pesticides in combination with improved productivity will result in lowered operating costs.

7.3 Macro-environmental analysis

The macro-environmental factors are analysed using the PESTEL-framework aimed to support the Porter analysis by including external macro elements. Most external factors affecting the agriculture industry are in favour of the vertical farms' future performance. Conventional farmers will face a greater challenge in meeting these external changes since they have already spent a considerable amount on their current resources and capabilities. The political, economic, social, technological, environmental, and legal factors affecting the urban agriculture industry are discussed below.

Political

Food tech. The goal by UN to ensure sustainable and resilient food production could be accomplished with the implementation of vertical farming. Further technological advancement is, however, needed before vertical farming becomes a viable alternative for a wider range of produce than leafy greens and herbs. Furthermore, it is in the interest of the Swedish Government to let vertical farms succeed due to the many societal and environmental benefits it brings. Grönska received the "Stockholm Innovation Scholarship" in 2016 for their efforts towards a more sustainable food production. It can be assumed that innovations within the agriculture industry will continue to receive attention in the future.

Subsidies. Since subsidies are a major factor income for Swedish farmers there is a risk that the low profitability in the food industry will affect vertical farms negatively in the long run. If vertical farms will not be able to take part of these subsidies they will have to compete based on more efficient agricultural practices. Being forced to create more efficient processes could potentially create a competitive advantage in the long term and solve the issue of low industry profitability.

Economic

No external economic factors which could potentially change the outcome of the urban agriculture industry could be identified. The demand for food is assumed to not follow the economic cycle and is therefore almost constant over time.

Social

Health focus. The changes in consumer lifestyle and attitude towards more locally grown, environmental positive and healthy greens is a favourable shift in consumer behaviour for vertical farms. Vegetarian and vegan food is becoming increasingly popular in Sweden with the demand for organic produce following. It is an indication that the demand for vertically grown greens will be increasing for the coming years which would allow for scalability and increased profits.

Societal focus. A social trend towards more environmentally conscious choices from individuals has been prevalent in Sweden the past years. Climate activists like Greta Thunberg have created a social pressure towards reducing greenhouse gases and recycling our resources. All vertical farms in Sweden interviewed have named Sweden as a strong candidate to adopt vertical farming due to the Swedes' climate consciousness. If vertical farms succeed with marketing their produce as the most environmentally conscious alternative, they can potentially expect to see a rise in demand.

Environmental

Climate change. The number of natural disaster events have increased rapidly during the last decades (Ritchie & Roser, 2018). During the summer of 2018 serious drought issues, in both Sweden and in countries where Sweden imports greens from, caused an undersupply of produce. It highlights the importance of having agricultural practices that can cope with climate change so that food can be provided to the population at any time. Since VF is a very resilient and secure way of producing greens it can be a way to cope with climate change.

Technology

LED technology. Based on the projections given by U.S. Energy Information Administration (2014) the LED-technolgy is expected to develop rapidly the coming years, leading to an expectation of reduced energy prices over time for VF. Figure 12 shows LED-light efficacy projections and historical development and the cost per bulb/lamp. Average lightning efficacy means light output per unit of energy consumed.

