Viability Assessment of Vertical Farming

A Decision Support Framework with a Case Study on York, Pennsylvania

By

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TU Delft

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Executive Summary

Global food production faces increasing challenges due to population growth, urbanization, and climate change. Even in developed countries such as the United States, a significant number of people experience food insecurity (U.S. Department of Agriculture, 2025). Therefore, alternative crop growth methods such as vertical farming are considered. Vertical farming is the practice of growing crops in an indoor facility by stacking multiple layers of production (Agritecture & CEAg World, 2025). While the vertical farming market is expected to grow yearly, multiple large bankruptcies of vertical farming companies in the U.S. in 2023 showed that it has severe drawbacks and difficulties competing with traditional farming (field farming). High electricity costs, too much focus on technology instead of crop production, and the hype factor have contributed to vertical farming focusing on quick expansion without first developing an economically viable business model. Therefore, a framework is needed to assess the viability of vertical farming. This led to the following research question: *Which decision support framework can support the assessment of the viability of vertical farming?*

The research approach used to support the development of the decision support framework is a single case study method. The case was on an ongoing project at the York State Fair in York, Pennsylvania, in the United States, which involved several stakeholders including local partners, research & universities, industry, and public authorities. The York State Fair in the city of York has unused terrain where 4 hectares (10 acres) could be used to build a vertical farming facility. In this research, the advantages and disadvantages of vertical farming were first compared to traditional farming in terms of economic viability. Disadvantages such as high investment costs and energy usage were found to be more financially impactful than the advantages such as no-pesticide use, and water efficiency. The literature has been mostly concerned with the technology involved in vertical farming and less with the economic viability. Therefore, literature in urban farming was used, which describes six different business model types that could be used. Urban farming includes vertical farming and other agricultural practices in an urban environment. In addition, literature on vertical farming has specified the most critical parameters for profitability: investment costs, energy costs, wages, and revenue prices.

This master's thesis is in collaboration with Priva, enabling access to the case and stakeholders involved. The stakeholders in the case were analyzed. It was found that multiple important stakeholders had concerns about profitability. In addition, there is potential for conflict due to different interests in what the workforce must be in the project. The most suitable solution was to include educational aspects such as hiring interns. In addition, to cope with possible external factors such as shortages in the agricultural workforce, including automation via robotics, could make the project more resilient. The business models best suited to the project are the differentiation and experience business models. The differentiation business model focuses on offering desired products but lacks in the business environment. York, PA, and its areas lack locally grown fresh produce. The experience business model entails implementing educational activities as found necessary in the stakeholder analysis. Based on the factors critical to the viability of vertical farming, a financial model tool was made in Excel. This tool can calculate a vertical farm project's profitability and test how resilient the profitability is to changes in the critical parameters. For the case study, short-term (1-year) profitability is unlikely, but profitability would be likely in three years due to yield and energy savings improvements. However, changes in electricity prices and usage and revenue prices for the lettuce were found to impact profitability highly. Therefore, it is suggested that the project in York aims for a fixed electricity price for several years and tries to establish stable wholesale prices for its lettuce sales.

A decision support framework was created, consisting of the following six stages: "identify drivers," "analyze business environment," "analyze stakeholder alignment," "develop business case," "analyze viability," and "implement vertical farm initiative." The stakeholder methods that should be used include a power-interest matrix, value network analysis, and, depending on potential conflicts between stakeholders, a system diagram analysis. A Business Model Canvas can be used to develop the business case. The vertical farm's viability can be assessed using the financial model tool. If the viability is satisfactory, the vertical farming initiative can

be implemented. Private organizations and public institutions can use the decision support framework to assess whether a vertical farming initiative is profitable in a specific location, what type of business model fits the vertical farm, and whether policies need to be changed to increase a vertical farm's viability. Furthermore, this study integrated stakeholder analysis methods and business and financial tools in a comprehensive framework based on a study case used for empirical data. Since the decision support framework was not validated, its applicability to other cases must be tested, for example, for cases outside the United States. In addition, a limitation of the framework is that viability mainly concerns financial success. Factors such as sustainability, food resilience, and food waste can be implemented in the business case that would widen the decision-making on a vertical farming initiative.

Acknowledgments

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I also would like to express my deepest thanks to Dr. Jan Westra who gave me the chance to participate in a project at Priva and his support throughout my master's thesis. The project was in collaboration with Priva, and I also would like to thank my colleagues for their support, and the company for their work environment and valuable work experience I gained.

I also would like to thank all the participants I interviewed for my master's thesis. Jan Westra at Priva was very valuable in introducing me to potential interviewees as part of the Priva network. In addition, I visited the York State Fair on February 3rd, 2025, and several companies/universities related to the case. The 3.5-day trip, which began in York, Pennsylvania, and concluded in Pittsburgh, was organized by Ian Kanski, who also initiated the project and to whom I am deeply grateful.

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Contents

1. Introduction

In the world, it is estimated that only two-thirds of food produced will be consumed in the end (European Union, 2024). This is mainly due to food produced in Western countries being wasted during transportation (Mena et al., 2011). Food insecurity, while not as prevalent in developed countries compared to poorer countries, also has its presence. In the EU, 1/12 of the population is unable to afford proper meals in 2022 (Eurostat, 2023). In the US, 1/8 of the population in 2022 experienced food insecurity, which spans from eating less varied diets to having periods where households financially were not able to acquire sufficient food supplies (U.S. Department of Agriculture, 2025). Since there were 116 million households in the U.S. in 2022, 17 million households experienced food insecurity. Climate change will undoubtedly have significant consequences for food production in the future. In a review of climate change effects on agriculture, it is argued that extreme climate events are dangerous for both agriculture and humanity (Anwar et al., 2013). 44% of the Earth's habitable land is used for agriculture (Ritchie & Roser, 2024). Crops use 1/3 of this area and the rest is used as grazing ground for livestock. Half of the crops are used for direct human consumption while the other half is used for animal feed. The world’s crop production in different climate change scenarios is also expected to decrease by 10 to 20% (Parry et al., 2004). While agriculture itself is under pressure from climate change, it is also a cause of CHG emissions. Agriculture contributes to carbon dioxide mainly through livestock and fertilizer use (Fellmann et al., 2018). It accounts for 10% of the total CHG emissions in the EU. The current way of farming cannot prevent decreases in production if CHG emissions need to be lower (Fellmann et al., 2018).

Extreme events such as droughts and floods are expected to occur more and heavier due to climate change as well (Anwar et al., 2013). This also has its effects on food production. In 2001, it was reported that 70% of water available for human consumption was used for agriculture (Somerville & Briscoe, 2001). California, an agricultural powerhouse in the US, was experiencing multi-year droughts from 2012 to 2016. The state mainly depends on its vast water management network and agriculture in its cities. During the drought of 2014, California could only cope with the drought as it unsustainably pumped much groundwater for its agriculture (Cooley et al., 2015). In the Central Valley, they started using different crops to cope with the droughts to compensate for the higher water prices (Gebremichael et al., 2021). In a study on how the water shortage impacted different groups in California, it was concluded that agriculture and civilians on farmland saw a 30% reduction, while more affluent urban users mainly were exempted from the water reductions (Stewart et al., 2020).

In the EU, the Farm to Fork Strategy, which is part of the European Green Deal, is aimed partially at reducing food loss (European Commission, 2024). Furthermore, while 50% of the global population is living in urban environments, it is expected that this will increase to around 70% in 2050 (Milan Urban Food Policy Pact, 2024). The current farming method may not be sufficient to combine the different challenges to agriculture, such as climate change, urbanization, population growth, and CHG regulations. Therefore, the idea of integrating agriculture in cities has been developed. Except for several small historic examples, the pioneer of the concept of vertical farming was Dickson Despommier, a professor at Columbia University in New York, who supposedly theorized with students in 1999 how to feed citizens in New York with food produced in the city (Farms, 2019). A concept was developed where a multi-level building, which could be the size of a skyscraper, contains many layers of different indoor growing agriculture practices. In addition, the various layers should complement each other. Ultimately, it should include a grocery store or a restaurant, which would decrease food transportation to an absolute minimum. He wrote a book called: *The Vertical Farm: Feeding the World in the 21st Century,* in 2010, on how vertical farming could be world-changing (Despommier, 2010).

The main benefit is that crops can be grown year-round due to the circular environment and in significant quantities by being vertical. This way, the yield can be substantially increased, and water and nutrient use will be much lower. Furthermore, shorter supply chains and reduced food waste are great benefits of integrating farming into cities. The EU itself has outlined farming in the towns as a solution for the growing demand for food (European Commission, 2023). In addition, universities have developed specific programs and courses in sustainable farming, such as Purdue University in urban agriculture and Wageningen in vertical farming (Purdue University, 2024; Wageningen University & Research, 2025). In a study on Consumers' opinions on vertical farming, they were largely positive in the tested countries (UK, USA, Singapore, and China) (Ares et al., 2021).

While using LEDs instead of sunlight can increase the yield, it implies that much electricity needs to be used instead of using the sun for free. Moreover, initial investment, scaling up a farm, and labor are all much more costly than traditional farming (Benke & Tomkins, 2017; Butturini & Marcelis, 2019; Moghimi & Asiabanpour, 2023). Dickson Despommier himself commented on the concerns he faced about the concept, where one of them was how it could be profitable while property values are so high in many Western cities (Despommier, 2009). He argued that abandoned space could be used in cities. The other concern mentioned was the supply of water and energy. This could be dealt with by, for instance, sunny locations having their vertical farms more spread out and less high to take advantage of sunlight, while in, for example, New York City, household water waste could be used by vertical farms.

15 years later, vertical farming businesses have not been massively successful yet (Garwood, 2022). In addition, while the initial idea of vertical farming was highly integrated food systems, as of 2024, most vertical farming has been concerned with growing only a few different crops, such as lettuce (Benke & Tomkins, 2017). While the industry is still expected to grow yearly, in 2023, due to rising energy prices and a big decrease in venture capital in the vertical farming market, several smaller and larger vertical farming companies went bankrupt or had to scale down their business substantially (Garwood, 2022). It was concluded by Buscher et al. (2023) that the 21st century does possess the 'window of opportunity' for vertical farming due to climate change impacting field farming and adaptation in urban planning. Literature has mostly been concerned with yield optimization and the technology involved in controlled environment agriculture (CEA) (Oh & Lu, 2023). The current downfall of several vertical farming companies and investments has shown that vertical farming needs to address its financial performance (Gordon-Smith, 2023). Therefore, this study aims to address the issue of vertical farming's viability. The idea is that a framework can be created for vertical farming that addresses which stakeholders to consider and which critical factors are essential to profitability.

1.1 Knowledge Gap, Problem Statement & Research Objective

Urban farming literature describes several different business models that can be used, where their economic viability depends partly on the farm's specific business environment (Pölling, Sroka, et al., 2017). Drivers and Challenges are also identified for the different business model types (Appolloni et al., 2022). As described in Appendix B, urban farming also encompasses other farming methods, such as vertical farming. For vertical farming specifically, business parameters are analyzed, as well as risks to the financial model of vertical farming (Marczewska et al., 2023), (Baumont de Oliveira et al., 2022). Furthermore, the different factors of vertical farming impacting its cost structure are described in the literature (Moghimi & Asiabanpour, 2023). However, a literature gap exists in how information such as the cost structure can be applied to a vertical farming initiative. Moreover, it is unclear what the business case can be and who should be involved.

In the United States, multiple vertical farming companies went bankrupt during 2022 and 2023 (Garwood, 2022). Quick growth expectations by investors led to a focus on technology instead of achieving positive unit economics and a viable business model (Vertical Farm Daily, 2023b). The vertical farming market is expected to grow in North America in the following years (Fortune Business Insights, 2024). It will not be successful without a viable business case and addressing the factors that led to the bankruptcies. Furthermore, while there has been public support for urban farming in the US, including vertical farming, it has been generally lacking (Senate Committee On Agriculture Nutrition & Forestry, 2023). Funding by investors also has declined by almost 90% compared to the years before the bankruptcies (Glasner, 2024; Vertical Farm Daily, 2024b). Unlike the UAE and Singapore, where the government sets specific goals due to its reliance on food imports, the U.S. does not have this incentive (Cairns, 2024; The Arab Gulf States Institute in Washington, 2024; Wood et al., 2020). The challenges to the food system are rising globally and in the U.S., e.g., in California, there are increasing droughts (Cooley et al., 2015). Furthermore, 12.5% of the population experienced food insecurity (U.S. Department of Agriculture, 2025). Without more resilient agriculture, such as vertical farming, crop production will eventually decrease despite a growing world population (Parry et al., 2004).

Goal & Research Question

A decision support framework must be developed to support a vertical farming initiative. This will encompass a decision-making tool that can be used to identify which business factors need to be considered. The core of this framework is financial viability. In addition, a financial model can include critical business factors and calculate the overall economic viability. This framework could be used by project managers who need support in decision-making on the viability of a vertical farm. Moreover, it can support private organizations in assessing what type of business model must be applied for a vertical farming initiative. It can also benefit policymakers to see which critical factors are missing for vertical farming to be financially viable, which may lead to more focused public support on these factors. This leads to the following research question: *Which decision support framework can support the assessment of the viability of vertical farming?*

First in Chapter 2, the research approach is explained, including the research methods. In Chapter 3, the current state of vertical farming is explored. Chapter 4 consists of a literature review on vertical farming and business models. Chapter 5 entails a stakeholder analysis of the case study. In Chapter 6, the business model is analyzed, including a financial analysis in a separate Excel Document. In Chapter 7, the business model framework is explained. The conclusion of the research can be found in Chapter 8, including limitations and future research perspectives.

2. Research Approach

The objective is to develop a decision support framework to assess the viability of vertical farming. In the literature, several studies have provided an overview of business elements being used in vertical farming. However, insights into how a specific vertical farm should manage these business concepts with the aim of viability have not been researched. A case study approach will be used as input to design the decision support framework. A real-world case will be used as empirical data to develop the framework. First, the research method is explained. Secondly, the study case is introduced. Lastly, the research design is described, which includes the different sub-questions supporting the goal of answering the main research question.

2.1 Research Method

A case study approach was used since it enables in-depth insights into the phenomenon to be studied (Johannesson & Perjons, 2014). A case study is defined as: *"a research approach that is used to generate an in-depth, multi-faceted understanding of a complex issue in its real-life context"* (Crowe et al., 2011). It can be used to explain, describe, or explore a phenomenon and is specifically helpful for exploratory "how," "what," and "why" questions (Crowe et al., 2011; Yin, 2012). A case study approach consists of several stages: defining the case; selecting the case; collecting and analyzing the data; interpreting data; and reporting the findings (Crowe et al., 2011). A descriptive case study will be used, which "*aims to produce a rich and detailed description of an instance and its environment"* (Johannesson & Perjons, 2014, p.45). The instance to be studied in the case is the vertical farm itself (Johannesson & Perjons, 2014). In this analysis, only one case will be studied since the goal is an in-depth analysis of the business model framework. This means that findings will have limited generalizability compared to a multiple-case study approach (Crowe et al., 2011).

Data Collection

In the book by Yin (2012), six different data collection methods were identified, that can be used in a case study. The following methods were used in this research: direct observations, open-ended Interviews, and documents. On February 3rd, 2025, the location of the study case was visited, and conversations between several stakeholders and the area where the vertical farming project will be developed were observed. Open-ended discussions were conducted with the stakeholders involved in the project. Furthermore, interviews with industry experts in the economics of vertical farming were held to create a deeper understanding. Documents include e-mails, articles on York, textual data by Priva on the project, and also images provided by stakeholders of the case (Johannesson & Perjons, 2014). An informed consent document was made for the interviews, and the summaries of the interviews have been made available to the TU Delft supervisors of this research.

It is important to have multiple data sources since it increases the internal validity of the research (Crowe et al., 2011). In addition, triangulation should be used to make the findings more robust (Yin, 2012). The different data collection methods should be checked for differences and similarities, and the more convergence occurs by various sources, the more confident the findings will be. For the stakeholder analysis, interview findings will be compared to those of other interviewees since the aim is to find alignment between the stakeholders. In addition, general interviews were conducted to learn more about the business environment for vertical farming in the U.S and the economic factors impacting vertical farming.

2.2 Study Case

The case chosen is a vertical farm project in York, Pennsylvania. There are several reasons why this specific project was selected. First, this research will be conducted in collaboration with Priva, allowing access to their data and easier access to stakeholders involved in the case. Second, the case must represent the average vertical farming project (Crowe et al., 2011). The project in York falls into the category of a "typical" case since vertical farming in the US has no extensive public support, e.g. the UAE and Singapore, but also does not experience the more challenging conditions in Europe, where energy costs are relatively high (Crowe et al., 2011). Initial interviews were conducted to find out what the case is about and what the concerns are. In Appendix C, interviews with respective stakeholders involved in the project or for general information on CEA and vertical farming can be found. In text, they are referred to as sources by: *(Interview. Abbreviation).* CEA (Controlled Environment Agriculture) is more commonly used in the United States than vertical farming. Since the study case is in the U.S., the project will be called: “CEA project.” This will encompass the vertical farming facility and the educational services related to the CEA facility. Since the project is under development, information on the funding resources will not be disclosed.

Starting Phase

The case used to develop a decision support framework for vertical farming is on a project in development in York, Pennsylvania. The idea for building a CEA facility and related educational and research services was initiated after the problem owner visited the Netherlands, notably the Delphy Improvement Centre *(Interview PO)*. In the Netherlands, the Delphy Improvement Centre is a high-tech facility where agritech research and demonstration take place (Delphy, 2024). This entails having greenhouse and indoor farming facilities where research (e.g. Wageningen University & Research, which focuses on life sciences and agricultural research), industry (e.g. Priva), and government collaborate on projects. In Pennsylvania and the U.S., such a site does not exist yet *(Interview BL & PA).* The idea for the project is in line with the Delphy Improvement Center, to be a location where innovation and demonstration of agritech takes place *(Interview PO & BL)*. Furthermore, it can show what other countries such as the Netherlands, Scandinavia, and Canada have been doing, and showcase what can be improved, such as labor efficiency. In January 2023, the idea was set in motion for the next phase, when the York State Fair was found as a possible location for such a project.

York State Fair

The York Fair was founded in the 18th century in York, Pennsylvania, when it was only a two-day agricultural market, as the first fair in the United States (York State Fair, 2024). In 1853, the York Fair expanded to a three-day agricultural fair due to the formation of the York County Agricultural Society by York County agrarian leaders. In 1888, the York Fair was expanded to its current location. In 1926, the event expanded from three to five days, and more types of entertainment were added, such as horse races and dancers. The Memorial Hall was constructed in 1950 and can be rented out annually. In the Next 50 years, it was expanded to a nine-day and then a ten-day event. Nowadays, the properties are used for many events throughout the year, such as train shows, spectator events, and motorcycle events. In 2003, an Arena was constructed with an Expo Center. An overview of the York State Fair can be seen in Figure 2.1. In Figure 2.2, a picture is showcased from the York State Fair during 2018.

