Creating an inventory for vertical farming cultivation techniques coupled to the concept of people, planet and profit.

Bachelor Thesis Business and Consumer Studies

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BSc program:	BSC Bedrijfs- en Consumentenwetenschappen
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Course code:	YSS-81812
Period:	3,4,5,6,1
Study load:	12 credits
Date:	19-10-2020

Abstract

This thesis aims to create insight for researchers, investors, and other stakeholders in the vertical farming business. Although a lot of research has been done regarding vertical farms and the cultivation techniques that can be used, a recent comprehensive literature review is missing. The aforementioned insight is created by analyzing the benefits and challenges of three different vertical farm cultivation techniques.

These benefits and challenges are analyzed on a checklist with elements of the Triple-Layered Business Model Canvas. This way insight is created in how each vertical farming cultivation technique performs on multiple elements within the economic and environmental dimension of the checklist with elements of the Triple Layered Business Model Canvas. The methodology used in this thesis is a literature review. Papers from peer-reviewed journals are analyzed, used, and put into context.

It was found that as of now there is one cultivation technique that performs better than other techniques concerning vertical farming, namely, aeroponics. This thesis also shows that aeroponics is the most promising cultivation technique. Furthermore, this thesis discusses that depending on a stakeholders priorities, their view of what is the optimal cultivation technique can differ from what other stakeholders might consider the optimal cultivation technique. This view is subject to each stakeholders' objective combined with their Triple Bottom Line approach.

Examples based on current vertical farming cases are given to showcase the benefits and challenges of each vertical farming cultivation technique, and how each technique would perform based on the same case.

Contents

Preface

This BSc thesis is written at the chair group of Business Management & Organization, under the supervision of dr. Emiel Wubben for Wageningen University in 2020. This thesis is the culmination of my development on a personal and academic level through my time studying in Wageningen. It is the last step in finishing my university education for the BSc in Business & consumer studies. The years before writing this thesis have been filled with numerous extracurricular projects regarding event organization for the Wageningen student association Ceres, as well as dipping my toes in several professional working environments, such as Wageningen University Fund and Operator Group Delft, which has served to further enhance my learning experience.

With no personal agricultural background other than growing up in a rural community in my youth, I was surprised with my fascination for vertical farming. The further I read into it the more I became interested in the possibilities associated with vertical farming. For me, it has shaped a positive outlook on what science can do for the global food supply. I am a firm believer in the mantra that problems do not exist, but challenges do, and we can overcome these by working together and striving to be the best person we can be every day.
Although writing this thesis in isolation during a time of international crisis regarding the Covid-19 virus in combination with personal sickness which left me unable to work for three months was challenging. It has also been a great chance for myself to see what I am capable of. I hope the reader enjoys reading this report as it was an interesting journey as well as a pleasure to create it.

1. Introduction

Continuous improvements in agricultural techniques have increased crop yield in agriculture significantly (Despommier, 2009). This increase in production has led to a broad field of production possibilities. One of these possibilities involves the implementation of vertical farms in urban areas. Although still a relatively young idea, the possibilities for food production in these areas are large. Due to the industrialization of food supply, humanity has a widespread food production on a large scale which is available throughout the year and all over the world. However, this system will not be feasible in the future, in the following paragraphs this will be further elaborated (Despommier, 2009; 2010).

First, it is estimated that by 2050, 9.8 billion people will inhabit the planet, with each needing at least 1500 calories of food every day (Roser, 2020). Currently, the world's 7.7 billion inhabitants use a landmass equal to the size of South America to provide enough food for all humans on earth. To feed 9.8 billion people by 2050 we will need to cultivate an extra landmass the size of Brazil. This much farmable land is not available (Despommier, 2009).

Second, because of the use of fertilizers and pesticides up to 70% percent of all water used for agriculture is undrinkable (Despommier, 2009). The intensive groundwater pumping necessary for irrigation is also depleting aquifers which can lead to negative effects such as increased energy costs for water extraction, reduced surface-water flows, deterioration of water quality, and subsidence of land, i.e. a gradual settling or sudden sinking of the earth's surface (U.S. Geological Survey, 2004). Another effect of using fresh water for irrigation is the fact that the water becomes undrinkable due to water contamination with herbicides, pesticides, and fertilizers. Continuation of using irrigation in a way that negatively affects the environment might even lead to the unavailability of fresh water in densely populated areas. (U.S. Geological Survey, 2004).

Third, the 3rd assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2001) estimated that worldwide agriculture was accountable for 3 percent of global energy consumption, but more than 20 percent of global greenhouse gas emissions (Woods et al, 2010). One of the main contributors to these emissions is the amount of transport needed to get crops from the place where they have been grown to the places where they are being sold. The average crop travels between 2400 and 4800 kilometers between their production location and where they are eventually sold (O'Hara, 2011). The combination of little available landmass for agriculture, the impact of fertilizer and pesticides on groundwater, and large GHG emissions requires that alternatives for food production must be identified and utilized to keep feeding the earth's population.

Vertical farming introduces a completely autonomous environment that enables food production. This is also known as Controlled Environment Agriculture (Philips, 2016). It has been developed to run automatically, whilst being controlled by an environmental computer controlling lighting, temperature, nutrients, and airflow. When making a quick comparison with traditional farms, vertical farms are 100 times more efficient concerning the usage of space, 70-99 percent less reliant on water and have a lower carbon dioxide footprint (Philips, 2016).

An overview is made in which three cultivation techniques are explored. This will be done by creating an inventory of these techniques, which will be split into three main cultivation techniques regarding vertical farming. Being, hydroponics, aeroponics, and drip irrigation.

The Triple Bottom Line will be used to analyze the benefits and challenges of the three cultivation techniques on an economic, and environmental dimension which will further be referred to as Planet and Profit (Elkington, 1994;1998). The concept of the Triple Bottom Line was created by John Elkington in 1994 to measure sustainability by creating a framework that could be used to analyze sustainable performance in corporate America (Elkington, 1994; 1998). The Triple Bottom Line is also used in analyzing sustainable performance regarding its social dimension, however, early on in the research, it was deemed that which cultivation technique a vertical farm chooses to use has no effect on its performance regarding the social dimension.

Elements from the Triple-Layered Business Model Canvas will be used for a more in-depth analysis of each cultivation technique (Joyce & Paquin, 2016). The use of elements from this canvas will lead to a greater variety of elements on which each cultivation technique can be evaluated regarding its Planet and Profit dimensions. This will help with the creation of a cohesive and concise overview.

1.1 Problem statement

The need for alternative crop cultivation techniques are on the rise as current techniques are viewed as unsustainable (Despommier, 2009; Zasada et al., 2017). Although some research is done regarding vertical farms, a recent comprehensive literature review is missing. Especially one where the concepts of vertical farming are linked to the interests of potential sustainable aware investors or other stakeholders that want to enter the vertical farming arena. By analyzing the benefits and challenges of vertical farm techniques on an economic, environmental, and social level, an inventory can be made in which the benefits and challenges of current techniques can be viewed. This will help in developing an overview which can support the vertical farm industry whilst simultaneously creating oversight in all the different techniques currently used. With the Triple Bottom line and the concept of People, Planet, and Profit as a criterion on which each technique will be judged.

1.2 Research objective

This thesis aims to make a multitude of knowledge regarding vertical farming cultivation techniques accessible, while also providing much-needed clarity for researchers, stakeholders, and businesses, interested in vertical farming. By creating an overview of operational alternative farming cultivation techniques within vertical farming, and by showing the benefits and challenges of these techniques at the economic and environmental dimensions of the Triple Bottom Line this clarity can be provided.

1.3 Research questions

Followed by the problem statement and the research objective, the main research question of this thesis is: What are the benefits and challenges of the three main vertical farming cultivation techniques for the concepts of the Triple Bottom Line regarding the feasibility of cultivating leafy greens in vertical farms?

The following sub research questions are used to answer the main research question:
RQ1- What are the benefits and challenges regarding the environmental and economic dimensions for hydroponics in vertical farms?
RQ2- What are the benefits and challenges regarding the environmental and economic dimensions for aeroponics in vertical farms?
RQ3- What are the benefits and challenges regarding the environmental and economic dimensions for drip irrigation in vertical farms?
Rq4- How does each vertical farming technique perform on the checklist with elements of the Triple-Layered Business Model Canvas?

1.4 Research outline

Chapter two will contain the methodology used for this thesis. The chapter will start with how the literature study was done, followed by the sub-questions that were used in answering the main research question. The queries used in answering each sub-question will also be shown in this chapter coupled with a table that shows how much hits each query generated and how many hits were included in this thesis. The chapter will conclude with a checklist with elements of the Triple-Layered Business Model Canvas which will be used to see how each cultivation technique performs.

Chapter three will consist of background information necessary to comprehend the main research question and how each sub-question was answered. The chapter will start by explaining the Triple Bottom Line. This will be done by first explaining the seven drivers that have led to the existence of the Triple Bottom Line. Then the Triple Bottom line itself will be explained and how the concept of People, Planet and, Profit relates to that. Lastly, the Triple-layered Business Model Canvas will be introduced and how some elements from this canvas can be used in analyzing the benefits and challenges of a cultivation technique.
The second part of the background chapter will give a short elaboration regarding vertical farming as a whole and will elaborate on each specific technique that will be researched in this thesis.

Chapter four contains the results from the four research sub-questions. The chapter is divided into 4 sections. In the first 3 sections, the results regarding the benefits and challenges of hydroponics, aeroponics and, drip irrigation will be shown. The last section will show how each technique performs regarding the checklist with elements of the Triple-Layered Business Model Canvas.

Chapter five consists of 2 sections. The first section contains the answer to the main research question. This is done by listing the answers given to the sub research questions given in the previous chapter. This will then lead to the conclusion which answers the main research question.

The second section contains the discussion as well as suggestions for further research regarding the subject of this thesis. Potential shortcomings of the research will be discussed as well as threats to the validity and reliability of the research. The last part of this section is devoted to suggestions for future research which may help to progress research in the field of vertical farming.

2. methods

The main research question will be answered by conducting a systematic literature study. The sub research questions support the main research question.

For the literature study Google Scholar, Scopus, and The Web of Science were used to identify influential papers on cultivation techniques suitable for vertical farming. (Martin-Martin et al., 2017) showed that, due to broad coverage and efficient sorting algorithms, Google Scholar is a suitable search engine for identifying the most suitable scientific papers. (Burnham, 2006) showed that Scopus indexes over 14.000 Science, Technical, Medical, and social science titles from over 4000 publishers and Scopus claims that "it is the largest single abstract and indexing database ever built". The Web of Science provides a common search language, navigation environment, and data structure allowing researchers to search broadly across many resources and use the citation connections provided. That enables the retrieval of relevant research results. With over 34.000 journals, books, proceedings, patents, and data sets Web of Science has a rich collection of credible sources (Web of Science, 2020). Other sources such as Facebook groups that were recommended by this writers' supervisor and influential books such as The vertical farm and Plant factory were also used for the extraction of information (Despommier & Carter, 2010); (Kozai, Niu, & Takagaki, 2015). This, to cover the entire domain of the three cultivation techniques used in this inventory. To cover each cultivation technique a broad search query was used to gather information from peer reviewed journals, namely: "vertical farm*" OR "Plant factory*" OR "Indoor farm*" AND "hydroponic*" OR "aeroponic*" OR "drip irrigation*".

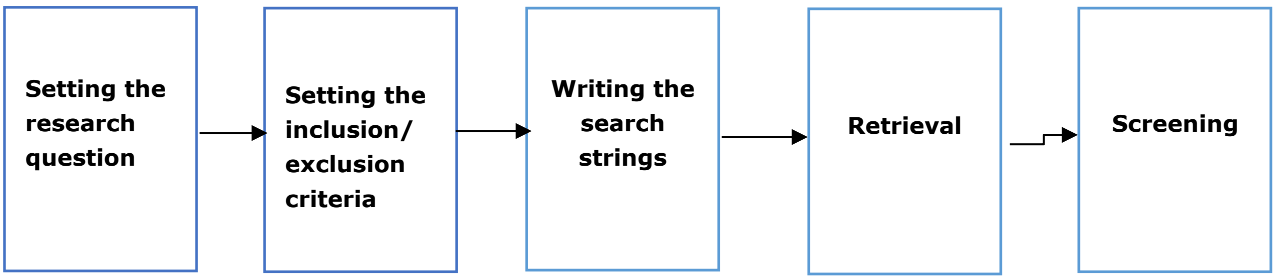
The papers that were included in the literature study had to be published in peer-reviewed journals and the content of the paper had to discuss vertical farming in combination with one of the cultivation techniques. A selection was made of 120 papers that were screened and which either had over 50 peer reviews and/or were published in the last 10 years. This resulted in 34 papers eventually being included in this research as shown in appendix 2. The criteria for papers to be included that are mentioned earlier were made to ensure that papers used were of high quality, while also ensuring the recency of each article included. Ensuring recency of each paper was important due to rapid advances in the field of vertical farming (Benke & Tomkins, 2017).
If these criteria were satisfied it was assumed that the paper correctly represented vertical farming and that the analysis of the contents would give insight into one of the three cultivation techniques. The two books mentioned earlier, The vertical farm and Plant factory are considered influential works in vertical farming as they are referred to by many peer reviewed journals. By utilizing these criteria, the gathered literature consisted of a combination of the most seminal pieces of work combined with the most current studies.