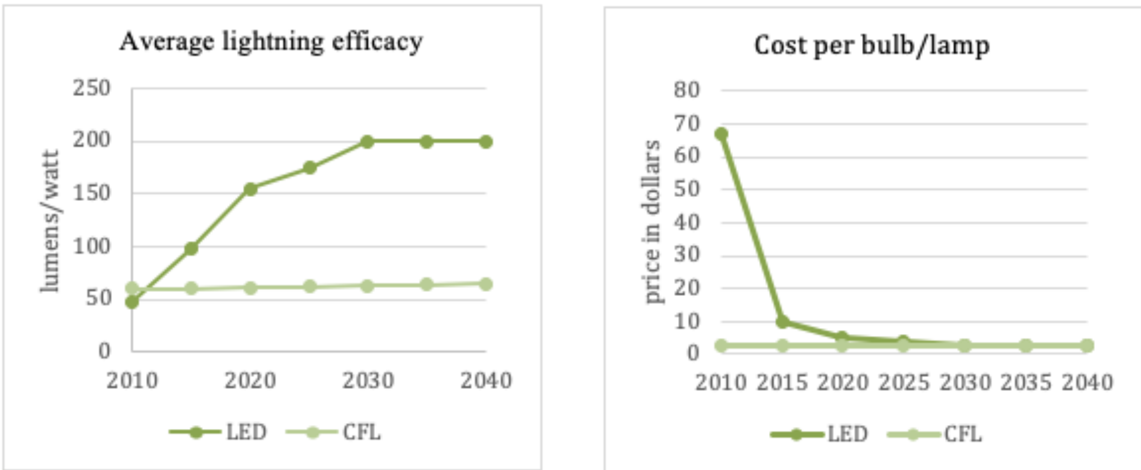

Figure 12. Average lighting efficacy, based on U.S. Energy Information Administration (2014)

Legal

Certification. Organic products usually have one or several markings to indicate that a certain level of sustainable production is met. Some of the most common certifications include KRAV-marked products in Sweden and EU's organic certification, but a myriad of new certifications has emerged in conjunction with the rapid growth of the market for organic products. The certifications were created for conventional farming methods and often include criteria such as crop rotation and soil health, factors that are not necessarily relevant for vertical farms as they use no soil. This, in turn, can lead to a problem of promoting the message of organic products for this new type of farming. On the contrary, vertical farms are marketing their crops in other ways to highlight a sustainable production process. Grönska, for example, have a description on the packaging of their herbs which explains that the crops are grown sustainable, in the local area without the use of pesticides. To overcome the challenge, the certifications need to be evaluated and analysed, and a need for new certifications or alternative methods for communicating ecological farming might emerge. Vertical farms should aim to align their certification goals with already existing options since too many different types of certifications likely will cause consumer confusion and distrust.

Disposable plastics. Grönska mentioned that the government might take action to reduce disposable plastics within packaging. Thus, it is important for vertical farms to incorporate a strategy that can solve the distribution without the use of plastic. This is not a problem that is isolated to VF but will affect the whole industry. Vertical farms have the possibility to start their distribution network incorporating renewable packaging options right away which could create a competitive advantage in the short- to mid-term.

7.4 Business model analysis

The business models are evaluated based on theory and empirical data from interviews. This chapter aims to identify the challenges and opportunities of each business model. A conclusion of how the different business models can be implemented in Sweden can be found in Chapter 9. Four key challenges to profitability, which the different business models aim to leverage, have been identified: scale, automatization, removing the middlemen, and creating a competitive edge.

7.4.1 Large-scale

Industrial premises with a large growing area mean economies of scale can be reached. Such a business model creates value by offering high-quality products at a competitive price. In order to reach economies of scale, the high initial investment costs compared to conventional farming methods, like that of Kajodlingen, need to be distributed over higher sales volumes. By dividing the fixed costs over more crops, the price per crop can be reduced to gain a competitive pricing advantage. A large-scale farm can create a moat to competitors by always pricing their crops lower and securing a significant market share. Competitors will have a hard time replicating the business model and need to put in huge investments while trying to compete for customer relations with a well-established actor.

Automatization becomes increasingly important with scale in order to lower operating costs such as labour. Automatization can be achieved through advanced monitoring systems and the introduction of robots in different stages of the process. The farm does not need to be fully automated; the most time-consuming activities, such as seedling and harvesting, are where most of the value is to be gained. In an interview with Owe Pettersson on 28 February 2019, he argued that a high degree of automatization is a necessity as farm height and scale increases with most of the labour induced in seedling, harvesting and cleaning the racks. Horizontal planes are expected to be adopted by large-scale producers as the vertical planes does not scale as efficiently in regard to production capacity per area. As height increases, automating part of the harvesting process by introducing rotating planes becomes increasingly significant to avoid a dependency on scissor lifts that create bottlenecks. Rotating shelves are included in the Plantagon patent portfolio and could potentially be used to combine greenhouses with vertical farms, as previously discussed by Grönska and Spisa.

Another important factor for large-scale production is the technology used to supervise crops remotely. Supervision technology is used to monitor all crops at all times and eliminates the need for manual supervision which reduces labour costs. The technology can either be developed in house or licensed. Developing an own system requires extensive R&D spending but can create a competitive advantage in the long term. Having total control of the collected data makes it possible to develop the most optimal growing conditions for crops. If software is licensed the collected data might be unavailable for other competitors to use, minimising the competitive edge.

