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The Future of Industries: How Indoor Vertical Farming Will Disrupt the Agriculture Supply Chain

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Abstract

Title: The Future of Industries: How Indoor Vertical Farming Will Disrupt the Agriculture Supply Chain

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The world faces challenges in terms of population growth, climate change, and changing eating habits. To guarantee food production, the sustainability of its operations is essential.

Over time, the agricultural industry has evolved, and the last crossed frontier corresponds to the development of vertical farming in a controlled environment.

This dissertation intends to evaluate the disruptive effect of vertical farming in a controlled environment in the agricultural supply chain. To answer this question, a qualitative analysis was carried out in the form of expert interviews and analysis of secondary literature.

Results indicate that vertical farming can contribute with integrated solutions to the improvement of the agriculture landscape and the global food crisis. Vertical farming can contribute to food security as well as to sustainable food production with less environmental impact. However, to spread the technology on the market, vertical farming needs to prove its concept and profitability. To achieve both profitability and cost efficiency, government intervention becomes crucial. Governments could assume a primary role in providing educational and financial investments, as well as supporting the creation of legislation and regulations that favor vertical farming implementation in the market.

Keywords: Agriculture, Agri-Tech, Agri-Food Supply Chain, Disruption, Innovation, Urban Agriculture, Vertical Farming, Sustainability

Sumário

Título: O Futuro das Indústrias: Como a Agricultura Vertical Afetará a Cadeia de Abastecimentos Agrícola

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O mundo enfrenta desafios em termos de crescimento populacional, alterações climáticas e mudança nos hábitos alimentares. De modo a garantir a produção alimentar, a sustentabilidade das suas operações é fundamental.

Ao longo dos tempos a indústria agrícola evoluiu e a última fronteira ultrapassada corresponde ao desenvolvimento da agricultura vertical em ambiente controlado.

A presente dissertação pretende avaliar o efeito disruptivo da agricultura vertical em ambiente controlado na cadeia de abastecimentos agrícola. Desta forma, foi realizada uma análise qualitativa sob a forma de entrevistas expert e análise de literatura secundária.

Os resultados indicam que a agricultura vertical pode contribuir com soluções integradas para a melhoria do panorama agrícola atual e no combate da crise alimentar global. A agricultura vertical pode contribuir para a segurança alimentar bem como para uma produção de alimentos mais sustentável e com menos impacto ambiental. No entanto, para uma difusão da tecnologia no mercado, a agricultura vertical necessita de provar conceito e rentabilidade. De modo a atingir rentabilidade e eficiência de custos, a intervenção governamental torna-se fulcral. Os governos poderão assumir um papel primordial através de investimentos educacionais e financeiros, bem como através de apoios à criação de legislação e regulamentação que favoreça a sua implementação no mercado.

Palavras-Chave: Agricultura, Agri-Tech, Agri-Food Supply Chain, Disrupção, Inovação, Agricultura Urbana, Agricultura Vertical, Sustentabilidade

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List of Abbreviations

B2B: Business-to-Business

B2C: Business-to-Consumer

CAPEX: Capital Expenditure

CEO: Chief Executive Officer

COVID-19: Coronavirus Disease 2019

GMOs: Genetically Modified Organisms

IoT: Internet of Things

LED: Light-Emitting Diode

NASA: National Aeronautical and Space Administration

NGOs: Non-Governmental Organizations

OPEX: Operating Expense

R&D: Research and Development

RQ1: Research Question 1

RQ2: Research Question 2

US: United States

Chapter 1. Introduction

1.1. Background Information

1.1.1. The Agriculture Industry

1.1.1.1. From Open Field to Vertical Farming

The agriculture industry emerged about 10 000 years ago and rapidly spread to different cultures. Throughout history until the Modern Age, agricultural techniques were used in accordance to the same initial models, through farming in open fields, focusing solely on cultivation, natural fertilization, irrigation, and harvesting, so that food could later be stored or sold. Subsequently, levels of additional control have been applied to the agricultural practice with the introduction of mechanization, the use of advanced irrigation systems, modern fertilizers, pesticides, until reaching the indoor route (Despommier, 2013).

Indoor farming aims to develop agriculture production in a controlled environment, benefiting from the combination of synergies between agriculture and the protected environment of a building (Eigenbrod & Gruda, 2015; Specht et al., 2014). Technological and scientific development has continued, and the last frontier has been reached. This pertains to the rise of vertical farming through strict controls at the climatic and lighting levels. By managing these factors, humidity, temperature, lighting, water, carbon dioxide concentration, and nutrients, the main variables of plant growth are controlled and optimized (Despommier, 2013; Eigenbrod & Gruda, 2015).

1.1.1.2. Global Challenges

The pressure on food production represents one of the main problems that society will face in the future. On a planet where the world population is estimated reach around 10 billion people by 2050, food production would have to rise almost 50 %, compared to 2012 (FAO, 2018). The global food system is also responsible for producing 26 % of the planet´s gas emissions, occupying 50 % of global habitable land, and consuming 70 % of the planet´s freshwater withdrawals (Ritchie, 2020).

Over the past 40 years, the planet lost 1/3 of the arable land (The Guardian, 2015). Deforestation, mainly for farming, has been responsible for the production of greenhouse emissions, which are responsible for the intensification of climate change and global warming (FAO, 2017).

This biodiversity damage increasingly calls into question the existence of sufficient land to face the population increase. Hence, new solutions and production strategies will have to emerge to improve future food production in a resource-sustainable way.

1.1.1.3. Sustainable Food Trends

In societies where demographic growth, food waste, scarcity of resources, and climate change are increasing, disruption of the agriculture industry and the food sector becomes progressively urgent and inevitable. Advances in science and technology have allowed a transformation in the food industry, with the aim of both restructuring the food value chain and satisfying consumer needs. Innovation has leveraged corporate profitability and has ensured the efficiency, safety, and sustainability of the food chain. Genetic modification, cultured meat, vertical farming in a controlled environment, nanotechnologies or artificial intelligence are some of the new technologies that are changing how stakeholders look at today´s agriculture industry and how they project tomorrow´s future (De Clercq et al., 2018).

1.1.1.4. Urbanization Trends

In recent years, urban centers have experienced exponential growth as a result of populations increasing and better living standards. It is estimated that 68 % of the world´s population will live in cities by 2050, an increase of 38 % since 1950 (UN, 2019). Giving rising desertification and existing pressure upon rural agriculture, available spaces in urban areas could be repurposed to produce local food for consumption, guaranteeing not only constant availability but also food security and sustainability (Eigenbrod & Gruda, 2015; Kalantari et al., 2020).

Nevertheless, production, processing, and distribution of food within cities, also referred to as urban agriculture, faces challenges (Armanda et al., 2019). Land insecurity (FAO, 2007), pollution risks (Mok et al., 2014), contamination of food due to the use of heavy metals and organic chemicals (Russo et al., 2017), and increasing health issues due to lack of basic sanitation (Cofie et al., 2005) and vector diseases (Hamilton et al., 2014) are issues facing urban agriculture (Armanda et al., 2019). Attempts to meet these challenges have led to advances in both science and technology, which have allowed urban agriculture practices to evolve into an innovative urban agriculture approach.

Overpopulation in cities needs new agriculture techniques to cope with the massive food production required. The solution could include vertical farming in a controlled environment, an innovation that has the potential to ensure sustainable food production in urban areas and to revolutionize the agriculture industry of the 21st century (Kalantari et al., 2020; Kalantari, Mohd Tahir, et al., 2017).

1.2. Problem Statement and Research Questions

This thesis explores how to innovate food production through Indoor Vertical Farming practices. This technology-driven innovation has the potential to contribute to the diffusion of global food security by providing local food for consumption, strengthening the food value chain, and applying more sustainable practices to make the supply chain a more consistent and adaptative network across all levels of value creation.

Thereby, the present dissertation aims to evaluate *the disruptive effect of Indoor Vertical Farming in the Supply Chain of Agriculture.*

To accomplish this purpose, the following research questions were framed:

- **RQ1:** What is the potential impact of indoor vertical farming in the agriculture supply chain?
- **RQ2:** What would the global agriculture supply chain evolve into, assuming the widespread deployment of indoor vertical farming?

1.3. Academic and Managerial Relevance

The pressure on agricultural production is tremendous. Furthermore, the demand for food continues to increase. Together, science and technology can contribute to a more sustainable system through the transformation of the global food industry. Innovators and entrepreneurs are joining forces to design new ways of responding to both consumer trends and preferences, as well as to the urgency of improving global sustainability and human health.

This dissertation contributes to the academic knowledge by engaging with a significant domain that is of increasing interest to the academic community. Vertical farming is among the few emerging opportunities to be fully exploited into the following 10 to 20 years (Kalantari, Mohd Tahir, et al., 2017). Public interest in this topic has increased, especially with regard to its capabilities and sustainability (Al-Kodmany, 2018).

From a managerial perspective, this dissertation contributes with relevant insights from one of the main sectors of the economy, agriculture. We can expect vertical farming to play a critical role in the future of the food industry and to generate a revolution in the development of agriculture. This study delivers relevant insights on how to leverage disruption in the global agriculture supply chain through vertical farming practices.

1.4. Dissertation Outline

The structure of this dissertation starts with the second chapter, a Literature Review of the vertical farming business. It intends to provide a detailed analysis of the vertical farming concept, systems, growth mechanisms, technology, the impacts on society, as well as the global challenges and opportunities that innovation may face when implementing. Additionally, an overview of the global agriculture supply chain disruption is included. The third chapter describes the methodology used in this study. In the fourth chapter, analysis, and discussion of the primary data, obtained through Semi-Structured Interviews with Industry Professionals is carried out as well as the assessment of the legitimacy of each of the research questions. Finally, the last chapter summarizes the main conclusions of this dissertation, presents the general limitations faced during the study, and advice for future research.

Chapter 2. Literature Review

2.1. The Vertical Farm Business

2.1.1. Vertical Farming Concept

The concept of vertical farming has gained traction as an initiative for developing sustainable urban agriculture (Besthorn, 2013). Before the environmental crisis and the food security problem became a reality in the 21st century, the American geologist, Gilbert Ellis Bailey, in his book *Vertical Farming* (1915/2011), recognized that the only way to address looming challenges would be through multi-story buildings located in urban centers (Besthorn, 2013).

Recently, the concept has been further developed. Vertical farming has been highly discussed by Dickson Despommier, a Columbia University Emeritus Professor, who suggests that using in-house production centers could provide sustainable, safe and abundant products and at the same time repair the earth´s damaged ecosystem (Benke & Tomkins, 2017; Besthorn, 2013; Despommier, 2013). Over the years, Despommier has promoted the concept of vertical farming in urban centers as a solution for food security and to obviate food deserts.

2.1.2. Vertical Farming Systems

Nowadays, there are three vertical farming systems in a controlled environment commonly used: Vertical Home Farms, In-Store Vertical Farms, and Indoor Vertical Farms (Jürkenbeck et al., 2019).

Vertical Home Farms are used for domestic consumption. Through a smartphone device, the consumer can fully control the main variants that will contribute to the plant growth in terms of production, lighting, and nutrients supply (Jürkenbeck et al., 2019).

In-Store Vertical Farms are used in retail. Products are displayed in a production chamber, where consumers can observe the growth process and purchase the products directly for consumption (Jürkenbeck et al., 2019).

Finally, Indoor Vertical Farms refer to enclosed multi-story buildings where everything that is required to grow crops, that is, humidity, temperature, lighting, water, carbon dioxide concentration, and nutrients, is supplied, controlled, and monitored to produce data. In turn, this data will be used to develop better techniques and results (Despommier, 2013; Eigenbrod & Gruda, 2015).

2.1.3. Vertical Farming Growth Mechanisms

Indoor vertical farming production operates through three different techniques: Hydroponics, Aquaponics, and Aeroponics (Despommier, 2019).

The Hydroponic technique is the predominant growing system in vertical farming. This system does not require soil usage, since plants grow in nutrient solutions (Birkby, 2016). This type of technique uses between 60 % and 70 % less water than traditional outdoor agriculture (Despommier, 2019) and can be easily used in places with an arid climate since it increases the humidity and lowers the temperature. Also, it reduces the carbon dioxide concentration, thus contributing to global warming prevention (Schnitzler, 2013). By following a Hydroponic system, the choice regarding the business location is free, eliminating concerns about external environmental conditions, such as soil, precipitation or temperature (Despommier, 2009).

Aquaponics technique uses nutrient-rich wastes produced by indoor-grown fish to feed plants, thus combining both species in the same ecosystem. In turn, plants filter and purify the wastewater ending up recycled into the fish tanks (Birkby, 2016).

Finally, the Aeroponics technique, developed by K. T. Hubick in 1982 and further improved by NASA in the 1990s (Despommier, 2009), was designed to find an efficient plant growing system in space. This soilless technique requires 70 % less freshwater than hydroponics, and the aeration of the nutrient solution becomes unnecessary, thus contributing to a more profitable and efficient system (Despommier, 2019).

2.1.4. Vertical Farming Technology

Vertical farming uses several technologies, including water recycling methods, temperature and humidity control, solar panel lighting and LED illumination (Benke & Tomkins, 2017). Still, the game changing component of vertical farming technology is the ability to collect high-quality data very quickly through smart-equipment and sensors, in order to control and measure the main environmental factors that affect plants growth (Eigenbrod & Gruda, 2015).

Those key emerging technologies include Cloud Computing, Artificial Intelligence, Machine Learning, LED, among others.

By using Cloud Computing, data can be easily monitored, collected, analyzed, and optimized to improve yields and produce sustainable, fresh, safe, and nutritious food at a lower cost (Spencer, 2018).

Artificial Intelligence can be used to find more efficient combinations of the main variables that will contribute to plant growth (Spencer, 2018). This technology enables more efficient, cost-effective, and less labor-intensive practices (Lakshmi & Corbett, 2020).

Furthermore, Machine Learning can be integrated into the cloud to analyze and produce models with optimal configurations, by adjusting the lighting intensity to create better yields or by providing the best ratio of nutrients to plant growth (Spencer, 2018).

In a vertical farming production system, crops are isolated from sunlight exposure. Since lighting is essential for photosynthesis, artificial light is used in the form of LED (Eigenbrod & Gruda, 2015). This system delivers a programmed spectrum of light that is optimal for plant growth, development, and quality.

Gruda & Tanny (2014) state that a combination of the red and blue light spectrum could contribute to a reduction of fertilizing and chemical usage due to the shortening of the vegetation period and improvement of the plant´s morphology. However, although the LED equipment offers increased longevity, low heat emissions and reduced energy consumption, energy costs remain high (Eigenbrod & Gruda, 2015; Morrow, 2008).

2.1.5. Opportunities and Challenges: Environmental; Social; Political; Economic

Producing sustainable food in urban areas requires considering environmental, social, political and economic factors (Kalantari, Mohd Tahir, et al., 2017).

The environmental advantages of growing food within urban centers are numerous, among them: the elimination of chemical pesticides, non-contamination of soils and groundwater, reduced use of fossil fuels by a substantial decrease of transportation, reduction in the global air pollution and carbon dioxide concentration, reduced food waste since vertical farming is not reliant of the favorable weather conditions, and a year-round production using significantly less water (Benke & Tomkins, 2017; Birkby, 2016; Despommier, 2009, 2011).

Despite the numerous environmental advantages of vertical farming, some challenges remain regarding this technology-driven innovation.