For the concept of People, Planet, Profit, the Triple Bottom Line, and the Triple Layered Business model over 70 papers were screened, of which there were 15 that got included in this research as shown in appendix 2. Only one constraint was deemed necessary during the search for papers to be screened which was that it had at least over 30 peer reviews. During the screening of each paper it became clear that not many papers that discussed the Triple Bottom Line had over 50 peer

reviews. Therefore, this researcher opted to lower the number of peer reviews deemed necessary to 30. This still ensured a form of quality control without missing out on certain papers containing valuable information. There was no boundary set as to when a paper had to be published as the concept of the Triple Bottom Line is not subject to too much change. It was however, interesting to see how the concept was used early on and in more recent approaches (Elkington, 1994;1998; Sitnikov, 2013).
The search query that was used was: "triple bottom line" OR "people, planet, profit" OR "PPP" OR "TLBMC" OR "Triple Layered Business Model Canvas". The papers included in this literature study had to be published in peer-reviewed journals and had to discuss either the TBL or the concept of People, Planet, Profit, or the Triple Layered Business Model Canvas or a combination of these three. If these criteria were satisfied it was assumed that the paper correctly represented the Triple Bottom Line or the concept of people, planet, profit, or the Triple Layered Business Model Canvas.

This research followed the process of a systematic literature review according to Hagen-Zanker & Mallet as showcased in figure 1. After having determined the search queries, screening began and the PRISMA flow diagram was for further in/exclusion of papers deemed vital for this research. The abbreviation PRISMA stands for " Preferred Reporting Items for Systematic Reviews and Meta-Analysis " and is the method used for systematic literature reporting (Moher et al., 2009).

Figure 1.



For each sub-question, a related PRISMA flow chart was made in which each step of the systematic literature review was shown. Using a PRISMA flow chart is important for the research as it shows the used dataset and ensures that the research can be reproduced in the same way. In appendix 1, the PRISMA flow chart is shown coupled with a table in which the number of hits coupled with the search queries is shown.

Each article that was selected for this research was read using the three-pass approach (Keshav, 2007). This approach consists of three passes, the first one is a quick scan of each article read. Completing this pass will result in the researcher being able to decide whether the article is interesting for the scope of this research.

In the second pass the article is read with greater care, but details such as proofs can be neglected. It helps to make notes of the key points and to write comments regarding certain parts. After this pass the researcher should be able to grasp the content of the paper (Keshav, 2007).

The third pass helps the researcher fully understand the paper. In this pass, the researcher makes the same assumptions as the author. This helps identifying not only the innovations a paper has made, but also its potential failures and assumptions. This pass requires great attention to detail of the paper, but helps the reader in identifying in its strong and weak points (Keshav, 2007).
These 3 steps for identifying, screening, and eventually using a paper, were made for each paper which ended up in this research.

3. Background

This chapter contains background information deemed necessary to understand the content of this research. The chapter is divided into 4 different sections. First, an introduction to the Triple Bottom Line will be made (Elkington, 1994). The Triple Bottom Line itself will be defined coupled with how the concept came to be and the link will be made with the eventual checklist with elements of the Triple-Layered Business Model Canvas which will be used to see how each cultivation technique performs. Following this short introduction, section 3.1 specifies and explains the seven drivers that have led to the creation of the Triple Bottom Line. Section 3.2 contains the definition for the concept of People, Planet and, Profit. Section 3.3 elaborates the concept of People, Planet and, Profit by introducing the checklist with elements of the Triple-Layered Business Model Canvas. This chapter will close with section 3.4. Here vertical farming and each technique that is to be researched is introduced and defined.

The TBL was created by John Elkington in 1994 to measure sustainability by making a new framework that could be used to measure performance in corporate America. This framework was dubbed the Triple Bottom Line (Elkington, 1994). It went beyond conventional measures such as profits, return on investment, and shareholder value, to incorporate environmental and social dimensions. The framework focusses on investment results regarding performance which is related to the dimensions of People, Planet, and Profits. These dimensions are supported by seven drivers which complete the TBL. The TBL is essentially a way for corporations to express their responsibility beyond shareholders alone, and provides an understanding of their public reporting, dealing and, exposure concerning their economic, environmental, and social dealings. (Elkington, 1994; 1998; Sitnikov,2013). The TBL was further developed by Joyce & Paquin (2016) who developed the widely used Triple-Layered Business Model Canvas which comprises three layers that are based on the economic layer that was created by Osterwalder & Pigneur (2010).

3.1 The seven drivers of the Triple Bottom Line

The TBL focuses not only on the economic value that businesses provide but also on the social and environmental value that they either provide or fail to provide. The idea of the TBL relies on seven closely related “drivers” which change capitalism into sustainable capitalism.

The first of these drivers is market competition. In the future, businesses will be operating in markets that are more open to competition, both on a domestic level and at an international level. This will increase even more due to globalization and digitalization(Elkington, 1994;1998; Sitnikov, 2013). As entire markets will turn to absorb companies and even industries. It will be key for businesses to be able to spot market conditions that are key indicators for this process. As it will be extremely important for businesses to survive, or to even be successful. In this changing environment, many businesses are already finding themselves to be challenged by both financial markets and customers regarding their TBL commitments and their performance. In the future, these cycles will continue to widen based on social, political, and economic trends and the pressure that comes along with these changes will continue to grow over the long term (Elkington, 1994). This will eventually lead to businesses shifting to a new approach, the TBL approach, in which TBL thinking as well as accounting will become the new norm for businesses for both their actions and their investments. In short, whereas businesses used to comply with how the competition was handled this will now change to a form with higher competition between businesses due to increasing globalization and digitalization (Sitnikov, 2016).

The second driver is a general global shift regarding societal and humanistic values. Regarding businesses, most societal values are taken as given. These values however are a product of how a generation has grown up regarding these values (Elkington, 1994). These values tend to change with each new generation, which means that businesses who might have thought they were standing on solid grounds about societal values may find that the world and its values has turned upside down over time. A strong example is the company shell in the 1990s in Nigeria with the oil controversies, where the oil company announced it would consult NGOs on issues concerning the environment and human rights before starting production developments (Sitnikov, 2016).

The third driver is about transparency, which is speeding up due to the increasing global transparency about the dealings of businesses. This will result in businesses finding that their reasoning and actions are under examination on a global scale due to increasing transparency being demanded by populations worldwide (Elkington, 1998). A strong example that is currently relevant is China not being transparent about their Belt and Road projects, as European companies that are seeking involvement with the initiative are finding a lack of information and transparency regarding the project (Bangkok Post Public Company Limited, 2020). In short, this opening up will lead to a variety of stakeholders to increasingly request information on what businesses are working on and on what they are intending to do. Whereas businesses themselves are using this information as well to measure the performance of other businesses. A current example of this phenomenon is the approach that is taken by Transparency International and its developments (Transparency International, 2020).

The fourth driver is in turn powered by and one of the driving forces for the transparency evolution. This revolution is life-cycle technology whereas in the past the importance of recyclability was neglected. In modern times it is almost a necessity for every product.
Businesses are confronted with the standards of the TBL regarding industrial or agricultural actions back down in their supply chain or about the effects of their products that are either in transit, in use, and most importantly after their useful life has ended (Elkington, 1998). Currently, a shift is ongoing whereas businesses previously focused on the acceptability of their projects, they now focus on the concept of "from cradle to grave" which means that from the extraction of raw materials needed for a product, through the recycling or disposal of those materials. Businesses manage the life cycles of both products and technologies to manage the environmental impacts associated with all stages of a product's life (Life Cycle Assessment - an overview | ScienceDirect Topics, 2020).

The fifth driver is one in which businesses will go from subversion towards other businesses, to symbiosis. This revolution will increase the speed at which new forms of co-operation between businesses will be formed. In this situation, businesses that saw each other as enemies in their respective markets will now start involving new forms of association with their former business competitors if they believe that these competitors hold the keys to success in current markets. This does not mean that there will come and end to friction between competitors as competition is the best incentive for businesses to become the most productive and efficient version of themselves. The challenge here will be for competing businesses to work out strategies in which they can both challenge their competitors whilst also working together (Elkington, 1998).

The sixth driver is time. People and businesses alike have always been told that time is short, and money is shorter. This has become the basis on which the dealings of many a business has been based. Revolution six however will go against this business mantra as it is about long-term planning for businesses instead of accruing an as large as possible profit in the shortest amount of time. The sustainability program focuses on businesses in the other direction towards long term planning. If most policymakers for businesses, industries, and even governments have trouble planning for up to three years ahead then that means that planning for a decade or even multiple decades is an even larger challenge. Especially as in business competition is often time-based. Everything needs to be done in the shortest possible amount of time. A strong example is the JIT principle which many businesses apply in their daily operations. This drives the acceleration of tempo between businesses, which is counter-effective for businesses trying to create a more powerful long-term plan for their business. Therefore, creating a long-term vision for the sake of sustainability will become more challenging as time becomes costlier (Elkington, 1994;1998).

The seventh driver of the TBL is driven by the previous six drivers. This driver is about corporate governance of businesses and new questions arise such as, who should have a say in how a business is run, what is the correct balance between shareholder other stakeholders influenced by a business, and how should a company balance its interest with the TBL?
As of now, most TBL campaigners have focused their activities on product design and the process of delivering a product to the market. It is clear, however, that the growing proportion of issues entangled with corporate social responsibility are about the intrinsic design of businesses and their value chains.

In short, these seven drivers: market competition, societal values, transparency, life cycle technology, symbiosis, time, and corporate governance/business are what lead to a new way to measure corporate performance. Instead of only focusing on economic incentives these drivers have created a new awareness in businesses. This awareness has lead to these businesses to also focus on the environmental and social aspects of business.
"experience suggests that the best way to ensure that a given corporation fully addresses the TBL agenda is to build the relevant requirements into its corporate DNA from the very outset, and into the parameters of the markets it seeks to serve" (Elkington, 1994). Due to vertical farming being a relatively new business concept, the aforementioned quote by Elkington fits perfectly in the vertical farming narrative. By creating a vertical farm that focuses on economic, social, and environmental incentives, instead of only economic incentives, Triple Bottom Line reporting can become a fact, and in doing so create a modern approach for doing business. The next two sections will elaborate on what these environmental, social, and economic incentives entail and how they can be used to

measure these incentives. Setting these steps will lead to a new standard for sustainable agriculture.

3.2 People, Planet, Profit

In this section, each dimension of the concept of People, Planet and, Profit will be elaborated upon. First People will be explained which will lead to a larger understanding of the social part of People, Planet and, Profit. The second part contains an in-depth explanation of the People part, which relates to sustainable environmental conduct. The third and last part of this section will explain the Profit part which is the economic value a business provides.

The term "People" is related to correct and proper business dealings for both employees but also people not directly employed by a business, as well as the area in which the business conducts its operations. A business that upholds the principles of the TBL utilizes a social framework in which the collective welfare of corporate, the laboring parties, and the population affected directly and indirectly by a business its dealings is mutually beneficial. A company that upholds the TBL adheres to benefitting as many parties as possible which are within the companies' sphere of influence. An example of this is upstreaming a part of the company's revenue from selling their finished goods to the first manufacturer of raw materials needed for production (Sitnikov, 2013). In the case of vertical farming, this is often not a possibility since most costs are generated in the initial overhead costs necessary to start production. A more realistic approach for vertical farms is for example opting to not only utilize cheap labor for their crop production, pay fair wages to their employees, supply secure working conditions coupled with reasonable hours, and altogether not impose any negative effects on their workforce or the local community. Another characteristic of the "people" part of the TBL is to give back to the community. This can be done in numerous ways such as providing healthcare and education. Trying to set this bottom line, however, may prove to be difficult as it is subject to bias and often proves to be troublesome in practice. to adhere to this bottom-line, businesses can follow the advanced guidelines provided by the Global Reporting Initiative (GRI) (Global Sustainability Standards Board, 2016).

Next, the term "Planet" is related to sustainable environmental conduct. A business that adheres to the TBL attempts to benefit its natural surroundings as much as possible or should at least strive to do no environmental damage. By adhering to the TBL concerning the environment a business tracks their handling about its use of energy and non-renewable resources, while lowering production waste, as well as managing its waste by transforming it into less toxic matter before disposing of it in a way which is not harmful to the environment, or even completely re-using it and turning their waste disposal into a closed-loop system (Sitnikov, 2013; Elkington, 1998).
A term which is very important for the planet part of the TBL is "cradle to grave" which means that concerning production that is in line with the TBL, businesses should conduct a life cycle appraisal of its products to calculate what the environmental ramifications are when looking to the entire process of raw materials needed for production, to product delivery and subsequently the final disposal by the end-user (Sitnikov, 2016). Companies that adhere to the TBL prevent environmentally damaging practices such as using too much of the available resources, or ineffective waste management. (Global Sustainability Standards Board, 2016).