Reaching economies of scale is necessary to leverage bargaining power towards retailers. More volume leads to a better starting position in negotiations as the retailers' dependency on the VF's production increases. Selling to retailers is currently the only viable option for a large-scale farm as they have a distribution- and marketing network in place to handle large volumes and reach enough customers to meet supply. The disadvantage of lower margins needs to be mitigated by the added value of the retailers' networks.

The challenges with the large-scale distribution model mainly concern distribution networks, investment costs, and finding appropriate facilities. A production capacity of over 1,000 tonnes of greens per year, as planned by Ljusgårda and already executed by Spread, requires efficient and widespread distribution networks. The people at FutuFarm and Kajodlingen argued that such volumes removes part of the value in hyperlocal production and distribution, while other companies like Ljusgårda, Plantagon and Spisa argued that Swedish production is good enough. Finding space close to the city centre will become increasingly difficult and expensive with high production, forcing companies to move further from their customers. Moving away from the city increases transportation and reduces the local presence. Lastly, the high investment costs associated with large-scale production might deter investors. The theory on new innovations by Rogers (1962) suggests finding initial believers in a new technology can be difficult. The notion was enforced by Pettersson, who named finding investors as one of the most problematic activity in the company and the reason the Linköping-project was not completed. The lack of initial funds is why many companies start off with a smaller proof-of-concept production.

7.4.2 Small-scale

The value of small-scale production is that the crops are sold in close proximity to the production site. Local producers like Ljusgårda have a competitive edge towards climate conscious customers by offering low-emission distribution by reducing transportation distance. Large-scale farms will have a more difficult time delivering with low emissions since longer distances and a higher need of storage will be inevitable.

A smaller farm is easier to monitor and control and can adapt more quickly to meet customer demand. The supervision technology used mainly monitors temperature, humidity and CO2 content and crops health are monitored manually. This reduced initial investment costs and makes operations less reliant on technology. The challenge of matching supply with demand and delivery times to restaurants can be mitigated in small-scale farms. A large farm is more reliant on their distribution network. Spisa, producing 20 million pots of herbs per year, outsources all distribution and marketing to wholesalers in order to focus on their core capabilities in producing high-quality crops. Spisa relies on delivery schedules and pre-ordered quantities to ship everything they produce, making sudden changes to crop variation or capacity difficult to handle. Jonna Hansson explained in an interview on 1 April 2019 that the extraordinarily hot summer in Sweden 2018 greatly increased output, but the demand did not follow as the distribution network and purchasing departments did not have time to catch up. As a result, thousands of plants were left unsold and quickly got spoiled by the heat.

A small local VF will need to expand through new locations which means fixed costs are not mitigated by EOS and automatization in the same way they are for a large-scale farm. Many smaller farms will lead to a more fragmented market compared to if a large farm controls a majority of the market. A fragmented market means more competitors and an increased reliance on brand equity. Small-scale vertical farms might need to focus more on marketing and branding to gain a competitive edge, while expanding in a manner similar to a franchise concept. However, a small-scale farm is not as reliant on the wholesaler when it comes to distribution and marketing, which suggests margins could be higher.

Lower production also facilitates direct sales to the end customer as a way to circumvent the middlemen. As smaller farms will have a hard time becoming profitable selling to retailers, they are likely to pursue direct sales to consumers or restaurants. These customers can pay a higher price as they are not trying to profit from reselling the product at a higher price as in the case with retailers. Removing the middleman who doubles or triples the purchase price of the produce might result in a market opportunity where small-scale farms can become profitable faster. Currently, the break-even point for small-scale farms in Sweden seems to lie close to the inflexion point of becoming a large-scale producer. Yurii Voronkov (2019) at the Public Relations Department of Spread, the world's largest profitable vertical farm, agreed with the previous statement and argued that small-scale farms can become profitable but stated that a key ingredient to Spread's financial success was scaling up.