The first challenge concerns the amount of energy needed for plant growth and the costs associated (Banerjee & Adenaeuer, 2014; Kalantari, Tahir, et al., 2018). Production in vertical farming implies the constant use of artificial light. However, this issue is always improvable since technology is steadily evolving, enabling production optimization. Alternative artificial illumination is used, such as LED lighting or solar panels, both cost-effective solutions that contribute to the efficient growth of plants (Kalantari, Tahir, et al., 2018; Mendez Perez & Perez, 2014; Thomaier et al., 2015). An issue closely related to lighting is the heat produced. Yet, vertical farming uses the excess energy produced to heat the building (Kalantari, Tahir, et al., 2018; Thomaier et al., 2015).

The second challenge concerns the limited number of crops suitable for this business model (Benke & Tomkins, 2017). Vertical farming producers give preference to leafy vegetables and other greens (Beacham et al., 2019). Nonetheless, the productivity per unit of area in vertical farming is higher than in traditional farming, allowing, simultaneously, more than one crop. Also, because it is indoors, it is not affected and does not depend upon weather conditions. Consequently, this allows year-round production with multiple harvests in a vertical farming system, whereas traditional farming entails a single crop per year. Moreover, indoor vertical farming will be protected from pests and climate change, allowing fewer production losses during the year (Kalantari, Tahir, et al., 2018; Sivamani et al., 2013).

Bringing vegetable production closer to consumers is one of the main goals of vertical farming. The social impacts of this production systems are quite relevant, among them: the creation of new job opportunities (Despommier, 2011; Kalantari, Tahir, et al., 2017; Miller, 2011), influence on mental health due to close contact with nature (Afrin, 2009; Kalantari, Tahir, et al., 2018), improvements in food nutrition and food security (Despommier, 2011; Kalantari, Tahir, et al., 2018), sharing of information and knowledge related to methods of food production between producers and consumers (Kalantari, Tahir, et al., 2018; Specht et al., 2014), and contribution to nutritional and health education (Kalantari, Tahir, et al., 2018).

From a political point of view, vertical farming represents a commitment to combatting climate, supporting the preservation of biodiversity and environmental sustainability (Benke & Tomkins, 2017).

Vertical farming also has an impact on the economic level. It reveals itself as a solution for countries that are not self-sufficient in food production, especially vegetables, allowing to reduce the high dependency on food supply from foreign countries (Kalantari, Tahir, et al., 2018). However, it also faces challenges.

The first issue concerns the expensive energy requirements and high upfront investment (Banerjee & Adenaeuer, 2014; Kalantari, Tahir, et al., 2018). Yet, as the business grows and matures, costs are reduced, especially the ones related to energy provision (Kalantari, Tahir, et al., 2018).

Another often-debated issue relates to the availability of accessible land and its economic feasibility (Despommier, 2009; Eigenbrod & Gruda, 2015; Kalantari, Tahir, et al., 2018). Despite the scarcity of land, both in urban centers and in the countryside, vertical farming does not intend to seek additional estate to develop the business. Instead, it expects to make use of existing empty and unoccupied buildings to accommodate their projects (Ellingsen Eric, 2008; Kalantari, Tahir, et al., 2018; Thomaier et al., 2015).

2.2. Indoor Vertical Farming as a Disruptor of the Agriculture Supply Chain

2.2.1. Value Creation in Vertical Farming

A consistent supply chain management across all levels of the value creation in the farming sector is of great importance.

Value creation is an essential concept in management and organizational literature. The debate remains regarding the theory and the strategies needed to achieve it. Porter & Millar (1985) defined value as "the amount buyers are willing to pay for what a firm provides them". That value depends on the activities involved in delivering an advantage to the customer, that is, on the value chain. In this way, "a business is profitable if the value it creates exceeds the cost of performing the value activities". Value is obtained through product differentiation and a premium price or by performing value chain activities at a lower cost. Thus, urban vertical farming value creation occurs when the profits from the sale of urban vertical farming products exceed the cost involved in producing such goods.

While value creation is the primary objective of any business, the way value is created is vastly affected by the business environment challenges that companies face. Thus,

sustainable value creation implies the integration of environmental, social, and financial goals into business strategies.

2.2.2. Agriculture Supply Chain

One of the key success factors of a business refers to efficient management and control of its supply chain (Duarte et al., 2011).

A successful supply chain will develop its operations striving to reduce waste, achieve time efficiency, provide a flexible response to the consumer and reduce unit costs per product (Duarte et al., 2011).

The agriculture supply chain includes the flow of products, knowledge, and information between the agriculture stakeholders, producers, and consumers, at each stage of the production process (Braun et al., 2018). It starts with suppliers and concludes by satisfying consumer needs through a specific distribution channel. Empirically, researchers have proposed different definitions of the agriculture supply chain concept (Routroy & Behera, 2017). The European Commission (2015) defines it as "the direct exchange of food from the farmer to the consumer, or the different stages of activities such as the processing of raw agricultural commodities as well as the checking of consumer safety standards and packing or transport activities which add value to food products before they are sold" (Routroy & Behera, 2017).

The agriculture supply chain includes five main elements: farmer, processor, distributer, retailer, and consumer. The agriculture supply chain can be customized by adding or removing segments depending on several factors, among them the type of crops produced, the place of production, the market environment, and the logistics infrastructure (Routroy & Behera, 2017).

The agriculture supply chain is one of the most complex supply chain networks due to the perishable nature of products and the fact of being customer-oriented (Routroy & Behera, 2017). Additionally, food safety represents a major concern to the industry (Routroy & Behera, 2017).

2.2.3. Vertical Integration on Vertical Farming Supply Chain

The vertical farming food supply chain has a similar structure to the traditional farming chain. Yet, the operation's length can be reduced due to the proximity of the point of consumption, leading, consequently, to a reduction in terms of fossil fuel consumption.

To achieve sustainability throughout the chain, supply chain collaboration in different stages of the production process becomes essential. Thus, supply chain sustainability depends on the positioning in the chain, on the company size and power, as well as on the level of vertical integration selected (León-Bravo et al., 2017; Thomé et al., 2020).

Vertical integration, by definition, aims to bring together two or more stages of production usually operated by separated companies into one. Companies use this approach to proceed to quality control, reduce costs through economies of scale, and increase market share (Dongoski, 2020).

New digital technologies, together with data and analytics, reveal to be significant drivers of vertical integration (Dongoski, 2020), contributing to shape enterprise´s processes and operations for sustainable development in a supply-chain context (Duarte & Cruz-Machado, 2017; Luthra et al., 2020).

As the number of steps in the supply chain process determines the number of stages of integration (Harrigan, 1985), vertical farming has four possible ways of disrupting the actual food supply chain. Through a closed-circuit production cycle and combining different levels of the value chain within a single one (Hanf, 2014), the business model can assume control over farming, processing, distribution, and retail.

By controlling and managing the entire supply chain from "farm-to-table", starting with farming and processing, going into distribution, and ending up by selling the final product to the end-consumer as a retailer, the extreme case scenario of full vertical integration occurs.

Vertical integration on vertical farming has several advantages and disadvantages. On the one hand, it contributes to providing a consistent supply and cost control, optimizes the value chain by reducing transaction costs due to fewer chains involved in the food supply chain, ensures more transparency and traceability (Dongoski, 2020), and provides the consumer superior and fresher products at a lower price, since one company is managing the entire supply chain. On the other hand, a higher degree of vertical integration requires more investment in terms of production and coordination, higher fixed costs and capital requirements, and an incremental risk of focusing on additional non-core operations (Kaiser & Obermaier, 2020).

2.2.4. Traditional Farming and Vertical Farming Supply Chain

The creation of value in the agriculture sector takes place under a strongly environmental exposure, characterized by the high uncertainty and influence of weather conditions, including soil and nutrients dynamics, photosynthesis activity, and pest contaminations (Braun et al., 2018).

In the case of vertical farming, this unpredictability of operations does not happen. Unlike traditional agriculture, vertical farming is resilient to climate change. Because production occurs indoors, the seasonal changes have no effect on plant growth, with plants also being protected from pests and diseases that lead to lower harvests in traditional farming (Kalantari, Mohd Tahir, et al., 2017).

Moreover, the agriculture supply chain relies on low specialization skill level workers and recruits the workforce in a familiar context depending on most seasonal workers. These factors make the demand for employees harder when compared to other industries (Braun et al., 2018).

Vertical farming requires specialized knowledge and a skilled staff. In an indoor growing system, there is a vast spectrum of job opportunities, not only directly involved with the technology but also indirectly (Kalantari, Mohd Tahir, et al., 2017).

Vertical farming systems further offer reduced environmental impacts compared to the existing supply chains of traditional agriculture.

The distance needed to transport products to the final consumer is shortened since vertical farms are set up in urban centers (Beacham et al., 2019). However, according to research, of the total greenhouse gas emissions of food systems, production accounts for 83 %, while transport accounts for 11 % (Beacham et al., 2019). Regardless of this factor, due to shorter distances, the energy and fuel consumption required for transportation is reduced, driving down the total costs for the consumer (Beacham et al., 2019).

Also, vertical farms use space more efficiently compared to conventional farming. In vertical farming, multiple crops can be produced simultaneously on different floor levels, allowing maximization of crop output per acre of land (Kalantari, Mohd Tahir, et al., 2017). This technology-driven innovation represents a solution not only for metropolitan areas but also for areas that face severe weather conditions, where altitude

or climate conditions do not support production. Additionally, in areas with sufficient natural lighting, solar panels could be used to reduce energy costs. Thus, location represents a crucial factor in the reduction of operational costs.

To achieve global food security and environmental sustainability, agriculture systems must be rebuilt to face the challenges proposed by the food industry (Eigenbrod & Gruda, 2015). Vertical farming technology addresses several food-related issues, including food security and safety, environmental concerns, and the sustainability of the food supply chain (Despommier, 2011).

By improving the availability, access, and quality of food, urban food security is achieved (Eigenbrod & Gruda, 2015). Following this proposition, the population can always have access to adequate, healthy, and nourishing food required to live actively and healthily (Kalantari et al., 2020).

According to Miller (2011), health can be improved by locally farmed organic produce from a vertical farming environment. Thus, overall health in a community can rise (Kalantari, Mohd Tahir, et al., 2017).

Moreover, the localness of crops makes its traceability easier to capture. Therefore, consumers can easily understand where and how their food was raised (Dongoski, 2020). Due to the widening gap between production and consumption, lack of transparency regarding food products has risen (Feldmann & Hamm, 2015; La Trobe & Acott, 2000). As a counter-reaction, many consumers have reoriented themselves towards locally fresh food consumption (Feldmann & Hamm, 2015; Holloway et al., 2007; Watts et al., 2005). An efficient traceability system can minimize the production and distribution of poor-quality products and thus contribute to food safety (Routroy & Behera, 2017).

Around 14 % of the world´s food is lost from production before reaching the retail stage of the supply chain. Empirically, food losses can occur along the entire supply chain up to the retail stage, whereas food waste occurs solely at the retail and consumer level (FAO, 2019).

The reduction of food losses and waste along the supply chain is of extreme importance. Shrinkage of waste will lead to food security improvement and will contribute to a decline in overall land and water consumption at the global level (FAO, 2019).

Food loss and waste can occur at any stage of the supply chain, though in different degrees. On-farm losses arise due to inadequate harvesting time and the set of practices applied at harvest and handling, uncertain weather conditions, and challenges in the commercialization of production. At the storage stage, significant losses are caused by inadequate storage conditions and to decisions made at an early stage in the supply chain process that might predispose products to a shorter life cycle. During transportation, a resistant physical infrastructure and adequate trade logistics may prevent food losses. In the processing phase, losses occur due to inadequate facilities as well as due to technical and human errors. At the wholesale and retail level, food waste is based upon limited shelf-life, the need for food products to meet aesthetic standards in terms of color, shape, and size, and the variability in demand. Finally, consumption waste derives from poor planning in terms of purchase and meal preparation, excess buying, expiration dates, and poor storage management at home (FAO, 2019).

Through implementation of vertical farming production systems, improvement of practices along the supply chain can prevent food losses. On-farm losses decline because indoor farms do not depend on adverse weather conditions and unexpected climate change, allowing multiple harvests during the year (Kalantari, Mohd Tahir, et al., 2017). Since the system runs without soil usage, there is no risk of attack from a variety of microbes or plant pests (Despommier, 2013). Regarding storage, vertical farming offers indoor growing facilities that supply, control, and monitor humidity, temperature, lighting, water, carbon dioxide concentration, and nutrients to maximize plant growth (Despommier, 2013; Eigenbrod & Gruda, 2015). In terms of transportation, food losses are prevented since vertical farming helps to provide food locally, thus reducing the need for long-distance transportation (Banerjee & Adenaeuer, 2014; Kalantari, Mohd Tahir, et al., 2017). In conventional farming, about 30 % of food is lost (Despommier, 2009) due to spoilage and infestation occurring during the transportation from the site of production to the destination (Kalantari, Mohd Tahir, et al., 2017; Miller, 2011). Concerning the processing phase, vertical farming incorporates the production processing easily, taking into consideration the infrastructure associated with integrated ecological systems (Miller, 2011). Moreover, advances in technology allow the industry to operate in a more profitable, efficient, safe, and sustainable way (De Clercq et al., 2018).

Vertical farming benefits from a set of recent technologies that can transform the challenges of the agriculture supply chain into opportunities (Zambon et al., 2019). These technologies can be easily organized and used by all involved stakeholders along with the supply chain management. However, to carry out this digital transformation along the supply chain, technologies must be combined with adequate infrastructure, training and qualifications, and a favorable structural and legislative operating environment (Braun et al., 2018; Zambon et al., 2019).

Chapter 3. Methodology

The objective of this dissertation is to understand *the disruptive effect of Indoor Vertical Farming in the Supply Chain of Agriculture.* Two research questions were formulated to achieve this purpose.

Therefore, the methodology outlined below was deployed to gather the required data, and to answer the problem statement and the proposed research questions

3.1. Secondary Data Collection

Secondary Data was collected through the Literature Review as a means to get critical insights, information, and data for the development of the present research. Moreover, the material collected was fundamental to design the primary data collection since it provided the relevant knowledge to build Semi-Structured Interviews. The literature used focused primarily on academic papers, top journals, international research institutes, organizations, specialized corporations, and consulting reports.

3.2. Primary Data Collection

The primary data collection was conducted through Semi-Structured Interviews with Industry Professionals as a means of accessing relevant qualitative information for the research. The objective was to get the stakeholders´ vision on the development of urban agriculture and vertical farming and also to gain insights concerning opportunities and challenges that the agriculture industry may face in the future in light of the vertical farming disruption effect. A Semi-Structured Interview format was preferred over an Unstructured one in this empirical study. This method of research allows interviewees to elaborate on their points of view, opinions, and experiences, encouraging them to share more relevant information to the data analysis (Kumar, 2019).

Forty-seven people were contacted, of whom ten replied to the request for testimonies, but only five volunteered to participate in the interview. The five interview participants were representative of different stakeholders within the vertical farming and the agriculture industries and were chosen based on their professional experience and involvement with the sector (Appendix 7). Four out of five interviews were run in Portuguese and, subsequently, translated into English, and the last one was performed directly in English.