Figure 2.1: Schematic overview of the York State Fairgrounds

Figure 2.2: Picture York State Fair on September 7, 2018

However, despite the expansions over the decades, the York State Fair is not used as much as the owners would like. Many buildings are from the late 19th century, though they have been updated. The buildings and surrounding area are utilized for the annual fair. Still, the idea is that the site could be put to better use because maintaining such a site is economically unsustainable from a real estate perspective *(Interview SRE)*. Already in Downtown York, a much smaller urban farming project is underway. This led to considering taking it to a much larger scale at the York State Fair *(Interview SRE).* It is also necessary that the agricultural heritage be maintained at the York State Fair.

The CEA project could support the agricultural community *(Interview YCEA)*. It can help existing farmers learn about new technologies, and the educational aspect can help young people learn about CEA. The York State Fair can also function as a location where senior and college students can take classes to get hands-on experience with farming *(Interview YSF)*. Furthermore, next to pitching to students how they can further study and become farmers and growers, education at the York State Fair can be about programming and sales, which are also needed at the CEA facility. The project could also be significant for the fairgrounds *(Interview YCEA).* They have been going more toward the convention center instead of the agricultural center, and this project can bring them back to their roots and a new revenue stream.

In a meeting with the following stakeholders in January 2024, the CEA project ideas and possibilities were more formalized: York State Fair, Susquehanna Real Estate, Priva, Borlaug, and York County Economic Alliance *(Stakeholder meeting January 2024*). This first meeting with the stakeholders can be considered the starting point of formalizing the ideas of the CEA project. The mission of this project is focused on three elements: “circular economy,” “local resiliency,” and “future-proofing.” The objectives are that this project functions as a “lighthouse,” a “toolkit of proven solutions/systems,” and as a demonstration site. A new agritech invention can be tested and commercialized if successful. The project horizon is 5 years. Figure 2.4 shows the idea of the physical sites and their functions as characterized in the meeting. The pillars of the physical sites are: innovation, validation, demonstration, and education *(Interview YSF).* On February 3rd, 2025, I visited the York State Fair myself, where a meeting was held with several stakeholders involved in the project. Information at this meeting was not used in this research project since the meeting was after the data collection period for this research, and permission was not explicitly requested from the participants.

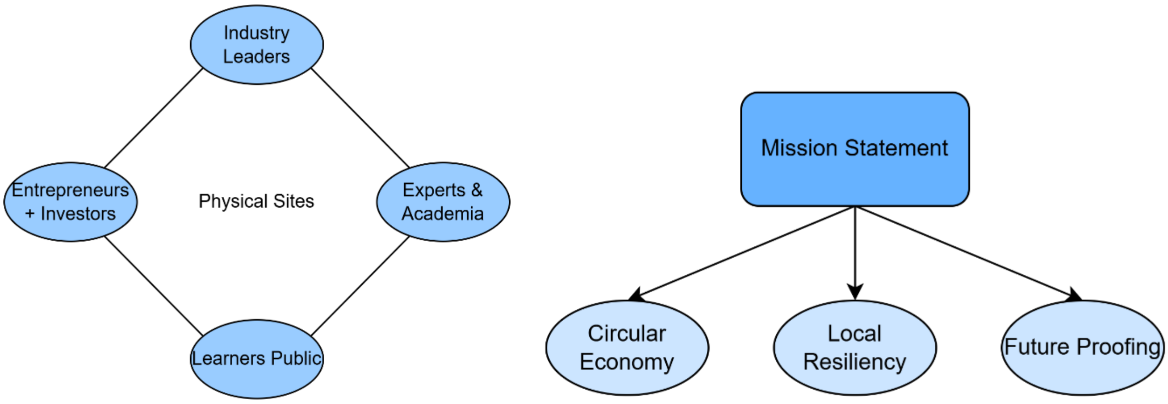

Figure 2.3: Joint Model CEA project (Stakeholder meeting January 2024)

Facility

The starting concept is to design a CEA facility of 4 hectares (10 acres / 435,000 Square Feet / 40,000 square meters) (*Interview SRE)*. In a later stage, it could be expanded to a maximum of 16 hectares (40 acres). The York State Fairgrounds, which is held yearly in the summer, needs to stay (therefore about 50% of the total area at the York State Fair can be eventually used for the CEA project). In Figure 2.4, a schematic overview of the York State Fair can be seen. Development Parcel 1 and 2 are proposed as locations where the CEA facility can be developed. The buildings surrounding the facility's location can be seen in Figure 2.5. In Figure 2.6, a more detailed view of the CEA facility, located at Development Parcel 2, can be seen. A research center will be built next to the CEA facility at Development Parcel 1. Furthermore, there will be a water pond to collect rainwater. The projected site where the facility could be located was observed on February 3rd, 2025.

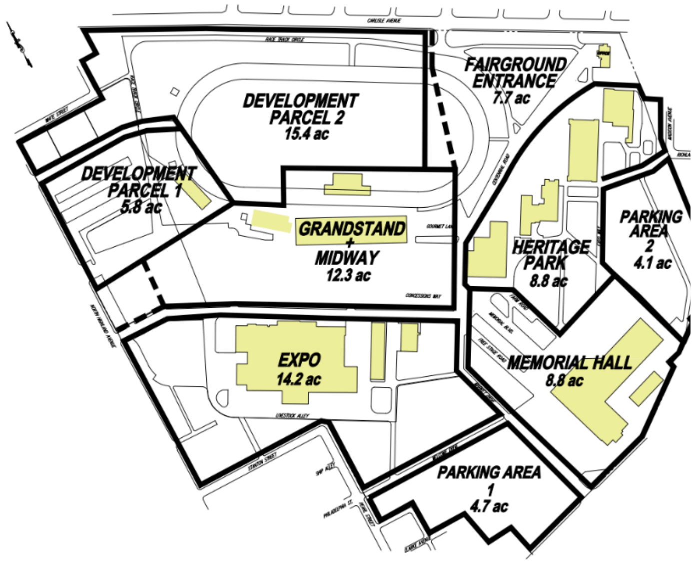

Figure 2.4: Overview Building Locations at the York State Fair (Figure by courtesy of Susquehanna Real Estate)

Figure 2.5: Schematic overview of CEA Project (Figure by courtesy of Susquehanna Real Estate)

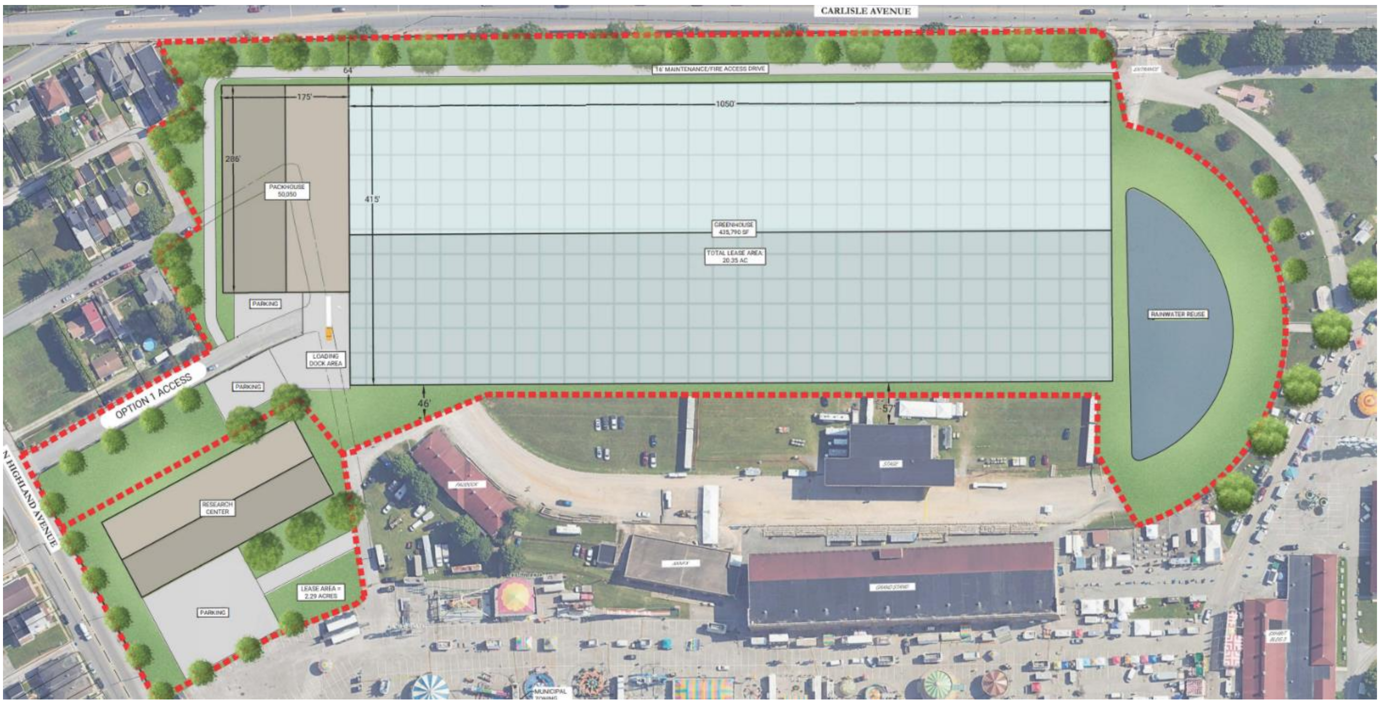

Figure 2.6: Detailed Overview CEA Facility (Figure by courtesy of Susquehanna Real Estate)

Concerns

In the initial conversations to create understanding of the CEA project, stakeholders expressed several concerns. The most common concern among stakeholders was whether the project could become economically viable. In addition, the investment costs, wholesale prices of crops, and the scale of what the CEA facility must be to become profitable are unknown. There is also uncertainty of who will be involved, their role, and what employment could look like. Therefore, a stakeholder analysis is needed to identify the roles of different stakeholders and determine whether there is alignment or a possibility for conflict. A business case analysis must be done to address the viability concerns.

2.3 Sub-Questions

Several sub-questions were developed based on the research's goal. For every sub-question, it will be briefly explained what methods will be used and how data will be collected. For this research, internal interviews have been conducted at Priva to gain technical knowledge on vertical farming.

Sub-Question 1: What is the current economic landscape of vertical farming?

Before the business model framework for vertical farming was considered, it was essential to analyze which factors are critical to the economic viability of vertical farming. This would help determine which factors are more important than others and which aspects must be considered more thoroughly in the business model. Furthermore, an overview of how vertical farms performed financially in the U.S. was needed to understand the potential focus areas for the business case. This will create an understanding of the opportunities and pitfalls faced by vertical farms. The latest literature on Scopus, Google Scholar, and Google was used to identify the current economic landscape of vertical farming.

Sub-Question 2: What business models can be used for vertical farming?

A literature review on business models used in vertical farming and related concepts was conducted to support the business case for vertical farming initiatives. This contributed to the overall understanding of what type of business models are possible for vertical farming and which business factors need to be considered. Furthermore, it can indicate the opportunities and challenges of a vertical farming. This supports the viability analysis by highlighting key factors influencing cost structure and identifying potential business risks of vertical farming. Literature was found mainly via Scopus, Google Scholar or snowballing.

Sub-Question 3: How can the stakeholder ecosystem for the vertical farming case be developed?

For a vertical farming project, the stakeholders involved must be considered since this may or may not lead to specific decision-making for a business model type. Furthermore, alignment between stakeholders is impactful for organizational success (Brereton, 2023). The case was used as empirical data for a stakeholder analysis in vertical farming. Information on the case's business environment was analyzed to understand stakeholders' perceptions and potential opportunities and challenges in the study case. This information is retrieved from reports on York County and interviews with stakeholders. For the stakeholder analysis, several tools were used to identify how stakeholders are aligned on different subjects. First, a power-interest matrix was made to find out which stakeholders are important to consider (Buser, 2024). A value-network analysis dives deeper into this by seeing what value stakeholders exchange (Allee, 2008). Also, a system diagram analysis was done to assess the causal relationship between a problem owner's options and how they affect the goals of various stakeholders. This was used as input to determine what type of business case fits the study case and what the focus areas must be to align the stakeholders.

Sub-Question 4: What business and financial model can be developed based on the study case?

As explained in the introduction, there is a knowledge gap in how a vertical farming business can be set up to be economically viable. The business case for the study case is developed by combining the literature found in sub-question 1 and 2, and the information on the case in sub-question 3. A Business Model Canvas was used to visualize the business model (Osterwalder & Pigneur, 2010). A financial model was created in Microsoft Excel. The data used in the financial model for the study case was based on reports and sources on Google, such as the U.S. Department of Agriculture, and interviews if necessary. Experts reviewed the financial model. The financial model can be used to assess the viability of a vertical farm, and by using empirical data from the case study, the case study was evaluated to determine whether the CEA project is viable. The Business Model Canvas

Sub-Question 5: How can stakeholder analysis methods and business model tools be combined in a decision-support framework?

A decision support framework was created to assist other vertical farming initiatives determine their viability. This framework combines the stakeholder analysis methods used in sub-question 3 with the business model tools developed in sub-question 4. The aim is that this framework can be used by industry and public institutions to identify locations that could be financially attractive for a vertical farming facility.

3. Economic Landscape of Vertical Farming

To develop a business case for vertical farming, it is important to analyze what, as of 2024, the current situation is of vertical farming, because it will review what the most important aspects are for a viable business case. Therefore, this chapter aims to answer the following question: *What is the current economic landscape of vertical farming?* First, an overview was made of the difference between traditional and vertical farming. Traditional farming can be defined as: *“horizontal agriculture on the surface of the land”* (Khalil & Wahhab, 2020, p.2). Specifically, the financial advantages and disadvantages compared to traditional farming were analyzed since this will identify the focus areas for the business case. Secondly, the performance of vertical farms in the U.S. was analyzed to explore the potential causes for worse financial performance and what should be addressed in the business case for vertical farming. Scopus, Google Scholar, and Google were used for the literature; specifically, advantages and disadvantages were based on the most recent Literature available. In Scopus and Google Scholar, literature was found by combining the keywords: “vertical farming” and another concept such as “yield” or “labor.” Then the title and abstract of the articles were assessed to identify whether the economic aspects were considered.

3.1 Vertical Farming vs Traditional Farming

There is no consensus on terminology. Related concepts such as urban farming and controlled environment agriculture (CEA) are interchangeably used with vertical farming. Therefore, in Appendix A, a glossary can be found in how the concepts are used in this study, and in Appendix B, the concepts are explained in more detail. Since 2013, the number of scientific papers on “vertical farming” has grown from 9 to 95 in 2022 and 125 in 2023 (Saxena et al., 2024). Most literature on vertical farming has been about optimizing yield, nutrient use, and the controlled environment since these are the main advantages of vertical farming. To a lesser degree, the economic viability of vertical farming has been explored. It was found that in vertical farming, there is more literature on the ecological impact than the economic aspects (Kalantari et al., 2018). This chapter compares different aspects of vertical farming to traditional farming, specifically the economics of that aspect.

Yield

One of the most recognized advantages of vertical farming is the higher crop production volume compared to traditional agriculture. Not all light of the sun is used for growing. Therefore, based on crop needs, specific wavelengths of LEDs can be used to optimize the growth of the crop (Nájera et al., 2022). The most used LED spectrum is the color blue, which is associated with the best performance for the growth of crops and photosynthesis (Nguyen et al., 2021). Secondly, red is used, which is associated with flowering and the growth of leaves in crops. A combination of blue and red LEDs has shown the most significant success in the yield of crops in indoor farming (Wong et al., 2020). This explains why vertical farms have purple colors due to the mixed use of blue and red, but it makes it more difficult for humans to inspect the crops visually (Nguyen et al., 2021). For lettuce, it has been analyzed in detail how specific light wavelengths contribute to its growth (Nguyen et al., 2021). For lettuce, yield can be more than 80 times higher per square meter compared to outside farming and 12 times higher than greenhouses (Van Gerrewey et al., 2022). For wheat, a 10-layer vertical farm (1 meter needed between layers) can have 220 to 600 times more yield compared to the global average of traditional farming (Asseng et al., 2020).

Circular Environment

The main factor in increasing the yield is the circular growing environment of crops. This allows for close temperature, humidity, and air circulation monitoring. In addition, benefits of a closed-loop climate are that water and nutrients can be reused (Carotti et al., 2023). While theoretically, water use could be net zero in a closed-loop vertical farm, it can reach around 90% reduction in practice. Compared to greenhouse lettuce, water use can be reduced by 28% in the UAE, to more than 90% in the Netherlands (Graamans et al., 2018).

For an aeroponic system for lettuce, it was found that water use could be reduced by more than 50% compared to an Ebb-and-flow system (Carotti et al., 2023). In the U.S., water costs for vertical farming are, on average, 12 times lower compared to traditional farming (Moghimi & Asiabanpour, 2023).

The indoor environment allows for whole-year production with no seasonality (Benke & Tomkins, 2017). For wheat production, the closed environment meant that instead of once a year, wheat could be harvested 5 times a year (a 70-day growing period) (Asseng et al., 2020). Moreover, experiments with optimized lighting and increased CO2 levels benefited wheat production. Another benefit of a closed environment is that much fewer pesticides must be used, making food healthier. Food security increases since there are lower risks of diseases among crops due to invasive species (Benke & Tomkins, 2017). In addition, environments that are not suitable for outside agriculture can become food producers (Van Gerrewey et al., 2022). Another factor favoring vertical farming is its more stable production than traditional farming. This leads to traditional farmers paying for insurance and subsidies by, for example, the U.S. government, to compensate for loss of production (Moghimi & Asiabanpour, 2023).

Land use

When vertical farming is compared to traditional farming, much less land is needed (Van Gerrewey et al., 2022). In addition, studies showed that vertical farming compared to other types of urban farming and greenhouses is more space-efficient (Wicharuck et al., 2023). Vertical farming is found to increase the yield compared to horizontal hydroponics by 13.8 times by stacking crop production in lettuce (Touliatos et al., 2016). In lower-income countries, the feasibility of farming in larger cities is less effective compared to higher-income countries due to the lack of suitable space in cities (Badami & Ramankutty, 2015).