Lastly, the term profit, profit is defined as the economic value produced by a business after subtraction of all costs regarding materials, labor, and capital invested (Sitnikov, 2016). However, within the context of People, Planet, and Profit the term "Profit" differs from the definition derived from traditional accounting. Within the sustainability framework from the TBL "profit" needs to be perceived, not as how much money is accumulated when all costs are subtracted at the end of the line, but as the economic advantage that those living around or that are affected by a business enjoy (Sitnikov, 2016). Simply put, "profit" is the noticeable positive economic effect a business has on its economic setting and should therefore not be confused with its internal revenue in the traditional meaning of profit. This means that the TBL cannot be measured and explained through conventional accounting revenue where the social and environmental impacts are added as well. This can only be done when social and environmental benefits can also be addressed as profits (Elkington, 1998; Sitnikov, 2016).

3.3 The checklist with elements of The Triple Layered Business Model Canvas

The concept of People, Planet, and Profit can be used to analyze the benefits and drawbacks of each vertical farming technique. This is done by creating a checklist for each of the three parts that form the concept of PPP. This checklist is based on every benefit and challenge that the literature has shown to be related to vertical farming cultivation techniques regarding People, Planet, and Profit. The checklist is further expanded by elements of the Triple Layered business model canvas (Joyce & Paquin, 2016). It must be noted that not all elements of the 3BM are used in this checklist. Regarding profit, elements such as customer relationships, customer segments, channels, and partners are missing. For the Planet dimension the elements, end of life, use phase, distribution, and suppliers/outsourcing are left out. Since that which cultivation technique is being used has no influence on these elements of the 3BM (Joyce & Paquin, 2016). Therefore, these elements are left out and this subsequent process results in the following checklist that is used to analyze the benefits and challenges of each vertical farm cultivation technique.

Table 1. Checklist with elements of the Triple-Layered Business Model Canvas

Profit	**Planet**	**People**	**Questions**
Value proposition	Functional Value	Social value	What are key values and functions (i.e., activities, services, or products the technique provides?
Key resources	Materials	Employees	Which key human and material resources does the technique require?
Key activities	Production	Governance	What are the key processes that enable and produce the value proposition related to?
Costs	Environmental Impacts	Social impacts	Which technique has the highest costs? What are negative

			impacts that are created for the environment and society?
Revenues	Environmental benefits	Social benefits	Which technique generates the most revenues? Which benefits are created for the environment and society?

Even though academic literature does not always state exact numbers regarding vital scoring components such as costs, revenues, and yield of leafy greens. It does often state how different techniques perform concerning the cultivation of leafy greens. Based on this information each technique can be evaluated on each section and get a ranking score ranging from 1 being the highest score that is awarded to the technique that performs best on said element. The technique that performs not the best nor the worst gets a 0 and -1 is awarded to the technique which has the worst performance regarding an element. If it is not possible to discern from the literature which technique performs better than other techniques regarding for example the element key resources. All techniques will get 0 points for that element. When all three techniques perform on the same level regarding a certain element then each technique will be awarded 1 point. This scale in which the scoring ranges from 1 to 0 to -1 was chosen because it gives a clear distinction regarding how a technique performs compared to the other two techniques per element shown in Table 2. Scoring will be done by the researcher himself based on literature in which the cultivation techniques are discussed. Separate tables will be created for the Profit and Planet dimensions in which each cultivation technique will be awarded points corresponding with how they perform regarding each element within their respective dimension. After the points have been awarded, they will be added up for each cultivation technique. Based on the score each technique achieved, a ranking is made which will show how each cultivation technique performs regarding each dimension of the checklist shown in table 2. Although this checklist also contains a "People" section, it will not be used for the final judgement of each cultivation technique. This, because as stated during the introduction of this research it became apparent that which cultivation technique a vertical farm uses, has no influence on how it performs regarding the "People" part of the checklist with elements of the Triple Layered Business Model Canvas. Therefore, the "People" part is omitted when analyzing the benefits and challenges of each cultivation technique in the results of this research.

3.4 Vertical farming cultivation technologies

This section will start off with the definition of vertical farming. In later sections each of the three techniques that are to be used in this research will be defined as well. Vertical farming relates to a multitude of definitions such as, rooftop farming, urban food systems, controlled environment agriculture, completely controlled growing system, city farming, urban agriculture, container farming, food factory and more (Despommier, 2009;2010). According to the association for vertical farming, vertical farming can be defined as: *"Vertical farming is the practice of growing food and/or medicine in vertically stacked layers. Vertically inclined surfaces and/or integrated in other structures. The modern idea of vertical farming uses Controlled Environment Agriculture (CEA)* *technology, where all environmental factors can be controlled. These facilities utilize artificial control of light, environmental control (humidity, temperature, gases,) and fertigation. Some vertical farms make use of techniques similar too greenhouses, where natural sunlight can be augmented with artificial lighting."* (Glossary for Vertical Farming, 2017)

Although there are multiple definitions for vertical faming, the one previously mentioned is used as the definition in this research. Based on the literature there are certain characteristics which are frequently used when defining vertical farming. Examples of these characteristics are: They are located in dense urban centers, creative reuse of land, utilize soil-free growing methods, are vertically oriented, utilize advanced systems to control growing conditions, inputs are recycled, and they serve local markets (Despommier, 2009; Zasada et al., 2017; Specht et al.,2019). The aforementioned definition includes all these characteristics, whereas others do not, which is why this researcher has opted for this definition.

This research delves into three cultivation techniques that are commonly used in vertical farming. These techniques are hydroponics, aeroponics, and drip irrigation.

Hydroponics can be defined as the production and growth of plants in soilless conditions with water, plant nutrients, and a chemically inactive (inert) medium such as sand, pearlite, gravel, and other substances (Resh & Howard, 2012; Glossary for Vertical Farming, 2017). The inert medium is used in almost every hydroponic system and is often called "soilless culture" (Treftz & Omaye, 2016).

When comparing hydroponics to normal agriculture with soil-grown plants here are few dissimilarities between both systems. In both systems when administering any element to the plant, the elements both organic and inorganic must be broken down into the water flow.

The difference being that in soil-based plants the elements attach themselves to the soil particles and eventually move into the soil solution where the elements are drawn up into the roots of the plant. Whereas with hydroponics this process is different. Here the nutrient solution in which the elements are dissolved meets the plant roots, after which the plant roots absorb the mineral and water.

Aeroponics can be defined as the cultivation of plants without the use of soil or chemically active mediums. Crops are grown in the air assisted by nothing but devices that keep them suspended. Simply put, aeroponics is a culture cultivation system that uses air and water, the roots of the crop are suspended in a closed system and are exposed to air which is routinely sprayed with a water spray which is full of nutrients which enhances crop growth. Aeroponics uses this nutrient-rich spray with the help of foggers or pressure nozzles to achieve as much growth as possible under controlled conditions. The fact that the crops can be stacked makes the system perfect for vertical farming (Lakhiar, Gao, Syed, Chandio, & Buttar, 2018).

The last of the three main cultivation techniques used in vertical farming is drip irrigation. When utilizing drip irrigation, crops are rooted in troughs of lightweight, inert materials such as vermiculite which is known for its ability to encourage seed germination and has higher aeration and water-holding properties compared to normal soil. Vermiculite does not rot and can be used for years and each crop is connected by small tubes through which water and nutrients are given to each crop (Dixon, 1989). As with aero and hydroponics, drip-irrigation was developed with the idea of an increase of water usage with population growth and more intensive agriculture in the future (Córcoles, de Juan, Ortega, Tarjuelo, & Moreno, 2012). Furthermore, increasing costs concerning the production costs in traditional agriculture such as seeds and fertilizers have further driven up uncertainty regarding the economic certainty of land (Lamm et al., 2016).

After reading this chapter the reader will now know why Triple Bottom Line reporting can be used to measure business performance on an economic, environmental, and social level and what the drivers have been for the development of the theory. The checklist with elements of the Triple Layered Business Model Canvas is used to give a score to the performance of each of the vertical farming cultivation techniques defined in this chapter.

4. Results

This chapter is divided into 4 sections. In the first section the benefits and drawbacks of hydroponics will be listed based on their importance. The same is done for aeroponics in the second section, and for drip irrigation in the third. The benefits and drawbacks were listed based on their relevance according to the literature. How relevant each benefit or drawback was, was based on how often they were quoted by the literature and on the relevance each paper attributed to each benefit or drawback. In some papers, it was not possible to discern whether a benefit or challenge was more important than others. If this was the case, then other papers were used to establish the importance of each benefit and drawback. In section 4.4 each technique will be judged on how it performed on the Profit and Planet dimension of the checklist with elements of the Triple Layered Business Model Canvas.

4.1 Hydroponics

This section will answer the sub research question: *What are the benefits and challenges regarding the environmental and economic dimensions for hydroponics in vertical farms?*

In order to give a concise and cohesive answer to this question reports by: (Al-Chalabi, 2015), (Specht et al., 2019), (Thomaier et al., 2014), (Treftz & Omaye, 2016), (Safikhani, Abdullah, Ossen, & Baharvand, 2014), (Kalantari, Tahir, Joni, & Fatemi, 2018), (O'Hara, 2011), (Despommier, 2009;2010) (Jensen, 1999) and (Benke and Tomkins, 2017) were used to create a list of benefits and challenges associated with hydroponics. Appendix 3 contains the table which shows the databases used coupled with the search queries, the amount of hits that were generated and, the number of eventually used articles. In this section the benefits and challenges on an environmental level will first be shown, followed by the same format but on an economic level.

4.1.1 Environmental benefits of hydroponics

Literature states six clear environmental benefits linked with hydroponics as seen in table 2

The main environmental benefit of hydroponics as a cultivation technique for vertical farms. Is due to how water recirculation is used in the production process it employs concerning the cultivation of crops. Water Use Efficiency (WUE) or the weight of every crop which gets harvested for every unit of water supplied is optimized when using hydroponics (Treftz & Omaye, 2016). This is since hydroponics takes place in enclosed systems. This means that water loss is restricted to a minimum due to even water that evaporates is caught in the system and reimplemented for use.

Second, the hydroponic system can be implemented in even non-arable areas of the world, such as dry or urban areas. This is especially important as currently an estimated 65% of the total land on earth is classified as arid and 54% of the total human population is currently living in urban areas and this number is expected to increase up to 66% by 2050 (Our world in data, 2017; Food and agriculture organization of the United Nations, 2013).

Third, a major advantage for producers who use the hydroponic system is the fact that traditional farming practices require intensive labor such as tilling, cultivating, fumigation, and is intensive in land use. Whereas for the hydroponic system this is not the case (Treftz & Omaye, 2016). In hydroponics plants can be planted closer to each other than in soil-based agriculture due to the only growth-limiting factor in hydroponics is the amount of light the crops receive, as there is no soil they need to share with other crops.

Fourth, agricultural run-off is collected and reused for the next batch of crops that is to be cultivated. An example that illustrates this benefit of hydroponics over soil-based agriculture is the fact that hydroponically grown lettuce uses an estimated 10 % compared to soil-based grown lettuce. When this is done within a vertical farm in an urban environment the emissions caused by fossil fuels can be decreased as well as there is no longer a need to transport crops from rural to urban locations (Benke & Tomkins, 2017).

Fifth, Hydroponics also enables the possibility to re-use the wastewater which is released during the cultivation process of the crops. Besides ecological value, this also has economic value for hydroponics as it decreases water costs even more (Despommier, 2009).

Lastly, by allocating areas that are used for agriculture to urban areas such as cities. It becomes a possibility to give the fields previously used for agriculture back to nature. This will result in less pollution and a higher groundwater level which results in less soil decline (Oskam, Lange, & Thissen, 2013).

Table 2. Environmental benefits of hydroponics.

Water loss is restricted to a minimum
Hydroponics can be implemented everywhere.
Less intensive use of labor compared to traditional agriculture.
Water use is 10% compared to traditional agriculture.
Wastewater can be re-used.
Due to less land use, fields previously used for agriculture can be relocated to nature or urban development.

4.1.2 Environmental challenges of hydroponics

Although there are lots of benefits associated with hydroponics. Literature also states a lot of challenges associated with hydroponics in vertical farming as shown in table 3. There are 5 clear environmental challenges associated with hydroponics.

First, there is the challenge associated with the lighting needed for hydroponics. A critical disadvantage of hydroponics is how crops growing inside a vertical farm will be provided with enough light needed for their growth (Specht et al., 2014). Even if natural light is in abundance, it will not be enough to guarantee optimal crop growth. It is estimated that if agriculture in the USA would implement a vertical approach, the electricity required to power this move would be eight times that of all electricity generated by all powerplants in the USA. Therefore, providing enough lighting in a vertical farm is still a large challenge (Specht et al., 2014).

Second, there is the challenge of sufficient cooling/heating needed for hydroponics in a vertical farm. Heat is closely related to lighting as it is a by-product of lighting. Especially during summer, this heat could overload the air conditioning in a vertical farm. This is a problem as healthy crop growth needs sufficient humidity as well as the correct amount of air conditioning. This combination of heat and the need for air conditioning can also put a large strain on the power grid (Despommier, 2009).

The electricity needed to run a vertical farm leads to a third environmental challenge. This amount of electricity severely increases the GHG output of a vertical farm. For comparison, the GHG output of water use is only 5% for a vertical farm, whereas, this is 40% for the electricity required to keep it running (Molin & Martin, 2018). Bringing the output of GHG emissions down will prove to be one of the largest challenges for hydroponics (Molin & Martin, 2018).

Fourth, there is the challenge of nutritional food provision. Food with high nutritional values such as proteins, vitamins, and minerals are increasing in demand. Not all these foods can be produced profitably using hydroponics (Despommier, 2010).