The first interview was conducted with António Fernandes, former Marketing Project Manager at Jungle Greens, one of the pioneering vertical farming projects in Portugal. The second interviewee was João Pereira, Area Sales Manager at Aralab, a Portuguese manufacturer of climatic chambers that simulate any controlled environment for the pharmaceutical, automotive, or agriculture sectors. The third interview was conducted with Mariana Mota, Agronomist at Instituto Superior de Agronomia, the most qualified undergraduate and graduate school in Agricultural Sciences in Portugal. The fourth interviewee was Elvira Ferreira, Researcher at Instituto Nacional de Investigação Agrária e Veterinária. David Slattery, Partner of DESCO Arizona, LLC, was the fifth and last interviewee (Appendix 7).

To ensure a sensible analysis, four interview guidelines were developed (Appendix 6), seeing as the interviewees were representative of different stakeholders within the industry, with different backgrounds, experiences, and knowledge of vertical farming, and thus, their level of expertise varied according to the topics covered. The first script was distributed to all study participants, containing generic questions related to the agriculture industry as well as about urban and vertical farming. Subsequently, the remaining three interview guidelines were designed specifically for vertical farming practitioners, academics, and other experts.

3.3. Data Analysis

Content analysis was used to analyze the information from the Semi-Structured Interviews with Industry Experts. Krippendorff (2013) defined it as "a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use". This technique was fundamental to translate insights into meaningful data to answer the problem statement and the research questions.

All interview transcripts were based on open-ended questions regarding different topics. Those questions provide the best fit for the Semi-Structured Interviews since they enable the participants to freely share their views, opinions, and understanding of the subject (Kumar, 2014). To validate the gathered information, four out of five interviews were recorded, enabling to ensure the accuracy and the credibility of the data.

Chapter 4. Analysis and Discussion

4.1. Indoor Vertical Farming Disruption on the Agriculture Supply Chain

4.1.1. Short to Medium-Term Impact of Vertical Farming on the Agriculture Industry

The scarcity of resources will put tremendous pressure on the agriculture industry. To respond to the increasing global demand for food, farmers will need new technologies to produce more with less land (FAO, 2009). Thus, the agri-food industry will be affected by changes but also will be the source of some of the changes, as is the vertical farming example (van der Duin & den Hartog, 2018).

Vertical farming will have the capacity to change the structure and principles of the agriculture industry (Fernandes, 2020, Appendix 1). With the latest and most sophisticated technologies, this new way of production will be able to increase the food supply in highly populated cities while at the same time will contribute to the footprint reduction of traditional farming (van der Duin & den Hartog, 2018).

The growth of urban farming, facilitated in part by vertical farming, can bring food closer to customers and leverage transparent decision making by knowing exactly the inputs used in production and tracking the journey all the way from "farm-to-fork" (Pereira, 2020, Appendix 2).

This method of production can significantly reduce the distribution chain due to the proximity of the point of consumption. Due to a reduction in terms of energy and fuel consumption, and shorter distances, it delivers benefits at the scale level that will allow, in the long-run, to lower costs for the consumer and consequently increase the self-sufficiency of the city (Beacham et al., 2019; Pereira, 2020, Appendix 2).

From a business perspective, when proving concept and profitability, that is, the ability to prove that producing in vertical farming is more profitable than in the open field, it becomes clear the real and disruptive potential that vertical farming could have in the agriculture industry (Fernandes, 2020, Appendix 1).

The potential disruption of the agriculture sector is an emerging issue due to demographic growth, food waste, scarcity of resources, and climate change. According to Pereira (2020), vertical farming “is an inevitable trend in the future that farmers will sooner or later have to adopt” (Pereira, 2020, Appendix 2).

The short and medium-term impact of vertical farming on the agriculture industry is expected to be contained, motivated by the high costs implied by the technology. Nevertheless, with the increasing technological development over time, those costs will tend to decrease, leading to an increase in the sustainability and profitability of the business (Benke & Tomkins, 2017). A sustainable transition to controlled environment agriculture will only be possible with strategy and planning in terms of education, infrastructure development, and government support (Fernandes, 2020, Appendix 1).

4.1.2. Factors Triggering Disruption Risks

With the introduction of vertical farming as a disruptive innovation, some difficulties emerge in managing this change, affecting the firm's strategic decision-making regarding how to deal with the rise of a new trend. Uncertainties and market characteristics may create some constraints in the general adoption of disruptive technology.

4.1.2.1. Uncertainty

A disruptive technology, as is the case of vertical farming, can change the basis of competition in an industry. The literature shows that companies face severe difficulties in managing innovation that fall outside of the previous experience in the field, where earlier strategies and practices cannot be applied (Christensen, 1997). However, there is not a consensus on whether the source of that difficulty lies in the technical characteristics themselves, on the set of processes used to manage it, or in the means used to access the surrounding resources (Chesbrough & Rosenbloom, 2002).

The uncertainty surrounding disruptive technologies makes it difficult for managers to predict technology longevity and sustainability over time. In this way, careful planning becomes essential for success in sustaining technology (Christensen, 1997).

In a vertical farming business, it becomes imperative to understand whether the market values this type of produce or not and how much customers are willing to pay for it (Pereira, 2020, Appendix 2). Thus, a credible business plan, including capital costs, marketing strategies, staffing, and customer potential, becomes essential, not only to solve significant uncertainties but also to attract investment.

The central questions of vertical farming are to prove concept and profitability, that is, to be able to prove that this new way of producing work, and that it can be more profitable than production in an open field. Thus, it is essential to understand how much

it is necessary to invest in financial terms so that 1 square meter of vertical farming fulfills the promise of being more productive than 1 square meter in traditional agriculture. Once this profitability is proven, then this uncertainty is eliminated. The risk of investing in a vertical farming business model is mitigated, making the attractiveness of the investment clearer (Fernandes, 2020, Appendix 1).

Vertical farming also faces some uncertainty in terms of consumers, which differs according to their level of affinity towards new food technologies or knowledge about the system (Jürkenbeck et al., 2019). However, by using the right marketing strategy, that uncertainty can be overcome (Fernandes, 2020, Appendix 1).

Vertical farming could focus on trying to transmit a vision of organic and sustainable production, communicating the ancestral image of agriculture. By following this strategy, instead of focusing on the operations side and on the technology used as a production engine, consumer acceptance arises. Thus, it is essential for vertical farms to transmit the most traditional image possible, all around the farming storytelling, showing vertical farming as something sustainable and not as a "plant factory" (Fernandes, 2020, Appendix 1). Marketers could focus on the main benefits of the product and ensure that the organoleptic properties are as good or better than the alternatives on the market (Pereira, 2020, Appendix 2).

Moreover, the world has seen a change in terms of customer habits. Customers have become more careful about their decision-making and more attentive to their health and the quality of the food (Corallo et al., 2018). Vertical farms want consumers to see their products as something safe, fresh, nutritious, and sustainable instead of something artificial (Fernandes, 2020, Appendix 1).

4.1.2.2. Market Characteristics

The industry characteristics also have a significant influence on disruption risks. The agriculture sector dates back thousands of years. The use of new technologies by conventional farmers has been lower than expected in part due to the complexity and the unintended impacts associated with its use (OECD, 2001). This slow adoption of innovation is motivated by the uncertainty in terms of economic profitability, familiarity and expertise with the technology, unpredictable support policies, and structural factors such as the size of the company, technology costs, and scale of production (OECD, 2001). The receptiveness of farmers regarding agriculture innovations is all about

cost/benefit, and the main reasons to implement it is to get more yields, sales, and volume (Slattery, 2020, Appendix 5).

Currently, there is a growing need for cutting edge and modern technology that did not exist in the past due to huge challenges and pressures from the global population increase (Fernandes, 2020, Appendix 1) and due to the need for environmental preservation (Mota, 2020, Appendix 3). As stated by Fernandes (2020), the agriculture industry could adopt "a more irreverent stance and become an early adopter in technologies and new ways of producing". Moreover, as vertical farming is a type of agriculture based on a technological principle, teachings from this new way of production can be passed on to the agricultural industry, for instance, in the way technology is applied to optimize production (Fernandes, 2020, Appendix 1). According to Fernandes (2020), "this technology is constantly evolving and will affect the agriculture sector in the short, medium, and long-term" (Fernandes, 2020, Appendix 1). Thus, once vertical farming proves to be commercially scalable at a better profit margin, everybody will jump on board (Slattery, 2020, Appendix 5).

4.1.3. Competitive Environment of Vertical Farming

Porter´s Five Forces Framework was used to assess the vertical farming competitive landscape. Porter (2008) suggests analyzing the industry´s underlying structure in terms of five forces: the power of buyers, the power of suppliers, the threat of entry, the threat of substitutes, and rivalry among existing competitors. Thus, the higher the intensity of competitive forces, the lower the potential return on investment. Understanding those forces as well as their causes can reveal the roots of the industry´s attractiveness in terms of profitability while at the same time provide clues to the right business framework to act strategically over time.

Although this framework is one of the most popular management models, some criticism emerged in recent years. Since the model dates back to 1979, and it has not been modified, it is arguable if the five forces are still relevant (Dälken, 2014). Some authors criticize the fact of being a static model that does not take into account the time factor. Thus, there is an increased difficulty in determining and analyzing markets subject to dynamic competition (Dälken, 2014; Thurlby, 1998).

This analysis was developed assuming its application in a global context and not in a specific geography. Additionally, the product was defined as high-quality produced at a

low scale. Finally, all conclusions drawn are only valid as long as the industry is considered recent.

4.1.3.1. Porter´s 5 Forces

Vertical farming buyers include restaurants, retailers, and end consumers. Buyers have the power to choose their consumption options, the quantities bought, and the ability to switch to other industry participants. On a global scale, buyer´s concentration in the vertical farming market is still reduced. Thus, as the number of buyers decreases, in comparison to the competition, the bargaining power increases. Furthermore, in an early stage of the business, profitability is reduced (Fernandes, 2020, Appendix 1). Thus, intermediate customers, that is, customers that are not end-users, have some bargaining power since they are investing in a business with a low level of profitability and, at the same time, can influence the purchasing decision of end consumers (Porter, 2008). Overall, the bargaining power of buyers is high.

Vertical farming suppliers include vendors of the main equipment used for production, energy and water providers, and packaging, seeds, and nutrients suppliers. The bargaining power of suppliers is influenced by price sensitivity, the quality provided, and the shifting costs to industry participants (Porter, 2008). Generally, system suppliers have a lot of power since the vertical farming business depends on a huge technological base (Fernandes, 2020, Appendix 1). Also, to guarantee the product´s high quality, it is critical to have equipment that allows obtaining that advantage (Pereira, 2020, Appendix 2). There are not many suppliers that produce specific equipment for the industry, so the ones that exist can capture the market and can have greater power over it (Fernandes, 2020, Appendix 1). Vertical farms can also create their own production systems and, thus, mitigate the high bargaining power from system suppliers (Pereira, 2020, Appendix 2). However, building an in-house production system is an expensive process with a high degree of risk, and that requires high expertise (Pereira, 2020, Appendix 2). Overall, the bargaining power of suppliers is moderate.

The threat of new entrants in the vertical farming competitive environment depends on the intensity of entry barriers that are present in the industry (Porter, 2008). In this case, one of the major constraints of the system corresponds to the high capital requirements needed to develop the business. Such capital requirements include high upfront investment, high building expenses, and the energy costs associated with the technology (Fernandes, 2020, Appendix 1; Pereira, 2020, Appendix 2). Moreover, the need for

highly specialized knowledge to control the production process represents a barrier to new entrants (Fernandes, 2020, Appendix 1). Overall, and assuming a low-scale production as well as low profitability in the early stage of the business, the threat of new entrants in the vertical farming market is low.

The threat of substitute products in the vertical farming competitive landscape depends on the availability of substitutes that perform the same or a similar function as industry´s products, and for which the consumer is willing to switch (Porter, 2008). One of the major threats identified occurs when vertical farming competitors, in this case, traditional farmers, produce high quantities year-round at a reduced cost and supply relatively inexpensive products to consumers guaranteeing reasonable levels of quality (Fernandes, 2020, Appendix 1). Additionally, as vertical farming is a recent industry, customer loyalty has yet to be consolidated. Thus, the threat of substitute products is high.

One of the pioneering countries to implement vertical farming technology was Japan, where the import dependency was aggravated by the contamination of agricultural soil, after the Fukushima nuclear accident, in 2011 (Despommier, 2019). Due to the fact of being a very new and recent industry, there is more of a partnership between vertical farming companies than rivalry, with constant sharing of knowledge and know-how for business development. Nonetheless, the rivalry is more prominent with traditional farmers since they can offer lower prices (Fernandes, 2020, Appendix 1). Thus, assuming that existing competitors are traditional farmers, the rivalry among existing competitors is high.

4.1.3.2. Logistics Flow

In terms of operations, the most obvious dimension of how the vertical farming business could disrupt the agriculture supply chain is in terms of transportation. With the expected increase in urbanization, there will be an increasing need for agricultural products within cities (Fernandes, 2020, Appendix 1). Vertical farming will help with the reduction of long transportation distances since production occurs alongside cities (Fernandes, 2020, Appendix 1; Pereira, 2020, Appendix 2). Additionally, vertical farming could solve the main traditional agriculture bottlenecks by specializing in a specific stage of the production process (Pereira, 2020, Appendix 2).

The second fundamental point is associated with food loss and waste. By strictly controlling the main variables of plant growth, there is no risk that production is ready a week earlier or a week later, leading consequently to food losses and waste along the supply chain (Pereira, 2020, Appendix 2). Thus, it is possible to determine with a very high degree of accuracy when vegetables should be produced to be available in-store on a given date, relieving pressure on food production (Pereira, 2020, Appendix 2). Vertical farming manages to control the entire production process with industrial precision, and this is critical in logistics (Pereira, 2020, Appendix 2). It allows trucks to arrive on time, substantially reduces waiting time, and allows delivery to be made on time without penalties due to delays (Pereira, 2020, Appendix 2). In this way, it is possible to ensure that if there are no delays in production, there are no empty displays in retailers (Pereira, 2020, Appendix 2).

Finally, there is an improvement in terms of food security by developing a system where it is possible to offer high-quality products throughout all year, with certifications that guarantee to the consumer that there is a decreased risk of contamination (Pereira, 2020, Appendix 2). The emergence of pests and food contamination is drastically reduced since production occurs in closed cycles (Fernandes, 2020, Appendix 1; Pereira, 2020, Appendix 2). This significant decline in terms of contamination coupled with a reduction of human error due to the automation of production processes and the usage of cutting edge and modern technology represents an enormous gain from the food security point of view (Fernandes, 2020, Appendix 1).

4.1.4. Research Question 1 Acknowledged

The way food is grown will have to drastically change to meet the promise of feeding 10 billion people by 2050 (FAO, 2017). Food production would have to almost double within the next 30 years to meet the demand (UN, 2009). 68 % of the world's population will live in cities by 2050 (UN, 2019). Thus, there is a severe urgency to increase yields to feed this growing urbanized population. The need to raise production to meet the declining arable land capable of growing crops represents a great opportunity for new disruptive technologies to take place. Vertical farming could be a solution to this problem, and its potential impact on the traditional agriculture supply chain is significant.

From a production perspective, which can occur alongside the cities, there is a tremendous reduction in transportation distances, meaning less carbon dioxide

emissions since vertical farms can be placed anywhere, independent of climate conditions with year-round production. By having a centralized distribution hub, it shortens the supply distribution chain. As a result, vertical farm produce can have a quicker time-to-market with greater quality. The freshness is guaranteed since customers can purchase products slightly after being picked, retaining all its original nutritional composition that would have been lost during transportation and refrigeration otherwise (Ferreira, 2020; Appendix 4).