Social & Educational

Since vertical farms are located in cities, they can bring educational services. It enables a platform for a society where people can be educated on food production and health (Kalantari et al., 2018). Furthermore, cooperation between vertical farms and schools can be established to facilitate learning activities. Vertical farms can also beautify a city if it does not have much greenery yet (Khalil & Wahhab, 2020). Next to beautifying a city, vertical greening can reduce the air temperature in urbanized areas (Khalil & Wahhab, 2020). This is especially relevant in hotter cities around the world. Another benefit is that vertical farms create new job opportunities in cities (Wood et al., 2020). These can be very diverse jobs in engineering, bio-chemistry & technology, and construction & maintenance (Benke & Tomkins, 2017). In addition, moving food production in cities can improve food availability in poorer neighborhoods. For instance, in the U.S., poorer neighborhoods suffer from “food deserts” where access to healthy food is limited (Wood et al., 2020). Cities in the U.S. such as Detroit, which experienced severe economic and population decline, have seen developments in urban agriculture (Specht et al., 2016). In a questionnaire among citizens of Berlin, vertical and aquaponic farming was seen as one of the least favorable forms of farming in a city. In contrast, rooftop farming and other less technically advanced methods were perceived much more favorably (Specht et al., 2016). Moreover, consumers are generally skeptical about food innovations, which harms the perception of vertical farming (Avgoustaki & Xydis, 2020). However, it was found that consumers’ opinion on vertical farming is not much affected by the fact that LEDs are used and that perceived sustainability is the main driver for consumers accepting vertical farming for food production (Jürkenbeck et al., 2019).

Electricity Use

Energy costs for vertical farming can be divided into three categories: lighting, climate control, and crop operations (Appolloni et al., 2022). Vertical farming, unlike urban farming and greenhouses, excludes the use of sunlight, which implies LEDs. Most electricity is used to power LEDs (between 42 to 80 percent), then climate control (between 16 and 43), and lastly a few percent for crop operations, depending on the crop type. For Lettuce, around 70% of the electricity costs were by lighting, and for tomatoes, it was almost 75%. Despite LED prices having reduced substantially, such as in the U.S. from more than 10 USD in 2010 to below 1 USD in 2019 (Freeing Energy, 2021).

In optimal growing conditions for lettuce in a highly optimized environment, the electricity use would be 4371 kWh for 1000 kg of lettuce (Lozano-castellanos, 2024). Based on this electricity figure, vertical farming on a large scale could hardly be economically viable (Stanghellini & Katzin, 2024). This is due to the high electricity usage when LEDs are used. In contrast, sunlight can be used without any costs and does not have polluting side effects (fossil-fueled power generators for electricity). Furthermore, if all electricity produced is from sustainable sources, balancing the electricity grid would be needed, which does not match the high usage of LEDs in vertical farms. For the US, energy costs were on average 10 times higher than traditional farming (Moghimi & Asiabanpour, 2023). For lettuce, it was estimated to be 0.464 USD/kg. A study on indoor wheat production calculated that despite yields being 100 times more than traditional farming, electricity costs would still make it not competitive in the current environment (Asseng et al., 2020). Half of the total costs were associated with electricity powering the artificial lighting. Due to energy efficiency, it could be more cost-effective not to maximize yield (Asseng et al., 2020).

Skilled Labor & labor costs

Vertical farming can lead to many different job opportunities compared to traditional farming, including higher-paid jobs in engineering. A big difference between traditional and vertical farming is that skilled labor is much more needed in vertical farming. This will make labor costs almost 5 times as high for vertical farming compared to traditional farming. Labor costs account for 2/3 of the total production costs for crops and are almost 1 USD/kg for lettuce (Moghimi & Asiabanpour, 2023). However, in countries with a shrinking labor pool such as Japan, it can create opportunities as vertical farming is less labor intensive, and could be faster to adopt robotics (Achard, 2024).

Initial & Equipment costs

The costs of setting up a vertical farm are high (Oh & Lu, 2023). Compared to greenhouses, the initial costs for vertical farming can be 10 times more expensive than greenhouses, and operating the farm more than 5 times per square meter (Butturini & Marcelis, 2019). Furthermore, real estate costs can be very high in cities. For Melbourne and Sydney in Australia, respectively, square meter costs are 870 times higher in the cities compared to farmland in their surrounding areas in the same state (Benke & Tomkins, 2017). In the U.S., there are affordable, sometimes vacant buildings in industrial areas such as New York, Chicago, and Detroit. AeroFarms converted a lumberyard to a vertical farm in Newark, New Jersey. For larger-scale high-tech vertical farms, the average infrastructure of existing buildings might not be sufficient (Specht et al., 2014). Scaling up a farm is also more complex and costly than traditional farming (Benke & Tomkins, 2017). In urban environments, the areas next to the facility may be unavailable or very costly to purchase. In addition, urban and thus vertical farming is not well considered in the city infrastructure (Petts, 2001; Pölling, 2016). Another issue is that equipment costs are much higher than the actual building costs for vertical farming (Asseng et al., 2020). Unlike traditional farming, equipment in vertical farming is also much more prone to maintenance and depreciation. LEDs need replacement approximately every 5 to 10 years (Hortibiz, 2021). It is estimated that around 10 LEDs are needed per square meter, which leads to much heat creation. Some vertical farms have incorporated exporting excess heat to nearby residential areas for extra income since radiators also increase electricity use even more.

Crops

A limited number of vegetables, such as lettuce, strawberries, and tomatoes, can be used for vertical farming (Benke & Tomkins, 2017). Mushrooms do not require light for photosynthesis, and many types of mushrooms are grown in stacked layers indoors (Shields, 2020). Wheat, grapes, and tree fruit would theoretically also be an option. However, for wheat, it was estimated in an experiment that the cost/return for producing wheat in a vertical farm would be 45/1 despite yield being a few hundred times higher than traditional farming (Asseng et al., 2020). Therefore, vertical farming has been looking into crops with a high value per kg produced. One of them is lettuce, which is the most used produce in vertical farming. Therefore, most vertical farming and indoor growing studies have tested lettuce (Nájera et al., 2022). In addition, it has short growth cycles, which is easier to track for data collection. In the indoor growing industry, the most used crops are leafy vegetables (lettuce), tomatoes, herbs, flowers, and microgreens, with leafy vegetables being used in more than 50% of indoor growing globally (Wong et al., 2020). This is believed to be an issue in Singapore, where indoor-grown crops such as lettuce are not as much used in the Asian kitchen as in Western countries (Tham, 2024). On the contrary, CEA does make growing crops possible in environments where they cannot be grown outdoors (Achard, 2024). Cost-effectiveness can be increased by marketing vertical farming crops as locally, fresh, and healthier (pesticide-free) food, which makes consumers willing to pay a higher price for the crop (Van Gerrewey et al., 2022). Although the US allows food produced without soil to be sold as organic food, the EU does not. A side note is that vertical farming does not improve food affordability or secure better availability (Badami & Ramankutty, 2015).

Public Support

In Appendix E, an overview was made of the public support by governments in vertical farming. Singapore and the United Arab Emirates, due to their small size and hot climate, specifically identified vertical farming as a solution to improve its shortcomings in reliance on food imports. This has not led to significant funds yet for vertical farms in these countries. In Western countries, while there is financial support from governments, the exact amounts directly supporting vertical farming are unclear. Although sustainable agriculture receives significant financial support, China does not explicitly inherit vertical farming. Japan on the other hand can be considered an exception since funding can be traced back to vertical farming. Next to the EU with the farm-to-fork strategy, individual cities are also concerned with food policies. In 2015, initiated by the city of Milan, the Milan Urban Food Policy Pact was signed when Milan held the EXPO (Milan Urban Food Policy Pact, 2024). Only 32 out of 148 cities from the Milan Urban Food Policy Pact incorporated effective food measures (Filippini et al., 2019). A little more than a handful of cities focus specifically on food security, which could theoretically entail increasing urban food production.

Sustainability

Global transportation of food entails carbon dioxide emissions, which are significantly reduced by vertical farms being much closer to large population areas, since they can be located in urban or peri-urban environments (Benke & Tomkins, 2017). In addition, reduced food waste due to smaller transportation distances and water consumption all contribute to vertical farms' sustainability. Transportation costs of food almost do not exist with vertical farming, with supply and demand closely integrated (Benke & Tomkins, 2017). The transport of fruit and vegetables accounts for 36% of all emissions of global food transportation, which has a big impact, considering that food transportation accounts for just over 5% of global carbon dioxide emissions, estimated in 2017 (Li et al., 2022).

On the contrary, vertical farming does have high electricity costs, which are mainly produced with fossil-fueled power generators. If vertical farming's electricity were solely self-produced with solar panels, it would need 20 times more roof space than is available on a multi-layer vertical farm (Benke & Tomkins, 2017). For two cases, solar panels on a vertical farm could account for only 11.6% and 8.4% of total energy consumption (Teo & Go, 2021). This means that the carbon dioxide from reduced transportation might be offset by energy use, and sustainability is therefore questionable. One study concluded that, everything considered, vertical farming leads to lower CHG emissions, however, the study concerned only a case in Sweden (Martin et al., 2023).

Financial Aspect of Vertical Farming

The advantages and disadvantages of vertical farming compared to traditional farming are summarized in Table 3.1. Some advantages are large improvements compared to traditional farming, such as the yield and reduction of water, nutrients, and pesticides. The financial impact, however, is relatively low for these advantages. At the same time, the disadvantages in increased energy costs, labor difficulties, and maintenance have a significant financial impact. Therefore, energy, labor, and investment costs must be considered thoroughly for the financial assessment of the business case.

Table 3.1: Summary of financial advantages and disadvantages of vertical farming

Practice	Cause	Source	Difference to traditional farming	Financial importance
Advantages				
Yield	Optimized use of LEDs to grow crops	(Van Gerrewey et al., 2022)	Large	Medium
Circular Environment	A closed-loop system limits the use of water, nutrients,	(Carotti et al., 2023)	Large	Low
Land use	Due to verticality, more efficient space use	(Wicharuck et al., 2023)	Large	Depends
Social & Educational	Beautify a city, lower heat, job opportunities, and increase equality	(Wood et al., 2020)	Large	Uncertain
Disadvantages				
Energy costs	High electricity costs due to the use of LEDs	(Moghimi & Asiabanpour, 2023).	Large	High
Skilled Labor & Labor costs	Labor costs are much higher due to skilled labor needs	(Moghimi & Asiabanpour, 2023).	Large	High
Initial costs & maintenance	Set-up costs are much higher, as well as scaling up	(Butturini & Marcelis, 2019)	Large	High
Crops Variety	A limited number of crops can be grown as economically viable	(Benke & Tomkins, 2017)	Medium	Medium
Public Support	Limited financial support by governments for vertical farming	(Filippini et al., 2019)	Large	Unknown
Uncertain				
Sustainability	Transportation emissions reduction, increased electricity use	(Benke & Tomkins, 2017)	Uncertain	Low

3.2 Vertical Farms as of 2024

In 2022 and 2023, there were notable bankruptcies and declines in vertical farming companies in the United States. In Appendix F, the projected market size in vertical farming is compared in various sources, and the market size is expected to grow, especially in North America. The causes of the bankruptcies are explored to determine what potential business risks must be accounted for in the business case. Since the bankruptcies were very recent, academic literature studies have not been conducted yet, therefore available sources on

Google were used to examine the decline in vertical farming. Table 3.2 showcases an overview of U.S. vertical farming companies that went bankrupt or had to scale down their business.

Financing has been characterized as one of the significant issues of vertical farming since investors expect quick growth, which is harmful in the long run (Garwood, 2022; Gordon-Smith, 2023). This, for example, led to the bankruptcy of Fifth Season, which incorporated robotics into its vertical farm (Marston, 2023). In 2023, there was a decline of almost 90% of venture capital in vertical farming after significant funding from 2019 to 2022 (Glasner, 2024; Gordon-Smith, 2023; Vertical Farm Daily, 2024b). Kalera filed for bankruptcy in 2023 due to its lack of performance in the trading market (Garwood, 2022). Vertical farms such as Bowery Farming and Iron Ox had to decrease their workforce substantially to stay afloat (Bradbury & Fishlow, 2023; Wessling, 2022). This was partially because vertical farming needs both engineers and growers as labor. For Upward Farms, the owner mentioned that the reason it closed is due to the complexity of vertical farming (Harvey, 2023). This is also caused by the fact that vertical farms focus too much on R&D (Gordon-Smith, 2023). In general, vertical farms were caught between being a technology company or a farmers' business, leading to too low involvement of experienced growers (Gordon-Smith, 2023; Vertical Farm Daily, 2023a). Vertical Farms' sales pitch to Silicon Valley investors has been to picture themselves as a tech company instead of a farm (Peters, 2023). Many vertical farming start-ups developed complex software around their operations, incorporating high costs. Low interest rates fueled the issue of quick growth expectations and FOMO (Fear of missing out) by investors. The most notable bankruptcy was by the most prominent U.S. vertical farming company, AeroFarms. The leading cause was high operating costs (Vertical Farm Daily, 2023a). However, a few months later in 2023, it was reported that new financing had been realized among investors and the business could continue (Petrak, 2023). Focus areas for the business model of vertical farming are, therefore, focusing on long-term growth, energy efficiency, and the core business model of establishing positive unit economics (Vertical Farm Daily, 2023b). Energy usage was listed as the key issue for many vertical farming companies that are financially unstable or filed for bankruptcy (Garwood, 2022). Unit economics also includes labor costs and sales prices.

Table 3.2: Overview of the recent bankruptcies, most notable vertical farms in the U.S

Vertical Farms	Type	Issue	Cause	When	Employees	Funding	Source
AeroFarms	Vertical Farm	Bankrupt, but continuing	High operating costs (Energy, Labor, Construction)	2023	130 - 160	$240 – 313 million	(Vertical Farm Daily, 2023a)
Fifth Season	Vertical Farm (Robotics)	Bankrupt	Cash Flow, Investors	2022	100	$35 million	(Marston, 2023)
Kalera	Vertical Farm	Bankrupt	Performance Trade Market	2022	200	$10 million	(Garwood, 2022)
Upward Farms	Vertical Farm (Aquaponics)	Bankrupt	"Infinitely complex challenges," scaling issues	2023	100 +	$134 - 142 million	(Harvey, 2023; Heater, 2022)
Bowery	Vertical Farm	Lay-offs, Valuation drop	Financial challenges	2023	400 - 500 (before Lay-offs)	$650 million	(Bradbury & Fishlow, 2023)
Iron Ox	Vertical Farm (Robotics)	Lay-offs	Strategic shift to refocus on the core business	2022	100 Before Layoffs → Little over 50 after	$98 million	(Wessling, 2022)
AppHarvest	High Tech Greenhouse	Bankrupt	Labor & Productivity challenges	2023	500	$475 million	(Banchhor, 2023)
Smallhold	Vertical Farm	Bankrupt, continued business	Decline Venture Capital, Stagnant growth mushrooms	2024	81	$28.8	(Marston, 2024; Vertical Farm Daily, 2024d)

3.3 Conclusion Chapter Vertical Farming in 2024

The sub-research question aimed to be answered is: *What is the current economic landscape of vertical farming?* From the literature review, it becomes clear that vertical farming currently has many advantages related to its circular environment, such as no pesticide use, high yield, much less water usage, and year-round stable production. However, the disadvantages, such as higher electricity use, labor, and investment costs, have a much higher financial impact. Therefore, these factors must be thoroughly considered to assess the viability of vertical farming. Furthermore, lettuce has been used the most as produce in vertical farming. The disadvantages of vertical farming (investment, labor, and energy costs) have led to multiple bankruptcies of vertical farms in the U.S. in 2022 and 2023. Another cause is the hype among investors, which led vertical farms not to focus on their core business of growing crops. This implies that labor resources must concentrate more on growers than engineers for a profitable business model. In addition, achieving positive unit economics in the business case is important, which was lacking in other vertical farms. The next step is to find which type of business models can be used for vertical farming and what makes them more successful than others, including the parameters critical in the business model.

4. Business Models for Vertical Farming

In Chapter 3, it was found that while vertical farming has several advantages compared to traditional farming, the disadvantages are financially more significant. This led to multiple bankruptcies of vertical farms companies in the U.S. Literature on business models used in vertical farming will be reviewed to support a business case. Therefore, the following sub-question was aimed to be answered: *What business models can be used for vertical farming?* Since the literature on vertical farming business models is limited, the review was broadened by incorporating urban farming business model literature. First, different business models in urban farming are explored, and their economic impact is examined to determine which performs better than others. This contributes to understanding the overall business model. Secondly, business parameters, risks, and the cost structure for vertical farming are analyzed, which are used as considerations for the financial analysis of the business case.

Literature Review Protocol

The following search engines were used in the literature review in September 2024: Scopus, Google Scholar, and Google. ChatGPT was used to find alternative keywords to "vertical farming" and "business model". In addition, a visual map of research concepts related to vertical farming was used to find keywords (Stein, 2021). In Table 4.1, an overview of the keywords found and used in Scopus is showcased. Table 4.2 shows an overview of articles found by combing a "vertical farming" related keyword and a "business model" related keyword. The numbers indicate the articles found and the selected articles are given in brackets. Several articles included multiple keywords and thus were seen numerous times. Therefore, 19 articles were selected, while the table counts 35. In addition, keywords from Table 4.1 were omitted if no valuable articles were found, and related keywords were combined, such as "Indoor growing" and "Indoor farming." Pölling, Sroka, and Van der Schans are the most notable contributors to urban farms' business models literature (Pölling et al., 2016, 2017; Van Der Schans, 2010; Van Der Schans et al., 2016). Figure 4.1 shows the structured literature review selection process. After keywords were selected, articles were found. These articles were filtered based on the abstract and title, after which 19 were found. In Appendix G, in Table G.9, an overview is made of all the literature, including how a specific study was found, the concept, the study field, and its findings.