7.4.3 Integrated solution

The integrated vertical farm aims to capture similar values to that of a small-scale farm while adding the potential of removing the middlemen. It is the most environmentally conscious business model of the three as it completely removes the need of transportation. An integrated solution allows the VF-supplier to partner with customers. Partnerships are particularly beneficial when the implementer also wants to control the output, as has been seen with restaurants and retailers. The integrated rooftop farm operated by Kajodlingen at Clarion Hotel Post allows the chefs to influence the produce and gain inspiration from the farm on a daily basis. Similar solutions have been adopted by Freight Farms' customers outside of Sweden. The Grönska GrowOff concept allows retailers to choose the crops while serving an important role in the marketing process to attract curious customers. ICA's in-store container allows them to expand their offer while capturing more of the value than competing vertical farms can. Selling directly to end customer means the calculation does not need to take the retailer's mark-up price into account which leads to higher margins.

Further advantages of an integrated farm include harvesting at the exact time of use. The crops can be harvested at peak ripeness to be either used by a restaurant or sold by a retailer, giving the crops better taste and appearance. The integrated solutions are often easy to set up and require little experience to maintain and monitor, making it a good stepping stone for anyone wanting to try out vertical farming. A container farm could also be used and for market research purposes by evaluating the demand for certain crops that could not be justified purchasing in low quantities.

The challenge of the integrating solution is making sure the advantages exceed the high investment costs. Rademaekers further mentioned that finding someone capable and able to operate the farm for 20 hours per week is a challenge for many companies. While an integrated farm succeeds in cutting out middlemen and creating a competitive edge, it lacks the ability to reach economies of scale through size and automatization. Scaling up an integrated farm is limited to adding new units without significantly reducing the cost per unit. If large-scale farms become widely adopted, competing on price with an integrated farm could prove difficult. Moreover, an integrated farm suited for all actors, like a container farm that can be placed anywhere, might be easy for competitors to copy. Any short-term success is likely to be met by copying from competitors and driving down margins. Freight Farms do, however, have a first-mover advantage and are ahead of new entrants in regards of R&D and sales- and distribution channels.

8 Discussion

The aim of this thesis is to explore the financial, logistical and environmental prerequisites for successfully implementing vertical farming in Sweden. Three research questions formed the basis for the study. The key findings for each research question are interpreted and elaborated upon below.

The first research question *"How can different stakeholders benefit from vertical farming in Sweden?",* was answered by interviewing different actors in the industry and analysing the interview data from an economic, social, and environmental standpoint. The data gathered from interviews aligned with previous research on the benefits of vertical farming, strengthening the notion of VF being a sustainable alternative to conventional agriculture. Environmental and social benefits, concerning both the producer and other actors, were identified and point towards more sustainable agricultural practises. The challenges lie in reaching financial success without compromising the sustainability benefits.

The sustainability gains concern actors at three different levels. Firstly, at a broad scale, reduced transportation and lower environmental impact affect the whole world by reducing greenhouse gases released into the air. Secondly, the local area surrounding the VF benefit from a wider and healthier supply of crops year-round while not suffering from water- or land pollution from agricultural activities. Lastly, VF incurs economic benefits from removing costly parts of the value chain, increasing yield per area, and minimising waste products. The costs associated with the creation of a new industry, including marketing, R&D, and business development, currently outweighs the economic benefits. More time in the market is necessary to assess whether VF can remain sustainably profitable.

Vertical farms can be connected to the district heating and ventilation systems of the facilities they are located in. A connected system lowers the energy costs for the whole building and improves air quality in its offices. Actors outside of the food value chain, such as property owners and office workers, could therefore take advantage of the implementation of vertical farming. Plantagon showed a proof-of-concept of such a symbiotic relationship but the high investment costs associated with the system led to a negative return on investment. A symbiotic system likely has greater potential in larger production facilities where the cost of implementing the system can be counterbalanced by a larger production volume. Symbiotic systems will have to be evaluated and improved over time before any definite conclusions can be drawn.

Factory visits in Japan, the world leaders in commercialised vertical farming, showed that further social benefits can be gained from vertical farming than what is currently pursued in Sweden. Japan, with densely populated cities, have additional drivers for implementing VF than the environmental and consistency challenges mostly concerned in Sweden. Japan aims to improve output in small areas as arable land becomes scarcer and the population ages with low birth-rates. The westernisation of diets has led to an increased rate of heart disease in Japan which ESPEC works to counteract by producing supplement-like crops high in calcium and magnesium. The increasing urbanisation and reduction of young farmers in Japan has heightened the importance of automatization. Highly automated farms can operate with less physical interaction from employees. Fewer employees reduces labour costs and increases growing area as the need for ladders, aisles and working area is removed with the introduction of robots.