Even though developments in technology have allowed a reduction in supply chain losses (Laugerette & Stöckel, 2016), around 14 % of the world's food today is lost from production before reaching the retail stage of the supply chain (FAO, 2019). In traditional agriculture, about 30 % of food is lost (Despommier, 2009) due to spoilage and infestation occurring during transportation from the site of production to the destination (Kalantari, Mohd Tahir, et al., 2017; Miller, 2011).

Vertical farming manages to control the entire production process with industrial precision, avoiding waste, and better controlling production loss. By using a closed production system and with water conservation technologies or renewable sources, all waste could be recycled and reused (Pereira, 2020, Appendix 2). Moreover, since production does not depend on weather conditions and on the harvesting time, the transportation and storage requirements are drastically reduced, and human error and the emergence of pests are highly mitigated. Thus, food loss is significantly reduced (Fernandes, 2020, Appendix 1).

The food quality system is much safer today than in the past due to increased requirements by quality management systems. Nowadays, a retailer cannot afford to report products with pesticides in stores. In addition to all the regulation that exists, a retailer has its internal quality control procedures. Therefore, when a product reaches a shelf, it has already gone through multiple stages of certifications and food quality control. However, the existing trade-off is the uniformity of products to meet aesthetic standards in terms of color, shape, and size, leading to food waste. With an optimized and streamlined supply chain, vertical farming significantly reduces production waste and food losses, contributing positively to drive improvements in terms of food security and safety while at the same time providing customers with sustainable and healthy production (Pereira, 2020, Appendix 2).

Today, farmers face high complexity along the value chain. In the future, traditional farmers will deal with even more players and technologies emerging and disrupting the industry (Laugerette & Stöckel, 2016). Vertical farming can contribute with integrated solutions that may improve the agriculture landscape. Through innovation and technology and a more efficient supply chain, it can drive yield optimization, overcome the limited land area, and reduce farming environmental impacts detrimental to the ecosystem development.

4.2. The Future of the Global Agriculture Supply Chain with the Widespread of Indoor Vertical Farming

4.2.1. A Forward-Looking into the Agriculture Industry

The pressure on food production to meet future demand is becoming a serious issue, driven by demographic impacts, scarcity of resources, climate change, and food waste. These challenges reinforce the need to produce more sustainably and with less environmental impact (Pereira, 2020, Appendix 2).

Advances in technology can shape a new era in the agriculture sector, allowing the industry to operate in a more profitable, efficient, safe, and sustainable way (De Clercq et al., 2018). Agriculture innovations are highly dependent on the scale of production. Nowadays, most large companies benefit from more accessible technologies and already use advanced technological systems to control their production processes and to guarantee product availability over time. In the short and medium-term, existing technology will continue to evolve. Whereas in the long-term, technological disruptions coming up from other sectors will most likely be applied in the agricultural industry, like artificial intelligence, robotization, or vertical farming practices (Pereira, 2020, Appendix 2).

The future of the agriculture industry will most likely go through Agriculture 4.0 (Ferreira, 2020, Appendix 4). It refers to a technology-driven approach aiming to impact consumer needs and transform the food value chain (De Clercq et al., 2018). By combining and integrating production technologies and devices, information and communication systems, and data and services in a global network, Agriculture 4.0 would enable enterprises to operate efficiently, safely, and with reduced operating costs (Zambon et al., 2019).

Farmers must be aware of the need to evolve and produce sustainably (Ferreira, 2020, Appendix 4). Future agriculture will use sophisticated technologies such as drones and sensors, enabling farmers to have more visibility into their farm and knowing what the field looks like twenty-four hours a day, seven days a week, in an affordable manner (Fernandes, 2020, Appendix 1; Ferreira, 2020, Appendix 4). Moreover, robotics, machinery, and precision agriculture techniques could help farmers to improve their return on investment while at the same time, could improve yield productivity, avoid food loss and waste, and contribute to safer and environmentally friendly operations (Fernandes, 2020, Appendix 1).

4.2.2. The Current State of Vertical Farming

The worldwide value of the vertical farming market is expected to reach $6.4 billion by 2023, compared to $403 million in 2013, with almost half of the growth attributed to the development of the business in the US (BBC News, 2019) (Figure 1),

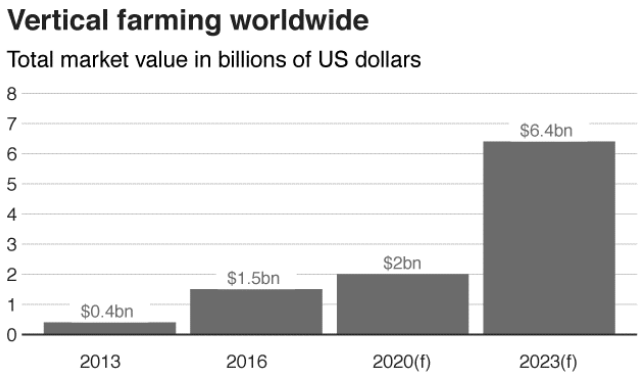

Figure 1 - Vertical Farming Total Market Value (BBC Research, 2019)

Obtaining financing for any agricultural project is quite difficult, especially for commercial-vertical farming projects (Birkby, 2016). However, over the past years, both public and private entities have financed projects in the area, motivated by a better business model supported by technological improvement and evolution.

Farm Tech startup's investment has grown by about 370 % since 2013 (Agfunder, 2020) (Figure 2). Farm Tech or Agri-Food Tech is defined as the "growing segment of the startup and venture capital universe aiming to improve or disrupt the global food and agriculture industry" (Agfunder News, 2017).

Figure 2 - Annual Farm Tech Financings (Agfunder, 2020)

Despite the high costs of the vertical farming business, the industry has been shown to be an attractive investment for entrepreneurs and investors (De Clercq et al., 2018).

In July 2017, SoftBank Vision Fund led a $200 million bet on Plenty, a major vertical farming player in the US. Other participants in the round of funding included Amazon CEO Jeff Bezos and the tech billionaire Eric Schmidt, former Google CEO (Bloomberg, 2017; De Clercq et al., 2018).

In August 2017, IKEA, the world-renowned chef David Chang and the ruler of Dubai, Sheikh Mohammed bin Rashid, invested $40 million in AeroFarms, the world´s largest indoor vertical farm, joining core investors and partners including MissionPoint Capital, Middleland Capital, Prudential and Goldman Sachs (AeroFarms, 2017; De Clercq et al., 2018).

Vertical farming revenue comes from major market players, among them Aerofarms and Plenty from the US, Infarm (Germany) and Signify Holdings (The Netherlands) from Europe, and Sky Greens (Singapore) and Spread CO., Ltd. (Japan) from Asia (Vertical Farming Market, 2020).

The Asia Pacific accounted for the largest market size in 2019, driven by the growing land scarcity in some regions, the need to meet demands from the rising population, and increasing investment and partnerships between vertical farming enterprises and technology providers (Vertical Farming Market, 2020).

4.2.3. Limitations of Vertical Farming

Vertical farming finds some limitations to its development as a business, including education, costs, and policy-related constraints.

4.2.3.1. Education

Most vertical farming practitioners do not come from the agriculture industry, but instead, they come from other areas, such as marketing, management, engineering, biology, programming, or data science (Pereira, 2020, Appendix 2).

Vertical farming requires a lot of specialized knowledge and therefore requires investment in terms of education and research to ensure that the product is of value-added to the consumer (Fernandes, 2020, Appendix 1; Pereira, 2020, Appendix 2).

When coming up with the vertical farming production system, data mining and specialization are fundamental to cope with a set of innovative technologies required (Fernandes, 2020, Appendix 1). Thus, investing in data science, mobilizing research into the industry, and spending resources on business development becomes fundamental for technology diffusion (De Clercq et al., 2018).

For the future transition from rural to the urban agriculture industry, incentives, from the lowest level of education, could be provided by reinforcing the educational contents of in-school programs (Mota, 2020, Appendix 3). To stimulate the sector growth, schools of agriculture could provide specialized degrees in urban farming, focused on training and incentivizing city dwellers to work in them (Despommier, 2019).

The interest in vertical farming has risen. However, the degree of knowledge and education on this new agricultural practice is reduced when compared to other agriculture techniques since it is still residual in terms of practice (Ferreira, 2020; Appendix 4; Mota, 2020, Appendix 3).

Governments can take a leading position and support the development of this technology-driven innovation by contributing and providing incentives to a highly skilled and educated population (De Clercq et al., 2018). Through the promotion of training actions in different contexts, such as municipalities, schools, and associations (Mota, 2020, Appendix 3) and by enabling a cooperation ecosystem between companies, universities, startups, and research centers, the disruption of the value chain would be facilitated (De Clercq et al., 2018), as well as the future widespread of vertical farming.

4.2.3.2. Costs

The main limitation of the implementation of vertical farming is at the OPEX and CAPEX levels (Pereira, 2020, Appendix 2). It is essential to define the technology cost/investment threshold and how efficient production can be compared to an open field or greenhouse, to understand the price difference to which the product may be subject (Pereira, 2020, Appendix 2).

To reduce energy and water consumption for greater efficiency of the system, renewable energy, and water conservation technologies can be used in the production process. Moreover, at the logistics level, placing the production facility as close as to the place of consumption is vital to reduce the footprint in the logistics chain (Fernandes, 2020, Appendix 1; Pereira, 2020, Appendix 2) since shorter distances will lead to energy and fuel consumption reduction.

Renewable energy sources and production schedules that are more compatible with cost and consumption reduction could lead to a more sustainable chain of operations. In a controlled environment, it is possible to simulate the daytime environment at night, when energy is more available on the network and is cheaper. During the day, when the cost of energy is much higher, it is possible to simulate the nighttime environment (Pereira, 2020, Appendix 2).

With water conservation technologies, it is feasible to measure and control the efficient amount of water to be used in production (Fernandes, 2020, Appendix 1). It is possible to reduce between 70 % to 80 % of water usage when compared to conventional farming techniques (Despommier, 2013; Fernandes, 2020, Appendix 1). Additionally, the water from the plant's breath can be reused in the production process. The next step will be to create filtration and disinfestation systems that will allow the reintroduction of this water and thus reduce the need for consumption in the network (Pereira, 2020, Appendix 2).

Finally, labor costs, which usually combine highly skilled work and traditional manual labor, could be highly reduced with the introduction of automation and robotics. Through controlling and monitoring systems, time could be allocated more efficiently during production (Fernandes, 2020, Appendix 1; Pereira, 2020, Appendix 2).

4.2.3.3. Policy

For the future widespread of vertical farming, public and private investments are essential. Governments could take a primary role in providing strategies to improve the enabling environment and work to foster a technology and innovation ecosystem within the society (De Clercq et al., 2018).

Nowadays, there is a lack of government support for vertical farming since the business does not receive the same incentives, support, and financing conditions as traditional agriculture (Pereira, 2020, Appendix 2; Slattery, 2020, Appendix 5). In the particular case of the US, a large portion of support from political leaders to the agriculture industry comes from agriculture lobbying groups. In the US example and not generalizing to other nations, lobbying has to exist for an industry to work. However, this is a tremendously expensive process. If there is a vertical farming lobbying group with enough power, then incentives might be more easily achieved (Slattery, 2020, Appendix 5).

Governments, in implementation and expansion of an upcoming new industry, such as vertical farming, could provide financial support and incentives, such as tax credits, regulatory flexibility, infrastructure price benefits as well as R&D partnerships (De Clercq et al., 2018; Slattery, 2020, Appendix 5).

Moreover, State intervention and European funds are necessary for producers to have access to advanced technologies (Fernandes, 2020, Appendix 1). Investment, especially in technological development, could be provided (Pereira, 2020, Appendix 2).

When it comes to regulation, the vertical farming business faces some issues. Due to the novelty of the industry, regulators are unsure whether to classify vertical farming as an agricultural, technological, or manufacturing business (Slattery, 2020, Appendix 5). This lack of clarity leads to delays and difficulties in delivering projects as well as on the final validation of applications (Pereira, 2020, Appendix 2). As an industry player, this lack of evidence raises questions as to how to tax the business and increases the difficulty of setting a proper business structure (Slattery, 2020, Appendix 5). Thus, profit incentives and favorable regulation are essential for vertical farming scalability (Slattery, 2020, Appendix 5).

4.2.4. Scenario-based Analysis

4.2.4.1. Vertical Farming Value Chain Stakeholders

The food value chain stakeholders might include producers, primary and value-added processors, retailers and distributors, consumers, and governments/NGOs/regulators. Starting from the beginning of the value chain, producers are responsible for the growth, and trade of food commodities. Secondly, primary and value-added processors process, manufacture, and market food products. Afterward, distributors, including wholesalers and retailers, market and sell commodities to consumers, which in turn are responsible for purchasing and consuming the final products designed to satisfy their needs. Finally, governments/NGOs/regulators monitor and regulate the entire food value chain (Deloitte, 2013).

Additionally, vertical farming competitors, in this case, traditional farmers, global input suppliers, such as the ones offering technology, production equipment, packaging, seeds, nutrients, water, light and energy, and research centers and educational institutions, were also considered stakeholders in the development of vertical farming.

4.2.4.2. Market Potential for Vertical Farming

To predict how the global agriculture supply chain might evolve, assuming widespread deployment of indoor vertical farming, a scenario-based analysis was performed. Three different scenarios allowed to postulate how key factors could influence indoor vertical farming market penetration. Those key factors included not only the business model but also the market size, production scale, capital expenditures, target market, and the appropriate product mix.

4.2.4.2.1. Conservative Scenario: Large-scale production and commodity products

In the conservative scenario, indoor vertical farming production systems would be used in exceptional cases. This minimum market penetration would be mostly driven by the major system bottlenecks.

At the initial stage of the business, a large-scale production scenario would imply high start-up costs as well as high energy, depreciation, and labor expenses. By focusing on a low product variety, based on low-margin commodity products, and in a high volume, it could take decades to pay back the initial investment.

Additionally, if traditional farmers could produce high quantities year-round at a reduced cost and supply relatively inexpensive products to consumers, competition could become a worrying factor for the vertical farming system.

Another issue that could arise is regarding consumer´s unwillingness to pay a premium for products produced in a vertical farming environment. According to Banerjee & Adenaeuer (2014), the vertical farming production system might become more feasible, particularly "in mega-cities with substantially high purchasing power". Although high prices would allow vertical farming to recoup costs easily, when combined with start-up and operating costs, the product´s final price might be too high for consumers (Beacham et al., 2019).

As in the conservative scenario, the technology might not be developed to the point of making the business financially sustainable, profitable, and viable. Thus, a technology with weaknesses would contribute to products´ marketability complexity.

The operational complexity would become greater in a large-scale vertical farm. Careful consideration of the plant science, together with planning an efficient logistics workflow, by identifying the major system bottlenecks and reducing the non-value adding activities would become essential to operate on a large-scale vertical farm.

When it comes to education and research, vertical farming would require highly specialized knowledge as well as investigation to consolidate the technology. High extent barriers regarding investment could condition the spread of vertical farming knowledge.

Finally, in a conservative scenario, regulation barriers would limit the scalability of the technology. Adding this to reduced agricultural incentives and subsidies as well as high operating costs, vertical farming viability would become unstable in the future.