Table 4.1: Keywords Search for Literature Business Models

Keywords	Related Keywords Found	Used Keywords
Vertical Farming	Hydroponics, Aeroponics, Aquaponics, Indoor Farming, Urban Agriculture, LED Lighting, Controlled Environment Agriculture (CEA), Crop Rotation, Sustainability, Resource Efficiency, Vertical Space, Soil-less Cultivation, Climate Control, Yield Optimization, Food Security	Indoor Farming, Urban Agriculture, Controlled Environment Agriculture (CEA)
Business Model	Value Proposition, Revenue Streams, Customer Segments, Cost Structure, Key Activities, Key Resources, Key Partners, Channels, Customer Relationships, Market Positioning, Competitive Advantage, Distribution Strategy, Pricing Model, Business Ecosystem, Scalability	Value Proposition, Revenue Streams, Cost structure, Customer Relationships, Pricing Model

Table 4.2: Articles found by: Article Title, Abstract, and Keywords

	Business / Pricing Model	Value Proposition	Revenue Streams
Vertical Farming	6 (6)	2 (1)	2 (2)
Urban Farming / Agriculture	Title & Keywords 9 (6), 30 (1)	14 (2)	15 (3)
Indoor Farming / Growing	46 (2)	3 (0)	2 (1)
Controlled Environment Agriculture (CEA)	50 (3)	0	0
PFAL (Plant Factory with Artificial Lighting)	6 (1)	0	0

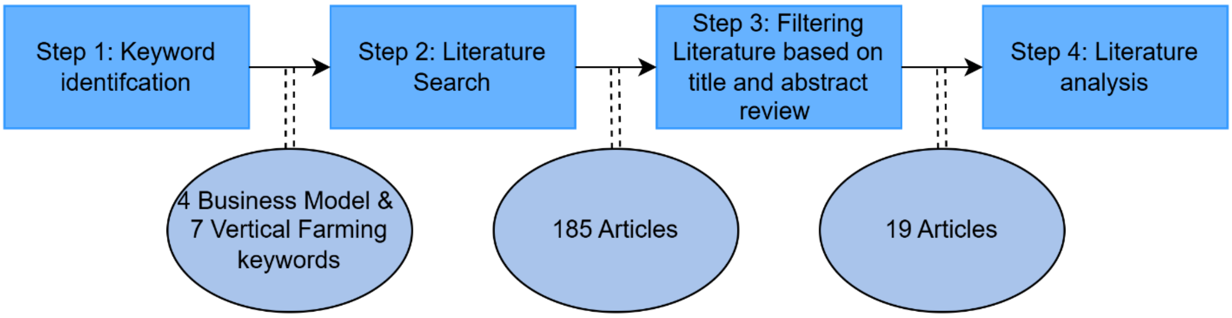

Figure 4.1: Structure literature review, vertical farming, and business models

4.1 Urban Farming Business Models

In this section, different business models of urban farming are identified, which could be used in a vertical farming initiative. An overview of all the different types of business models for urban farming described in the literature can be seen in Table 4.4. Only when multiple articles described a business model type were they included in the table. Literature in urban farming started in 2010 by Van Der Schans (2010), who described three different types of business models: “differentiation,” “diversification,” and “specialization” for urban farming. The study by Appolloni et al. (2022) summarized six business models of urban farming, and their success factors (“drivers”) and challenges. Table 4.4 can be used to compare an urban farm's different options for its business model. “Differentiation,” “diversification,” “specialization,” “experience,” and “low cost” have been primarily described in the literature. Despite the different business models, similarities between urban farms using different business models were found. While urban farms may use different business models, they mostly use the same set of solutions for business parameters (except for the “specialization” business model) (Sroka et al., 2023). These include the importance of customer relationships, short supply chains, promoting local food, and direct sales to customers. It is also common that instead of focusing on one business model, urban farms use a combination of different business models (Pölling et al., 2016; Pölling, Prados, et al., 2017). In Table 4.3, drivers and barriers that are mostly universal to urban farming are showcased. Business factors leading to improved financial performance are customer relationships, short supply chains, direct sales, and adjusting to an urban environment. The main challenges include managing supply & demand, scalability, and land access. External challenges that cannot be directly affected by an urban farm are indicated as more challenging, such as finding employees, wage costs, and scalability (Sroka et al., 2023). Furthermore, not adapting to the urban environment increases its challenges. Table 4.4, also showcases drivers and barriers that need to be considered for specific business models. For example, the “experience” business model has the following factors that should lead to better business performance: responding to consumer needs and communication strategy. Challenges with the “experience” business model are: keeping consumers, profitability, low-income levels, lack of public support, financial resources, and wage costs.

Table 4.3: Drivers & Barriers Urban Farming

Drivers	
Customer relationships	(Martin & Bustamante, 2021; Sroka et al., 2023; Wiśniewska-Paluszak et al., 2023)
Short supply chains	(Pölling, Prados, et al., 2017; Pölling, Sroka, et al., 2017; Sroka et al., 2023)
Direct sales	(Pölling, Sroka, et al., 2017; Sroka et al., 2023)
Adjusting to an urban environment	(Pölling, Sroka, et al., 2017; Sroka et al., 2023)
Promoting local food	(Sroka et al., 2023)
Sustainable values	(Wiśniewska-Paluszak et al., 2023)
Social & Educational services	(Specht et al., 2015)
Local resources	(Specht et al., 2015)
Challenges	
Managing supply and demand	(Martin & Bustamante, 2021; Sroka et al., 2023)
Variety produce	(Martin & Bustamante, 2021)
Scalability	(Martin & Bustamante, 2021; Sroka et al., 2023)
Finding employees	(Sroka et al., 2023)
Land access	(Richardson et al., 2024; Sroka et al., 2023)
Living wage farmer	(Richardson et al., 2024)

Usability Business Models

After identifying the business models, it is now explored which ones are the most suitable for profitability. A recurring important business factor is the importance of the location of an urban farm (Pölling et al., 2016; Sroka et al., 2023). The location of the farm affects the use of a specific business model, as was shown by the fact that urban farms in a higher population density area lean more towards a "low cost" business model (Pölling et al., 2016). In a "low cost" business model, economies of scale are needed for sufficient production and profitability. This may be difficult due to a lack of available land in an urban environment. Therefore, a lack of space means that urban farms mainly focus on "differentiation" and "diversification" instead of a "low cost" business model to be profitable (Pölling, Prados, et al., 2017). When the business model is not adapted to the urban environment, it burdens the farm (Pölling, 2016). Furthermore, the farms using a "diversification" and especially a "differentiation" business model also have stronger ties to their urban environment by providing social services and direct marketing (Pölling, 2016). The performance of urban farms based on their business model has not been much analyzed. However, it was found that urban farms using the "differentiation" and "diversification" business models were performing better than urban farms using the specialized business model (Pölling, Sroka, et al., 2017). This is because the "differentiation" and "diversification" business models can better take advantage of urban opportunities, such as using direct marketing in the "diversification" business model, and proximity to the market (short supply chain) for the "differentiation" business model. The "experience" business model was found to have the most significant barriers (Sroka et al., 2023). It suffers from low income levels and a lack of public support. Interestingly, public support was considered positive by farmers using a "differentiation" or "diversification" business model but negative when using a "specialization" business model (Pölling, 2016). It was found that "diversified" farms were mostly focused on social services and personal contact with consumers. Therefore, business models such as "differentiation" and "diversification" should be preferred when choosing a specific type. More importantly, the drivers and challenges must be considered when selecting a business model. For example, in Table 4.4, one driver for the differentiation business model is having skilled employees, while a challenge could be finding enough consumers. This implies that when one wants to start a farm with a "differentiation" business model, these factors need to be considered and satisfied to increase the probability of the farm being viable. Moreover, based on the business environment, one could choose the business model where the business environment suits the drivers and where the challenges are mitigated the most.

Table 4.4: Overview of Urban Farming Business Models

Business Model	Concept	Idea	Focus	Drivers	Challenges	Sources
Differentiation	Farms try to be different than competitors	Offer niche products	Search for the market gap	- Identify locally demanded high-value products - Quality produce - Skilled employees - Proximity to the market - Large number of distribution channels	- Finding enough consumers - Differ from competition - Finding skilled employees - Financial resources - Lack of appreciation for local agriculture	(Appolloni et al., 2022; Pölling, Prados, et al., 2017; Pölling, Sroka, et al., 2017; Sroka et al., 2023)
Diversification	Farms produce diverse products in small quantities	Concentrate on small buyers	Close relationship with consumers	- Attractive branding - Offering quality, demanded, and a wide range of produce - Being close to recreation increasing popularity - Proximity to the market - Human capital - Close relationship with consumers - Social media marketing	- Reach different consumers - Manage all activities - Wage costs - Finding employees	(Appolloni et al., 2022; Pölling, Prados, et al., 2017; Pölling, Sroka, et al., 2017; Sroka et al., 2023; Van Der Schans, 2010; Van Der Schans et al., 2016)
Experience	Farms focus on other activities, besides production	Offer educational services	Personal contact with consumer s, which implies skills in customer relationships needed	- Responding to consumer needs - Communication strategy	- Keeping consumers - Profitability - Low-income levels - Lack of public support - Financial resources - Wage costs	(Appolloni et al., 2022; Sroka et al., 2023; Van Der Schans et al., 2016)
Specialization	Farms concentrate on high-value products	Use economies of scale in urban environment s (heat, water)	Best suited around metropolitan areas	- High-quality products - Large Workforce	- Land access & resources - Profitability	(Pölling, Sroka, et al., 2017; Sroka et al., 2023; Van Der Schans, 2010)
Shared Economy	Farms cooperate with customers in production	Customers take part in activities such as harvesting or even have shared ownership	A community willing to be involved	- Strong community - Define the company's purpose	- Involvement of local government and consumers - Economic viability	(Appolloni et al., 2022; Van Der Schans et al., 2016)
Low Cost	Urban farms focus on cost-efficiency and economies of scale	Use vacant resources in cities	Production focused on one or a few products	- Benefit from synergies - Sufficient scale - Skilled employees - R&D pre-investment	- Minimize production costs - Find a market for a large quantity - Access to skilled employees	(Appolloni et al., 2022; Pölling, 2016; Pölling, Prados, et al., 2017; Van Der Schans et al., 2016)

4.2 Key business factors of vertical farming

This chapter explores which business parameters affect vertical farming to identify the most important parameters impacting profitability. Urban farming literature was examined to find business models broadly defining a farm operation. Literature studies on vertical farming's performance parameters, profitability risks, and cost differentiation were explored. This is integrated in the financial model.

Performance parameters

The study by Marczewska et al. (2023) aimed to find business model variables for vertical farms' performance. They set six different variables: location (urban environment with a population > 50,000), customer engagement (focus), revenue stream (multiple), crop types (multiple), B2B (present), and performance (high/good). It was found that the highest business performance is obtained by locating in urban areas, strong consumer engagement, and B2B sales channels. In addition, vertical farms should consider having multiple revenue streams and different crop types. Furthermore, various business combinations were tested. The vertical farms that incorporated the parameters below demonstrated improved profitability.

- Customer Engagement, B2B → (Both combined) → High Performance
- Location, Customer Engagement, B2B → (Both combined) → High Performance
- Multiple Revenue streams, Multiple Crop Types → (One of them) → Good Performance
- Multiple Revenue streams → (Sufficient / Necessary) → Good Performance
- Multiple Crop Types → (Necessary) → Good Performance

A study by Moghimi & Asiabanpour (2023) was conducted to find out which possible locations in the US will be most competitive for vertical farming compared to traditional farming. The locations were selected based on their differences in energy prices, physical location across the U.S., urbanization level, environment, and competition from nearby traditional farms. The cities of Austin and Miami were most attractive for vertical farming. Des Moines and Chicago were average, and New York, Los Angeles, and Boston were the least attractive. Austin was found to have low energy and labor costs and relatively high crop sell prices, while for Miami, the agricultural land price was relatively high and low energy prices. This reinforces the importance of energy prices for vertical farming, which was also found in a case study on a hypothetical vertical farm (Song et al., 2024). In addition, Song et al. (2024) found that price elasticity severely impacted financial performance. Urban, peri-urban, rural, or a specific climate does not guarantee positive or negative viability, although vertical farming does deliver substantial benefits to the environment (Baumont de Oliveira et al., 2022).

Risks

Several risks were identified for vertical farming, which can be seen in Table 4.5 (Baumont de Oliveira et al., 2022). This is important for the business case since these can substantially affect business performance. It also showcases that vertical farms, on average, have considerably more risks than greenhouses or field production. As can be concluded from Table 4.5, labor costs, retention, and energy costs are valued as a high risk to a vertical farm. Therefore, these factors were considered in the financial model analysis. Other high risks for vertical farming seen in Table 4.5 are related to planning and production. Planning risks are more associated with the location of the vertical farm. At the same time, production is more concerned with the technical details of a vertical farm, which were not considered in the financial model since technology factors were outside this research's scope. Other risks that were accounted for in the business case of vertical farming are market price variances and financial risks (Moghimi et al., 2020). Yield risk is weighted low for vertical farming by Baumont de Oliveira et al. (2022) but should be considered according to Moghimi et al. (2020). Therefore, yield variance was also tested in the financial model.

Table 4.5: Risk Parameters and Likelihood (copied from: Baumont de Oliveira et al., 2022, p.7)

Risk Parameters	Risk Type	Vertical Farm	Greenhouse	Field-production
Yield	Weather Conditions	Low	Medium	High
	Pest Outbreak	Low	Medium	High
	Pathogen Outbreak	Medium	Low	High
Production	Environmental control (malfunctioning HVAC)	High	Medium	Low
	Electrical outage	Medium	Low	Low
	Incorrect nutrient/pH dosage	Medium	Low-Medium	Low
	Irrigation (flooding, clogs)	High	Medium	Low
	Equipment failure	High	Medium	Low
Cost	Energy expense variability	Very High	High	Low
	Underestimated labor costs	High	Medium	Low
	Technology advances	High	Medium	Low
Labor	Poaching of staff/Loss of expertise	High	Medium	Low
	Accidental damage	High	Medium	Low
Safety	Fire	Low	Low	Low
Planning	Zoning codes	High	Medium	Low
	Change of lease agreement	High	Medium	Low
Market	Market competition	Medium	Medium	Low
	Local supply/demand situation	Low-Medium	Low	High

Costs

Since energy and labor costs are both considered risks and relatively high for vertical farming compared to traditional farming, it is essential to know how much these factors contribute to the cost structure in the business model and how they can be possibly reduced. For vertical farming, 2/3 of the costs are catered to labor and 1/3 to energy costs (Moghimi & Asiabanpour, 2023). Another source pointed out that production and market prices matter most to financial performance, including labor and energy costs (Armas et al., 2023). Crop yields, the space used, and depreciation costs, also impact financial performance (Baumont de Oliveira et al., 2022). These costs should thus all be included in the financial analysis. Another study found that labor accounts for 57% of the total costs, energy for 12%, nutrients for 6%, and other costs for 25% (Ion, 2022). Still, when rent is free, labor and electricity costs are low, and sale prices are premium, profitability is not guaranteed (Baumont de Oliveira et al., 2022). Lettuce and basil were found more profitable in most scenarios than tomatoes (Xydis et al., 2020). Lettuce is also the most researched crop for indoor and vertical farming (Benke & Tomkins, 2017; Nájera et al., 2022). Electricity use for crop production can be optimized where, based on the electricity prices on a day, the crop production is adjusted for optimal cost-effectiveness (Avgoustaki & Xydis, 2020). Another idea to reduce energy costs is to use small-scale wind energy sources in combination with hydroponics (Xydis et al., 2020). To decrease costs, digitalization could support vertical farms' business models more than traditional farming (Thomson, 2022). This can be achieved by faster learning, flexibility to market changes, increased productivity, and shortening the supply chain by placing vertical farms on strategic locations. Other interventions that could lead to higher profitability are: more considerable scaling of the vertical farm, decline of investment costs over time, improved labor and electricity use efficiency, and higher yield and revenue prices (Baumont de Oliveira et al., 2022). These improvement factors are considered in the financial analysis.

4.3 Literature review conclusion

The following sub-question was aimed to be answered: *What business models can be used for vertical farming?* According to the literature, six business models are used in urban farming. The "differentiation" and "diversification" business model is more profitable than the 'specialization" business model, while the “experience” business model entails more significant barriers. Furthermore, drivers and barriers for a business model type must be considered, as seen in Table 4.4. Preferably, a business environment that accommodates either the “differentiation” or “diversification model” for increased business performance must be chosen. Customer relationships, short supply chains, direct sales, and adjusting to an urban environment are business drivers leading to improved financial performance. The main barriers include managing supply and demand, scalability, and land access.

For vertical farming specifically, it was found that focusing on customer engagement, B2B, and additionally, a location with a population above 50,000 leads to high business performance. Multiple revenue streams and multiple crop types also lead to better business performance. Locations with lower labor and energy costs were identified as more likely to be profitable and thus need to be considered in the business case. The following risks must be considered as scenarios in the sensitivity analysis in the financial model: labor costs, labor retention rate, energy costs, market price, and yield. The next chapter will analyze the stakeholders in the case study. This will create an understanding of whether stakeholders' concerns with the project align with the literature on vertical farming. Furthermore, it can picture which type of business model is suitable based on the stakeholders' interactions and the case's location in York, Pennsylvania.

5. Stakeholder Analysis

In Chapter 4, business models in urban and vertical farming were analyzed. It was found that some business models can be more successful than others depending on the characteristics of the business environment. For a vertical farming project, the stakeholders must be analyzed to determine what roles and value they add to the business case. The case will be used as empirical data for the stakeholder analysis methods. In this chapter, the CEA project will be analyzed to determine if the stakeholders align or if there might be potential conflicts. The aim is to find an answer to the following sub-question: *How can the stakeholder ecosystem for the vertical farming case be developed?* This is important to find out since, depending on the stakeholder's interests, the type of business model(s) suitable for the case can be determined, as well as what value the stakeholders can provide for the project. The next chapter combines the business model literature, York business environment information, and stakeholder interactions to find a fitting business case.

5.1 York, Pennsylvania

Before analyzing the stakeholders, the business environment of York is described to understand stakeholders' concerns and potential opportunities for the CEA project. In Appendix D, information on York, PA can be found. This includes details on York's population, infrastructure, climate, wages, consumers, wholesale companies, and agriculture. This information is also used as input in Chapter 6 concerning the business model of the CEA project. A report in 2017 on the Eight-County Region of South Central Pennsylvania (Adams, Berks, Cumberland, Dauphin, Franklin, Lancaster, Lebanon, and York Counties), identified several SWOT factors and the ones below are relevant for the CEA project (PA South Central PREP, 2017).

- Strengths: Location (1-day drive, 40% US population), Transportation infrastructure
- Weaknesses: Workforce (Aging, not attractive for young people)
- Opportunities: Communities more interested in "buy local", educational opportunities
- Threats: lack of skilled workforce, competition with neighboring cities, loss of agricultural land and production, lack of financial capital access, and farming facing challenges due to environmental policies

York's Population is less than 50,000 (around 45,000) while having a population of above 50,000 was found supportive of higher business performance (Marczewska et al., 2023). A redeeming factor is that it is located close to highly populated areas and York has the transportation infrastructure to reach these places. A vital concern for the CEA project is the fact that there is an aging workforce and a lack of a skilled workforce. Based on the facility's automation and technology level, some highly skilled employees will be needed. Therefore, how this may impact the CEA facility's business case must be thoroughly considered. Furthermore, a lack of financial capital access is a threat. This requires the CEA facility to be economically viable within a reasonable time. Education is recognized as an opportunity and was also found to be one of the assets in the CEA project in Chapter 2.2. Interestingly, the threats of "loss of agricultural land and production" and "farming facing challenges due to environmental policies" may favor the CEA project since these will negatively impact traditional farming and make the CEA facility more competitive.