The fifth and last environmental challenge is the reduction in the manufacturing of pesticides. The frequency with which these have been used has doubled several times from 1960 till 1990. This has led to pollution of water reserves, depletion of surface water, and other negative environmental effects. The usage of pesticides can only be controlled by using expensive chemicals to ensure crop health (Kalantari et al., 2018).

Table 3. Environmental challenges of hydroponics

High electricity generation due to the large amount of energy needed for enough lightning.
Excess heat generation due to large amount of lighting will cost a lot of energy to cool back down.
Both the need for sufficient lighting and cooling excess heating leads to higher GHG output.
Nutritional food provision.
Reduction of pesticide use.

4.1.3 Economic benefits of hydroponics

The literature clearly states 7 economic benefits associated with hydroponics in vertical farming as shown in table 4.

First, in the book the vertical farm and several other studies hydroponically grown leafy greens produce a higher yield per area used than soil-based leafy greens (Despommier, 2009; Jensen, 1999). This is due to the possibility of being able to control and optimize growing conditions such as the number of light crops received, as well as the humidity and temperature in which the crops can grow.

Second, when applying hydroponics crops will be protected from external threats to crop yield such as floods, droughts, and sun damage (Despommier, 2009). Due to hydroponics taking place in a vertical farm in a closed loop system.

Third, there is the possibility to grow crops year-round due to the process taking place in a closed-loop system. (Jones, 1982; Jensen, 1999; Despommier, 2010).

The fourth economic benefit which accounts for yield optimization is the fact that the nutrient solution which the roots of the crops are exposed to can be optimized specifically for every crop which also maximizes the potential yield of every crop (Gruda, 2009).

Fifth, hydroponics can be done practically everywhere. This means that vacant buildings in the cities can be used to be transformed into hydroponic vertical farms. This gives potential buyers within these urban areas the possibility to buy locally grown produce which gives urban communities an economical boost. This because acquiring locally grown food, ensures that more money stays within the community. It is estimated that 65% of the profits are gained by the producer when producing locally, compared to 40% when the crops are sold by the grocery store or a supermarket (Brain, 2012).

Sixth, by applying hydroponics in urban areas potential customers can consume food that is produced close to home. This helps in reducing transportation costs as well as leading to an extra reduction in greenhouse gasses that are emitted in the production process of the crops. This is because the estimated average for soil-grown food is to be transported between 2400 and 4800 kilometres between their production location and the location where they are eventually sold (O'Hara, 2011).

Lastly, traditional agriculture uses a significant amount of energy to be able to produce crops. So much in fact that agriculture accounts for 17% of total energy output worldwide. By decreasing the energy costs of transportation by producing in urban areas with the use of hydroponics. A decrease in food costs, as well as greenhouse gasses, can be realized (Pelletier et al., 2011).

Table 5. Economic benefits of hydroponics

Higher yield per area compared to soil based traditionally grown leafy greens.
Crops are protected from external threats.
Year-round crop production.
Yield optimization for leafy greens compared to traditional farming.
Local crop production.
Reduced transportation costs due to production in urban areas.
Reduced energy costs compared to traditional farming.

4.1.4 Economic challenges of hydroponics

The literature study states 6 economic challenges concerning hydroponics as seen in table 6.

First, the costs of hydroponics are much higher compared to soil-based farming. In some instances, hydroponics has up to 20 times higher overhead capital costs than soil-based farms (Coolong, 2012). In this case, overhead costs are the costs within a business that are allocated to the business itself. However, these costs are not assigned to production purposes but are just the costs that are needed to enable production within the business itself.

Second, due to hydroponics being grown in mostly closes systems they will be vulnerable to diseases associated with the crops which are being cultivated within the closed system. Diseases such as Fusarium and Verticillium wilt(fungi). And Pythium which is the rotting of the roots can multiply rapidly in these closed systems (Jensen, 2013). Eliminating these risks will be important in making hydroponics economically viable.

Third, those that oversee caring and producing crops when using hydroponics will have to be very knowledgeable about the system and concept of hydroponics. This means that those operating the system might have to receive training and proper education regarding the concept. This also won't be without costs, which will also contribute to higher overheads.

Fourth, although hydroponics can be practiced practically everywhere the technique is very dependent on electronics to work. Therefore, the technique is susceptible to power outages for example as this can damage the crops (Jensen, 1999). This could prove to be a problem in developing countries where proper electricity grids are often found to be lacking. However, when implemented in modern western vertical farms where the electricity grid has proven to be reliable this should not be a problem.

Fifth, as of now there is a limited number of crops that can be successfully cultivated whilst still retaining profits such as most leafy greens, tomatoes, and strawberries. So, although it is beneficial to be able to produce these with a profit in a vertical farm. It will not solve the problem of feeding the future without more research into the crop cultivation techniques (Benke & Tomkins, 2017).

Lastly, concerning local food production. Both food safety and food quality have top priority (Brom, 2000). In soil-based agriculture, many cases of crop contamination are known. However, one of the differences between hydroponics and soil-based agriculture is the fact that hydroponics is done indoors. Here microbiological contamination can occur as well, as stated by (Orozco, Rico-Romero, and Escartín, 2008). Instances such as Salmonella, Escherichia, Enterobacteriaceae, and coliforms have been found on hydroponically grown crops. These microbes have also been found in puddles, washing cloths and sponges within hydroponic greenhouses. Therefore, hygienics are of utmost importance to be able to secure food safety for consumers (Orozco et al., 2008).

So, although hydroponics has many advantages such as its production versatility concerning crops and locations. More research must be done regarding the optimal growing conditions for different crops and the economic feasibility due to the high overhead costs. Especially concerning vertical farming.

Table 6. Economic challenges of hydroponics

High starting overhead capital costs.
Closed system crop diseases.
Higher overheads due to high levels of training and education for personnel.
High susceptibility to power outages in developing countries.
Limited range of crops that can be cultivated.
Food safety issues due to microbiological contamination.

4.1.5 summarizing the benefits and challenges of hydroponics

This section answers the first research sub-question as stated in section 4.1.
What are the benefits and challenges regarding the environmental and economic dimensions for hydroponics in vertical farms?

Hydroponics is in the middle of the pack when comparing the technique to drip irrigation and aeroponics. In categories such as water retention, capital costs, energy use, and yield, the water use of hydroponics is 60% more efficient compared to drip irrigation, but aeroponics is 98% more efficient compared to hydroponics (Benke & Tomkins, 2017). Capital costs are much higher compared to drip irrigation and somewhat equal to aeroponics (Coolong, 2012; Lakhiar et al., 2018). The energy use for hydroponics is tied with aeroponic and is much higher compared to drip irrigation. This is due to the high electricity costs both techniques need to achieve their yields (Banerjee & Adenaeuer, 2014). Other challenges of hydroponics are: Food safety issues due to microbiological contamination, limited crop cultivation possibilities, susceptibility to power outages in developing countries, and the need for expensive chemicals to ensure crop safety (Orozco et al., 2008; Pelletier et al., 2012; Kalantari et al., 2018).

Although hydroponics does not perform best regarding certain categories such as water retention, energy use, and yields, these are still benefits for hydroponics. Compared to traditional cultivation techniques, hydroponics still performs much better in these categories (Benke & Tomkins, 2017; Nasa, 2006).

Lastly, the technique has certain benefits which can be attributed to each cultivation technique due to these advantages being linked to vertical farming. These benefits are: year-round crop production, crops are protected from external threats such as flooding and storms, local production, reduced transportation costs due to crop production in urban areas, and the crops can be produced anywhere (Food and agriculture organization of the United Nations, 2013; O’Hara, 2011; Pelletier et al., 2011; Brain, 2012).

4.2 Aeroponics

This section will answer the sub question: *What are the benefits and challenges regarding the environmental and economic dimensions for aeroponics in vertical farms?*

In order to answer this question reports by: (Specht et al., 2019), (Thomaier et al., 2014), (Treftz & Omaye, 2016), (Safikhani, Abdullah, Ossen, & Baharvand, 2014), (Despommier, 2009; 2010), (Jensen, 1999), (Lakhiar, Gao, Syed, Chandio, & Buttar, 2018), (Oskam, Lange, & Thissen, 2013), (Stoner, 1998), (Martin-Laurent, Tham, He, Diem, 1999) and (Coolong, 2012).
Appendix 3 contains the table which shows the databases used, coupled with the search queries, the amount of hits that were generated and, the number of eventually used articles. The same format is used as in section 4.1. First the environmental benefits and challenges are shown, followed by the economic benefits and drawbacks.

4.2.1 Environmental benefits of aeroponics

Aeroponics shares many environmental benefits with hydroponics (Kalantari et al., 2018). Literature states seven clear environmental benefits regarding aeroponics as shown in table 7.

First, the main ecological benefit of aeroponics is the fact that it uses 98% less water, 60% fewer pesticides, and herbicides and it maximizes plant yield by 45% and up to 75% compared to hydroponics (Stoner, 1983; NASA, 2006).

Second, the nutrient solution which is sprayed onto the roots of the crops is easily recycled which means that fewer inputs are necessary for sustained crop production.

Third, Aeroponics allows for the provision of healthy organic food free from chemical contamination, as crops are produced in closed-loop systems when done in a vertical farm which uses the aeroponics technique.

Fourth, the aeroponic technique can be implemented in even non-arable areas of the world, such as dry or urban areas. This is especially important as currently an estimated 65% of the total land on earth is classified as arid and 54% of the total human population is currently living in urban areas and this number is expected to increase up to 66% by 2050 (Our world in data, 2017; Food and agriculture organization of the United Nations, 2013).

Fifth, as with hydroponics in aeroponics the need for intensive labor such as tilling, cultivating, fumigation, and intensive usage of the amount of land is not necessary. In aeroponics, crops can be planted closer to each other especially compared to traditional soil-based agriculture. This is because of the absence of soil and therefore crops can be cultivated much closer to each other (Treftz & Omaye, 2016).

Sixth, compared to hydroponics the agricultural runoff is even smaller due to less water being needed for crop cultivation in aeroponics. Hydroponically grown lettuce uses an estimated 10 percent of water to grow crops compared to traditional soil-based agriculture. Aeroponics uses 98 percent less water than hydroponics (Stoner, 1983; NASA, 2006). This means that aeroponics uses 0,002 percent of the amount of water needed to cultivate a crop of lettuce compared to traditional agriculture. The small amount of wastewater that is released during the cultivation process can be re-used. This means that in the end even less water is used. (Despommier, 2009).

Lastly, as with hydroponics allocating areas that are used for agriculture to urban areas such as cities. It becomes a possibility to give the fields previously used for agriculture back to nature. This will result in less pollution and a higher groundwater level which results in less soil decline (Oskam, Lange, & Thissen, 2013).

Table 7. Environmental benefits of aeroponics

Lowest water use of all cultivation techniques.
Nutrient solution for crop growth is recyclable.
No chemical crop contamination.
Aeroponics can be done everywhere.
Crops can be cultivated closer to each other so less intensive land usage is needed.
Even less agricultural runoff compared to hydroponics.
Due to less land usage, land previously used for agriculture can be given back to nature.

4.2.2 Environmental challenges of aeroponics

Literature states five environmental challenges for aeroponics. These challenges are shown in table 8.

First, since crops in aeroponics are suspended in the air it is expected that traditional methods of plant pest control will not be sufficient. Therefore, additional research regarding how this should be done in aeroponics needs to be done (Lakhiar et al.,2018).

Second, there is the challenge associated with the lighting needed for aeroponics. A critical disadvantage of aeroponics is how crops growing inside a vertical farm will be provided with enough light needed for their growth (Specht et al., 2014). Even if natural light is in abundance, it will not be enough to guarantee optimal crop growth. It is estimated that if agriculture in the USA would implement a vertical approach, the electricity required to power this move would be eight times that of all electricity generated by all powerplants in the USA. Therefore, providing enough lighting in a vertical farm is still a large challenge (Specht et al., 2014).

Third, there is the challenge of sufficient heating needed for aeroponics in a vertical farm.
Heat is closely related to lighting as it is a by-product of lighting. Especially during summer, this heat could overload the air conditioning in a vertical farm. This is a problem as healthy crop growth needs sufficient humidity as well as the correct amount of air conditioning. This combination of heat and the need for air conditioning can also put a large strain on the power grid (Despommier, 2009).

Fourth, there is the challenge of healthy food provision. Food with high nutritional values such as proteins, vitamins, and minerals are increasing in demand. Not all these foods can be produced profitably using aeroponics (Despommier, 2010).

The fifth and last environmental challenge is the reduction in the manufacturing of herbicides and pesticides. The frequency with which these have been used has doubled several times from 1960 till 1990. This has led to pollution of water reserves, depletion of surface water, and other negative environmental effects. The usage of pesticides and herbicides can only be controlled by using expensive chemicals to ensure crop health (Kalantari, Tahir, Joni, Fatemi, 2018).

Table 8. Environmental challenges of aeroponics.

Traditional pest control measures may not be sufficient.
Insufficient lighting.
Insufficient heating.
Healthy food provisioning.
Usage of pesticides and herbicides.

4.2.3 Economic benefits of Aeroponics

The literature study states 7 economic benefits for the aeroponics technique as shown in table 9. Aeroponics shares the same economic benefits as hydroponics with the main difference being that aeroponics can achieve higher crop yield and uses lesser inputs to realise those yields.