4.2.4.2.2. Reasonable Scenario: Low-scale production and differentiated products

In a reasonable scenario, indoor vertical farming production systems would be used sparingly due to the mitigation of some bottlenecks of the current business model.

At the initial stage of the business, there would be high fixed costs and an increasing need for profitability (Fernandes, 2020, Appendix 1). Thus, vertical farms could focus its strategy on a low-scale production scenario, which would imply lower capital

expenditure investments and, consequently, a more flexible business model with easier monitoring and control to meet customer demand.

Additionally, differentiated products, such as hard-to-import specialty and exclusive crops, could be offered to environmentally conscious consumers with greater purchasing power (Pereira, 2020, Appendix 2). By charging premium prices, higher sales margins could be generated.

Concerning competition, due to high costs, it would not be possible to compete in these terms. Thus, a differentiation strategy could be applied (Fernandes, 2020, Appendix 1; Pereira, 2020, Appendix 2), focusing on the product´s quality (sustainability, taste, or visual aspects), availability, and food security (Pereira, 2020, Appendix 2). Following this economic logic and by offering customers a difficult-to-match product, the competition issue could be overcome. For instance, technically, it is within vertical farming´s reach to have functional vegetables not only as a source of food satisfaction but also as a contributor to a better health through vegetables enriched in iron, calcium, or with less sodium for hypertense people (Pereira, 2020, Appendix 2).

Therefore, at the initial stage of the business, rather than focusing on mass production and commodity crops, where vertical farms would always struggle due to fierce competition from traditional farming, it might make more sense to operate on a smaller scale, focusing on high-value crops that command a premium price.

On a small-scale production system, operational complexity would decrease, allowing for more flexibility and agility in the production process.

In a reasonable scenario, vertical farming would continue to require highly specialized knowledge, nonetheless, on a smaller scale. With the consolidation of the technology in the industry, knowledge would become widespread, and it would be easier to scale up the business in the long-run.

Ultimately, as soon as there is more clarity about the vertical farming technology as well as the potential opportunities and risks that it might be subject to, it might be easier to obtain investments, incentives, subsidies, and overcome regulatory barriers.

4.2.4.2.3. Optimistic Scenario: Large-scale production and differentiated products

In the optimistic scenario, indoor vertical farming production systems would be used extensively, motivated by the rapid technological development and the overcoming of the main bottlenecks. Its reach and market penetration would be widespread.

The commercial viability of vertical farms would no longer be a challenge. Once the concept and profitability were to be proven, that is, as soon as it is possible to prove that producing in a vertical farming environment is more profitable than in the open field, the uncertainty regarding the potential of this technology would disappear (Fernandes, 2020, Appendix 1).

With the business development, scale benefits would arise based on the efficiency gains generated through the production process, especially in terms of operations, through the automation and usage of advanced monitoring and supervision systems, and in the best-case scenario in terms of technology (Pereira, 2020, Appendix 2). Once the business growth stage is reached, it would possible to produce on a larger scale, with significant, recurring, and long-term production (Pereira, 2020, Appendix 2). This shift corresponds to the transition from unsustainable to financially sustainable vertical farming (Fernandes, 2020, Appendix 1).

Moreover, production could be focused both at B2C and B2B levels. On B2C, leafy greens could be quite profitable to produce due to a fast growth rate, maximized turnover, fewer consumption resources, and lower production costs. On B2B, the production focus could be on high-value crops, such as cannabis, medical compounds, functional vegetables, vanilla, saffron, sweet potato sprouts, eucalyptus, or tomato. The economic parameters of these crop types are very well defined, with little fluctuation in the market. There is a clear notion of how much those high-value crops must be sold, allowing for greater predictability and, consequently, a higher production scale and profitability (Pereira, 2020, Appendix 2).

Urban agriculture is likely to become generalized, both in developing and developed countries (Orsini et al., 2013). In an optimistic scenario, the widespread of vertical farming among the population would be feasible and sustainable. This production system would be suitable not only in markets with high purchasing power but also in more deprived regions (Pereira, 2020, Appendix 2), such as Africa, where there is an increasing need for safe and nutritious food (Ngumbi, 2015).

Its future expansion would imply the involvement of local governments, international organizations, and commercial growers. In this way, technology would become democratized and accessible to everyone (Pereira, 2020, Appendix 2).

By having a highly educated and skilled population, low energy costs, and a government willing to provide incentives, policies, and favorable regulation to leverage the growth of this innovation, vertical farming could potentially become dominant in comparison to traditional agriculture (De Clercq et al., 2018).

4.2.4.3. Impact on Supply Chain Stakeholders and Likelihood of Possible Scenarios

Three possible scenarios were created and calibrated based on secondary research and on the interviewee's inputs (Appendix 8).

4.2.5. Research Question 2 Acknowledged

Based on the current development of vertical farming and its potential widespread, the most likely scenario to happen is the reasonable scenario based on a low-scale production and differentiated products.

According to Despommier (2013), the vertical farming concept "is still too new to conclude that these technology-driven agricultural initiatives will be successful on a worldwide scale, either from an economic and/or social perspective".

A mass adoption from a business perspective is quite hard to achieve due to high capital and operational expenses. Producing in a controlled environment comes at a cost. Vertical farming occurs in enclosed buildings, with total control and monitoring over light, air, water, and soil, whereas in an open field, those variants are freely provided. Therefore, it is essential to define the proper model since vertical farms are competing against farmlands with minimal costs (Slattery, 2020, Appendix 5).

Profitability would be a challenge on a large-scale business model based on commodity products. At an initial stage, it would require huge investments and would be severely arduous to overcome the low margins caused by high energy, capital expenditures, and labor costs. Following Benke & Tomkins (2017), although "low-value field crops are not economically viable at present, this may change in the future with an ever-changing climate, scarce arable land, and diminishing and intermittent resources such as water".

A forward-looking business based on large-scale production and differentiated products could bring more profitability. Despommier (2019) stated that there is "great hope that

vertical farming can become commercially viable at a large scale. Diversifying the crop selection could further contribute to the success of vertical farms". Thus, it is the scenario that most vertical farming companies aim to reach. Producing high-value crops, as is the case of cannabis, medical compounds, or functional vegetables, even with higher capital expenditure could bring more profitability. However, a "perfect scenario" with the total absence of bottlenecks reveals to be ambitious to achieve in the vertical farming business.

There is a common sense that the production scale solves cost problems. On vertical farming, the only factors where it is possible to have relevant scale efficiencies are in air conditioning and operations and not on lighting, which is the main cost factor in production. Nevertheless, right now, none of these advantages are enough to match the cost of open field production. There will always be a need to charge a premium price for vertical farming products. Thus, the scale benefit does not come from the technology itself but instead from the efficiency and gains obtained through the production process (Pereira, 2020, Appendix 2).

Although vertical farming costs are decreasing due to improvements in existing operations and technologies, such as lighting and automation (Benke & Tomkins, 2017), they persist too high. Moreover, regulatory ambiguities on indoor vertical farming operations remain (Simpson, 2019), as well as a shortage of highly qualified people to operate in the industry.

A low-scale vertical farm focusing on differentiated products to fill the existing gaps in fresh vegetable supply, sustained by tremendous technological improvement, reveals to be the most reasonable and sensible business model to implement.

By focusing on a niche market and producing products with higher margins, such as specialty and exclusive crops, combined with lower investment costs as opposed to a large-scale farm, higher profitability could be achieved. This could bring more stability and a greater focus on producing products consistently and with higher quality over time.

For the future widespread of vertical farming, public and private investment would be essential. Governments could take a primary role in providing strategies to improve the enabling environment and work to foster a technology and innovation ecosystem within the society (De Clercq et al., 2018). Investments and institutional support on education

and research, electricity and water incentives, clear regulation, and infrastructure price benefits are essential for the viability and future adoption of vertical farming.

Overall, vertical farming does not represent a risk for traditional agriculture (Benke & Tomkins, 2017) since it does not intend to replace it but rather to complement it (Pereira, 2020, Appendix 2) as a viable alternative that can contribute to a better and more sustainable future. According to Despommier (2019), “even if indoor farming does not fully replace outdoor farming, it may well complement the food system facing the increasing pressures of demographic growth coupled with land scarcity”. This confirms, indeed, that the market actually believes in the potential of a reasonable scenario rather than in the optimistic one.

Chapter 5. Conclusions

5.1. Conclusions

This dissertation aimed to evaluate *the disruptive effect of Indoor Vertical Farming in the Supply Chain of Agriculture.* Throughout the analysis, it was possible to conclude that vertical farming can contribute with integrated solutions to the improvement of the agriculture landscape and the global food crisis.

This emerging innovation allows reducing the dependency on the rural food value chain through urban production. Vertical farming contributes to food security and safety while at the same time solves current issues related to food production and environmental degradation.

For its future widespread deployment, indoor vertical farming needs to prove profitability and the premise of being more productive than traditional agriculture. To achieve both profitability and cost efficiency, government intervention is fundamental. Through investments in education and research, tax incentives or subsidies on electricity and water, clear regulation, and infrastructure price benefits, a gradual transition to this new type of production may occur.

5.2. Limitations and Potential for Future Research

When developing the present dissertation, some constraints and limitations arose.

Due to the fact of this being a qualitative and exploratory research, industry-wide generalizations could not be drawn. Nonetheless, it provided a directional perspective of the vertical farming industry and its future.

Since vertical farming is a recent business and is still in an early stage of development, there was some difficulty in trying to reach different industry stakeholders and from diversified nationalities. It would have been tremendously advantageous to the research to have more participants and from different backgrounds, which would make all the findings even more valid. For future research, having a variety of industry stakeholders from different nationalities could be advantageous and bring an added value to the analysis since it would be possible to have a more comprehensive understanding of the evolution of vertical farming worldwide.

Moreover, four out of five Semi-Structured Interviews were internet-mediated due to COVID-19 actual conjuncture. Some researchers find this to be a limitation in achieving the same outcome and interactivity as a face-to-face interview (Mann & Stewart, 2000).

Since the interviewees were representative of different industry stakeholders, their knowledge and opinions varied from subject to subject. One of the difficulties felt was trying to analyze each testimony critically and consistently throughout the study as well as interpreting interviewees' insights in an unbiased fashion.

Finally, Porter´s Five Forces Framework was applied under specific conditions, considering its application globally and not in a particular geography. Additionally, the framework was only valid for high-quality products produced at a low-scale and as long as the industry was recent. While this can be a reference point, it will hardly dictate everything that will happen everywhere.

Vertical farming could have several implications on the environmental, social, political, and economic domains. In the future, it would be interesting to evaluate the actual outcomes at these levels with real business facts. With the evolution of vertical farming, more companies will appear in the industry. Thus, future research could follow a more quantitative focus. An interesting path to explore would be to develop a financial and technological model, focusing on maximizing productivity and minimizing costs, so that it would be possible to evaluate the financial viability of vertical farming and to develop potential strategies for its scalability.

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Appendices

Appendix 1: Interview with António Fernandes (Jungle Greens)

General Questions

Agriculture Industry

How would the Agriculture Industry change within the short, medium, and long-run? A lot of teachings from vertical farming can be passed on to the agricultural industry, for instance, in the way technology is applied to optimize production. This technology is constantly evolving and will affect the agriculture sector in the short, medium, and long-term. The use of technology as an operating engine is currently used in several industries, such as the pharmaceutical industry. What the agriculture industry is doing is adopting a more irreverent stance and becoming an early adopter in technologies and new ways of producing.

What kind of agriculture innovations are being implemented within the market landscape? Currently, in the agriculture sector, several technologies are used, such as drones or sensors to make agriculture more sustainable, the use of electrical systems for hunting pests instead of chemicals, or new forms of irrigation by measuring and programming the efficient amount of water to be used. These innovations reduce constant in-person monitoring. In the collection of agricultural products, robotics and machinery are used, enabling more specialized work and avoiding so much food waste.

Urban Farming

What is your general opinion on Urban Farming? Within urban agriculture, we can distinguish between vertical farming and self-sustaining agriculture, where individuals use their land for private consumption. There is an increasing need for agricultural products within cities. However, many of these products come from locations 100/200/300 km away from urban centers. Long transportation distances lead to higher degrees of food waste and increase the difficulty of controlling a set of variables that will affect the product until reaching the final consumer.

Vertical Farming

What is your general opinion on Vertical Farming? All major industries have had huge developments. Agriculture dates back thousands of years, and until a few times ago, we have never had a great evolution in this technological sense. Vertical farming is

disrupting the agricultural industry for the first time. It allows us to optimize production and to apply the latest technology in a sector where there was no such possibility and vision. So, in that sense, it is disruptive. One of the greatest battles that we must have as a society should be planet preservation.

What are the critical benefits do you believe Vertical Farming could have? The impact on sustainability is one of the main advantages of this type of production. Through closed production systems, it is possible to reduce between 70 % to 80 % of water usage (Despommier, 2013). This production method allows us to drastically reduce chemical usage, contributing to the preservation of biodiversity and ecosystems. Moreover, production in urban centers allows rural areas preservation. By optimizing the main variables that will contribute to plant growth, it is possible to avoid tropical productions that end up destroying the ecosystem, such as the Amazon rainforest.

What could be the main barriers to Vertical Farming implementation? In traditional agriculture, fixed costs and the initial investment are lower when compared to vertical farming, where the opposite happens. Vertical farming also requires a lot of specialized knowledge and therefore requires investment in terms of education. State intervention and European funds are essential for producers to have access to these technologies.

How do you assess the Vertical Farming disruption in the short to medium-term? Vertical farming technology has tremendous potential, despite the barriers that exist regarding public investment. In the short and medium-term, we live in a testing phase to realize if the technology has potential in the long-term. The State, knowing that there is a need for public investment and that it could represent a solution both at environmental and economic levels, should intervene. Regardless of the country, agriculture is a must. If there are more sustainable alternatives and a way to disrupt a sector, then it should be something to invest in.

Do you see Vertical Farming as an uncertain technology? From a market perspective, not so much since sustainability is currently a market trend. People want to consume more sustainable products that help the environment. The big question of vertical farming is to prove concept and profitability, that is, to be able to prove that this way of producing can be more profitable than production in an open field. Thus, it is essential to understand how much it is necessary to invest in financial terms so that 1

square meter of vertical farming fulfills the promise of being more productive than 1 square meter of traditional agriculture. When we can prove this profitability, there is almost no uncertainty. It just becomes clearer the need for investment and to scale up the business.

What are the critical success factors that would determine the future evolution of Vertical Farming and its scalability? Public and private investment is essential for the future evolution of vertical farming and its diffusion in the market. It is crucial to break the existing paradigm between tradition and modern. The main challenge of vertical farming is to prove that this new way of producing is better than the old one and, in this way, to encourage a gradual transition to this new type of production.

Scenario

What could be a successful scalability scenario in the urban agriculture/vertical farming business in terms of market size, production scale, technology, capital expenditures, target market, and product mix? Vertical farming allows countries that cannot produce their food the possibility of doing it. By living in Portugal or France, we ended up benefiting a lot from our land and weather conditions to produce agricultural products. However, regions where climate conditions do not support agriculture end up importing a large part of their food products. Vertical farming brings enormous self-sufficiency to these regions as well as the possibility of exporting to other markets in the future. At the production scale, the optimum would be a large-scale production as well as the centralization of production in cities through a single factory. At the product level, despite the vertical farming industry model focus on differentiated products, the business should try to focus on commodity products since it represents most of the market in terms of consumption.