5.2 Stakeholders

Stakeholders are defined as: *"persons, groups, or organizations that are affected by the project, interested in the project, and/or able to affect the project"* (Buser, 2024, section 3.3). A stakeholder analysis can be done to analyze stakeholders which: *'aims to evaluate and understand stakeholders from the perspective of an organization, or to determine their relevance to a project or policy'* (Brugha & Varvasovszky, 2000, p.239). The analysis reviews stakeholders' positions, interests, influences, interrelations, and networks. They are used in policy making but also in management. By collecting this information, insights can be obtained on how decisions are made in different environments and perhaps identify possible chances to affect those decisions. In a stakeholder ecosystem, the potential of each stakeholder is analyzed, which supports the development of an effective relationship between the stakeholders, which creates value for a project or within an organization (Tarode & Shrivastava, 2021).

To analyze the ecosystem of the stakeholders, the stakeholders' roles, goals, and concerns will be described in this chapter. In Table 5.1, an overview of all stakeholders involved in the CEA project can be seen. The information on the stakeholders is based on interviews conducted with them, general information on the web, and to some extent information given by other stakeholders. It includes the stakeholders' role, goals, and challenges they perceive the CEA project might face. Stakeholders relevant to the project were initially based on a meeting in January 2024. At this meeting, Priva and Borlaug as agritech companies were introduced by the problem owner to the York State Fair where they met with representatives of the York State Fair, Susquehanna Real Estate, and York County Economic Alliance *(Internal Document).* Ideas were conceptualized for what the project could be and facilities at the York State Fair were examined to get an idea of what is needed for a CEA facility. These stakeholders were interviewed first. This includes the York State Fair, Susquehanna Real Estate, Priva, Borlaug, and the York County Economic Alliance, and the specific date and interviewee information can be seen in Appendix C. In these interviews, the participants were asked about potential other interviewees who may be essential and which organizations may still be missing from the project. Since the involvement of the Redevelopment Authority of the City of York (RDA) is limited and the ARM Institute is uncertain, these participants were not interviewed. Thus, the challenges they might perceive regarding the CEA project are unknown.

Table 5.1: Overview Stakeholder Partners in CEA project

Stakeholder	Type	Role	Goals	Perceived Challenges
York State Fair & Expo Center	Location (Landlord to CEA Project)	- Become Landlord of CEA facility (rent out facility to a grower)	- Have additional income to increase the economic viability of the Fairgrounds - Community is the number one focus for the Fairgrounds	- Possible 'Resistance of change' in the community due to emotional connection with fairgrounds - Concern if the CEA facility will still be economically viable in 5 years - Concern about the financial viability of the CEA industry overall
Susquehanna Real Estate	Location (Landlord to York State Fair)	- Identification Site Location - Information on the availability and location of resources (gas & electricity) at the York State Fair	- Increase the Economic Value of the York State Fair - Find out if a smaller urban farm in downtown York can work on a bigger scale	- Unsure if 40 acres is enough to make it commercially viable - Concerns if the electricity grid can be used at full capacity for the horticulture facility
York College	Education (knowledge, Workforce)	- Deliver interns for the CEA Project - Incorporate educational activities	- Attract more students by offering them internship opportunities in York	
Pennsylvania Department of Agriculture	Government (Investment)	- Soft support by bringing in partners helpful for the project - Provide funding	- Building a strong agricultural workforce - New market opportunities and investments in organic	- Unsure when the facility will be operational - Concerns about how employment will look

			- Protection for Pennsylvania agriculture (resiliency) - Bridging the gap between urban and rural context	
Redevelopment Authority of the City of York (RDA)	Local Government	- Potentially have the York State Fair acquire adjacent land now owned by the RDA for Scaling Up	- The renovated buildings should comply with building codes - Become economically beneficial (more taxes for the City of York) - In line with the city's larger development plans	
Borlaug	Company (Knowledge)	- Design Greenhouse and Execution - Service Provider Priva Systems - Budgeting of the project	- The project in York could serve as a demonstration ground for what the industry looks like in the present Regional center of excellence which does not exist yet in the U.S. for Controlled Environment Horticulture	- York State Fair location is limited for scaling up production
Greengrounds / Priva	Company (Knowledge)	- Climate Control Systems - Knowledge of Urban CEA Agriculture	- Foothold in North East USA for Priva - Showcase a successful project by Greengrounds	
York County Economic Alliance	Non-Profit → Civil Interest) (Project Manager, Investment)	- Project Manager (Manage Different Stakeholders & Assign Project Team) - Find Additional Funding Resources	- Offering High-paying Skilled Job Environment - Keep the York State Fair economically viable - Walkable job training & employment opportunity - Involve local or minority-owned contractors in the construction process - Brings back fairgrounds to their agricultural roots	- Long-run financial viability - Not clear to what degree the CEA facility will be commercial vs educational & workforce development - Difficult to access federal funding - Unknown construction costs
ARM Institute	Non-Profit → Private Interest (Investment, Knowledge)	- Test Ground Robotics	- Showcase Robotics Technology - Test Robotics Technology in Agriculture for Commercialization	

York State Fair

The York State Fair operates the yearly fairground and expo center that holds events throughout the year in the city of York. The role of the York State Fair is to become the landlord of the CEA facility *(Interview YSF)*. The CEA facility will be a “growers business” and thus will pay rent to the York State Fair. Therefore, while the York State Fair project will be developed on its location, they will not operate the CEA facility.

Susquehanna Real Estate

Susquehanna Real Estate owns the properties and land at the York State Fair. The York State Fair, however, is responsible for maintaining the buildings at the York State Fair. Susquehanna Real Estate is a relatively small real estate company and consulting company based in York, Pennsylvania *(Interview SRE)*. The name “Susquehanna” is from the river Susquehanna, which is an indigenous name. Clients include institutions, healthcare systems, and the York State Fairground. Before the project was considered in its current form, Susquehanna Real Estate did a financial investigation on the York State Fair *(Interview SRE)*. This included a review of the state of the buildings and also the economic prospects of the York State Fair.

York College of Pennsylvania

York College has a specific horticulture program near the York State Fair. The agricultural and educational aspects would be interesting for York College, for instance, for internships. They also have a strong entrepreneurial program, which could be beneficial (Interview YCEA). The CEA project can help York College attract students *(Interview YC).* In addition, it can be helpful for engineering programs as well. Students are also very interested in the York State Fair and the CEA project, which can benefit all of York County.

York County Economic Alliance

York County Economic Alliance (YCEA) was founded as a non-profit organization in 2012, by a collaboration between York County's chamber and economic development organizations (York County Economic Alliance, 2025). It is concerned with economic development in York County. The York County Economic Alliance will play a more considerable role and can take the role of project manager since the CEA project is materializing to the next stage *(Interview YCEA)*. York County Economic Alliance can help to work with all the stakeholders involved and support finding additional funding if needed (e.g. grants on the public level (federal, state, local) or private level). In addition, the York County Economic Alliance can assist in assigning the project team. Once the project is in operation, the York County Economic Alliance can take a step back where another stakeholder such as the York State Fair, York College, Priva, or a commercial grower can take over.

York County Economic Alliance aims to foster community growth by helping with economic development opportunities (York County Economic Alliance, 2025). In 2020, they released the York County Economic Action Plan, which was affected by the ongoing pandemic at that time (York County Economic Alliance, 2020). Several objectives and goals were set for the next 10 years (2020 to 2030). One objective is to offer more high-paying, skilled jobs by attracting more businesses. This could be directly affected by the CEA project. Other objectives that might be positively impacted with the CEA project are: more women and minority-owned businesses, decreasing the salary gap between white and non-white people, expanding cultural and recreational amenities, and reducing the number of households that have an annual income above the poverty line but only enough to cover necessities (York County Economic Alliance, 2020). The Bloom Business Empowerment Center was created to lend and grant capital to small businesses, and the majority of the funding is to support individuals of color or women *(Interview YCEA)*. This is a focus for the York County Economic Alliance and also is for the CEA project. Urban farming can be used to engage individuals who are not necessarily accustomed to farming as an employment opportunity that can also benefit the school district and historically disadvantaged communities.

ARM Institute

The ARM Institute was founded in 2017 as a non-profit when Carnegie Mellon University managed to win a bid to create the robotics-focused Manufacturing USA Institute funded by the Secretary of Defense ($80 million in federal funding) (ARM Institute, 2024). Pittsburgh, Pennsylvania, heavily relied on its steel industry for its economy, and once the industry declined in the late 20th century, the economy struggled, and the population declined firmly (Essey, 2024). However, it is becoming increasingly a technology and innovation-focused city led by the growing robotics sector. CEA can be the stepping stone of robotics since it is characterized by Carnegie Mellon University as the sector where robotics can be commercialized. In contrast, adoption in other sectors is still 10 to 15 years away *(Interview PO)*. The project at the York State Fair can set the stage for robotics in CEA. An opportunity for the CEA project is if it adopts robotics technology, which can reduce costs. Furthermore, students are generally not interested in traditional agriculture.

PA Department of Agriculture

The role of the Department of Agriculture in the project is to find appropriate resources and engage with partners *(Interview PA).* For instance, the potential of robotics from the ARM Institute and Carnegie Mellon University in combination with agriculture in York. This could also bridge the gap between Pennsylvania's urban vs rural context *(Interview PA)*. Several different grants are available, and the Department of Agriculture can give soft support. One of those grants is the Agriculture Innovation Program, which receives 2 million dollars a year. Climate change is a challenge for agriculture in Pennsylvania, and CEA development can be a method to cope with its effects and make agriculture more resilient.

The Department of Agriculture is focused on agriculture development and is concerned with the state's policies on agriculture *(Interview PA).* They have outlined focus areas for a successful future for agriculture, which entails promoting education in agriculture, protecting the environment, and supporting farmland. (Department of Agriculture, 2024). In 2019, the Pennsylvania Farm Bill was signed, which resulted in several grants for agriculture (Department of Agriculture, 2019). In 2021, an update on the status of the economic impact of agriculture in Pennsylvania was released (Econsult Solutons Inc., 2021). Eight policy focus areas were reported and the following three can be positively impacted by the CEA project: *"workforce development must be a priority," "strengthen and support organic promotion and enforcement," "Expand urban agriculture programs and opportunities"* (Econsult Solutons Inc., 2021, p.36). Urban agriculture is mentioned explicitly with the following explanation: *"The next frontier for agriculture in Pennsylvania will occur in urban communities, as vertical and indoor farming expands, as well as urban land reclamation will allow for more availability. Commonwealth programs and policies will need to be inclusive of urban opportunities, and additional supports and promotions may be required"* (Econsult Solutons Inc., 2021, p.36). The Urban Agricultural Grant Program also supports this policy focus (Commonwealth of Pennsylvania, 2024).

Redevelopment Authority of the City of York (RDA)

The RDA of the City of York is concerned with renovating or demolishing unused buildings in the City of York (City of York, 2024). The three objectives are that the renovated buildings comply with building codes, become economically beneficial (more taxes for the City of York), and align with the city's more extensive development plans. The RDA's role is to preserve residential and commercial properties in the City of York. The RDA acquires properties by donation, tax sale, or purchase.

The local government, including the City of York and York County, are involved and engaged but not actively *(Interview YCEA)*. They have similar interests as the York County Economic Alliance in keeping the fairgrounds economically viable, but also in the fact that it has the potential of providing walkable (the York State Fair is located in the city) job training and employment opportunities. The city government of York staffs the Redevelopment Authority (RDA), but it has been mainly on the periphery for the CEA project. It is aware and supportive of the project but has not taken a direct role. However, the RDA owns a parcel of land next to the York State Fairgrounds and is also sizable enough to be helpful for the York State Fair, which is a way they could contribute to the project *(Interview YCEA)*.

Borlaug

Borlaug was invited to participate in the York project via Priva *(Interview BL)*. Before the project, they met employees from Priva informally at horticulture events and therefore have known the Priva North American organization. The company Borlaug refers to Norman Borlaug, an agronomist who contributed significantly to increased agricultural production worldwide. Borlaug is a CEA service company focusing on crop climate systems, water systems, and the construction and planning of a horticulture facility (Borlaug, 2024). For the project, Borlaug can be the greenhouse designer and thus the owner's representative in the project design and execution *(Interview BL)*. Furthermore, Borlaug can be involved as a service provider for the Priva systems in the York project. In addition, there will be design and budgeting iterations, and Borlaug can play a role in the project's budgeting. Priva will deliver the systems needed for indoor growing and horticulture but Borlaug will carry out the service when it needs adjustment or maintenance.

Priva / Greengrounds

Priva will develop the systems and site components *(Internal conversations)*. For Priva, the project in York can be an opportunity to 'get a foothold' in the Northeast United States market. Since this project will focus on CEA and be located in a city, it has been chosen to involve both Priva and Greengrounds for the York project since Greengrounds is a start-up company and is part of the Priva Group. Greengrounds mission statement is: *'From Brownfields to Greengrounds'* (Greengrounds, 2024b). Priva develops and sells systems and technology for climate control and water systems in horticulture and indoor farming. Greengrounds, on the other hand, focuses on three pillars that support the planning and implementation of indoor farming in an urban environment.

- Strategic Food Resilience Planning: *"We work with policymakers and entrepreneurs to create comprehensive food resiliency plans. We address current needs and future challenges by integrating grassroots efforts with government policies. This builds a strong framework for food security, community alignment, and fosters long-term resilience"* (Greengrounds, 2024a, Our work).
- Integrated Farm Network Modeling: *"We use proprietary advanced simulations to find the best farm structures and food types for each unique ecosystem. Our approach maximizes resource use and yield while adapting to the specific local factors. This ensures our solutions are efficient, adaptable, and capable of thriving in diverse urban and peri-urban environments"* (Greengrounds, 2024a, Our work).
- Real Estate Planning and Execution: *"We plan and oversee the construction of urban food parks, managing the process from securing key stakeholders and permits to obtaining investments and overseeing construction. This includes finding optimal locations, reducing construction risks, and ensuring projects are sustainable and beneficial to the community"* (Greengrounds, 2024a, Our work).

The focus for Greengrounds is 'building' the company *(Interview GG)*. This entails a focus on current projects and attracting new projects. A promising project is on a 'brownfield' (Unutilized/industrial area close to or in a city) in Lisbon. This is similar because the York State Fair also consists of underutilized buildings. For Greengrounds, it is also a goal to create awareness that there should be a future without subsidies, farmers can sustain a comfortable living wage, and agricultural companies can be profitable *(Interview GG)*. However, at this moment, the initiative has to come mainly from Greengrounds to governments to create awareness of the needs and possibilities of (peri-) urban food production.

Problematization

In the interviews with involved stakeholders, several concerns were mentioned on the project. Multiple stakeholders have concerns about whether the project could be economically viable *(Interview BL, YSF, SRE, YCEA).* Moreover, whether it will be viable in the long term *(Interview, YSF & YCEA).* For example, it is unclear what the margins and pricing model will be *(Interview SRE).* In addition, if it is sold via wholesale, it is not known what the sale price must be of the produce to be break-even and what the scale must be *(Interview YSF).* This also relates to the fact that the difference between the sales prices in supermarkets and the wholesale prices that the CEA facility will receive must be determined. The project's construction costs are also unknown *(Interview YCEA).* Federal funding may be challenging and time-consuming due to the upcoming government change *(Interview YCEA)*. Another consideration is the possibility of import tariffs and what they will mean for agriculture *(Interview PA).* President-elect Donald Trump announced that import tariffs on other countries might be imposed. This will make food imports to the U.S. from foreign countries more expensive. Possible repercussions are that foreign countries tax U.S. produced food. This harms agriculture in the United States since it increases food prices, and foreign countries have to pay the extra tax for U.S.-produced food. This will lower export levels since other countries are more inclined not to buy produce from the U.S. It could affect the CEA project since there might be more competition from U.S.-based farmers now selling crops in the U.S. instead of exporting them to other countries.

There is community support for the project *(Interview YSF & SRE)*. Using the fairgrounds for agricultural and financial purposes is also supported *(Interview SRE)*. Despite having support from the "right people," it is considered challenging to envision what the CEA project will look like *(Interview YSF).* For this project, a few buildings have to be taken down at the Fairgrounds and people in York County are concerned that it might be "the start of the end of the fairgrounds." Some buildings are over 100 years old, some are maintained, and others are not *(Interview SRE).* People have a very emotional connection with the fairgrounds *(Interview YSF).* There is an understanding (among stakeholders) that the community is placed at "number one" *(Interview YSF).* The state of utilities at the York State Fair is a concern *(Interview SRE)*. The capacity and infrastructure are there for such a CEA facility. However, it has not been used for about 20 years. Fairground operators sometimes bring their electricity power generators. Therefore, there are concerns whether the full capacity could be used. Lately, peak usage has been only 20 percent of the maximum capacity possible *(Interview SRE)*.

The fact that the CEA project will incorporate both commercial and workforce development / educational activities makes it unclear what the project focus will be and if it has to lean on the public sector in the latter case *(Interview YCEA).* Since a grower can have a larger CEA facility somewhere else, education also serves as an opportunity to compensate for the lack of scalability *(Interview YSF).* York County Economic Alliance expects a combination of both, but would like to know if the commercial grower sees a market for it, what the relationships will be with other stakeholders, and how this will impact profits *(Interview YCEA)*. It is a question mark when the project will be operational and what employment would look like *(Interview PA).* Labor is a significant challenge for agriculture as students generally are not interested in traditional agriculture. It is different for CEA, where it entails different jobs, but generally, there still is a lack of labor *(Interview PA).* York County Economic Alliance also values the involvement of local and minority-owned businesses in the project *(Interview YCEA)*. A task mentioned by the problem owner is that it would be important to "get the stakeholders together" and thus find alignment *(Interview PO)*.

Multiple stakeholders are concerned about the economic viability. This can be traced back to stakeholders being uncertain about the investment cost, price variance, electricity output, and labor. There are also seemingly opposing goals regarding the workforce in the CEA project. The ARM Institute and PA Department of Agriculture are more focused on the overall development of agritech. At the same time, York County Economic Alliance and the Redevelopment Authority are concerned with community development. Furthermore, unit economics implies that labor cost and efficiency are important for the economic viability of the CEA project. Therefore, the workforce is analyzed in more detail in the next paragraph.