Japan has more profitable vertical farms than Sweden, which was explained by the fact that indoor farming has been developing in Japan since the 1970's. The long history of indoor farming in Japan has increased customer acceptance and improved operational processes and automatization, which has made them world leaders in the industry. However, the presented data indicates that a number of prerequisites for implementing vertical farming are more favourable in Sweden, and some of the larger vertical farms in Sweden are expecting to reach profitability within one or two years as sales take off. Authorities and other stakeholders in the value chain create a better business environment for VF in Sweden. Firstly, rent costs are much lower in Swedish cities than in the large metropolises of Japan. VegetaFarm mentioned that a substantial operating cost came from rent where the companies have low bargaining power. Secondly, Swedish producers are free to set the market price, and can increase prices to increase profitability or lower prices to increase adoption rates. In Japan, free pricing is sometimes prevented by the government. Lastly, Swedish actors can focus on high value crops, such as herbs and micro-greens, to improve profitability. In Japan, the demand for herbs like basil or parsley is comparably low as highlighted by VegetaFarm. However, Japan has managed to establish a strong network of collaborating corporations and academia, which in part is led by JPFA. Their joint efforts have until this point created advanced technologies and the shared knowledge and experiences can be expected to continuously accelerate the development of VF.

The second research question *"Which business models exist and how can they be applied to the Swedish market?"* was answered by investigating and analysing the industry, its macro-environment, current business models, and required resources and capabilities. Three main business models for vertical farms were identified in Sweden and compared on benefits and challenges as well as logistical prerequisites. For large- and small-scale production, many of the business model elements are similar, with production capacity and required investment cost being the main differences. A higher production capacity requires extensive investments in distribution- and sales networks, technology, and automatization. Large-scale farms create their competitive advantage by reducing the production cost per crop through economies of scale. Small-scale farms instead leverage their ability to create closer relationships to their customers and shorten the distribution part of the value chain. Both small-scale farms and integrated solutions include the benefit of simpler and cheaper start-up periods. The value proposition of integrated solution providers is shifted from selling crops to selling a complete ready-to-use vertical farming system. In addition to the benefits of a small-scale farm, an integrated solution creates a competitive edge by offering its customers an easy way into vertical farming with the option to quickly scale up in case of initial success. An integrated solution can potentially remove all middlemen and distribution, increasing the margins for the producer. Furthermore, integrated solution providers move the value creation of selling crops to selling the ability to produce crops, which can lower the risk for both the systems-provider and the producer.

It will be challenging for actors interested in pursuing vertical farming to immediately start with large-scale production. Due to the novelty of VF, it is still difficult to gather seed money for the required resources and capabilities for a large-scale production facility. Furthermore, there are no established best practises for the operations of vertical farms and producers still rely on experience, and trial and error. It is therefore unlikely to reach immediate success without extensive funding and prior experience with VF. An uncertain investment at a high cost is likely undesirable for most incumbent actors wanting to transition into vertical farming. A lot of progress has been made by Swedish actors, such as Grönska and Ljusgårda, over the past years. These early starters have a first-mover advantage and a lot of experience with trial and error. The knowledge obtained has improved their operations and enabled them to transition towards large-scale production early in the industry life cycle.

Large-scale farms are likely the most competitive alternative to conventional farming in the long run. As with most new technologies, several smaller producers end up competing for the best solution until a dominant design emerges. To minimise the primary risks of starting a VF, the authors of this paper believe that actors aiming for large-scale production should pursue small-scale farms or integrated solutions initially. To show potential investors a proof-of-concept, a pre-existing system like ZipGrow can be licensed while simultaneously developing a system in-house. Developing a hydroponic system will lower future investment costs during the scale-up period and will make it more difficult for new entrants to copy the system. In-house development also allows a VF to tailor the equipment to its specific needs. Moreover, small-scale farms simultaneously pursued by several actors across Sweden would accelerate the development of the technology. Integrated solutions would allow established actors, such as grocery stores or restaurants, to experiment with vertical farming and test its viability which would accelerate market adoption. A combination of quick market adoption and technological advancement would work as a positive reinforcement loop. Higher market penetration leads to more money going into the development of VF-systems, leading to improved products that in turn facilitates market adoption and so on.