Specific Questions for Vertical Farming Practitioners

Technology and Innovation

How could technology and innovation influence the sustainability of Vertical Farming Operations? Vertical farming starts with a total technological assumption. There is a transition from traditional agriculture, which may not involve the use of technology, to vertical farming, a type of agriculture based on a technological principle. Currently, there is a growing need for cutting edge and modern technology that did not

exist in the past. In this way, this agricultural transition is only possible now since there are all the necessary means to implement it. Vertical farming requires data mining and uses a set of innovative technologies, such as sensors, water reuse systems, LED lighting, and systems for the production, measurement, and control of nutrients, oxygen, and carbon dioxide. Thus, it enables us to apply other advanced technologies such as Machine Learning and Cloud Computing. Through Machine Learning, it is possible to learn how to produce a better plant every day through the creation of optimized processes and a precise variation of the main variables that contribute to the growth of the plant. Through Cloud Computing, it is possible to have only one person who, instead of visually managing production, manages to do it digitally. It ends up with human error and time inefficiencies. Only through technology is it possible to prove that vertical farming can optimize production.

Environment

What could be the environmental opportunities and challenges of growing food within urban centers by using a Vertical Farming Production System? Environmental opportunities are huge in terms of pollution since the usage of closed cycles does not interfere with the environment. The main challenges of growing food within urban centers are in terms of fixed costs. Also, another environmental issue corresponds to the establishment of plant factories since several construction and isolation structures are needed and can eventually damage the environment.

Economics

What could be the critical economic opportunities and challenges of growing food within urban centers by using a Vertical Farming Production System? The main economic challenge is associated with the energy cost. The technology used has an electrical and energy base, essential to its performance. Additionally, urban real estate cost is also high. However, it can be attenuated with a reduction in transportation costs and a consequent decrease in food loss.

How could the relatively high cost of energy and technologies be reduced? The production process automation and the investment in sustainable energy, such as the implementation of solar panels, could allow a reduction of energy and technological costs.

What would be the first-mover advantage in the Vertical Farming Production System? The first-mover advantage in vertical farming is the ease of proving the concept, gaining reputation, and acquiring customers who want to associate themselves with sustainable concepts and brands.

Operations

In terms of operations, how could the Vertical Farming business disrupt the Agriculture Supply Chain? Vertical farming's impact on the traditional agriculture supply chain is huge. From a production perspective, that occurs alongside the cities, reduces transportation distance, product cutting process, and food losses.

How fragile could be the Agriculture Supply Chain in terms of Food Safety and Security? In terms of food safety and security, there are several points where traditional agriculture loses. During production, human error and toxicity may happen, which may lead to the sale of a product that is not in perfect conditions for consumption. During transportation and storage, human error can also lead to the emergence of pests. By increasing the waiting time in the supply chain process, the risk of food insecurity increases.

How important could be the collaboration between different members or stages in the food supply chain? Vertical farming needs a total differentiation in terms of how all the supply chain members see agriculture. Flexibility is essential for distributors since the product must be distributed and sold on the same day.

Product

To what extent would Vertical Farming products socially acceptable? The consumer´s acceptance of vertical farming products depends on the marketing strategy developed by the company. There are two ways, the right and wrong ones, to sell and communicate these products to the customer. The vision of organic and sustainable agriculture is all around the farming storytelling, aiming to transmit a traditional image of the business. Contrarily, vertical farming is the opposite of this ancestral view. It is a very disruptive concept for the consumer, offering a more futuristic view of agriculture. By following this strategy, that is, focusing on the operations side and the technology used as a production engine, we lose the consumer that looks at the product as something more artificial. In this way, it is necessary to transmit the most traditional

image possible, showing vertical farming as something sustainable and not as a “plant factory”.

What could be the main drivers of consumers´ acceptance of the Vertical Farming Food System? The product´s sustainability and the non-use of chemical pesticides are the main drivers that lead to the consumers´ acceptance of the vertical farming food system.

What could be the main drivers of consumers´ purchase intention in a Vertical Farming Food System? Generally, there are two types of consumers in the market. The first one is a type of consumer who chooses the product because it is more sustainable. The second one is a consumer who chooses the product because it is cheaper. The latter represents 72% of the market, according to a market research study conducted by Jungle Greens in the Portuguese and French markets. Vertical farming, when applied on a large scale, can reduce prices, although it remains positioned in the premium market. Thus, in small-scale production, the marketing strategy to be followed should be based on sustainability, while at large-scale production, the focus should be on combining both product sustainability and price.

What could be the primary market segment Vertical Farms should focus on? And for what type of customer? At the initial stage of the business, there will be high fixed costs and an increasing need for profitability. Thus, vertical farms should focus on low-scale production and must offer a more expensive and differentiating product to the consumer. During the growth phase, it is then possible to produce on a larger scale, slightly reducing prices but still operating in the premium market.

What type of crops would be more suitable for a Vertical Farming business, taking into consideration the economic logic and technological possibilities? The focus should be on differentiated products offered to consumers with greater purchasing power.

What kind of differentiating strategy could be developed regarding Vertical Farming products when compared to products produced in Traditional Agriculture? Due to high costs, it is not possible to compete in these terms, so a differentiation strategy should be applied, focusing on the product´s sustainability as well as on the taste or visual aspects.

Porter 5 Forces

How do you classify the threat of new entrants in the Vertical Farming business? Why? The threat of new entrants in the vertical farming market is very low, motivated by the high fixed costs and necessary investment as well as the highly specialized knowledge and education needed to control the production process. The risk is minimal initially, when the scale of production is low, as well as the level of profitability.

How do you classify the threat of substitute products? Why? The threat of substitute products depends on the scale of production. On a low-scale, the threat of substitute products is high due to the product´s high price. However, on a large-scale, the risk becomes minimal because it is easier to offer a better price for the consumer and, at the same time, a more sustainable product compared to competitors.

How do you classify the bargaining power of suppliers? Why? Suppliers have a lot of power since the vertical farming business depends on a huge technological base. There are not many suppliers that produce specific equipment for the industry, so the ones that exist can capture the market and can have greater power over it.

How do you classify the bargaining power of buyers? Why? The bargaining power of buyers depends on the scale of production. On the one hand, on small-scale production, buyers will have higher bargaining power, whereas, on large-scale production, the bargaining power will be slightly lower. Initially, in a B2B relationship, distributors' bargaining power will be high since they are investing in a non-profitable business in the short-run. They will behave like business partners. However, once a higher scale production is reached, the bargaining power of buyers becomes slightly reduced since distributors start investing in a more profitable business.

How do you classify the rivalry among existing competitors? Why? Due to the fact of being a very new and recent industry, there is more of a partnership between vertical farming companies than rivalry. The sharing of information and know-how becomes essential for business development. However, the rivalry does exist against traditional agriculture.

Appendix 2: Interview with João Pereira (Aralab)

General Questions

Agriculture Industry

How would the Agriculture Industry change within the short, medium, and long-run? The agriculture sector is a success story. The world population, in the last 200 years, increased from 1 billion to 7.7 billion people, along with a reduction in the proportion of hungry people. Today, food security is significantly higher than in the past, and products are available year-round. So, from that point of view, the agriculture system works quite well. We have achieved this success story, however, at the expense of brutal fertilization and mechanization, massive use of pesticides, etc. Today, there is greater awareness than there was 20 years ago. In the short, medium, and long-term, the main challenge is, at an initial phase, to continue to produce at least the same quantities we have provided so far but in a more sustainable way and with less environmental impact. One-third of all food produced globally does not reach our plate. So, if we reduce food waste, we also relieve pressure on food production.

What kind of agriculture innovations are being implemented within the market landscape? Agriculture innovations are highly dependent on the scale of production. The technology used by a small farmer is very different from the one used by a large-scale company. It is a matter of time for generational reasons until we have younger people who are familiar with these new technologies. Most large companies already use advanced technological systems to control their production processes and to guarantee product availability over time. Today, companies benefit from more accessible technologies. For instance, in the past, a drone could cost 5000 euros, today it would probably cost 1000 euros, and in 5 years it will only cost 200 euros. In the short and medium-term, we will observe the evolution and improvement of the existing technology. Whereas in the long-term, we will recognize the appearance of technological disruptions coming up from other sectors and applied in the agriculture industry, as artificial intelligence, robotization, vertical farming, or new conservation technologies.

Urban Farming

What is your general opinion on Urban Farming? Within urban agriculture, we can distinguish between vertical farming and self-sustaining agriculture, where individuals use their land for private consumption or as a hobby. Over the past years, vertical farming companies have started appearing in the market, aiming to centralize production in the city as a gain of scale and to disseminate the points of sale, supplying retailers with the final product. Urban farming significantly reduces the distribution

chain and brings benefits at the scale level that will allow in the long-run to lower costs for the consumer and consequently increase the self-sufficiency of the city. In Portugal, we pass a little by, due to the cities and country size but above all because we have favorable weather conditions to produce vegetables year-round in an accessible way. However, there are many regions in the world where this does not happen, which remain highly dependent on the food supply from foreign countries.

Vertical Farming

What is your general opinion on Vertical Farming? Vertical farming is an inevitable trend in the future. It requires a change in the production process that farmers will sooner or later have to adopt. Portugal is the world's largest tomato producer. For the country, it does not make sense to produce tomatoes inside a production chamber. However, it makes sense to germinate the tomato that will later go to the land. The bottleneck in the traditional production process may be in a particular stage of the process, as is the germination case. Indoor farming can solve this bottleneck, for instance, by specializing in specific parts of the production process. In the future, we will likely find companies specialized in functional vegetables or in the production of differentiating products. Flowers with wasabi flavor, vegetables without toxoplasmosis produced especially for pregnant women, or aromatic herbs specific from certain regions that become available in any urban center are some of the products that will likely be produced in the vertical farming production system.

What are the critical benefits do you believe Vertical Farming could have? Vertical farming has several implications in terms of control, lack of dependence on weather conditions, simplification in the logistics chain and the ecological footprint, and food quality. Vertical farming stands out by the absence of pesticides since plants grow protected from the outside environment. This production system is one step ahead of organic cultivation since these vegetables may contain pesticides, still of a different nature from conventional. A vegetable produced in an open field has about 300.000 bacteria per gram, a hydroponic vegetable grown in a greenhouse has about 30.000 bacteria per gram, and in the vertical farming production system, a vegetable can measure below 300 bacteria per gram. This significant reduction in terms of contamination represents an enormous gain from the food security point of view. In conclusion, the critical benefit of vertical farming is in terms of food security, by

creating a system where it is possible to offer quality vegetables throughout the year, with certifications that guarantee to the consumer that there is no risk of contamination.

What could be the main barriers to Vertical Farming implementation? The main barriers to the implementation of vertical farming are at the OPEX and CAPEX levels. The investment cost is typically higher, as well as the production cost, more particularly, in terms of technology. When we talk about vertical farming, we are comparing producing in an open field or at a greenhouse with an indoor in a controlled environment. It is essential to define the technology cost/investment threshold and how efficient in production we can be to understand the price difference to which this product may be subject. We must ensure that the final product is of added value. In this way, research and quality control of the process is essential to obtain a better final product.

How do you assess the Vertical Farming disruption in the short to medium-term? The Portuguese case is very different from the reality of the rest of the world. The sector will always need research on new products, especially regarding functional vegetables. Particular care should be taken to ensure that products are not placed on the market without being properly validated. If we start looking at vegetables as a food supplement, there are regulatory issues that have to be ensured. On the experimental side, there is ongoing research and a lot of work to be done. In what we consider as mainstream, such as lettuce and aromatic herbs, there are already commercially viable vertical farming companies like Infarm (Germany), SPREAD (Japan), or AeroFarms and Plenty (USA). There are many companies now emerging on a large-scale. In countries like Portugal, where the critical mass of the population that is available to pay a premium for a vegetable is not that great, the viability of this business model becomes complex. Access to capital is also challenging in the Portuguese case. Public incentives that are available in Portugal correspond to the generic supports available in the agriculture sector. The question is whether there should be specific support for vertical farming projects. Investment should be provided in terms of technological development. From a State point of view, if there are a greenhouse and a vertical farming project, there should not exist an objective reason to choose one over the other since both should have the same opportunity. Thus, the vertical farming project cannot compete unequally with someone who has a greenhouse or farmland. Vertical farming projects must have equal access to the same financing conditions and incentives that are available for traditional

agriculture. In our personal experience, there is some difficulty in the delivery of projects as well as on the final validation of applications, perhaps due to the lack of specialized knowledge regarding the technology. This can only be improved with communication and the sharing of information.

Do you see Vertical Farming as an uncertain technology? What is uncertain is not the technology itself but the market environment. The great uncertainty is whether the market values this type of vegetables or not and whether it is willing to pay for it.

What are the critical success factors that would determine the future evolution of Vertical Farming and its scalability? The critical factors that will determine the future evolution of vertical farming and its diffusion in the market are the reductions in terms of production costs and the ability to offer products that cannot be provided by traditional agriculture.

Scenario

What could be a successful scalability scenario in the urban agriculture/vertical farming business in terms of market size, production scale, technology, capital expenditures, target market, and product mix? A successful scalability scenario would imply a significant, recurring, and long-term production, not necessarily being the biggest company or the largest supplier of the market. In an optimistic scenario, the customer would become loyal and would see advantages in the product. On the production side, it would mean that the company would be able to produce in significant quantities consistently over time, in terms of color, texture, or flavor. In the long-run, technology would become accessible to all. I consider that it is not possible, and it is not desirable to compete directly with traditional farmers. I believe that vertical farming is not going to replace conventional agriculture but rather to complement it. As organic products, also vertical farming vegetables should be an extension of the product´s range.

Specific Questions for Vertical Farming Practitioners

Technology and Innovation

How could technology and innovation influence the sustainability of Vertical Farming Operations? Technology and innovation could lead to a reduction in terms of energy and water consumption and a reduced footprint in the logistics chain. Renewable energy sources and production schedules that are more compatible with cost and

consumption reduction could lead to a more sustainable chain of operations. The way lighting is produced, and the amount generated per each kilowatt of energy expended is a critical factor. LED lighting has increased efficiency harshly. Currently, one LED is at least twice as much as efficient as one LED six years ago. With water conservation technologies, it is possible to spend only 1 liter of water per kilogram of lettuce produced (Graamans et al., 2018), compared to 250 liters in open field production and 20 liters in a greenhouse (Barbosa et al., 2015). But we can go even further in terms of production optimization. The water from the plant's breath can be reused in the production process. The next step will be to create filtration and disinfestation systems that will allow to reuse of this water and thus reduce the need for consumption in the network. Concerning the logistics chain, the key point is to place a production facility as close as to the place of consumption.

Environment

What could be the main environmental opportunities and challenges of growing food within urban centers by using a Vertical Farming Production System? The main environmental challenge of growing food within urban centers by using a vertical farming production system corresponds to energy consumption. It is essential to reduce energy consumption for greater efficiency of the system and to try to ensure that the consumption is from sustainable sources and then to introduce renewable energies.

Economics

What could be the critical economic challenges of growing food within urban centers by using a Vertical Farming Production System? Economically, food production in urban centers, through a vertical farming production system, can bring jobs to places where people are. The population that lives in an urban center that is available to work outside the city is not as large. Therefore, through vertical farming, it is possible to create an alignment between offer and demand on the labor market. Most vertical farming practitioners do not come from the agriculture industry, but instead, they come from marketing, management, engineering, biology, programming, or data science. If we look at the automotive industry, the major disruptions of the past ten years were made by companies outside the sector.