5.3 Stakeholder Interactions

Stakeholders' interests can lead to opposing preferences for the type of workforce. Several analysis methods were used. First, a power-interest matrix indicated the more essential stakeholders than others whose concerns might be prioritized. A value-network analysis visualized the value stakeholders exchanged and how they interacted. Then, a system diagram of the workforce in the CEA project was made, which analyzed the stakeholders' goals, options available for the problem owner, and external effects influencing the outcome.

Power-Interest Matrix

A power-interest matrix can assist in indicating the actors of interest (Buser, 2024). Power can be the ability to make decisions, economic power, or knowledge. High power/low interest stakeholders are considered the most difficult to collaborate with since they can mostly be decisive in the success of a project. Therefore they need to be kept satisfied. Low power/high interest are mostly directly involved and may be important for the project, so they must be kept informed. Low power/low interest stakeholders are generally of low importance, whereas high power/high interest stakeholders should be considered and managed closely in the project. For the CEA project, a power-interest matrix was made which can be seen in Figure 5.1.

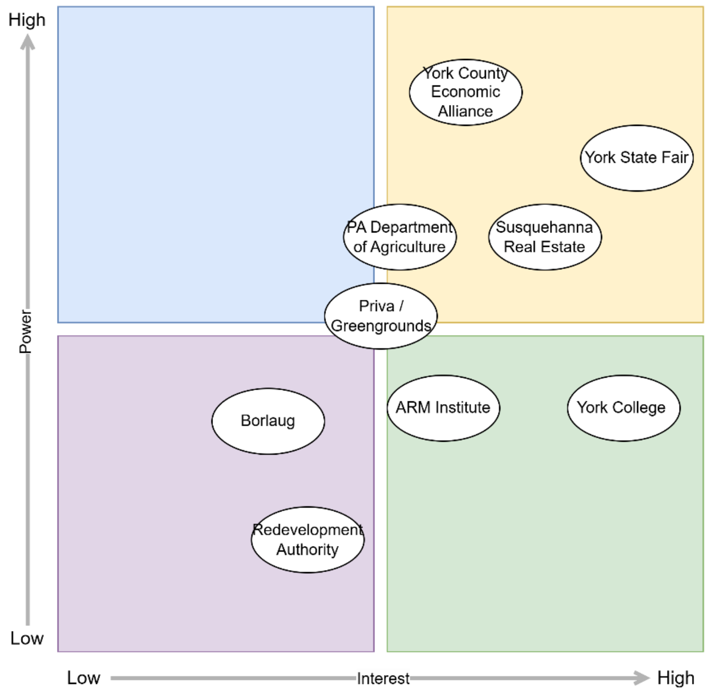

Figure 5.1: Power-Interest Matrix Vertical Farm Case

Redevelopment Authority is rated the lowest in power since it is not actively involved in decision-making. Borlaug has the lowest interest due to being mostly only commercially involved via Priva. The ARM Institute, and especially York College, have a high interest in the project since, for York College, it is an excellent opportunity to boost their agricultural education. The commercial part of the CEA project is not as dependent on them as they perhaps would like, which lowers their power. The same applies to the ARM Institute regarding robotics, which is not in York, making them less “powerful” than other stakeholders while being “quite interested” in the project. Priva/Greengrounds are right in the middle. While they can earn income and exposure from selling Priva systems, the company has other projects and business activities that create value. The Department of Agriculture contributes with funding. It is also an opportunity for agritech in Pennsylvania, but they are not as involved as stakeholders in York itself. Susquehanna Real Estate has an interesting position since, essentially, as a landlord to the York State Fair, who will be the landlord to the CEA project, will have ‘power’ over what can be developed at the York State Fair location and what not. It is also concerned with the financial situation since if the York State Fair becomes in financial trouble, it will also affect Susquehanna Real Estate. The two most important stakeholders are the York County Economic Alliance and the York State Fair. The York County Economic Alliance has an important role in bridging the private and public interest and being in the lead for developing the project itself. This makes them the most “powerful” stakeholder. The York State Fair wants to improve its financial situation, which makes it the entity with the highest interest. It is also quite “powerful” since the CEA facility will be placed at their location. Therefore, it is crucial to manage the stakeholders: York County Economic Alliance, York State Fair, Susquehanna Real Estate, and PA Department of Agriculture closely with their expectations. York College and the ARM Institute mostly need to be kept informed. Borlaug and the Redevelopment Authority need to be monitored with the minimum effort. Priva/Greengrounds needs to be managed.

Value Network

Before considering the different interests of the stakeholders, a value network analysis was done to identify how the stakeholders interact and what type of tangible and intangible value they exchange (Allee, 2008). This creates an understanding of how stakeholders interact and are aligned with each other. Figure 5.2 showcases the value network analysis of the CEA project. It can be seen that there are two agritech companies involved (Priva and Borlaug in blue), two companies involved being related to the physical location of the CEA facility (York State Fair and Susquehanna Real Estate in orange), two non-profit organizations (York County Economic Alliance (in red and yellow) & ARM Institute in red), one institution (York College in purple), and two public institutions (Redevelopment Authority & Pennsylvania Department of Agriculture in yellow). They are distinguished from each other by their different colors. York County Economic Alliance is mixed between red and yellow since it is a non-profit. Still, it is focused explicitly on York and shares interests similar to those of the government in York *(Interview YCEA)*.

A significant relationship exists between Priva, Borlaug, and the CEA project. Priva will deliver climate control, water nutrients, and other systems, transfer knowledge in agritech, and get in return funding. Borlaug will be the local partner already collaborating with Priva and can do the service, maintenance, and service on the Priva systems in return for funding. They can also construct and plan the facility. Priva and Borlaug are connected to the CEA project. York College and York County Economic Alliance are focused on the educational aspect and the impact the CEA project could have on job opportunities and attracting skilled people. It can also be seen that the York County Economic Alliance and the Pennsylvania Department of Agriculture will contribute financially to the project. At the same time, Priva and Borlaug will get income for their contribution. In addition, the York State Fair will earn revenue for their role as the landlord. Information on exact funding resources such as grants and loans will not be disclosed due to possible future funding and privacy reasons.

A key relationship between the three stakeholders is York College, York County Economic Alliance, and the CEA project in the education and employees aspect. First, an issue for York is the difficulty of retaining skilled workers *(Interview YCEA)*. This ties nicely with York College, which would like to offer their students hands-on experience and internships at the CEA facility in several majors. For the CEA project, this could be beneficial for acquiring future employees. For the York County Economic Alliance, it will make it more likely that highly skilled young people will stay in York if there are job opportunities. The ARM Institute also comes into play here with the inclusion of robotics and thus internship and educational opportunities in robotics. Therefore, these stakeholders were being considered in the workforce system diagram in Chapter 5.4.

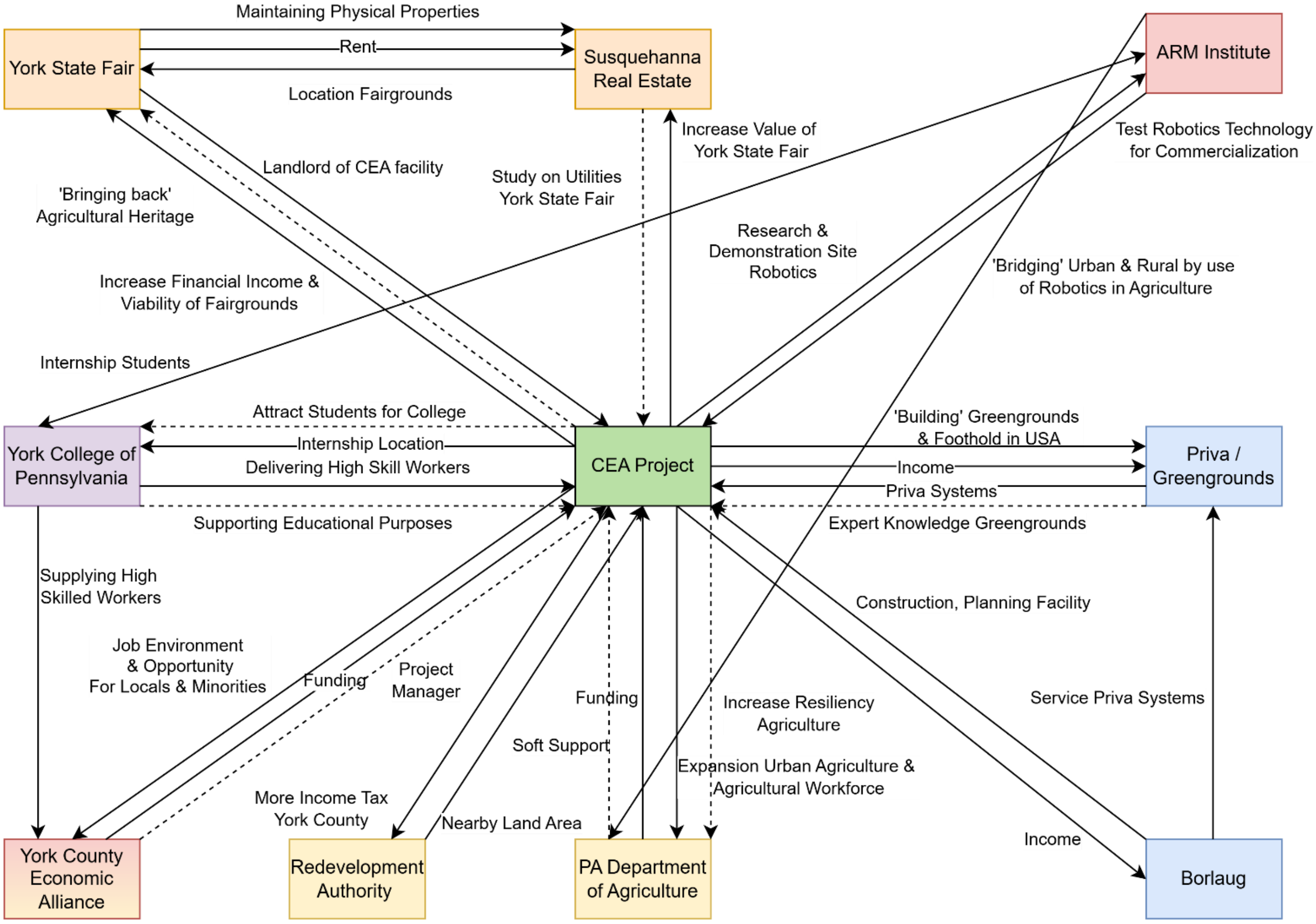

Figure 5.2: Value Network Analysis

5.4 System Diagram

A system diagram can visualize causal relationships between factors. It consists of a means-end analysis, objectives, and criteria for problem definition (Hinrichs-Krapels, 2022). After creating the system diagram, the consequences of external factors, means, and possible scenarios can be evaluated. A structured overview of stakeholders' actions, goals, boundaries, and external factors will be given. The potential for conflict can be identified, as well as the potential for coalitions and a general understanding of how stakeholder interests align or misalign. In Table 5.1, the overview of the different stakeholders indicates that stakeholders' goals regarding the workforce do not align. Therefore, a system diagram was developed to identify the actions available to the problem owner of the CEA project, the goals of the various stakeholders, and how external factors affect the system.

Goals

The interviews with the stakeholders and other information sources regarding their roles and goals in the York project identified different goals affecting the workforce. The misalignment in terms of employment with several of the stakeholders' goals can be seen in Table 5.2. The various stakeholders are showcased with their goals, and they would like this goal to be "increased" as showcased in the column "factor." The Pennsylvania Department of Agriculture aims to strengthen the agricultural workforce as part of its agricultural goals. It has grants for this purpose, focused on agricultural education (Department of Agriculture, 2019). As part of their economic action plan, York County Economic Alliance aims to expand and attract industries that offer high-paying, skilled jobs. The CEA project could encompass this by having higher-paid jobs in engineering (York County Economic Action Plan, 2020). While every stakeholder is concerned with the profitability of the CEA project, the focus on unit economics, which implies optimizing revenues and costs related directly to an individual crop, was mentioned by the problem owner as key to the CEA facility's economic viability *(Interview PO)*. This also means reducing the workforce costs as much as possible. The Redevelopment Authority has the objective of increasing the tax base of the City of York through properties (City of York, 2024). Engineers have generally high wages, making it more likely that more expensive properties in York County will be bought, contributing to the city's tax base. The ARM Institute would like to develop its robotics for commercial use, which they believe can be found in agriculture *(Interview PO)*. Robotics does not imply replacing growers and other agricultural-related jobs. Moreover, in manufacturing, robotics has not led to decreased employment in York *(Interview YCEA)*. However, it creates new jobs, such as engineering jobs. This might mean increased spending on those jobs at the expense of the growers' budget. As was found in Chapter 3, the bankruptcies of vertical farms were partly due to the focus on technology instead of growing crops (Vertical Farm Daily, 2023b). Furthermore, the intention of commercializing robotics does not consider the local community in York.

Table 5.2: Goals Stakeholders (Impacting Employment)

Goals	Stakeholder	Explanation	Factor
Agricultural Workforce	PA Department of Agriculture	Building a strong agricultural workforce	Increase
High Paid/Skilled Jobs	York County Economic Alliance	Retain, expand, and attract employers in industries offering high-paying, skilled jobs	Increase
Unit Economics	CEA Project	Focus on optimizing direct revenues and costs per unit crop	Increase
Robotics Development	ARM Institute	Commercialization of robotics	Increase
Local Property Taxes	Redevelopment Authority	Increase property taxes by having high-paid employees in York County who buy more expensive properties	Increase

Means

The CEA project has several employment options. Means are actions that the project owner of the CEA facility can take. It does not indicate that the others will be impossible if it focuses on one option. However, it could suggest that the workforce distribution at the CEA facility will be different. For instance, focusing on just education could imply less budget for robotics and local workers.

- **Focus on Education:** education becomes essential for the operation. In addition to educational aspects, such as lectures, the CEA facility will rely on internships to partly fill the labor demand. This implies having less budget available to focus on robotics and local growers.
- **Hire Local Workers:** this focuses on hiring local agricultural workers instead of migrants. This may reduce the budget available for focusing on education and robotics.
- **Implement Robotics:** If robotics becomes the main area for employment, the CEA project will become more technologically focused, possibly at the expense of the budget for other options. This will entail a bigger focus on engineering jobs next to growers.

External Factors

A report in 2017 on the Eight-County Region of South Central Pennsylvania (Adams, Berks, Cumberland, Dauphin, Franklin, Lancaster, Lebanon, and York Counties) identified several threats, and one of them is concerned with the lack of skilled workforce (PA South Central PREP, 2017). York is primarily an agricultural county and competes with two much larger cities in Pennsylvania, Pittsburgh and Philadelphia *(Interview YCEA)*. Companies are not as inclined to locate in York, and thus young and skilled people leave the city of York. Therefore, the potential of a "lack of skilled workforce" was included as an external factor. Another weakness is that the workforce is aging in York, and the city is not attractive to young people (PA South Central PREP, 2017). York finds it challenging to attract businesses and investment. Therefore, "aging population" is also an external factor.

President-elect Donald Trump, who will return to office on January 20th, 2025, has been vocal about sending back (undocumented) migrants to the United States (Alvarez & Mattingly, 2024). In 2020, more than 40% of crop farmworkers were foreign-born and undocumented, and another 20% were documented and foreign-born (Gutierrez-Li, 2024). 35% of workers are U.S. citizens, both foreign-born and U.S.-born. This will, therefore, impact labor in the farm industry. In interviews, it was also noted that migrant workers are essential to farming in the U.S. *(Interview BL, IRR, YCEA). "*Migrant policies," making it more difficult to find growers and increase growers' wages, were added as the third and last external factor in the system diagram.

System Diagram CEA Project

A system diagram is used to show the causal relations between the means and goals related to the CEA project's workforce, which can be seen in Figure 5.3. The means (actions) available to the problem owner on the left side are showcased and indicated with M1, M2, and M3. On the right side, the goals of various stakeholders can be seen, as indicated in G1 to G5. Below the system diagram, it is showcased by the different colors to which stakeholder a goal relates to. On the top of the system diagram, the external policies are indicated by X1, X2, and X3. The causal relationships are showcased in the light blue area with arrows between the variables. A positive relationship indicates that an increase in one variable leads to an increase in the other variable or that a decrease in one variable leads to a decrease in the other variable. For example, "local growers" is positively related with "average wage CEA facility", which implies that if the number of local growers increases, the average wage in the CEA facility increases as well. A negative relationship indicates that an increase in one variable leads to a decrease in the other or that a decrease in a variable leads to an increase in the other variable.

Both agricultural and agritech internships are negatively related to average wages since it is assumed that interns can partly take over tasks of regular growers and engineers working in the CEA facility. They are also positively related to local growers and engineering jobs since it is assumed that a larger number will likely stay at the CEA facility as full-time employees if there are more interns. Local growers positively relate to average wages since local growers are more costly for the CEA facility than hiring migrant growers *(Interview RII)*. Local growers positively related to the goal of increasing the agricultural workforce. The average wages are negatively related to the unit costs since the costs per unit increase if wages are higher. In a CEA facility, the learning experience affects overall KPI improvements over time (Azzaretti & Carleton, 2023). Employee retention is an essential contributor to this learning experience. In the United States, employees who quit their jobs have been in 55% of the cases due to demanding a higher wage (DeBara, 2022). Therefore, higher wages are positively related to higher employee retention in the system diagram, which is positively related to unit economics.

Engineering jobs positively relate to average wages since the average salaries of engineers are higher than that of growers in York County, and thus increase the overall average wages in the CEA facility (York County Economic Alliance, 2024a). Engineering jobs are also positively related to high-paid and skilled employment. York County does not have additional sales or income tax for its inhabitants (next to Pennsylvania's taxes). However, it has property taxes directed to the county. Indirectly, taxes for York County increase when higher-paid employees buy more expensive properties such as houses in York. Therefore, the goal of high-paid/skilled jobs is positively related to local taxes. Robotics negatively relates to average wages since it is assumed that robotics can partly replace the growers' tasks in the CEA facility. Robotics positively relates to robotics development since it is assumed that more robotics testing will foster the overall development of robotics.

It is assumed that since there are budget constraints, there is a limit on how many growers and engineers can be hired. Therefore, both variables are negatively correlated with each other. This implies that there will, for example, be fewer engineers if there are more growers, and because there are fewer engineers, there will be even more growers. The other way around also holds. A reinforcement (positive) loop was added indicating the positive relationship since a double negative relationship leads to a positive relationship. However, since engineers generally have a higher salary, for every hired engineer, potentially multiple growers are hired, which indicates that the negative relationship between engineering workers and local growers is stronger than the other way around. Practically speaking, the reinforcing loop does not make as much sense since there will be a lower limit on how few personnel of one type you can have (e.g. the CEA facility cannot run without any (local) growers) and an upper limit due to budget constraints.