First, aeroponics is perfect for vertical farming since crops are easily stackable when using this technique. This means that the number of crops that can be produced for every square meter is much higher compared to soil-based agriculture. The only constraint is how high a producer wishes to stack the crops (Lakhiar et al., 2018).

Second, as with hydroponics, aeroponics also allows for the perennial production of crops which results in higher yields compared to soil-based agriculture, it also allows for multiple harvests from a single crop (Martin-Laurent, Tham, He, Diem, 1999).

Third, another benefit from aeroponics is the accelerated growth cycle, due to the optimization of nutrition and the growing conditions for every crop (Martin-Laurent et al., 1999).

One characteristic aeroponics share with hydroponics, when applied in a vertical farm set in an urban area, is that it can be done in vacant buildings. This enables local food production and gives inhabitants of these city's the possibility to buy locally grown food. As stated earlier a producer gains 65% of the profits when producing crops locally. Whereas this number is 40% when there is a third party such as a grocery store or a supermarket involved (brain, 2012).

Fourth, the same argument for aeroponics can be given for the reduction of transportation costs compared to soil-based agriculture. As stated, before soil-grown food is on average transported between 2400 and 4800 kilometers. By producing locally in a vertical farm these costs can be cut as well as emissions that are related to the transport can be reduced (O'Hara, 2011).

Fifth, when applying aeroponics crops will be protected from external threats to crop yield such as floods, droughts, and sun damage (Despommier, 2009).

Sixth, the nutrient solution which the roots of the crops are exposed to can be optimized specifically for every crop which also maximizes the potential yield of every crop (Gruda, 2009).

Seventh, aeroponics can be done practically everywhere. This means that vacant buildings in the cities can be used to be transformed into hydroponic vertical farms. This gives potential buyers within these urban areas the possibility to buy locally grown produce which gives urban communities an economical boost. This because acquiring locally grown food, ensures that more money stays within the community. It is estimated that 65% of the profits are gained by the producer when producing locally, compared to 40% when the crops are sold by the grocery store or a supermarket (Brain, 2012).

Table 9. Economic benefits of aeroponics

Higher yield per area, higher compared to hydroponics.
Year-round production.
Accelerated growth cycle.
Reduced transportation costs.
Protection from external threats.
Crop nutrition can be optimized per crop.
Aeroponics can be done everywhere.

4.2.4 Economic challenges of aeroponics

The literature study states 5 economic challenges regarding aeroponics. These challenges are shown in table 10.

First, the costs of aeroponics are much higher compared to soil-based farming. In some instances, aeroponics has up to 20 times higher overhead starting costs than soil-based farms (Coolong, 2012). In this case, overhead costs are the costs within a business that are allocated to the business itself. However, these costs are not assigned to production purposes but are just the costs that are needed to enable production within the business itself.

Second, what also makes aeroponics more expensive compared to hydroponics and especially compared to soil-based farming is the fact that the system requirements for aeroponics are of a high standard as it needs a combination of high-pressure pumps, atomization nozzles, EC, pH measuring devices, correct temperature, light intensity, and the correct timing to let it all work synchronized. These requirements are very costly especially when implemented on a larger scale as any failure could prove to be disastrous for crop yield (Lakhiar et al., 2018).

Third, those that oversee caring and producing crops when using aeroponics will have to be very knowledgeable about the system and concept of aeroponics. This means that those operating the system might have to receive training and proper education regarding the concept. This also will not be without costs, which will also contribute to higher overheads.

Fourth, although aeroponics can be practiced practically everywhere the technique is very dependent on electronics to work. Therefore, the technique is susceptible to power outages for example as this can damage the crops (Jensen, 1999). This could prove to be a problem in developing countries where proper electricity grids are often found to be lacking. However, when implemented in modern western vertical farms where the electricity grid has proven to be reliable this should not be a problem.

Fifth, as of now there is a limited number of crops that can be successfully cultivated whilst still retaining profits such as most leafy greens, tomatoes, and strawberries. So, although it is beneficial to be able to produce these with a profit in a vertical farm. It will not solve the problem of feeding the future without more research into the crop cultivation techniques (Benke & Tomkins, 2017).

Table 10. Economic challenges of aeroponics.

High overheads due to high capital and operational costs
Costly system requirements
Operating personnel needs to be knowledgeable and well trained
Electronics dependent, so often not feasible in developing countries.
Limited number of crops that can successfully be cultivated.

4.2.5 Summarizing the benefits and challenges of aeroponics

This section answers the research question as stated in section 4.2: *What are the benefits and challenges regarding the environmental and economic dimensions for aeroponics in vertical farms?*

Aeroponics comes out on top compared to hydroponics and drip irrigation. Aeroponics scores best in multiple categories regarding the benefits of the cultivation techniques. Aeroponics is leading in: Water retention, yield, fertilizer use, and pesticide reduction (NASA, 2006; Treftz & Omaye, 2016). The technique uses 98% less water, 60% fewer pesticides, and it maximizes plant yield by up to 75% compared to hydroponics, which is more efficient compared to drip irrigation (NASA, 2006; Benke & Tomkins, 2017).
Aeroponics also enables more efficient use of fertilizer as it uses 60% less fertilizer compared to hydroponics and hydroponics uses less compared to drip irrigation (Coolong, 2012; Banerjee & Adenaeuer, 2014). The higher yield achieved by aeroponics is due to the accelerated growth cycle which the technique enables which is even higher than hydroponics, coupled with the possibility to stack crops more efficiently compared to either of the other two techniques (Martin-Laurent et al., 1999).

Although the benefits of aeroponics are promising, some challenges need to be overcome. Some challenges that are specific to aeroponics are crop pest control. In aeroponics crops are suspended in the air, this means that traditional pest control won't work in case of crop disease(Lakhiar et al., 2018). Aeroponics also shares some of the same challenges as hydroponics such as: Very high capital costs, energy usage, limited crop cultivation possibilities, the need for expensive chemicals to ensure crop safety, and susceptibility to power outages when done in developing countries (Orozco et al., 2008; Pelletier et al., 2012; Kalantari et al., 2018).

Lastly, aeroponics shares the following benefits with hydroponics and drip irrigation as these benefits do not depend on which cultivation technique is used. These benefits are instead related to the use of a vertical farm, they are the following: year-round crop production, crops are protected from external threats such as flooding and storms, local production, reduced transportation costs due to crop production in urban areas, and the crops can be produced anywhere (Food and agriculture organization of the United Nations, 2013; O'Hara, 2011; Pelletier et al., 2011; Brain, 2012).

4.3 Drip irrigation

This section will answer the sub research question: *What are the benefits and challenges regarding the environmental and economic dimensions for drip irrigation in vertical farms?*

In order to give a concise and cohesive answer to this question the following reports were used: (Specht et al., 2019), (Thomaier et al., 2014), (Treftz & Omaye, 2016), (Safikhani, Abdullah, Ossen, & Baharvand, 2014), (O'Hara, 2011), (Córcoles, de Juan, Ortega, Tarjuelo, & Moreno, 2012) and, (Lamm et al., 2012). Appendix 3 contains the table which shows the databases used, coupled with the search queries, the amount of hits that were generated and, the number of eventually used articles. The same format is used as in section 4.1 and 4.2. First the environmental benefits and challenges are shown, followed by the economic benefits and drawbacks. Again all benefits and challenges are in descending order starting with the most important benefit or challenge and ending with the least important ones.

4.3.1 Environmental benefits of drip irrigation

Although drip irrigation shares some of the same environmental benefits with aeroponics and hydroponics. The technique is often less efficient when comparing it to the other two techniques. Literature states four clear environmental benefits for drip irrigation shown in table 11.

First, as with hydro and aeroponics, drip irrigation uses less water compared to sprinkler systems used for soil-based agriculture. Studies show that the efficiency regarding water retention compared to sprinkler systems is up to 60 percent (Lamm et al., 2016).

The second comparison which can be made with hydro and aeroponics is the conservation of resources being enabled by this technique (Camp, 1998).

By watering crops using drip irrigation the number of pests found on crops is also reduced, this is due to the wet foliage of crops allowing bugs and fungal pathogens to thrive. By utilizing the drip irrigation technique this is prevented because only the roots get watered, which keeps the foliage of crops free from water (Camp, 1998).

Third, another benefit of directly watering the roots is inhibition of weed germination due to the area between crops not being wet. The use of drip irrigation also leads to leaching losses which means that less nitrogen and other chemicals are watered down that eventually end up in wastewater, or in the water that is re-used in vertical farms (Causapé Valenzuela, 2009).

Lastly, allocating areas that are used for agriculture to urban areas such as cities. It becomes a possibility to give the fields previously used for agriculture back to nature. This will result in less pollution and a higher groundwater level which results in less soil decline (Oskam, Lange, & Thissen, 2013).

Table 11. Environmental benefits of drip irrigation.

Uses less water compared to traditional crop cultivation, but more than hydro and aeroponics.
Several pests found on crops are reduced.
Leaching losses
Land areas previously used for agriculture can be given back to nature.

4.3.2 Environmental challenges of drip irrigation

Literature states five environmental challenges of drip irrigation as shown in table 12

The main challenge of drip irrigation is that a fine balance must be maintained between the right amount of water provision for crops. As under-watering of crops will lead to losses regarding the market value of crops due to yield reduction and a reduction in crop size and quality (Department of Economic Development, Jobs, Transport and Resources, 2018).

Whilst over-watering has many negative effects such as unwanted vegetative growth such as weeds which leach nutrients and water of the crops which also results in lesser yields. Over-watering of the crops can also lead to the clogging of drainage ditches and increase the need for water treatments.

Second. Drip irrigation can cause pathogens, weeds, and pesticides to spread into the run of water, however, in vertical farms, the technique of drip irrigation will be done in a closed system which mitigates the harming effects of pesticides, weeds, and pathogens running of as wastewater as it will be re-used.

Third, another drawback of over-watering in both urban and arid areas is that it puts unnecessary pressure on water resources, which are already pressurized by the increasing demands from a growing urban population (Department of Economic Development, Jobs, Transport and Resources, 2018; Roser, 2020). Therefore, maintaining balance whilst applying the correct amounts of water for every crop is key in this technique especially when this is done on a larger scale as small mistakes will result in larger losses due to the larger production scale.

Fourth, when utilizing subsurface drip irrigation is that most of the system is buried underground which leads to direct observation of the water flow from individual sub-surface water emitters being impossible. At first sight, this doesn't seem to be a problem, but it leads to two problems. Firstly, an evaluation of the drip irrigation system and subsequent measurement becomes hard. Secondly, when repairs are needed it becomes hard to locate where the problem is occurring, which results in more time being needed to locate the problem which leads to higher costs compared to the same problem occurring when using surface irrigation (Camp, 1998).

Lastly, the largest drawback of drip irrigation as a technique to be used in vertical farms. As of now most literature shows that it is only done horizontally instead of vertically, this endangers the viability of this method for vertical farming. Due to a lack of research into the technique and knowledge regarding its feasibility and optimality for vertical farms.

Table 12. Environmental challenges of drip irrigation.

The amount of water given to crops needs to be exactly fine-tuned.
High risk of pesticides, weeds and pathogens ending up in waste-water.
Over-watering of crops leads to unnecessary pressure on water resources.
Direct observation of the watering process is not possible which can lead to flaws not being discovered which leads to resource depletion.
Lack of knowledge on drip irrigation combined with vertical farming.

4.3.3 Economic benefits of drip irrigation

The literature study states four clear economic benefits of drip irrigation shown in table 13. Although, drip irrigation shares some interesting economic benefits. These benefits are often offset by the much lower yield this technique generates compared to the two aforementioned cultivation techniques.

First, the main economic benefit which both surface and subsurface irrigation produce is that this technique has low costs when applying the various nutrients, chemicals, and pesticide crops need to produce the maximum amount of yield (Camp, 1998). Especially compared to hydro and aeroponics these costs are lower, however as stated before this is partly due to the expensive nature of hydro and aeroponics and partly because of the low costs associated with drip irrigation. (Coolong, 2012; Roser, 2020).

Second, the literature does not state any problems with not being able to cultivate certain crops when using drip irrigation. This means that when using drip irrigation, it is possible to achieve higher profits compared to hydro and aeroponics. As it is possible to cultivate crops with a higher value and lower costs.

Third, another benefit of the frequent nutrient drips is that it can result in leaching losses. The process of leaching can be defined as:" When soil becomes excessively wet, the soil will reach a point in which it cannot hold any more water. This happens because the air spaces between soil particles become filled with water. As these air spaces fill, gravity will cause water to move down the soil profile. As water moves down through the soil, nitrogen and other chemicals can be carried with it" (University of Missouri, 2013). This means that due to less leaching losses, the more nutritional value is retained in crops which lower costs related to the fertilization of the crops.

Fourth, another benefit drip irrigation has over soil-based farming is that the growing season can be lengthened. This also allows producers who use drip irrigation to produce their crops out of season which enables them to ask a higher price which results in higher profits (Department of Economic Development, Jobs, Transport and Resources, 2018).

Fifth, the same argument for drip irrigation can be given for the reduction of transportation costs compared to soil-based agriculture. As stated before soil-grown food is on average transported between 2400 and 4800 kilometers. By producing locally in a vertical farm these costs can be cut as well as emissions that are related to the transport can be reduced (O'Hara, 2011).