How could the relatively high cost of energy and technologies be reduced? Energy costs can be reduced through renewable energy or wind turbines. In a controlled

environment, it is possible to simulate the daytime environment at night, when electricity is more available on the network and is cheaper. During the day, when the cost of energy is much higher, it is possible to simulate the nighttime environment.

What could be the first-mover advantage in the Vertical Farming Production System? I would say that the main advantage of being the first mover in the vertical farming business is the mediatic disclosure. Producing the final product is crucial to test the market and find out if consumers are available to pay for the product. Another advantage is being able to start earlier and not be afraid to fail, to be able to do wrong and correct. Two or three years later, we have much more knowledge and know-how than our competitors who are still learning. This work experience leads to a higher reputation as well as facilitating customer acquisition. This work experience leads to a higher reputation and customer acquisitions.

Operations

In terms of operations, how could the Vertical Farming business disrupt the Agriculture Supply Chain? The most obvious dimension is transportation. There is a tremendous reduction in the necessary distance since production is centralized in cities. Also, the distance between the producer and the point of consumption influences the product produced. The second fundamental point is associated with food waste. It is possible to determine with a very high degree of accuracy when vegetables have to be produced to be available in-store on a given date. With strict control of climatic variables, there is no risk that these vegetables are ready a week earlier or a week later, consequently leading to food waste. We managed to control the entire production process with industrial precision, and this is very critical in logistics. For example, it allows trucks to arrive on time, substantially reduces waiting time, and allows delivery to be made on time without penalties due to delays. In this way, it is possible to ensure that if there are no delays in production, there are no empty displays in retailers.

How fragile could be the Agriculture Supply Chain in terms of Food Safety and Security? In my opinion, the agricultural system is a success story. I believe that the food quality system is much safer today than it was 20 years ago. A retailer cannot afford to report lettuce with pesticides in his stores. In addition to all the regulations that exist, a retailer has its internal quality control procedures. Therefore, when a vegetable reaches a shelf, it has already gone through 3 or 4 stages of certifications, food quality

control, etc. From that point of view, it is much safer now than in the past. The trade-off of this is uniformity, leading, consequently, to food waste.

How important could be the collaboration between different members or stages in the food supply chain? Usually, there is a product´s cadence in terms of supply, and this rate corresponds to what the distributor expects to sell. If the distributor anticipates that he will sell more or less, he gets in touch very quickly with the producer. The reaction speed cannot be abrupt and must be done in advance. Communication between the different members or stages in the food supply chain is fundamental as well as the proximity of the relationship.

Product

To what extent would Vertical Farming products be socially acceptable? I see no differentiation in the acceptance of products produced in vertical farming compared to the conventional ones. I do not consider that there is an acceptance issue but a communication problem.

What could be the main drivers of consumers´ acceptance of the Vertical Farming Food System? From a consumer perspective, flavor, texture, quality, and safety guarantee are essential. It is necessary to ensure that those characteristics can be generated through the production system and ensure transparency through communication strategies. I consider that the operations side and the technology used, as a production engine, should not be communicated directly to the consumer, but instead the benefits of the product, such as the absence of pesticides, a greater shelf-life, etc.

What could be the main drivers of consumers´ purchase intention in a Vertical Farming Food System? The organoleptic properties should be as good or better than the alternatives on the market. Additionally, shelf-life plays a key role. Since the vegetables are free of bacteria and below the level of washing, not requiring centrifugation, the products produced in vertical farming may have a shelf-life of up to 30 days.

What could be the primary market segment Vertical Farms should focus on? And for what type of customer? There is a common sense that the production scale solves cost problems. On vertical farming, the only factors where it is possible to have relevant

scale efficiency are in air conditioning and operations and not on lighting, which is the main cost factor in production. However, none of these advantages are enough to match the cost of open field production. There will always be a need to charge a premium price for vertical farming products. The scale of production must always be as large as possible to have scale benefits. On vertical farming, the scale benefit is not so much in the technology itself but on the efficiency gains obtained through the production process. Regarding the consumer, vertical farming products are more suitable for urban consumers with high purchasing power, who are environmentally conscious and concerned with health issues.

What type of crops would be more suitable for a Vertical Farming business, taking into consideration the economic logic and technological possibilities? On B2C, leafy greens are more suitable as they have a higher growth rate, consume fewer resources, and are cheaper to produce. On B2B, the production focus should be completely different, such as cannabis, medical compounds, functional vegetables, vanilla, saffron, sweet potato sprouts, eucalyptus, or tomato. The level of profitability between B2C and B2B depends on the market and on the consumer´s willingness to pay. I would say that B2C on a large scale can be quite profitable. However, the difficulty is to reach that scale. In terms of B2B, the main advantage is that the economic parameters are very well defined, and there is little fluctuation in the market. There is a clear notion of how much a given plant must be sold, allowing for greater predictability and, consequently, a higher production scale.

What kind of differentiating strategy could be developed regarding Vertical Farming products when compared to products produced in Traditional Agriculture? In the vertical farming business, competitive advantage can only be achieved through a differentiation strategy. Differentiation can occur through quality (flavor), availability (a vegetable produced year-round that cannot be produced regularly in an open field or greenhouse), or food security. I usually say that what happened in the milk market should be applied to the vegetables. In the past, there were only three milk categories. Nowadays, the variety that exists is huge. It is perfectly possible to follow the same strategy for vegetable production. Technically, it is within our reach to do this, that is, to have functional vegetables not only as a source of food satisfaction but that can also contribute to our health, through vegetables enriched in iron, calcium, with less sodium for hypertense people. An interesting example is that of

the Japanese vertical farming company, SPREAD. SPREAD produces about 20,000 lettuces a day. Through a market study, the company realized that there is an increasingly older population in the country that does not like crispy lettuce. In this way, they started to produce softer lettuces to capture this market demand.

Porter 5 Forces

How do you classify the threat of new entrants in the Vertical Farming business? Why? The threat of new entrants in the vertical farming business is relatively low due to the high investment required. However, if the project is good, and if there is a market, the investment appears. The entry of new competitors is perfectly possible, and it is advantageous because it helps to validate the industry.

How do you classify the threat of substitute products? Why? The threat of substitute products depends on how we define the product. If the product is defined as common lettuce, then the threat of substitute products is high. However, if the product is defined as lettuce with a bacterial count, without being washed, below 300, then the threat of substitute products becomes low.

How do you classify the bargaining power of suppliers? Why? Regarding the power of suppliers, there are two approaches. A company can either decide to buy its productive equipment from suppliers or develop its production systems, which in turn will mitigate the suppliers' power. Nevertheless, to have product differentiation, it is critical to have equipment that allows us to obtain this advantage, and these projects generally carry out a high degree of risk.

How do you classify the bargaining power of buyers? Why? The bargaining power of buyers is very high since the consumer has the power to choose and to change to this new type of product.

How do you classify the rivalry among existing competitors? Why? Assuming that the existing competitors are traditional farmers, if we talk about a conventional product, then the rivalry among existing competitors is high since they can lower prices. If we talk about a differentiated product, such as functional vegetables, then the rivalry among existing competitors is low since farmers cannot produce such greens.

Appendix 3: Interview with Mariana Mota (ISA - Instituto Superior de Agronomia)

Agriculture Industry

How would the Agriculture Industry change within the short, medium, and long-run? In the future, the agricultural sector could intensify while becoming more sustainable. There will be a better choice of production factors, for instance, in terms of timings and quantities, a more intensive occupation of the soil as well as a greater diversity of agents coexisting at the same time, such as specialized workers with amateurs. Along with greater crop specialization in large areas, there will be an enormous crop diversity in small-scale agriculture, namely in urban agriculture.

What kind of agriculture innovations are being implemented within the market landscape? Mechanization has been applied in night crops and in the irrigation process. There is a much greater concern with the promotion and sustainability of the soil factor. Farmers are generally receptive, either by improving productivity or by the greater diversity of perspectives they anticipate, for instance, in terms of a wider range of crops to be produced in each location.

Urban Farming

What is your general opinion on Urban Farming? Urban farming is an example of agriculture that has become progressively more important, mostly due to its social function, through the promotion of personal and community well-being (playful factor, social integration, outdoor coexistence). In some cases, especially among communities with lower resources, it assumes a very relevant economic role, but in others, the social purpose dominates. Urban agriculture faces several environmental, social, political, and economic risks and opportunities. At the environmental level, urban agriculture faces risks in terms of urban pollution, poor availability of water, and an over-use of scarce space. At the social and political level, it is currently very protected, however in the future, it may suffer pressure from the city and real estate sectors, as well as from internal conflicts in more asymmetric communities. At an economic level, in my view, urban agriculture does not face huge risks because it varies according to the availability, by shrinking or expanding according to the conjuncture. In terms of opportunities, at an environmental level, urban agriculture can be established within abandoned buildings, converting them to green spaces. In a social dimension, at this moment, urban agriculture is extremely protected and encouraged due to its playful role, allowing for consolidation at the social and intergenerational level between communities. Finally, in

political and economic terms, it is currently strongly encouraged as an alternative source of income and to reuse spaces that were previously abandoned.

Vertical Farming

What is your general opinion on Vertical Farming? Vertical farming is an interesting variant of agriculture in terms of reduced availability of space (and time), very much focused on fulfilling the farmer's welfare function. It has a lot of potential in urban areas, especially for self-consumption. There are situations, not very frequent, but existing, in which industrial agriculture makes use of this technique to optimize crop intensification according to the available areas, for instance, in strawberry cultivation.

What are the critical benefits do you believe Vertical Farming could have? The critical benefits of vertical farming are in terms of space-saving, less physical fatigue, better functioning of organisms, and the ease in interrupting the spatial sequence of crops, allowing better phytosanitary control and greater versatility.

What could be the main barriers to Vertical Farming implementation? One of the main barriers for vertical farming implementation corresponds to phytotechnical factors. Vertical farming is more demanding in terms of phytotechnics, with regards to the cultural practices and to the economic extent, since it is more expensive than traditional agriculture.

How do you assess the Vertical Farming disruption in the short to medium-term? I think that for now, vertical farming will continue to grow, to establish itself, especially in the larger urban communities.

Do you see Vertical Farming as an uncertain technology? No. Vertical farming can benefit a lot from the phytotechnical concepts of conventional agriculture and adapt them as needed.

What are the critical success factors that would determine the future evolution of Vertical Farming and its scalability? The critical success factors that will determine the future evolution of vertical farming and its scalability are in terms of urban pressure on space, the consumer perception of the product´s quality, the existence of alternatives, and the phytotechnical bottlenecks.

Scenario

What could be a successful scalability scenario in the urban agriculture/vertical farming business in terms of market size, production scale, technology, capital expenditures, target market, and product mix? A horticultural area such as the one of Alta de Lisboa, situated in a densely populated area, and selling to Lisbon North, especially in the Lumiar. It has enough dimensions to develop agricultural production and ease of access to water and solar exposure.

Specific Questions for Academics

Education

What role could education play in the implementation of a new industry, such as Urban Agriculture / Vertical Farming? Education could play a significant role in disseminating knowledge and experiencing new crop practices (testing new rotations, new substrates).

Could you give a concrete example of educational intervention in the implementation and development of Urban Agriculture? The setup of an inter-generational garden, through the installation and maintenance of cultivated spaces, adapting and optimizing crop practices to local edaphoclimatic and social constraints, is a concrete example of educational intervention in the implementation and development of urban agriculture.

How do you assess the degree of knowledge and education of Vertical Farming in Portugal? The degree of knowledge and education of vertical farming in Portugal is still reduced but increasing. The interest in these topics has risen.

How do you evaluate the State's intervention at an educational level in support of Urban Agriculture / Vertical Farming? Could you give concrete examples of measures and incentives that were implemented in this area? I think the State's intervention has been progressively more present through municipalities and the sponsorship of local associations, street markets, etc. It has promoted training actions in different contexts, for instance, in schools and associations. Some measures that have been implemented in this area concern urban farms in parish councils, school gardens, and the development of infrastructures for horticultural parks.

What strategies could be considered at the educational level for the future transition from rural to urban agricultural industry? For the transition from rural to

urban farming, some measures should be implemented, including incentives from the lowest levels of education, reinforcement of educational contents and training, and in-school programs for greater agricultural development in urban areas.

Appendix 4: Interview with Elvira Ferreira (INIAV - Instituto Nacional de Investigação Agrária e Veterinária)

General Questions

Agriculture Industry

How would the Agriculture Industry change within the short, medium, and long-run? The agricultural sector has many exciting challenges ahead of it. The future of agriculture will have to pass through Agriculture 4.0, that is, through the digitalization and more technological agriculture with the use of sensors and computer programs that are becoming increasingly accessible. Farmers must be aware of the need to evolve and produce more sustainably.

What kind of agriculture innovations are being implemented within the market landscape? Digitalization is becoming faster and easier to access. There is an increasingly new generation of farmers, highly educated and involved in the need for digitalization. In my opinion, farmers are increasingly receptive to change and are increasingly open-minded. Nowadays, drones and computer programs measure crop states at the water and solar radiation level, and infrared thermometers are applied to measure leaf temperature. There are many regions in Portugal, especially in large areas, where robotization is being highly adopted, such as in olive groves and large crops, such as corn.

Urban Farming

What is your general opinion on Urban Farming? Urban agriculture is now emerging with a greater impact on populations. There is an increasing need for communities to "go back to the countryside" and have a connection with nature, especially the older generations. Moreover, there is a learning opportunity at the inter-generational level through direct contact between the youngest and the oldest generations. Urban agriculture can be a catalyst for physical and mental well-being, social interaction, and non-isolation. This method of production allows a tremendous reduction in the distribution chain since products can be directly consumed after harvesting. Regarding the main risks, urban agriculture, since it occurs in city

environments, is more subject to pollution. In such situations, crops that are not so absorbent of these pollutants should be used.

Vertical Farming

What is your general opinion on Vertical Farming? Vertical farming may have some future. However, a large investment is required as well as technical and physiological knowledge of crops. This method of production is not as easy as traditional agriculture.

What are the critical benefits do you believe Vertical Farming could have? In countries with vulnerable agricultural conditions, vertical farming can be a sustainable and beneficial solution, allowing them to be self-sufficient in the production of certain products.

What could be the main barriers to Vertical Farming implementation? A high level of technical knowledge and investment are some of the main barriers to vertical farming implementation.

How do you assess the Vertical Farming disruption in the short to medium-term? Not to say that there are no situations where vertical farming can be beneficial. However, we are still at a very early stage in terms of its development. In Portugal, vertical farming must be used as an experiment due to the country's favorable weather conditions. However, in other regions with poor agricultural conditions, vertical farming may be used more extensively and can be a sustainable and beneficial solution for self-sufficiency production.

Do you see Vertical Farming as an uncertain technology? More or less. There is still some research needed to be done.

What are the critical success factors that would determine the future evolution of Vertical Farming and its scalability? A high level of technical knowledge, as well as investment and costs, would be critical factors that will determine the future evolution of vertical farming and its scalability.