It can be argued that more engineering workers should increase robotics development, while in the system diagram, there is no link between both variables. Although this would imply that if only 'focus on education' were applied and not 'implementation of robotics', there would still be robotics development since educational activities are linked with agritech internships and thus to engineering workers. This would make analyzing the system diagram less valuable and representative of the CEA project in reality, and therefore this linkage was left out.

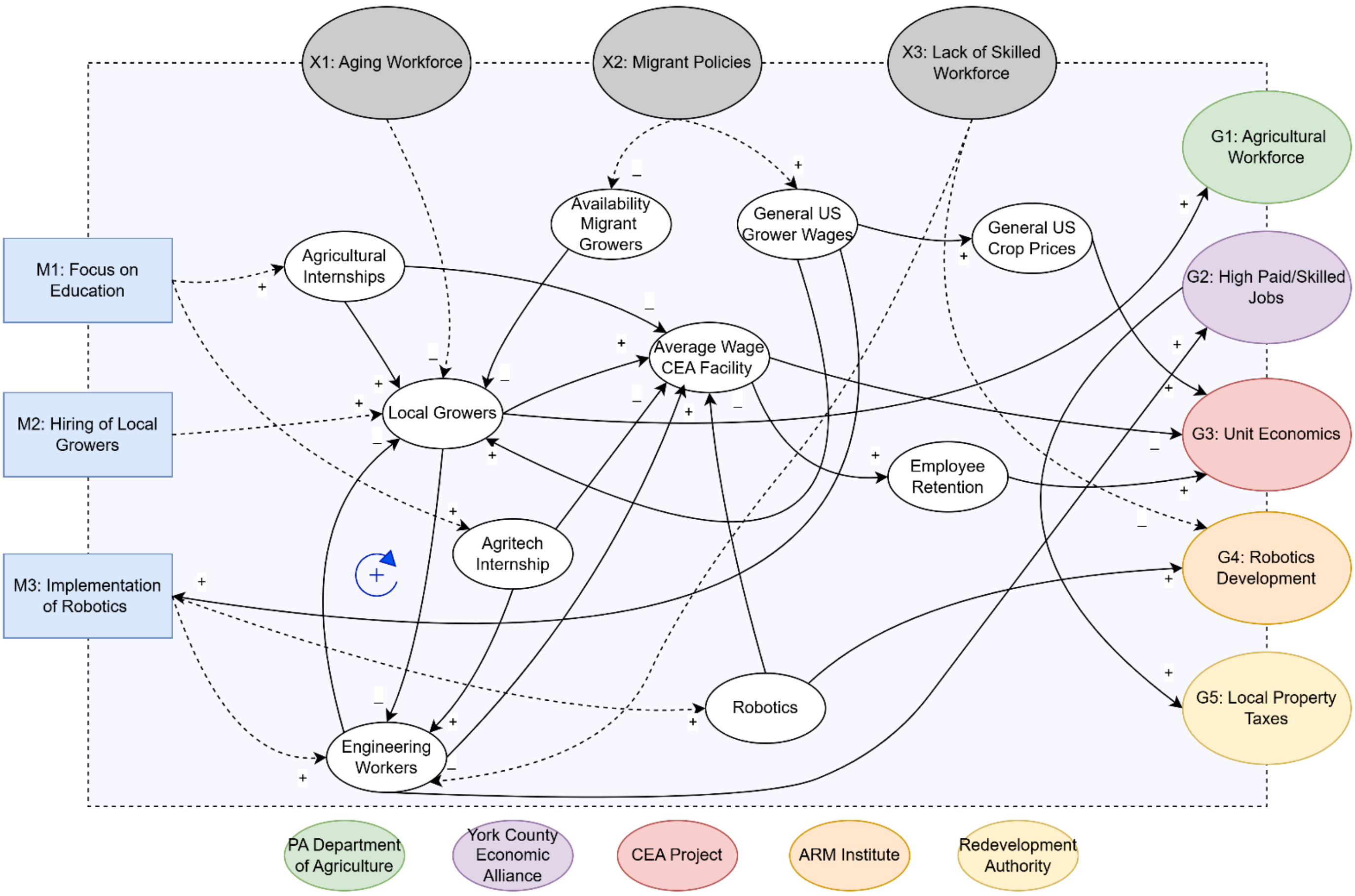

Figure 5.3: System Diagram CEA Project

5.5 Analysis System Diagram

First, the means and their outcomes regarding the goals are analyzed. Then, the external factors with possible scenarios are considered. Potential conflicts or coalitions between stakeholders based on the system diagram are examined, and the implications are given for the CEA project.

Consequences of Means

Since the model is conceptual, how strong variables relate to each other is unknown. This means that, for instance, two positive relations do not offset one negative relation for a variable. Therefore, it is only indicated whether a relation is positive, negative, or both and not whether it is e.g. multiple times positive via numerous routes in the system diagram. Means (e.g. M2), external factors, and goals are indicated with a number to support readability. It can be seen in Table 5.3 that unit economics (G3) will be positively and negatively impacted by every means. If average wages increase, the unit economics are negatively affected due to employee costs. Still, employee retention may mitigate this effect or even positively impact the unit economics since productivity will increase. Therefore, it depends on which relationship is stronger whether average wages positively or negatively correlate with unit economics. It also means that the conceptual system diagram is not sufficient to determine the strategy that must be taken to improve the unit economics.

Focus on Education (M1) will increase the number of internships for both agriculture and agritech. Hiring interns increases the number of local growers, positively impacting the agricultural workforce (G1). Higher-paid/skilled jobs (G2) and local taxes (G5) are both affected positively or negatively since a focus on education (M1) can increase or decrease the number of engineer workers. **Hiring of Local Growers (M2)** is positively related to local growers. This leads to an increasing agricultural workforce (G1). However, it negatively impacts high-paid/skilled jobs (G2), and local taxes (G5). It might be surprising that hiring local workers negatively affects local taxes (G5). Although local growers already live in York, they are not expected to see significantly higher pay at the CEA facility than at other jobs. On the other hand, engineers will more likely not be living in York County already and increase the tax base of York County. **Implementing Robotics (M3)** is positively related to robotics and engineering workers. This in turn is positively related to higher paid/skilled jobs (G2), robotics development (G4), and local property taxes (G5).

If the effect of the means on the goals is valued without considering the stakeholders and relative importance, implementation of robotics (M3) is the preferred action since it has one negative outcome but three favorable outcomes as shown in Table 5.3. However, since the PA Department of Agriculture is a more critical stakeholder than the ARM Institute as identified in the power-interest diagram in Figure 5.1, focusing on education (M1) is the preferred policy. A focus on education (M1) is always preferred above hiring local workers (M2) since both higher paid/skilled jobs (G2) and local property taxes (G5) can still be positively affected rather than negatively. If the budget allows it, implementing robotics (M3) also must be included as a preferred action. In this case, the agricultural workforce (G1) will be neutral, but robotics development (G4) will have a positive outcome. Since this model is conceptual, it cannot be sure whether two positive relations offset a negative relation with a variable. Otherwise, High Paid/Skilled Jobs (G2) and local property taxes (G5) are positive if the actions: M1 and M3 are applied.

Table 5.3: Means Impact Assessment

	G1: Agricultural Workforce	G2: High Paid/Skilled Jobs	G3: Unit Economics	G4: Robotics Development	G5: Local Property Taxes
M1: Focus on Education	Positive	Positive/Negative	Positive/Negative		Positive/Negative
M2: Hiring of Local Workers	Positive	Negative	Positive/Negative		Negative
M3: Implementation of Robotics	Negative	Positive	Positive/Negative	Positive	Positive

Consequences of external factors

In Table 5.4, the impact of external factors on the goals of different stakeholders can be seen. **Aging workforce (X1)** negativity relates to local growers. This negatively impacts the agricultural workforce (G1) but positively impacts high-paid/skilled jobs (G2) and local property taxes (G5). **Migrant policies (X2)** are negatively related to the availability of migrant growers but positively associated with the general grower wages in the U.S. While the exact number of migrants working in CEA is unknown, there are also migrants working in CEA, as with field farming (Petrovic, 2013). Working in CEA and traditional farming is not seen as attractive (especially when not interested in growing) *(Interview SRE)*. However, since CEA does not have seasonal labor (year-round production), CEA cannot take advantage of labor programs specifically for this industry *(Interview Borlaug & RII)*. Certain subsidies in states allow these people a better wage through government support. This is also a complaint heard by people in the CEA industry that they do not have access to these programs, while they do have to pay local people higher wages *(Interview RII).* This implies that the CEA facilities are less affected than field farming if migrant policies are imposed. Therefore, it is assumed that competitive field farms in York County will have more issues acquiring labor (their workforce consists mainly of growers) than the CEA facility. Over time, there will be an increase in local growers due to General U.S. grower wages being affected positively by the migrant policies. In the short term, there will be more competition for local growers; thus, fewer local growers will be available for the CEA facility. General U.S. grower wages also increase crop prices in the United States, which correlates positively with unit economics (G3) since higher crop sales can be demanded. All in all, due to the uncertainty with how migrant policies (X2) relate to local growers, the agricultural workforce (G1), higher paid/skilled jobs (G2), and local property taxes (G5) are all positively and negatively impacted. However, the demand for engineering workers increases due to the increase in the average wages of growers in the U.S. The pay gap closes between growers and engineers, making hiring engineers in favor of growers more attractive. This in turn leads to an increase in robotics development (G4). **Lack of skilled workforce (X3)** is negatively related to robotics development (G4) and engineering workers. It positively impacts the agricultural workforce (G1) while being negatively related to high-paid/skilled jobs (G2) and local property taxes (G5).

Table 5.4: External Factors Impact Assessment

	G1: Agricultural Workforce	G2: High Paid/Skilled Jobs	G3: Unit Economics	G4: Robotics Development	G5: Local Property Taxes
X1: Aging Workforce	Negative	Positive	Positive/Negative		Positive
X2: Migrant Policies	Positive/Negative	Positive/Negative	Positive/Negative	Positive	Positive/Negative
X3: Lack of Skilled Workforce	Positive	Negative	Positive/Negative	Negative	Negative

Possible Scenarios

Scenario 1: Migration Policies (Changes → X2)

The new government administration of President-elect Donald Trump will impose impactful restrictions on agriculture to hire migrants. This means the CEA facility cannot hire migrants and must rely on local growers. However, due to more competition among local growers, hiring engineering workers who have become more affordable relative to local growers becomes more tempting. Thus, the CEA facility will become more technologically advanced and may incorporate robotics, which is positively related to robotics development (G4) as can be seen in Table 5.4. The effect migration policies will have on unit economics is uncertain. On the one hand, less labor availability by migrant policies will increase the general grower wages in the US and raise the prices of crops. Since migrant labor is less prevalent for CEA due to seasonal labor programs, it should imply that these businesses will be less affected. Thus, their unit economics will increase due to their relative competitiveness to field-grown crops. On the other hand, migrant policies also increase wage costs and competition for labor. They might have a more significant impact on unit economics than the offset of relative competitiveness and employee retention. It can be projected that more Americans are inclined to be growers over time since wages increase, which will mitigate the effects of a lack of migrants. Although this analysis is outside of the scope of this research, it can be concluded that implementing robotics can be considered a mitigation policy against possible migration policies. Possible migration policies might be a positive outcome for the CEA industry in the long term since agriculture might be more inclined to invest in CEA and robotics technology.

Scenario 2: "York fails to deal with its labor challenges" (Changes → X1, X3)

In this scenario, younger people keep leaving York and the workforce becomes smaller due to aging. In addition, York fails to keep skilled workers in its area due to a lack of overall job availability, and the lower price of living cannot make up for it. The aging workforce (X1) negatively impacts the agricultural workforce (G1) but is positively related to high-paid/skilled jobs (G2) and local property taxes (G5) as showcased in Table 5.4. A lack of skilled workforce (X3) while impacting the agricultural workforce positively (G1), hurts high-paid/skilled jobs (G2), robotics development (G4), and local property taxes (G5). When both are combined in this scenario, it implies that the CEA facility is in a challenging position to reach any of the goals of its stakeholders because an aging workforce (X1) can be mitigated by hiring engineers which will be difficult or even impossible if there is also a lack of a skilled workforce (X3). The other way around also holds. If there is a lack of skilled workforce (X3), the CEA project should focus on local growers, which might be impossible due to the aging workforce (X1). Therefore, the stakeholders must be aware of and analyze these external effects thoroughly since if both are affecting the CEA project simultaneously, as in this scenario, the CEA project is likely not viable.

Conflicts & Coalitions

Below, possible conflicts and coalitions that may be formed between stakeholders based on the system diagram and stakeholders' comparison of goals were analyzed.

Conflicts

There is a division between the York County Economic Alliance and the Redevelopment Authority, which is concerned with York, the PA Department of Agriculture, which is concerned with the agricultural workforce, and the ARM Institute, which is concerned with robotics. This is reflected by the different means and their impact on stakeholders' goals. PA Department of Agriculture will favor hiring local workers (M2) since it positively impacts the agricultural workforce (G1). The York County Economic Alliance and Redevelopment Authority would oppose it since it negatively impacts high-paid/skilled jobs (G2) and local property taxes (G5) respectively. In the case of a focus on education (M1), PA Department of Agriculture would favor it while York County Economic Alliance and Redevelopment Authority will be neutral based on the system diagram in Table 5.3. Although in the case of the implementation of robotics (M3), it is preferred by the ARM Institute, York County Economic Alliance, and Redevelopment Authority while being opposed by the PA Department of Agriculture since it decreases the goal of the agricultural workforce (G1). Another conflict might occur between the ARM Institute and other stakeholders concerning migrant policies (X2). Robotics development (G4) is the only goal that is certain to be positively impacted while others are uncertain. This might create a division of perspectives since the ARM Institute might oppose any action taken by other stakeholders to increase the grower workforce, which will further limit the robotics development.

Coalitions

York County Economic Alliance and the Redevelopment Authority have similar interests since they are concerned with community benefits. Their goals are also, in any circumstance, aligned since paid/skilled jobs (G2) are positively related to local property taxes (G5). Furthermore, the scenario of an aging workforce and a lack of qualified workforce negatively impacts the goals of all stakeholders included in the system diagram. A benefit will be that stakeholders have a consensus to mitigate these risks as much as possible in the CEA project.

An important factor from the stakeholder analysis is that stakeholders' opinions on the opportunities and challenges are primarily in line with each other and with the business environment analysis on York's economy in Appendix D. This can contribute to shared understanding and support for the CEA project's strategy. In addition, it means that the stakeholders are generally very aware of the opportunities and challenges the project may face, which can prevent possible unexpected disappointments. The following factors in York are shared among the stakeholders (PA South Central PREP, 2017).

- Opportunities with York's location in proximity to large neighboring cities and the fact it is a transportation hub *(Interview SRE, YCEA, YSF)*
- Farming in general faces environmental challenges *(Interview PA)*
- Competition with Pittsburgh and Philadelphia *(Interview YCEA)*
- Difficult to attract young people and lack of skilled workforce *(Interview YCEA)*
- Lack of financial capital access *(Interview YSF)*

Implications

Based on the system diagram analysis concerning the workforce in the CEA facility, focus on education (M1) is the optimal strategy in case the budget only allows for one means to be applied in the CEA project. The agricultural workforce (G1) goal from the PA Department of Agriculture is positively related to this action. For the implementation of robotics (M3), the agricultural workforce (G1) is negatively affected. In this case, robotics development (G4) is also positively affected, which is a goal of the ARM Institute. Since the PA Department of Agriculture is a more critical stakeholder than the ARM Institute, focusing on education (M1) is the optimal policy. Furthermore, York College is not part of the system diagram since it concerns employment in the CEA project. However, only the action focused on education (M1) implies a role for York College since they are the entities that benefit from internships that they can offer locally for their students. In the scenario analysis of external factors, it was concluded that to cope with migrant policies, implementing robotics could mitigate the effects of a lack of labor. Therefore, if the budget allows both to be implemented, focusing on education (M1) and implementing robotics (M3) must be considered actions for the CEA project. In addition, if both means are considered conceptually not a single goal in the system diagram is negatively affected. In addition, the model does not capture the possible funds the stakeholders will allocate when their preferred actions are taken. Therefore, implementing both actions is more beneficial since it considers all stakeholders.

Hiring of local workers (M2) in this system diagram has more negative effects on the goals than positive effects. However, in practice, it might be a hard sell for the stakeholders (e.g. York County Economic Alliance, York State Fair) to convince the local community in York that focusing on outside investment and stakeholders (robotics) has more value to the community than hiring local workers. The local community and government have also been skeptical about the CEA project on the historical York State Fair site *(Interview YSF)*. Therefore, the task of the project team will be to monitor these concerns and create awareness among the local stakeholders about what the other actions can bring to the community in York. The system diagram also shows that the unit economics is always positively and negatively affected by all actions. This is because higher wages decrease the unit economics directly, but employee retention may mitigate this effect or even positively impact the unit economics since productivity might be higher. However, this is difficult to determine before the CEA facility operates. A financial analysis must be done to assess the impact of wages on the CEA project. This will be explored in Chapter 6 as part of the business case.

5.6 Conclusion Stakeholder Analysis

This chapter aimed to answer the following research question: *How can the stakeholder ecosystem for the vertical farming case be developed?* The power-interest matrix and value network show that the York County Economic Alliance and the PA Department of Agriculture are key stakeholders in the workforce system diagram. It was found that there is potential for conflict among stakeholders in the CEA project since different goals impact the workforce. Focusing on the educational aspects was identified as the optimal strategy to find the best possible alignment in the stakeholder ecosystem. This is preferred above choosing "hiring local workers" or "implementing robotics." Although considering the resiliency of the CEA project to external factors, implementing robotics must also be incorporated next to focusing on education, because it would make the CEA project more resilient to possible labor shortages. This is due to different possible external impacts such as migration policies and a lack of workforce in York County. In Chapter 5.2, it was found that many stakeholders have concerns about profitability and do not know precisely the CEA project's business case and value proposition. Therefore, Chapter 6 aimed to find a suitable business model and determine the viability of the CEA project.