Table 13. Economic benefits of drip irrigation

Lowest costs of all cultivation techniques.
A higher variety of crops can be cultivated.
Lower fertilization costs due to leaching losses.
Longer growing season compared to traditional farming.
Reduction in transportation costs when done in urban areas.

4.3.4 Economic challenges of drip irrigation

The economic challenges for drip irrigation show overlap with hydro and aeroponics.
The literature states four economic challenges regarding drip irrigation shown in table 14

First, as with hydro and aeroponics, drip irrigation has high initial overhead costs when starting a vertical farm (Coolong, 2012). The initial starting overhead costs are much lower however due to the technique necessary to perform drip irrigation being much cheaper compared to hydro and especially aeroponics.

Second, as with hydro and aeroponics the location chosen for a vertical farm is an important factor as the price of land has a high influence on where a vertical farm using drip irrigation will be built (Voss, 2013).

Third, although drip irrigation can be practiced everywhere. It still has a high dependency on a working electricity grid. As failure will result in the inability to give proper heating, moisturization, and nutrition to crops which leads to high costs (Jensen, 1999).

Fourth, Literature states that drip irrigation does not achieve the same high production standards compared to hydro and aeroponics (Martin-Laurent et al., 1999).

Table 14. Economic challenges of drip irrigation.

High overhead costs when starting, lowest of all three techniques.
Price of land has a high influence on costs.
High dependency on the working electricity grid, electrical failure will lead to high costs.
Lower production standards compared to hydro and aeroponics.

4.3.5 Summarizing the benefits and challenges of drip irrigation

This section answers the research sub-question as stated in section 4.3: *What are the benefits and challenges regarding the environmental and economic dimensions for drip irrigation in vertical farms?*

Based on overall evaluation, drip irrigation has the most benefits but, these benefits are often small and are offset by the challenges.
The benefits of drip irrigation are: the technique is 60% more efficient compared to traditional crop cultivation techniques. However, drip irrigation is the least efficient compared to hydro and aeroponics (Lamm et al., 2016).
A second benefit is, due to watering crops via drip irrigation the amount of wet foliage is minimized which reduces the amount of crop pests to a minimum (Camp, 1998).
The third real benefit is that drip irrigation has no constraints as to which crops can be cultivated when utilizing this technique. Which would hold significant value over the other two techniques, if this wasn't offset by the much lower yields that are produced by drip irrigation (Camp, 1998).
The last benefit that drip irrigation holds over the other two techniques is that the capital and energy costs required to enable production are much lower compared to hydro and aeroponics (Coolong, 2012). This means that not only the fixed costs for machinery, personnel, and utilization of drip irrigation are much cheaper (Banerjee & Adenaeuer, 2014). The variable costs, which mostly consist of energy and production-related costs are also much lower compared to hydro and aeroponics (Banerjee & Adenaeuer, 2014; Martin & Molin, 2018).

The challenges in drip irrigation are a low water retention rate, much lower yields compared to the other two techniques, there is a high risk of pesticides ending up in the wastewater, and is the most dependent on land price to even be economically feasible (Orozco et al., 2008); Benke & Tomkins, 2017); Banerjee & Adenaeuer, 2014).

As with hydro and aeroponics, drip irrigation has several benefits which can be attributed to the vertical farm instead of the technique itself. These benefits are: year-round crop production, crops are protected from external threats such as flooding and storms, local production, reduced transportation costs due to crop production in urban areas, and the crops can be produced anywhere (Food and agriculture organization of the United Nations, 2013; O'Hara, 2011; Pelletier et al., 2011; Brain, 2012).

Although the benefits from drip irrigation seems significant, these benefits will be downplayed in section 4.4.1 and 4.4.2 in which each technique will be analyzed, based on their performance regarding the profit and environmental dimension.

4.4 What are the differences between the scores for each cultivation technique?

This section will answer the research sub-question: *How does each vertical farming technique performs on the checklist with elements of the Triple-Layered Business Model Canvas?*

This will be done by combining the results generated in the previous three sections with table 1, the Checklist with elements of the Triple-Layered Business Model Canvas.
Two separate tables have been made in which each cultivation technique is awarded points based on how they perform with regard to the Profit and Planet dimension. Section 4.4 will be divided in 2 sections, the first section contains the table with the scores from each technique with regard to the Profit dimension. The second section is set up in de the same way but then for the Planet dimension. The queries in Appendix 2 were used to come up with the case studies and papers necessary to back up assumptions made in these sections.

4.4.1 Profit

Points will be attributed to each technique based on the profit dimension. Points are awarded based on five elements. As stated in section 3.3 these elements are: the value proposition, key resources, key activities, costs, and revenues.

The value proposition of each cultivation technique is about efficient year-round production of leafy greens (Berner, 2018). Each technique performs better compared to traditional farming (Lakhiar et al., 2018); Treftz & Omaye, 2016). When breaking down the three techniques towards each other aeroponics achieves the best results in this element. Aeroponics achieves the highest crop yield when producing leafy greens with yields of 45% and up to 75%, higher compared to hydroponics, and hydroponics achieve higher yields compared to drip irrigation (Despommier, 2010; Stoner, 1983; NASA, 2006).

Drip irrigation achieves the highest score regarding the element of securing key human and material resources. This is because both hydro and aeroponics have incredibly high costs compared to drip irrigation regarding high tech material that is necessary for daily operations (Coolong, 2012). This is also the case regarding human resources as the training necessary to be able to operate aero/hydroponic systems is of a much higher standard compared to drip irrigation, which leads to higher training costs for personnel (Lakhiar et al., 2018; Coolong, 2012; Joyce & Paquin, 2016). Aeroponics scores the lowest regarding this element due to the equipment necessary to use this technique is even more expensive compared to hydroponics (Lakhiar et al., 2018).

Regarding key activities, scoring was a bit more complicated due to these key activities consisting of multiple facets such as efficient water use, securing year-round production and ensuring sufficient electricity and heat for daily operations (Berner, 2018). Regarding efficient water use aeroponics scores best as aeroponics uses 2% of the amount of water needed to cultivate crops compared to hydroponics and hydroponics uses 60% less compared to drip irrigation (Nasa 2006; Benke & Tomkins, 2017). Each cultivation technique secures year-round production but aeroponics has the highest yields followed by hydroponics and lastly drip irrigation. (Nasa 2006; Martin-Laurent et al., 1999). Lastly, there is a need for electricity and heat, based on the energy needs that a vertical farm of 0.93 ha with 37 floors requires, an estimated power demand of up to 5,4 million Euros a year is to be expected (Banerjee & Adenaeuer, 2014). These numbers are for a hydroponic farm and as stated before aeroponics performs better regarding its use of energy compared to hydroponics. (Coolong, 2012; Lakhiar et al., 2018). Adding up all facets regarding the key activities then aeroponics scores best, followed by hydroponics and lastly drip irrigation.

The costs are divided into 2 parts, namely fixed costs and variable costs. By combining the numbers from the 2014 report on the economics of vertical farming by Banerjee & Adenaeuer and statements regarding the variable and fixed costs of each cultivation technique from the literature several statements can be made (Banerjee & Adenaeuer, 2014) ;(Lakhiar et al., 2018) ;(Coolong, 2012).
First, regarding the fixed costs based on the average land price in Berlin the costs of building a 37-story high vertical farm are estimated to be around 111.58 million Euros plus another 90.382 million euros of equipment costs. These numbers are based on the costs of a hydroponic farm (Banerjee & Adenaeuer, 2014). The literature clearly states that the equipment costs of an aeroponic vertical farm are higher compared to hydroponics, due to aeroponic being a more advanced technique. Whereas the equipment costs for drip irrigation are much cheaper compared to either aero/hydroponics (Coolong, 2012); Lakhiar et al., 2018).

Regarding the variable costs which include power, seed, fertilizer, and personnel costs. The same report was used as for the fixed costs (Banerjee & Adenaeuer, 2014). Variable costs per year are estimated to consist of € 5,400,000 for the power demand, € 45,000 seed costs, € 420,000 nutrient costs and €2,050,000 personnel costs which total in € 7,910,000 of yearly variable costs for a hydroponic system. Literature does not state anything about seeds costs changing with any of the cultivation techniques. Regarding personnel, the literature is clear in stating that aeroponics demands the highest qualifications for personnel followed by hydroponics and lastly drip irrigation which results in the highest personnel costs belonging to aeroponics and the lowest to drip irrigation. (Coolong, 2012). It is the other way around with nutrient costs being least expensive for aeroponics followed by hydroponics and then drip irrigation due to the descending efficiency of nutrient usage of each technique. These costs are much lower compared to personnel costs and therefore of a lesser magnitude regarding total costs. When aggregating the variable costs with fixed costs drip irrigation is the least costly technique followed by hydroponics and lastly aeroponics which is the most expensive.

To estimate yearly cash flow that can be generated by a vertical farm the same hydroponic farm case was used as for the costs (Banerjee & Adenaeuer, 2014). This was done by using the yields from the case study and coupling them to the current price paid per ton in the Netherlands. By combining yields from the case study with current supermarket prices table 15 was generated ("Albert Heijn assortment: keuze uit duizenden producten | Albert Heijn", 2020); (Banerjee & Adenaeuer, 2014).

Table 15 Vertical farm yields
Reprinted from "Up, Up and Away! The economics of Vertical farming" by Banerjee & Adenaeuer, 2014, Journal of Agricultural Studies, 2, p3.

Crops	Yield in VF due to Tech (tons/ha)	Yield (tons/ha)	Factor increase due to tech	Factor increase due tech and stacking	Price in €/ton per crop	Price in €/ton with factor increase due to tech and stacking
Carrots	58	30	1.9	347	€ 890.00	€ 308,380.00
Radish	23	15	1.5	829	€ 3,000.00	€ 2,487,000.00
Potatoes	150	28	5.4	552	€ 1,690.00	€ 932,880.00
Tomatoes	155	485	3.4	548	€ 2,580.00	€ 1,413,840.00
Strawberry	69	30	2.3	368	€ 7,980.00	€ 2,936,640.00
Peas	9	6	1.5	238	€ 6,480.00	€ 1,542,240.00
Cabbage	67	50	1.3	215	€ 2,650.00	€ 569,750.00
Lettuce	37	25	1.5	709	€ 2,360.00	€ 1,673,240.00
Spinach	22	12	1.8	820	€ 3,880.00	€ 3,181,600.00
Total (Avg)	71	28	2.5	516	€ 3,501.00	€ 1,671,730.00

This selection of vegetables was based on those used in the case study. These yields are possible due to a continuous cropping cycle which creates a continuous sowing and harvesting loop. This means that in 365 days 215 harvesting events can take place in which 68 ha is sown and harvested each year (Banerjee & Adenaeuer, 2014). The yield numbers in table 15 are based on the entire vertical farm producing only one vegetable for 1 year. These numbers are not realistic though, since the market in which a vertical farm operates demanding multiple vegetables, as it is unrealistic for an entire city block to only consume strawberries for 1 year (Helmers, Yamoah, & Varvel, 2001). Therefore, an average was made of all vegetables produced by the vertical farm in which each vegetable was assigned the same weight. This results in a yearly revenue of € 1,671,730 for a vertical farm which utilizes hydroponics. This is not nearly enough to obtain a positive yearly cash flow as variable costs for a hydroponic vertical farm are € 7,910,266 (Banerjee & Adenaeuer, 2014). Even when applying aeroponics which reduces water usage by 98%, fertilizer usage by 60% and, maximizes crop yield by 45 to 75% it still wouldn't be possible to obtain a positive yearly cash flow (Coolong, 2012); (Banerjee & Adenaeuer, 2014). Drip irrigation would be cheaper to utilize in a vertical farm but would also produce a much lower yearly yield. Therefore, aeroponics performs best, followed by hydroponics and lastly drip irrigation.

Table 16 Profit

Profit	Hydroponics	Aeroponics	Drip irrigation
Value proposition	0	1	-1
Key resources	0	-1	1
Key activities	0	1	-1
Costs	0	-1	1
Revenues	0	1	-1
Total	***0***	***1***	***-1***

Based on the scoring on each element of the profit dimension. Aeroponics performs best compared to the other 2 techniques and scores 1 point. Hydroponics is second with 0 points and is in the middle regarding its performance on every element. Lastly is drip irrigation with -1 points. Drip irrigation is often the cheaper option but gets outperformed by hydro and aeroponics on efficiency and obtainable yields. So, although drip irrigation is cheaper in the short run, it will be outperformed by the other two techniques due to them achieving higher efficiency and much better yields.

4.4.2 Planet

In this section each technique is rated and awarded a score based on how they perform regarding the following 5 elements of the Planet dimension: functional value, materials required, least harmful production process, negative environmental impacts, and positive environmental gains. These elements have been introduced and are elaborated upon is section 3.3 as well.