Scenario

What could be a successful scalability scenario in the urban agriculture/vertical farming business in terms of market size, production scale, technology, capital expenditures, target market, and product mix? A successful scalability scenario

would be based on the production of small-scale crops, such as leafy greens or aromatic herbs. Production should be done on a high-scale and at a relatively low cost, as far as possible. Ideally, the main gain in vertical farming is productivity, that is, production per unit area, which can be much higher when compared to traditional agriculture. Vertical farming should also take advantage of the fact that it is possible to produce crops that are usually seasonal, year-round. Another advantage corresponds to the reduction of the need for labor since it is an automated production process. At the consumer level, the consumer is increasingly aware of food safety issues. The consumer must perceive the added value of buying a vertical farming product instead of a traditional one. Such benefits might include the absence of pesticides or a larger shelf-life. In my opinion, vertical farming would not feed an entire population, but it would complement the food value chain.

Specific Questions for Academics

Education

What role could education play in the implementation of a new industry, such as Urban Agriculture / Vertical Farming? Education has the function of educating and teaching others about new technologies, taking into consideration risks and opportunities of its implementation. Research is also essential for greater dissemination of knowledge.

Could you give a concrete example of educational intervention in the implementation and development of Urban Agriculture? Implementation of community gardens in educational institutions, for instance.

How do you assess the degree of knowledge and education of Vertical Farming in Portugal? For instance, in the case of small fruits such as strawberries, there are already some farmers who cultivate them vertically and without soil usage. A few years ago, in Portugal, there was a big boom in hydroponic crops, but in recent years I think it has stagnated. Therefore, in general, the degree of knowledge and education of vertical farming in Portugal is still relatively low.

How do you evaluate the State's intervention at an educational level in support of Urban Agriculture / Vertical Farming? Could you give concrete examples of measures and incentives that have been implemented in this area? At the municipal

level, there has been this concern by providing training for people to have minimal knowledge. Therefore, at this point, the entities are aware of the importance of education. At the level of the State itself, there may be a training of technicians, but I'm not really into that topic.

What strategies could be considered at the educational level for the future transition from rural to urban agricultural industry? In my opinion, we are still a little far from this transition, from rural to urban agriculture. At the educational level, some measures must be taken to proceed to this shift, such as the promotion of postgraduate courses for people who want to have some training in these subjects.

Appendix 5: Interview with David Slattery (DESCO Arizona, LLC)

General Questions

Agriculture Industry

How would the Agriculture Industry change within the short, medium, and long-run? The agriculture sector is a profit-driven industry. It must be profitable for farmers to take time off from continually harvesting year after year. You can't fault the farmer on the ground. There has to be an incentive for a farmer to take a year to help the soil recover. There is evidence of soil erosion, excess polluters, and the logistics of transporting food has to improve. But, once again, there should exist a profit incentive for change to take place. The regulation will be a strong pushback. It is not possible to disrupt a local economy in small farm towns without profit incentives and favorable regulation.

What kind of agriculture innovations are being implemented within the market landscape? There are better chemical fertilizers every year. GMOs are becoming a little bit better since they are essential to achieve better yields. Irrigation techniques and seed engineering are also being implemented to create more efficiency. Farmers care about the incentive piece to engage in innovation. However, nowadays, there is not a lot of economic incentives for innovation to arise, and that needs to happen. The main reason to implement agriculture innovation is to get more yields, more sales, and volume. The receptiveness of farmers regarding those technologies is all about cost/benefit. I do not think a lot of technologies, unfortunately, have proven to be commercially scalable at a better profit margin. However, once that happens, everybody will jump on board.

Urban Farming

What is your general opinion on Urban Farming? Urban farming is not going to be a very profitable business since it is not possible to have enough volume. What it solves, though, is the sense of community. A local community will be able to trade-off either labor or help in that farm for some food subsistence for their own family and their networks. The technology is there, and it is possible to plant a farm almost anywhere right now. It is a matter of if it makes sense. In the urban landscape, there is a lot of competition for land. So why would it be better a farm rather than a restaurant, an apartment building, a hotel, or another business? If the local government provides tax incentives, then it might be viable. But right now, it needs a lot of help. To start an urban farming business, it is essential to define if the land is owned or leased. If it is owned, then there is a huge need for capital. If it is leased, then the monthly costs are going to be very high. It is unlikely that the business is going to be profitable in the first two or three years of operations, so it is essential to be sure of having enough capital to pay to the landlord, the staff, and all the equipment. Also, to be successful, the community should be involved and support the business.

Vertical Farming

What is your general opinion on Vertical Farming? The boom in the cannabis industry has been very beneficial for reducing cost margins in vertical farming. As a vertical farmer, you do not need the latest and greatest stuff, but things that create margins. The technology in the cannabis market two or three years ago was far superior to everything you would find in vertical farming before the cannabis boom. What was sufficient for cannabis growers two or three years ago is more than good enough to grow lettuce in indoor vertical farming.

What are the critical benefits do you believe Vertical Farming could have? In the long-run, vertical farming is one of the main solutions to food safety and security.

What could be the main barriers to Vertical Farming implementation? Lack of incentives, high costs in terms of energy, real estate, and investment are the main barriers to vertical farming implementation.

How do you assess the Vertical Farming disruption in the short to medium-term? Vertical farming is a great local disruptor and perfect for neighborhoods. If you can do

it on a scale, and you can produce the greatest amount of yields per square meter, then it is when it starts to make sense to produce vertically. In the long-run, the business will tend to expand. It is an industry that will be around for a while. However, it is essential to define the right model since vertical farms are competing against farmlands in the middle of nowhere, with minimal costs.

Do you see Vertical Farming as an uncertain technology? There are certain types of crops, mainly fruiting crops, where the technology needs to get better. But without a doubt, for different kinds of lettuce and microgreens, it is a proven technology that works in a safe and better way than anything you can do outdoors.

What are the critical success factors that would determine the future evolution of Vertical Farming and its scalability? Profitability is essential for the future evolution of vertical farming and its scalability. The reduction of the operating cost piece is possible by having trained labor staff, systems that are easy to operate and that don´t require a lot of training in another market. To scale-up, vertical farming businesses should be present in many cities. Moreover, electricity and water incentives should be provided to the industry.

Scenario

What could be a successful scalability scenario in the urban agriculture/vertical farming business in terms of market size, production scale, technology, capital expenditures, target market, and product mix? I believe the proper business model is a series of smaller franchise types of operations that will serve specific restaurants and consumers. Right now, vertical farming is more feasible in a smaller market, but in the long-run, large-scale production would be more beneficial. You can produce high-end microgreens. However, that cuts your market size down. So, the number of available consumers to buy your product goes down exponentially, and you are not going to have a huge business. The game-changer of this industry is when you can compete with basic crops that any grocery store provides. For instance, it is possible to grow lettuce almost at the same cost margin as outdoors. Two years from now, vertical farms will be able to produce it cheaply than outdoors. For salads and anything that can be produced in the same systems as cannabis, in the future, it would be profitable to compete with the yield and cost structure of an outdoor. For other farm products, like fruits, it won´t.

Specific Questions for Other Practitioners

Policy

How is the government investing in food-tech? Governments are providing grant programs for job creation in the food industry. A large portion of support from political leaders comes from agriculture lobbying groups. On the one hand, some countries find it a little bit risky to invest in technologies that might disrupt future profitability. On the other hand, some governments are not afraid to invest in food-tech.

What could be the government´s role in the implementation and expansion of an upcoming new industry, such as urban agriculture/vertical farming? Governments, in the implementation and widespread of an upcoming new industry, such as urban agriculture/vertical farming, should provide tax credits, for instance, on water. Vertical farming is significantly better for the environment. It uses 95 % less water than traditional agriculture. What is the incentive for a vertical farm to do that? The vertical farming business does not receive the same kind of incentives and support as traditional agriculture.

To what extent is the government supporting urban agriculture/vertical farming business? Could you give concrete examples of measures or incentives implemented in this field? In the US, at least they are not trying to block it. They are not supporting it just because there is not a powerful enough lobby to push it. Usually, lobbying has to exist for this type of industry to work. You must go to the proper channels, you have got to have federal incentives, and those federal incentives have to push down on the local government. But that is a very expensive process. Maybe if Amazon´s investment works out, Jeff Bezos will do that.

Does urban agriculture/vertical farming business face issues regarding legislation and regulation? How could these obstacles be overcome? In terms of regulation, the vertical farming business faces some issues. Regulators don´t know how to classify vertical farming. Is it a farm, manufacturing, or a tech company? As an entrepreneur, you need that clarity to understand how to be taxed and to set the proper business structure. Legislation and regulation are taking so long because the business is not big enough, and it is not making enough money. Once companies start to pay meaningful taxes to the government, then things will step in.

Appendix 6: Interview Guideline

General Questions

Agriculture Industry

How would the Agriculture Industry change within the short, medium, and long-run? What kind of agriculture innovations are being implemented within the market landscape?

Urban Farming

What is your general opinion on Urban Farming?

Vertical Farming

What is your general opinion on Vertical Farming?

What are the critical benefits do you believe Vertical Farming could have?

What could be the main barriers to Vertical Farming implementation?

How do you assess the Vertical Farming disruption in the short to medium-term? Do you see Vertical Farming as an uncertain technology?

What are the critical success factors that would determine the future evolution of Vertical Farming and its scalability?

Scenario

What could be a successful scalability scenario in the urban agriculture/vertical farming business in terms of market size, production scale, technology, capital expenditures, target market, and product mix?

Specific Questions for Vertical Farming Practitioners

Technology and Innovation

How could technology and innovation influence the sustainability of Vertical Farming Operations?

Environment

What could be the environmental opportunities and challenges of growing food within urban centers by using a Vertical Farming Production System?

Economics

What could be the critical economic opportunities and challenges of growing food within urban centers by using a Vertical Farming Production System?

How could the relatively high cost of energy and technologies be reduced?

What would be the first-mover advantage in the Vertical Farming Production System?

Operations

In terms of operations, how could the Vertical Farming business disrupt the Agriculture Supply Chain?

How fragile could be the Agriculture Supply Chain in terms of Food Safety and Security?

How important could be the collaboration between different members or stages in the food supply chain?

Product

To what extent would Vertical Farming products be socially acceptable?

What could be the main drivers of consumers´ acceptance of the Vertical Farming Food System?

What could be the main drivers of consumers´ purchase intention in a Vertical Farming Food System?

What could be the primary market segment Vertical Farms should focus on? And for what type of customer?

What type of crops would be more suitable for a Vertical Farming business, taking into consideration the economic logic and technological possibilities?

What kind of differentiating strategy could be developed regarding Vertical Farming products when compared to products produced in Traditional Agriculture?

Porter 5 Forces

How do you classify the threat of new entrants in the Vertical Farming business? Why?

How do you classify the threat of substitute products? Why?

How do you classify the bargaining power of suppliers? Why?

How do you classify the bargaining power of buyers? Why?

How do you classify the rivalry among existing competitors? Why?

Specific Questions for Academics

Education

What role could education play in the implementation of a new industry, such as Urban Agriculture / Vertical Farming?

Could you give a concrete example of educational intervention in the implementation

and development of Urban Agriculture?

How do you assess the degree of knowledge and education of Vertical Farming in Portugal?

How do you evaluate the State's intervention at an educational level in support of Urban Agriculture / Vertical Farming? Could you give concrete examples of measures and incentives that were implemented in this area?

What strategies could be considered at the educational level for the future transition from rural to urban agricultural industry?

Specific Questions for Other Practitioners

Policy

How is the government investing in food-tech?

What could be the government´s role in the implementation and expansion of an upcoming new industry, such as urban agriculture/vertical farming?

To what extent is the government supporting urban agriculture/vertical farming business? Could you give concrete examples of measures or incentives implemented in this field?

Does urban agriculture/vertical farming business face issues regarding legislation and regulation? How could these obstacles be overcome?

Appendix 7: Expert Interview Participants

Expert Interviews							
Interviewee	**Company Type**	**Company**	**Function**	**Experience**	**Location**	**Data Collection**	**Date**
António Fernandes	Vertical Farming	Jungle Greens	Former Marketing Project Manager	1 year	Lisbon, Portugal	Face-to-face	17/10/2020
João Pereira	Manufacturing	Aralab	Area Sales Manager	6 years	Lisbon, Portugal	Video-conference	29/10/2020
Mariana Mota	University	Instituto Superior de Agronomia (ISA)	Agronomist	25 years	Lisbon, Portugal	Email	11/11/2020
Elvira Ferreira	Public Institution	Instituto Nacional de Investigação Agrária e Veteriária (INIAV)	Researcher in the Agrarian Systems Sector	40 years	Lisbon, Portugal	Video-conference	12/11/2020
David Slattery	Real Estate and Investments	DESCO Arizona, LLC	Partner	10 years	Arizona, USA	Video-conference	13/11/2020

Appendix 8: Likelihood of Possible Scenarios

Three Possible Scenarios				
Role		**Conservative**	**Reasonable**	**Optimistic**
Primary Stakeholder 1	**Producers**	Low-margin commodity products produced on a large-scale. Due to start-up and operating costs, the final price of products might be too high for consumers.	High-margin differentiated products produced on a low-scale with a lower capital expenditure investment.	High-margin differentiated products produced on a large-scale, with significant, recurring, and long-term production over time.
Primary Stakeholder 2	**Primary and Value-added Processors**	Operational complexity would be high. Thus, it would be hard to achieve a wider spread of value-added activities.	Operational complexity would be reduced, allowing more flexibility and agility into the production process.	Scale benefits would arise based on the efficiency gains generated through operations and in the best-case scenario in terms of technology.
Primary Stakeholder 3	**Consumers**	Consumers would be unwilling to pay a premium for products produced in vertical farming. Thus, they would migrate to other alternative players.	Occasionally, consumers would look for difficult-to-match products. Thus, they would be willing to try these new products and to pay a premium for its acquisition.	The widespread of vertical farming among the population would be feasible and sustainable. Customers would become loyal and willing to pay for the product´s acquisition.
Primary Stakeholder 4	**Competitors**	Traditional farmers would produce high quantities year-round at a reduced cost and supply inexpensive products to consumers.	Traditional farmers would not be able to offer consumers difficult-to-match products with such differentiated properties.	Traditional farmers would not be able to offer consumers difficult-to-match products with such differentiated properties.
Secondary Stakeholder 1	**Retailers and Distributors**	The distribution chain would be reduced. The bargaining power would be high.	The distribution chain would be reduced. The bargaining power would be high.	The distribution chain would be reduced. The bargaining power would become slightly reduced.
Influencer 1	**Governments/NGOs/ Regulators**	High extent barriers in terms of requirements, regulations, and investment would limit the development of vertical farming.	Vertical farming projects would have better access to financing conditions and incentives. The regulation would be applied more clearly.	Reinforcement of sustainable practices, through an intensive investment and flexible regulation.
Influencer 2	**Global Input Suppliers**	Suppliers would have high bargaining power since the equipment provided to the industry would be very specialized.	Suppliers would have high bargaining power since the equipment provided to the industry would be very specialized.	Vertical farms could develop their in-house systems. Although costly, risky, and time-consuming, this could remove some of the bargaining power of suppliers.
Influencer 3	**Research Centres and Educational Institutions**	High extent barriers, due to the large investment needed in terms of education and research, would limit the spread and consolidation of vertical farming knowledge.	Vertical farming would still require highly specialized knowledge. However, it would be easier to obtain it due to lower extent barriers.	Accessible educational opportunities and investment for rising people´s skills would contribute to the vertical farming scalability in the long-run.
Likelihood to happen (%)		**20%**	**50%**	**30%**