The third research question *"Can the business model be both environmentally and financially sustainable while keeping a competitive edge?"* was answered by investigating operating costs associated with vertical farming, mapping the Swedish market and interviewing VF companies on the value of vertical farming. The unique competitive edge against conventional farming methods comes from the ability to produce crops of consistent quality and quantity year-round in close connection to the consumers. Moreover, vertical farming enables special plant recipes to be developed to cater to the local demand. These advantages in turn lead to sustainability benefits in both a social and environmental context. Renewable energy sources are a prerequisite for environmentally sustainable vertical farms and access to renewable energy is therefore imperative. The adoption of vertical farms might be hindered in countries were green energy is less accessible. Sweden, with over 50 % renewable energy compared to 7 % in USA, has the prerequisites to supply sustainable crops, reinforcing a positive outlook for vertical farming in Sweden. Moreover, renewable energy can create a competitive edge over conventional farming methods that rely on fossil fuels to a greater extent.

The findings conclude that the identified business models can be environmentally sustainable, but it remains to see if vertical farms can remain economically sustainable over time. The financial challenges are to continuously develop the technology used for supervision and to increase automatization in order to reduce labour costs. Additionally, external development of LED technology is ongoing and can help increase profitability. An external risk-factor for the financial success of vertical farms is the great dependency on electricity as a source for plant growth. Energy prices have historically increased over time in Sweden, which decreases the firms' profitability and long-term planning ability.

At the current state of vertical farming, production is limited to high-value crops such as leafy greens and herbs. No actor has succeeded with growing calorie-dense crops profitably. Vertical farming is therefore not the solution to all problems associated with the food industry. Instead, it is a complement to imported greens and herbs. In theory, at the current state of technology, vertical farms can supply the total demand of greens and herbs in Sweden which would lead to a reduction of imported alternatives. With a market value of imported greens exceeding 4 billion SEK, there is much room for vertical farms to grow before competing with local suppliers. All alternatives to imported greens would lower the carbon footprint, reduce transportation, improve predictability and generate healthier produce, benefiting consumers, producers and suppliers.

There is a risk that the low margin in the food industry will catch up with vertical farms so that it never becomes profitable enough to pursue. Whenever an industry sees unusually high margins, new entrants are likely to emerge unless there are sufficient barriers to entry. This is especially true for commodity products where the large volumes and high turnover of goods allow companies to operate with low margins. If profit margins will ever be unusually high, or if technological moats will be strong enough to keep competitors at bay, requires future research and development of the VF-industry.

Future research

Some observations have been made that are not in direct connection to the research questions. For VF to become a viable alternative to conventional farming it requires customer acceptance. Grönska have received positive feedback on their produce and Ljusgårda are struggling to keep up with the demand for their crops. While no interviews with consumers were conducted to verify these statements, no data gathered points to the contrary. The adoption of vertically grown crops among customers is still an uncertainty as of the writing of this report and could be the foundation of future studies. Further research on how vertical farms can utilise certifications and branding to educate consumers on the sustainability benefits could further improve adoption rate. At the current state of the market, it is the authors' and the interviewed companies' view that the success of vertical farming in Sweden depends more on reaching profitability than convincing customers to buy the produce.

More time, experience and research are also needed to decide which business model is optimal for extensive adoption of vertical farming. Hydroponic systems are not limited to commercial distribution. Solutions exist for domestic use and office spaces but has not been covered in this thesis. Such systems are easy and cheap to develop and distribute, but the challenge lies in convincing consumers to produce their own greens. Their potential impact on lowering the need of imported greens is not fully investigated and it is difficult to assess consumer acceptance. Hydroponic systems for domestic use are an alternative business model that could be covered in future research.

9 Conclusion

Globalisation and urbanisation have created sustainability challenges in the global food system that require new methods for food production. The thesis aimed to explore how vertical farming (VF) could be implemented in Sweden to contribute to a more sustainable agriculture industry. Vertical farms have shown to be successful at a large scale abroad but are still novel and largely untested in Sweden. New entrants to the industry have increased in Sweden over the past years and several social, environmental and economic benefits of vertical farming have been identified. However, further business model development is required to overcome the financial challenges in order to compete with the low-cost global crop supply from conventional farming methods.