As stated before the functional value is how each cultivation technique realizes its production whilst using the least resources to do so. All three techniques will be judged based on their efficient use of resources such as water, electricity, and fertilizer. Starting with the efficient use of water it is aeroponics that uses 98% less water than hydroponics and hydroponics uses 60% less water than drip irrigation (Nasa 2006; Benke & Tomkins, 2017). A hydroponic vertical farm such as in the case mentioned earlier uses 217.000 liters of water a day of which 14.000 leaves the system in the form of wastewater whilst the rest is retained (Banerjee & Adenaeuer, 2014). This means that when using the percentages, an aeroponic vertical farm would only use 4.280 liters a day and loses about 280 liters. For drip irrigation, this means it would need 535.000 liters a day whilst generating 35.000 liters of wastewater. So aeroponics scores best regarding water use followed by hydroponics and lastly drip irrigation.

For electricity use both hydro and aeroponics score evenly bad. Literature states that if agriculture in the USA would go vertical with either technique all powerplants in the USA would need to generate 8 times their current electrical output (Specht et al., 2014). With all this electricity a lot of excess heat will be generated which also needs to be cooled down which in turn makes even more electricity. Therefore, drip irrigation scores best regarding the electricity needed as it uses the least of all techniques (Coolong, 2012). Drip irrigation also requires the least fertilizer mostly due to the techniques' inability to achieve the same yield as the other techniques it is followed by aeroponics and lastly hydroponics. (Banerjee & Adenaeuer, 2014) ;(Coolong, 2012). When looking at the absolute use of resources such as electricity and fertilizer drip irrigation uses least, and therefore performs best regarding the functional value. This advantage is offset due to its much higher water use. When looking at production levels attained relative to resources needed, drip irrigation is much less efficient (Nasa, 2006) ;(Benke & Tomkins, 2017); (Banerjee & Adenaeuer, 2014). Therefore, aeroponics scores best followed by hydroponics and lastly drip irrigation.

The second element on the planet dimension is the materials needed to ensure production. Although the materials and machinery for production are expensive for hydro and aeroponics and lesser so for drip irrigation literature does not state whether they are harmful to the environment or not (Coolong, 2012; Nasa, 2006). The only material on which literature states that its use can be harmful to the environment is the amount of fertilizer used. Drip irrigation uses the least of this material due to its slower year-round production. It is then followed by aeroponics which uses 60% less fertilizer compared to hydroponics (Banerjee & Adenaeuer, 2014) ;(Coolong, 2012).

The third element is which technique uses the least harmful production process. Literature does not state that certain cultivation techniques are harmful to the environment. It does state which technique uses the least resources (Nasa, 2006) ;(Benke & Tomkins, 2017); (Banerjee & Adenaeuer, 2014). Based on that the same score is given to each cultivation technique as was done regarding the value function. This means that aeroponics scores best followed by hydroponics and lastly drip irrigation.

Regarding the environmental impacts, a second case study was used in which numbers generated from a hydroponic farm in Grönska were used in combination with an earlier case study (Molin & Martin, 2018) ;(Banerjee & Adenaeuer, 2014). This was done because using a single case study would result in insufficient information in listing all the environmental impacts of each cultivation technique. When looking at the energy requirements of each vertical farm technique it must be kept in mind that the efficiency with which for example electricity is generated can and will vary per country.

For this study, an efficient electricity grid such as used by Norway was taken as a baseline (Molin & Martin, 2018). In this example, about 100 grams of CO_2 equivalents were generated per kWh. To grow 1 kilogram of lettuce which is to be sold at the location it is produced 0.36 kg of CO_2 equivalents are generated (Banerjee & Adenaeuer, 2014) ;(Molin & Martin, 2018). Which is efficient when compared to the same amount of lettuce produced in a heated greenhouse in the Netherlands which generates 2.67kg CO_2 equivalents per kg lettuce (Banerjee & Adenaeuer, 2014). The energy requirements for heating and lighting are assumed to be the same for aeroponics (Nasa, 2006). Drip irrigation creates on average between 218 and 917 kg CO_2 equivalents/ML for sufficient lighting and 3927 kg CO_2 equivalents per ha for watering crops depending on which crop the technique produces (Mushtaq, Maraseni, & Reardon-Smith, 2013).

When comparing this to the hydroponic farm case which states it produces 332 kg CO2 equivalents per square meter, drip irrigation has much less impact (Molin & Martin, 2018). This is per square meter, when recalculating this amount to one hectare, the total kg CO2 equivalent of a hydroponic farm is 332 * 10.000 = 3.320.000,00 kg of CO2 equivalents (Mushtaq, Maraseni, & Reardon-Smith, 2013); (Banerjee & Adenaeuer, 2014) ;(Molin & Martin, 2018).

This means that a vertical farm using hydroponics or aeroponics would need to be (3.320.000/4.844 = 685) stories high to reach the same efficiency regarding CO2 generation as a farm using drip irrigation. Even though hydroponics and aeroponics even more so use less fertilizer, freshwater and use less arable land. These factors contribute only to 1-5% of the total amount of GHG emissions (Molin & Martin, 2018). For these reasons hydroponics scores worst regarding environmental impacts due to the immense GHG emissions, it generates, closely followed by aeroponics and lastly drip irrigation.

Each technique will be judged based on how they perform regarding their usage of resources such as water, and fertilizer. As stated before, aeroponics uses the least water of all techniques with up to 98% less compared to hydroponics (Coolong, 2012); (Nasa, 2006). Hydroponics uses 60% less water compared to drip irrigation and 90% less compared to traditional agriculture (Nasa, 2006) ;(Benke & Tomkins). When using the numbers generated from the case study to translate these percentages to more absolute values the following stats are generated regarding the water use of each technique (Banerjee & Adenaeuer, 2014). A hydroponic vertical farm such as in the case mentioned earlier uses 217.000 liters of water a day of which 14.000 leaves the system in the form of wastewater whilst the rest is retained (Banerjee & Adenaeuer, 2014).

This means that when using the percentages, an aeroponic vertical farm would only use 4.280 liters a day and loses about 280 liters. For drip irrigation, this means it would need 535.000 liters a day whilst generating 35.000 liters of wastewater and for traditional agriculture, this number is 2.170.000 liters of water a day and 210.000 liters of wastewater being generated. Keep in mind, these numbers are for a 37-floor vertical farm which uses 0.93 ha for every floor (Banerjee & Adenaeuer, 2014). This means that next to a tenfold increase in water usage, an additional 35 ha of arable land is necessary whilst attaining lower yields compared to one of the three techniques (Banerjee & Adenaeuer, 2014) ;(Molin & Martin, 2018); (Mushtaq, Maraseni, & Reardon-Smith, 2013).

Then there is the use of fertilizer necessary to ensure the yields in chapter 4.1. Aeroponics uses 60% less fertilizer compared to hydroponics and drip irrigation uses even less (Mushtaq, Maraseni, & Reardon-Smith, 2013) ;(Banerjee & Adenaeuer, 2014). In terms of environmental gains, these are significant improvements for each technique especially compared to traditional agriculture. That is why aeroponics scores best regarding environmental gains, followed by hydroponics and lastly drip irrigation.

Table 17 Planet

Planet	Hydroponics	Aeroponics	Drip irrigation

Functional Value	0	1	-1
Materials required	0	-1	1
Least harmful production process	0	1	-1
Negative environmental impacts	-1	0	1
Positive environmental gains	0	1	-1
Total	***-1***	***2***	***-1***

When adding up the scores each cultivation technique has earned by the scoring process as shown in chapter 2.3 it is aeroponics that performs best, followed by hydroponics and lastly drip irrigation.

4.4.3 Wrapping up the scores from Profit and Planet

This section answers the sub research question: *How does each vertical farming technique performs on the checklist with elements of the Triple-Layered Business Model Canvas?*

From a Profit based standpoint, aeroponics is the best performing technique. It is the highest scoring technique regarding 3 of the 5 elements of the Profit dimension. Most importantly, the technique shows the most promise from a revenue standpoint. This is very important due to the high costs contributed to vertical farming; therefore, being able to produce the highest yields. When coupling these high yields with the most growth potential as stated in section 4.4.1 aeroponics performs best and shows the most potential.
Hydroponics seems to be right in the middle of the three techniques when looking at table 16; however, it must be noted that hydroponics is only slightly outperformed by aeroponics regarding elements such as: value proposition, key activities, and revenues. Regarding costs and securing key resources hydroponics scores slightly better than aeroponics, but is far behind drip irrigation. This justifies hydroponics being rated second of the three techniques.
Lastly, there is drip irrigation, the technique scores the lowest compared to the other 2 techniques, this doesn't mean that the technique may be disregarded. It has far lower costs compared to the other two techniques and is the most cost-efficient in securing its key resources. These benefits are offset by its challenges but outside a vertical farming design, the technique still has its merit.

When looking at the techniques from the Planet dimension the difference between aeroponics and the other two techniques becomes even more clear. Aeroponics leads in elements such as: functional value, the least harmful production process, and creates the most positive environmental gains. Drip irrigation and hydroponics share second place, but they do not perform the same regarding certain benefits or challenges.
Hydroponics is often right behind aeroponics in every category but is less efficient and therefore scores lower for every element. On the other hand, drip irrigation either performs very well on a certain element or falls of hard compared to the other two techniques. This is because of the simplicity of the technique compared to the other 2. Drip irrigation scores highest in the elements materials required and negative environmental gains. The reason for these scores is that drip irrigation requires fewer resources such as energy and material to be operational. This explains

why hydroponics and drip irrigation share the same scores but for different reasons.

5. Conclusion and Discussion

In section 5.1 the general research question is answered by interpreting the results from chapter 4 that answer the research sub questions. Section 5.2 discusses the validity, research limitations and suggestions for future research.

5.1 General research question

This study aimed to fill the current knowledge gap between vertical farming techniques and potentially sustainably aware investors or stakeholders that want to enter the vertical farming business. This was done by creating a recent and complete overview of vertical farming techniques, that provided much-needed oversight for all actors involved with vertical farming.
Therefore, the following research question was set up: *What are the benefits and challenges of the three main vertical farming cultivation techniques for the concepts of the Triple Bottom Line regarding the feasibility of cultivating leafy greens?*

By combining the results obtained from the research sub-questions, coupled with the checklist with elements of the Triple-Layered Business Model Canvas. Two conclusions can be made.
These conclusions have been derived by answering the research sub-questions.

The answer to the first research sub-question as shown in section 4.1.5 is: hydroponics share most of the same advantages and challenges that aeroponics has, but is also less efficient in these categories. This is also reflected in tables 16 & 17 with hydroponics often being awarded 0 points, meaning they are right in the middle regarding the Profit and Planet dimension.
The technique is much more efficient compared to drip irrigation and traditional cultivation techniques in categories such as water retention and yields (Lakhiar et al., 2018; Benke & Tomkins, 2017). Hydroponics has more advantages but these are related to hydroponics being used in a vertical farm and are not linked to the technique itself as stated in section 4.1.5.

The challenges in hydroponics are that the technique has high capital costs albeit lower compared to aeroponics and high energy costs due to the need for sufficient electricity and the need for air conditioning to cool the excess heat created by the need for lighting.
Hydroponics is also limited in its crop cultivation possibilities which constrains the techniques yield potential and therefore, its potential in the Profit dimension (Kalantari et al., 2018; Banerjee & Adenaeuer, 2014).

The answer to the second research sub-question as stated in section 4.2.5 is: the difference between aeroponics and hydroponics is that everything that hydroponics does well, is done better by aeroponics as shown in tables 16 & 17. The benefits of aeroponics regarding the Planet and Profit dimensions are: the highest water retention, the highest yields, the least fertilizer use needed, and a minimum of pesticides necessary to ensure crop health (NASA, 2006; Banerjee & Adenaeuer, 2014; Martin-Laurent et al., 1999).

The largest challenges for aeroponics are: the highest capital cost of all cultivation techniques, new ways of pest control are needed, high energy demands, being dependent on a fail-proof energy grid, and expensive chemicals are needed to ensure crop safety (Lakhiar et al., 2018; Orozco et al., 2008).

The answer to the third research sub-question starts with listing the benefits regarding the Planet & Profit dimensions of drip irrigation.
Drip irrigation has the same yield and water retention benefits as hydro and aeroponics compared to traditional agriculture but is the least efficient in realizing these (Lamm et al., 2016).
The largest benefit that drip irrigation holds over the other two techniques is that drip irrigation has no constraints regarding the variety of the crops it wishes to produce. This means that drip irrigation could be used to produce crops with higher profit margins compared to hydro and aeroponics (Camp, 1998).
The last large benefit for drip irrigation is that the technique has much lower operational and energy costs compared to the other 2 techniques. This makes drip irrigation a much cheaper alternative compared to hydro, and aeroponics (Banerjee & Adenaeuer, 2014; Martin & Molin, 2018).
The challenges for drip irrigation are that the technique has the lowest water retention rate, and yield numbers. The technique is also very dependent on land price to be economically feasible even though it is the cheapest of all three vertical farming cultivation techniques (Orozco et al., 2008; Benke & Tomkins, 2017).
Another challenge for drip irrigation regarding the environmental dimension is that due to the low water retention rate, there is a high risk of pesticides that are used to ensure crop safety, end up in the wastewater. This could lead to water pollution in urban areas which is to be avoided (Orozco et al., 2008).

The last research sub-question is answered in section 4.4.3. The results from this section clearly state that aeroponics performs best in both the Profit and Planet dimensions. Hydroponics performs second-best in the Profit dimension, it scores the same as aeroponics in all elements but is less efficient which gives the technique a lower rating. Drip irrigation has the lowest score in the Profit dimension. The technique has the lowest costs but this advantage is offset due to its low yield and efficiency.