The social and environmental sustainability benefits include efficient usage of space and a shorter value chain which benefit both the environment and the producers by lowering the carbon footprint and reducing wastage. There are economic advantages in reduced transportation and water usage, a higher degree of automatization, and improved productivity. Plant recipes improves the taste, looks, and nutrient contents of crops and give VF-crops a competitive edge over conventional farming methods. Indoor farming further secures non-weather-related consistency and quality of produce. However, vertical farms in Sweden are facing challenges in mitigating the fixed costs to offer a competitive price on their produce.

A Porter analysis showed a competitive industry landscape where new entrants are expected to emerge as the technology advances. It is therefore important for vertical farms to mitigate the threats from different actors. Creating a unique selling point and entry barriers will be crucial for upholding margins in the long-term. In-house developed technology will create barriers to entry through technological advantage and reduced bargaining power from suppliers. Efficient sales- and distribution channels are imperative to keep productivity high and to survive a high bargaining power from the retail oligopoly. While the competitive landscape is expected to intensify, 80 % of the market is made up by imported fruits and greens, and consumers are favouring Swedish producers. Each farm now needs to align their goals with a suitable business model to capture the benefits of vertical farming and encourage market adoption.

Large-scale production utilises economies of scale to drive down the production cost per unit. It is the most competitive business model but also the most capital intensive. Large-scale production does, however, reduce some of the sustainability benefits by increasing transportation- and storage time. While high-volume production removes some of the competitive advantage of a hyperlocal business model, it has the greatest impact in reducing the import of certain greens. Several small-scale farms could achieve similar results but would not reap the benefits of scale achieved by a large-scale farm. If the goal is to minimise transportation, small-scale or integrated production is the better business model as it shortens the value chain significantly. Moreover, small-scale farms can partner with restaurants and local stores. Partnerships are less accessible for larger producers who demand more detailed forecasting and an efficient distribution network. The integrated farm is suited for actors who want to add a competitive edge to their value proposition by expanding their offer and capture the interest of early adopters. Connecting the farm directly to a pre-existing sales channel can mitigate the high investment cost of small farms and increase margins. margins.

While strong evidence for future success of vertical farming has been identified, more research, investment, and time is necessary to evaluate the outcome for vertical farming as an alternative method of food production. Time-in-market is especially important and is what has made Japan world leaders in the industry. The vertical farms in Japan has had time to streamline the process, scale up and gain customer acceptance. The three main challenges to reaching profitability for Swedish vertical farms are to reduce labour cost through automatization, mitigate the bargaining power of other actors in the value chain, and reach economies of scale. This study indicates that Sweden is a promising country with the right prerequisites to adopt the new technology and expand on the success of vertical farms abroad. The adoption of vertical farming would be a step forward in reducing the environmental impact of agricultural practises while enabling a consistent production of high-quality crops in urban environments. Following the practises of sustainable development and corporate social responsibility, vertical farms could be part of the solution to reaching the long-term goal of ecosystem equilibrium.

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Appendix I - The template used for interviews with vertical farms

Background

- What is your role at the company?
- How did you come up with the idea to start with vertical farming?

Business

- What does your business model look like? (large/small scale, integrated solutions)
- Which business models did you evaluate before deciding?
- What has been/is your biggest challenge?
- Who do you regard as your competitors?
- How do you create value for customers?
- Who are your customers?
- How big are operating costs? (labour, energy)

Vertical farming

- What can/do you grow in your facilities?
- What is the most profitable to grow?
- How much crops can you produce per week/month?
- How big is your growing area?
- How many hours of labour are needed each week?
- Which equipment do you use?
- Why did you decide on that equipment?
- How does certification such as organic, KRAV look like for VF?

Closing

- Can we use your name and the company name in the report, or do you wish to remain anonymous?
- Is there something you want to add?
- Can we contact you again if other questions arise?

Appendix II - Urban agriculture actors

The Swedish vertical farms are presented first followed by the international vertical farms. Lastly, two Swedish competitors that are not vertical farms, Spisa and Kajodlingen, are presented. The first table shows when the respective company was founded, which equipment they use, where they are located, and which crops they produce. The second table shows production capacity, technology, growing area, water usage and customers for the same companies.