Hydroponics and drip irrigation has the lowest score in the Planet dimension albeit for different reasons. Hydroponics has the lowest score again due to being less efficient in almost every element compared to aeroponics and it has the most negative environmental impacts. Whereas, drip irrigation either attains the highest score in an element or the lowest score. This translates to a more fluctuating score and explains how both techniques end up with the same score, for different reasons.

The first conclusion to the main research question is to follow the aforementioned checklist coupled with the points allocated to each technique as has been done in tables 16 and 17. Based on the scores obtained in these checklists a straightforward argument can be made for which technique is the most efficient technique to use for either the Profit or the Planet dimension. For the Profit

dimension, aeroponics is the highest scoring technique followed by hydroponics and lastly drip irrigation. Aeroponics ends up with 1 point, hydroponics gets 0 points, and drip irrigation ends up with -1 point.
Regarding the Planet dimension aeroponics again performs best scoring 2 points, with hydroponics, and drip irrigation being tied last with both -1 points. Based on the results previously generated it can be concluded that on average aeroponics performs best with hydroponics second, and drip irrigation the least.

The second conclusion is that some elements of the checklist with elements of the Triple-Layered Business Model Canvas need to have more weight attached to them. Some elements are more important compared to others. For example the water efficiency of a vertical farm, water efficiency is what makes the concept of vertical farming as interesting as it is. What is neglected, are the high electricity requirements and costs that keep a vertical farm operational. Electricity demands are responsible for around 40% of the GHG emissions the average vertical farm generates each year. Whereas the combined use of water and fertilizer amount to a maximum of 5% of the GHG emissions that a vertical farm generates (Banerjee & Adenaeuer, 2014; Molin & Martin, 2018).

This is the largest drawback of both hydro and aeroponics. The initial costs of starting a vertical farm applying either techniques, coupled with the artificial lighting necessary to keep a vertical farm operational are much higher compared to traditional farms. To keep a vertical farm that applies either one of the three main techniques operational. Government support such as subsidies or funding is necessary. Furthermore, additional research into techniques used for vertical farming could make them more efficient and reduce both capital and operational costs.

When comparing the techniques to conventional farming in greenhouses or open fields. Vertical farms utilizing one of the three techniques studied in this paper showed a higher yield per m2 (Banerjee & Adenaeuer, 2014). Vertical farms are more efficient in their use of land and can be done practically everywhere with a reliable power grid, which leads to less arable land being used for farming.

Comparing the energy use and environmental impacts of each technique was possible due to closed-loop systems coupled with entire lifecycle perspectives regarding crop cultivation being used in the vertical farm. Altogether aeroponics shows the best perspectives in terms of yield, water retention, effective fertilizer use, and growth possibilities. Whilst being closely followed by hydroponics in terms of efficiency. On the other hand, capital costs and operating costs of vertical farms are as of now on a level that without government assistance most vertical farms are not feasible in terms of breaking even with their operational costs. Drip irrigation however is cheaper, uses much less energy, and still has higher yields compared to traditional farming.

Therefore, in the authors' view, there is no absolute best cultivation technique yet. Each technique performs great regarding certain elements of the checklist with elements of the Triple-Layered Business Model Canvas and worse compared to the others on certain elements. It is the authors' personal belief that aeroponics shows the most promise for the near future and that technology can only help in achieving higher efficiency rates which will cut costs, coupled with higher yields which will eventually lead to financial feasibility and in doing so, feeding the future.

5.2 Validity, limitations and future research

The Triple Bottom Line and elements of the Triple-Layered Business Model Canvas were used to evaluate how each cultivation technique performed. Each cultivation technique was assessed based on their respective performance regarding three dimensions of the Triple Bottom Line, these dimensions were People Planet and Profit. Each dimension was assigned 5 elements consisting of elements from the Triple-Layered Business Model Canvas combined with the benefits and challenges the literature attributed to each cultivation technique. The Triple Layered Business Model Canvas and the concept of People, Planet, and Profit are accepted models in literature and have been regularly used in recent research.

Furthermore, papers that were included regarding the benefits and challenges of the cultivation techniques had to be published in peer-reviewed journals. Papers that had either over 50 peer reviews or were published in the last 10 years or both were included in summarizing the benefits and drawbacks. Therefore, the data used is reliable data to use.

All data and papers gathered come from the databases Scopus, Google Scholar, and Web of Science. Data was further gathered by utilizing a systematic literature approach, combined with queries that generated valid papers. However, due to 3 months of the inactiveness of the researcher, it must be mentioned that new papers were added to the research which had not been selected byways of a systematic literature approach. This has partly compromised the research validity.

Another threat to validity might be the fact that some of the queries generated more than thousands of data sources of which only a few were picked. This, coupled with selection bias regarding certain papers from the researcher might result in different sources being used when the same research method is used in the future.

The biggest limitation of the research is the checklist with elements of the Triple-Layered Business Model Canvas in assessing the benefits and challenges of each cultivation technique. There are two reasons for this.

Firstly, how points are allocated to each cultivation technique based on how they perform regarding each element. Some elements such as costs in the Profit dimension should have been assigned a more significant weight as it is one if not the leading reason why vertical farms are not more present in the current farming industry. This holds for almost every element in the checklist as the significance of each element varies.

Secondly, the significance of each element is not objective. For example, a vertical farm business that is more interested in the Profit dimension will allocate more significance to costs and revenues and less about the environmental costs of the materials needed to ensure production. Whereas, a vertical farm business with a more Planet oriented business approach will care less about revenues but more about the environmental benefits in assessing which cultivation technique to use.

A third limitation of the research is that when building a 37-story vertical farm in a large city such as Berlin for example. The farm cannot simply produce crops that have the highest margins regarding the selling price, due to supply and demand as it would be quite a risk to purchase 68 acres of strawberries for one year (Banerjee & Adenaeuer, 2014; Helmers, Yamoah, & Varvel, 2001). When looking at Table 15, strawberries are the crop that sells for the highest price. What this research lacks, however, is a clear overview in a city such as Berlin in which supply and demand are mapped. In which how much of a certain crop can be produced yearly without creating a surplus and not being able to sell the said crop.

A fourth limitation is that the three cultivation techniques used in this have a lot of overlap in their respective benefits and challenges, though there are differences in efficiency in almost every category. Listing these differences and/or similarities in a more efficient way could have resulted in less redundancy of data within the research.

A fifth limitation is the scope of the research. This research is focused on the feasibility of each cultivation technique. What is neglected, however, are surrounding questions regarding the possibility for a vertical farm in for example Berlin. Most cities such as Berlin have many issues that need to be addressed such as sufficient housing, working utilities, and many more. This research as well as sources used for this research neglect the fact that building a vertical farm in a city does not have the same priority for the researcher as for a city council. Notwithstanding all the legal issues that need to be addressed before the build of a financial, environmental, and legally feasible vertical farm is realized.

Therefore, future research is necessary regarding electricity efficiency and the cultivation techniques themselves. This will lead to higher yields, lower costs, and lower emissions.
It is also interesting to research the legal possibilities of a vertical farm in a major city as current literature is lacking in highlighting these. This might even need to be the first aspect that proponents of a vertical farm in urban areas must research, as legal allowance is often the first step necessary in undertaking projects of such a large scope.
Lastly, research needs to be done regarding the willingness of the inhabitants of a large city for a large farm to be built in their midst. Public distrust as well as online misinformation can also be factors that can result in public unwillingness of a vertical farm being built in a city, regardless of what cultivation technique is used for crops.

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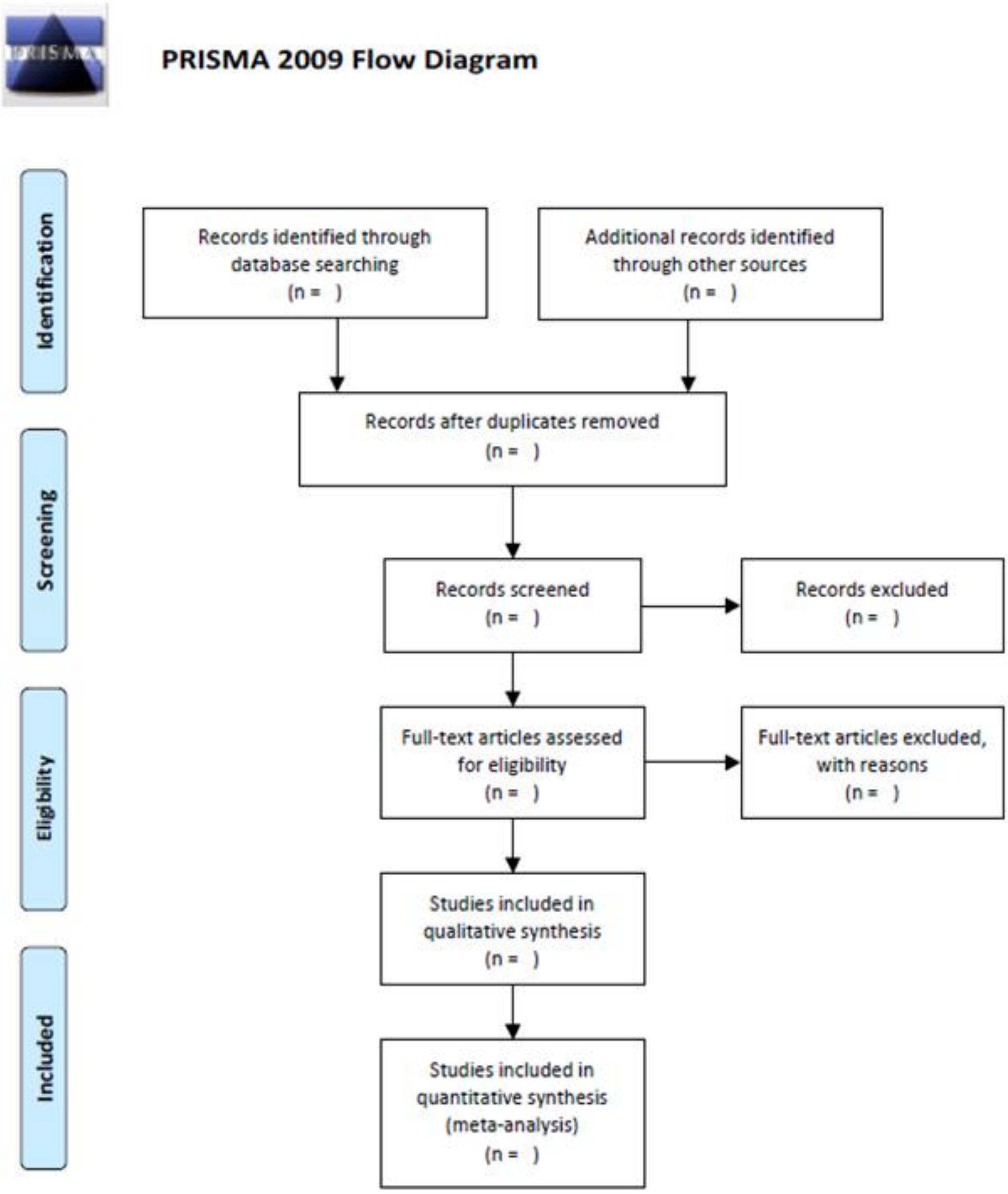
Appendix 1 Prisma flow diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *Preferred Reporting Items for Systematic Reviews and Meta-Analyses:* The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

Appendix 2

Database	Search query	Records identified	Records Screened	Records excluded	Full text articles	Reasons excluded	Studies included
Web of Science	“triple bottom line” OR “people, planet, profit” OR “PPP” OR “Triple Layered Business Model Canvas”	13.162	30	13	17	Irrelevant information	7
Scopus	“triple bottom line” OR “people, planet, profit” OR “PPP” OR “Triple Layered Business Model Canvas”	4.345	28	19	9	Irrelevant information	6
Google Scholar	“triple bottom line” OR “people, planet, profit” OR “PPP” OR “Triple Layered Business Model Canvas”	19.500	22	10	6	Irrelevant information, duplicates	2
Web of Science	“vertical farm*” OR “Plant factory*” OR “Indoor farm*” AND “hydroponic*” OR “aeroponic*” OR “drip irrigation*	5.021	50	31	19	Irrelevant information	11
Scopus	“vertical	121	30	15	12	Irrelevant	8

	farm*” OR “Plant factory*” OR “Indoor farm*” AND “hydroponic*” OR “aeroponic*” OR “drip irrigation*					information and duplicates	
Google Scholar	“vertical farm*” OR “Plant factory*” OR “Indoor farm*” AND “hydroponic*” OR “aeroponic*” OR “drip irrigation*	4.521	40	12	30	Irrelevant information and duplicates	15

Appendix 3 search queries used in chapter 4.

Database	Search queries	Hits	Used
Scopus	"Vertical farm*" OR "Plant factory*" OR "Indoor farm*" AND "hydroponic*" OR "aeroponic*" OR "drip irrigation*	121	8
Web of Science	"vertical farm*" OR "Plant factory*" OR "Indoor farm*" AND "hydroponic*" OR "aeroponic*" OR "drip irrigation*	5031	11
Google Scholar	"vertical farm*" OR "Plant factory*" OR "Indoor farm*" AND "hydroponic*" OR "aeroponic*" OR "drip irrigation*	4521	15