Company	Founded	Equipment	Location	Produce
Plantagon	2002	ZipGrow	Stockholm, Sweden	premium seedlings, microgreens, leafy greens, herbs and flowers.
Grönska	2015	Grönska in-house design	Stockholm, Sweden	Herbs and leafy greens
Futufarm	2016	ZipGrow (old) FreightFarms in-house design (new)	Halmstad, Sweden	Lettuce, leafy greens, microgreens, herbs
Ljusgårda	2017	ZipGrow	Tibro, Sweden	Arugula commercially but experimenting with several other crops
Urban Oasis	2017	Mix of multiple vendors	Stockholm, Sweden	Microgreens, leafy greens, herbs and mushrooms
Grönt Under	2018	ZipGrow and in-house design	Stockholm, Sweden	Leafy greens, microgreens and herbs
ESPEC-MIC Corporation	1988	VegetaFarm in-house design	Osaka and Tokyo, JPN	Frill lettuce, leafy greens
AeroFarms	2004	AeroFarms in-house design	Newark, NJ, USA	Baby greens, microgreens and leafy greens 300+ varieties

SPREAD	2006	Technofarm Developed by SPREAD together with partners	Kyoto, Japan	4 varieties of leafy lettuce
VertiCrop	2009	Verticrop in-house design -120 racks with 24 growing trays per rack on a conveyor system that rotates	Vancouver, Canada	Grow over 80 varieties of leafy greens, microgreens and strawberries
Plenty	2013	Plenty in-house design	San Francisco, CA, USA	Can grow almost anything, depends on cost. Plenty has experimented with >400 crops, including watermelons, tomatoes and strawberries
Spisa (greenhouse)	1995	Greenhouse	Påarp, Sweden and several other European countries	Herbs and leafy greens
Kajodlingen (conventional soil farming)	2016	Pallets with soil	Gothenburg, Sweden	Different kinds of vegetables

Company	**Production capacity (annual)**	**Technology**	**Growing area**	**Water usage**	**Customers**
Plantagon	73,000 kg at full capacity	Hydroponic	650 m² growing area 300 m² floor area	99% less than soil farming	ICA (supermarket)
Grönska	1.4 million plants	Hydroponic	900 m² (incl. office- and storage space)	90% less than soil farming	Coop, ICA, Hemköp, smaller retailers and restaurants

Futufarm	26,000/52,000 large/small lettuce heads or ~1250kg greens or ~900kg herbs	Hydroponic	30㎡ floor area 545 meters of ZipGrow towers Space for 4500 plants	90% less than soil farming	Supplier of VF systems. Has sold to private actors and supermarkets (ICA)
Ljusgårda	1M kg at max capacity	Hydroponic	using 1500 ㎡ with option for 7000 ㎡. 200 ㎡ currently used for growing	99% less than soil farming	Several ICA stores
Urban Oasis	22,000-36,000 kg annually planned for 2019	Hydroponic	60㎡ pilot with option of 2000 ㎡. 300 ㎡ planned for 2019	N/A	ICA and restaurants
Grönt Under	N/A	Hydroponic	N/A	90% less than soil farming	Selling integrated solutions to restaurants, property owners and hotels
ESPEC-MIC Corporation	N/A	Hydroponic	Varies from small to large scale	N/A	Retailers, restaurants, large enterprises
AeroFarms	907 tonnes in main farm + several other farms. Produced over 500 million plants 2018	Aeroponic	6500 ㎡ main farm + several other farms	95% less than soil farming and 40% less than hydroponic farming	Retail (brand name Dream Greens), restaurants and direct sales from production facility

SPREAD	7.7 million heads of lettuce	Hydroponic	1800 m² floor area 4780 m² growing area 2868 m² building area	N/A 98% of water is recycled	2300 stores and restaurants, mainly retail
VertiCrop	N/A Up to 20x more than normal field crops	Hydroponic	348 m²	92% less than soil farming	Retailers and direct sales to end consumer
Plenty	2.2 million kg of greens expected in Seattle facility Up to 350x yield per unit of area compared to traditional farming	Hydroponic	4645 m² building area in SFO 9290 m² building area in Seattle planned to open soon	99% less than soil farming	Online sales to end consumer, restaurants and retail stores
Spisa (greenhouse)	20 million plants annually	Hydroponic	35,000 m²	N/A	Retail stores in Europe, restaurants
Kajodlingen (conventional soil farming)	2,000 kg annually (7-month season)	Conventional farming in soil	250 m²	N/A	End consumers through a subscription basket