6. Business Case

In Chapter 5, it was analyzed which stakeholders are involved and how to find alignment in the stakeholder ecosystem. It showcased that focusing on educational aspects is preferred, which, e.g., involves interns in the CEA facility. In addition, if the budget allows, implementing robotics will make the CEA project more resistant to external effects. Based on this information and the specific business environment in York, this chapter aimed to develop the business case for the CEA project. Therefore, the following research question was aimed to be answered: *What business and financial model can be developed based on the study case?* First, literature was assessed to understand the appropriate theoretical framework for this analysis. Then, the business model for the case was made. Also, a financial tool was developed to increase the understanding of the parameters affecting profitability, and a scenario analysis and sensitivity analysis were made to improve the reliability of the results. The Business Model Canvas and financial analysis contribute to assessing the viability of vertical farming. In the financial analysis, only the commercial aspect of the CEA project (the CEA facility itself where crops are grown) is considered to assess the viability of the CEA project. For example, educational activities or other activities involved with the project are not considered. This was done to keep the viability analysis feasible with the available data and the duration of the research study.

Business Model Definition

Before using the case study to develop the business case, the "business case" and business model" concepts are explored to determine what it entails. A Business Case is aimed at justifying the start of a project (Murray-Webster, 2019). For accurate decision-making on the business case, alternative business models must be considered (Meertens et al., 2014). To justify a business case, a viable business model must be developed. A "Business model" is defined in many different ways. For instance, by Johnson et al. (2008, p.3) as the following: "*A business model, from our point of view, consists of four interlocking elements that, taken together, create and deliver value. The most important to get right, by far, is the customer value proposition. The other elements are the profit formula, the key resources, and the key Processes"* (Fielt, 2013, p.88). By Osterwalder & Pigneur (2010, p.14), it is defined as follows: *"A business model describes the rationale of how an organization creates, delivers, and captures value."* A business model can also be characterized as a set of assumptions about what a business will and won't do, which refers more to Michael Porter's theory of strategy (Ovans, 2023). Business model frameworks define the essential components that make up a business model. The most widely used framework is the Business Model Canvas, which showcases a business model in a visualized structured framework (Strategyzer, 2024). A Business Model Canvas is a *"shared language for describing, visualizing, assessing, and changing business models. It is focused on design and innovation, in particular by using visual thinking which stimulates a holistic approach and storytelling"* (Fielt, 2013, p.93).

6.1 Business Model Canvas

In 2010, the Business Model Canvas was developed as a tool for businesses to create a business model (Osterwalder & Pigneur, 2010). The Business Model Canvas will be used instead of other frameworks because it is considered the most comprehensive template (Ovans, 2023). The case study is complex, with many different stakeholders involved in a business field (CEA), where there have recently been several notable bankruptcies and challenges in achieving profitability. The Business Model Canvas consists of 9 elements: Key Resources, Key Activities, Key Partnerships, Customer Segments, Customer Relationships, Sales Channels, Value Propositions, Revenue Streams, and Cost Structure (Osterwalder & Pigneur, 2010). The Business Model Canvas for the CEA project at the York State Fair is showcased in Figure 6.1. The Business Model Canvas was built on the stakeholder analysis in Chapter 5, the business environment of the study case in Appendix D, literature from Chapter 3 & 4, and interviews with participants from organizations that can be seen in Appendix C. First, "Key Partners" will be explained since this ties back to the stakeholder analysis in the previous chapter. Then, “Key Activities” will be dealt with since this features the type of business models used and their respective success factors and challenges. This information will be helpful to the other elements in the Business Model Canvas.

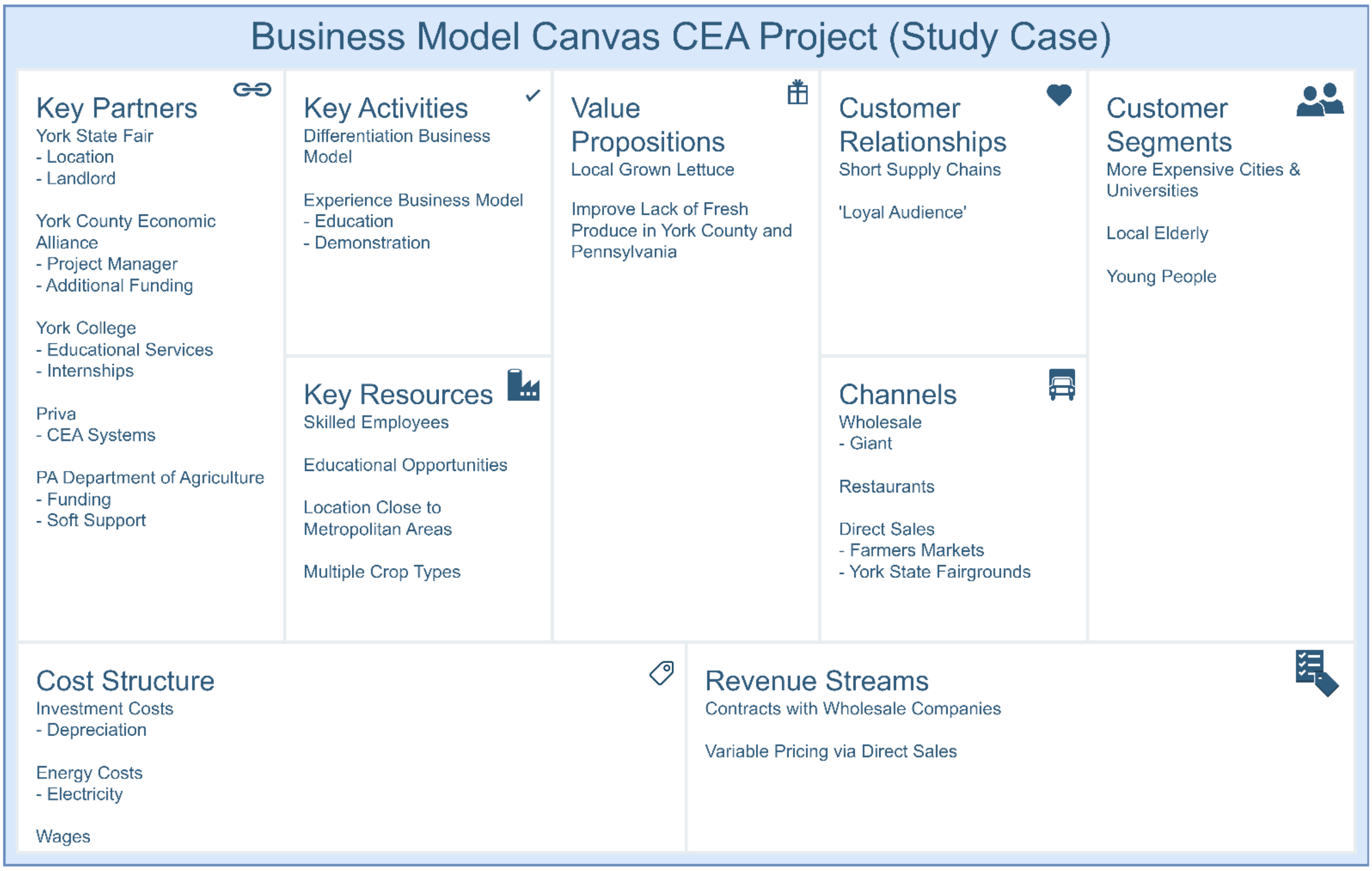

Figure 6.1: Business Model Canvas for CEA Project ([adapted] template by: Strategyzer, 2024)

Key Partners

The stakeholders' analysis in Chapter 5 indicates that key partners for the CEA project are the York State Fair, York County Economic Alliance, York College, PA Department of Agriculture, and Priva. The York State Fair will essentially function as the landlord of the CEA facility, and the York State Fairgrounds, which is held every year, can function as an opportunity to promote the activities of the CEA project and partly to sell produce directly to consumers *(Interview YSF)*. York County Economic Alliance will function as the project manager by assigning the project team. In addition, it can assist in working with all the stakeholders involved and finding additional funding if needed. York College can have students involved in the facility in growing, engineering, and sales. These students can also intern at the CEA facility and potentially start their first job *(Interview YC)*. Priva will deliver climate control, water, and nutrient systems needed for CEA. The PA Department of Agriculture contributes funding and soft support for the CEA project. Therefore, the York State Fair, York County Economic Alliance, York College, Priva, and the PA Department of Agriculture were added as key partners in the Business Model Canvas in Figure 6.1,

Key Activities

The CEA facility at the York State Fair combines the “differentiation” and “experience” business model. The CEA facility will focus on crops not being produced in large quantities already in York County or the Northeast United States to “differentiate” itself from the competition. This is represented in Table 4.4 under the category of “differentiation” with the idea to “offer niche products” and to focus on the “market gap.” In addition, the CEA facility will serve as a demonstration site and incorporate educational services. Education can also bridge the gap between robotics and food production *(Interview YSF).* This is represented in Table 4.4 in the "experience" business model category, implying that farms also focus on other activities next to production.

The business environment was an essential indicator for the type of business model. Since the City of York does not have a high population, a "low cost" business model would not be fitting (Pölling, 2016). A lack of space, which multiple stakeholders indicated in the interviews, will also be the case for the CEA facility. This means that the "diversification" and "differentiation" business models are appropriate to use (Pölling, Prados, et al., 2017). In Chapter 4.1, it was also found that the "diversification" and "differentiation" business models are the most financially viable options for urban farming. The "differentiation" business model incorporates strong ties with its urban environment (social services and direct marketing), which is also found to be essential for multiple stakeholders in the case (Pölling, 2016). However, the "experience" business model was found to have the most significant barriers since it suffers from low-income levels and a lack of public support (Pölling, Sroka, et al., 2017). In stakeholder interviews, the "experience" business model was primarily mentioned to have revenue streams other than only selling crops. Therefore, the stakeholders must be aware that, according to the literature analysis in Chapter 4.1, profitability is an issue when incorporating education as a primary asset. Public support is a challenge in the "experience" business model as indicated in Table 4.4. This is not necessarily true for this CEA project. On the one hand, the state of Pennsylvania, the York County Economic Alliance, and other local stakeholders such as York College and the York State Fair are involved. On the other hand, the City of York is mainly on the sidelines, with only the Redevelopment Authority involved *(Interview YCEA, YSF).* In addition, next to educational services, the CEA project aims to serve as a demonstration site for agritech, which may have better economic prospects than only educational services *(Interview PO)*.

Since profitability supposedly has to come from the "differentiation" business model and the actual product sales, the cost structure and revenue streams will focus on the growing aspect to identify whether the "differentiation" business model can be viable by just selling crops. The "experience" business model for the CEA project functions to satisfy stakeholders concerned with educational and workforce aspects. Therefore, both the "differentiation" and "experience" business model were added to the Business Model Canvas in Figure 6.1.

Key Resources

"Skilled employees" and accessibility to them are both a success factor and a challenge, and have also been identified as problematic for York County *(Interview YCEA)*. It was concluded in the System Diagram analysis in Chapter 5.5, that the collaboration with York College by providing internship opportunities could serve as a method to train and attract skilled growers, engineers, and sales employees. This combines the "differentiation" and "experience" business models since the educational services from the "experience" business model can support the "differentiation" business model with interns and skilled employees. Another resource is that the York State Fair possesses multiple large buildings that can serve various purposes. A challenge is that some buildings are over 100 years old, some are maintained, and others are not *(Interview SRE).*

The business environment was essential for urban agriculture and using local resources (Pölling, 2016; Specht et al., 2015). York City itself has a population of around 45,000. A population larger than 50,000 is, while not necessary, associated with high business performance in combination with a focus on customer engagement and B2B (Marczewska et al., 2023). However, York is located close to major metropolitan areas, which is reflected by the fact that there are many warehouses in York County and around 50 million people can be reached quickly *(Interview YSF)*. Pennsylvania is also characterized as a "middle stop" in the Northeast US since food is stored in warehouses and then goes to New York City and Washington D.C. *(Interview PA)*. Furthermore, having multiple crop types is also associated with "good performance" compared to having only one crop type (Marczewska et al., 2023). In summary, skilled employees, educational opportunities, the location of the CEA project being close to metropolitan areas, and having multiple crop types were added as key resources in the Business Model Canvas in Figure 6.1.

Value Propositions

In Table 4.4, “Identifying locally demanded high-value products” for the “differentiation” business model indicates that the CEA project must focus on crops not produced in large quantities in Pennsylvania and the Northeast US. In Pennsylvania, there are only a few leafy greens producers and several specialty crops, and CEA can thus fill a niche *(Interview PA)*. The most important sales factor for CEA-grown food is that it is produced locally *(Interview PA).* For South Central Pennsylvania, an opportunity for its economic development is that the community is interested in “buy local.” In Chapter 4.1, it was also found that promoting local food is a success factor for urban farming (Sroka et al., 2023). In addition, while York County is not specifically a “food desert,” there is still a lack of healthier and affordable food *(Interview YC).* This is also part of the value that the CEA facility creates in York, offering an alternative by having fresh-produced crops. Therefore, the goal is not to compete directly with locally grown crops but to be a “fresh” alternative *(Interview YSF).* Romaine and butterhead lettuce will be tested in the financial model since both are widely used in hydroponic (vertical farming) and to make sure that there are at least multiple types of crops grown in the CEA facility (Soto, 2024). Romaine lettuce's price per pound was more than 80% higher than Iceberg lettuce, which is also a reason why iceberg lettuce is generally not considered in vertical farming (U.S. Department of Agriculture, 2024). The two value propositions in the Business Model Canvas in Figure 6.1 are: local grown lettuce, and improving the lack of fresh produce in York County and Pennsylvania.

Channels

In Chapter 4.2, B2B was found to lead to high business performance in combination with customer engagement (Marczewska et al., 2023). A success factor mentioned in the literature is “direct sales” (Pölling, Sroka, et al., 2017; Sroka et al., 2023). It was noted that some growers participate in farmers markets for direct sales (kitchen box sales), but only a tiny segment *(Interview Borlaug)*. Medium to large-scale commercial CEA growers sell to distributors or large retailers (wholesale). While the CEA project at the York State Fair is relatively tiny, selling kitchen boxes would entail producing various types of leafy greens, which is not the case. Furthermore, there will not be a storage facility at the York State Fair *(Interview YSF)*. This means there must be relatively predictable sales, which cannot be guaranteed by relying only on direct sales. Therefore, direct sales can only contribute a small amount to the total sales level. There are two or three farmers markets in the City of York where the produce can be sold directly to consumers *(Interview SRE, YSF & YC)*. The York State Fair will have its yearly fairground in 2025, which celebrates agriculture in York County and can be used to promote and sell direct produce to consumers *(Interview YSF)*. This is in line with a success factor mentioned in Chapter 4.1: “adjusting to an urban environment” (Pölling, Sroka, et al., 2017; Sroka et al., 2023).

For CEA sales, partnerships with local restaurants are recommended *(Interview RII)*. CEA offers restaurants a stable supply and niche products that they may want to offer in their restaurants. Many smaller CEA farms in urban areas have partnerships with restaurants, and any extra produce they sell, e.g., at a farmers market. By offering restaurants niche offerings year-round (due to CEA environment), the sell prices for the crops can be slightly more than the competition depending on the niche offering. Although the sales value for selling to consumers directly is higher, relationships with local restaurants are considered the best option and are also frequently seen at CEA companies *(Interview RII)*.

For wholesale, the Giant Company is a major food retailer in Pennsylvania *(Interview SRE & PA)*. Sysco is a large company involved in food distribution, and its Central Pennsylvania distribution facility is located in Harrisburg. Restaurants in Pittsburgh and Philadelphia can be potential consumers of the produce *(Interview PA)*. It can be difficult to cooperate with supermarkets, but local supermarkets might be possible *(Interview RII)*. However, it can be challenging to assess what will have a high number of sales. In the Business Model

Canvas in Figure 6.1, selling via wholesale to Giant and restaurants, and direct sales at the farmers markets and the York State Fairgrounds were added as sales channels.

Customer Relationships

A challenge in the “experience” business model as found in Chapter 4.1 is “reaching and keeping customers” (Appolloni et al., 2022). Customer engagement was found in combination with B2B to lead to high business performance (Marczewska et al., 2023). In other literature, customer relationships were also found as key to urban farms’ success (Martin & Bustamante, 2021; Sroka et al., 2023; Wiśniewska-Paluszak et al., 2023). CEA also has shorter supply chains than traditional agriculture; thus, fewer parties are involved between production and the end consumer. This is because CEA-produced crops generally have less volume and are produced year-round *(Interview PA).* Shorter supply chains are also seen as a success factor for urban farming since margins can be higher (Pölling, Prados, et al., 2017; Pölling, Sroka, et al., 2017; Sroka et al., 2023). At the farmers markets, there is a very loyal audience. Additionally, people from Maryland and Lancaster visit the farmers markets *(Interview SRE)*. Therefore, in the Business Model Canvas in Figure 6.1 both short supply chains and having a “loyal audience” are key to customer relationships.

Customer Segments

A challenge in the “differentiation” business model is “finding enough customers” (Appolloni et al., 2022). It is easier to offer niche products in more expensive cities such as New York City and universities *(Interview NL)*. While Pennsylvania itself is ranked 23rd in terms of cost of living, nearby states such as Maryland, New Jersey, and New York including cities such as Baltimore, New York City, and Washington D.C. (part of the District of Columbia located next to Maryland) are in the top 10 states in terms of cost of living (U.S.News, 2024). The Northeastern US, including Pennsylvania, also possesses the more expensive and highly academically valued universities, such as those considered part of the Ivy League. In Pennsylvania, the University of Pennsylvania and Carnegie Mellon University are ranked in the top 25 universities in the World in 2025 according to Times Higher Education (Times Higher Education, 2024). The farmers markets in York have a mix of elderly and younger people *(Interview YSF)*. Older adults come there mainly for traditional reasons, while younger people are primarily concerned with the freshness of the food. However, local food is much more important than whether it is organic or other attributes *(Interview PA)*. Therefore, more expensive cities and universities, local elderly, and young people were added as being the customer segments in the Business Model Canvas in Figure 6.1.

Cost Structure

Almost all stakeholders indicated economic viability and profitability as a concern for the CEA project *(Interview Borlaug, SRE, York State Fair, YCEA).* In Chapter 4.2, it was found that both labor and energy costs are essential to consider (Moghimi & Asiabanpour, 2023). In addition, depreciation costs are essential, which relates to the high investment costs of vertical farming (Baumont de Oliveira et al., 2022). For energy costs, both electricity and heating need to be considered *(Interview Borlaug)*. While not entirely comparable, manufacturing companies in the area would probably find the utility costs generally affordable *(Interview YCEA).* Since it is a CEA facility and the initial design encompasses a tank for rainwater to be used, water and its costs will not be a concern. For natural gas, it is possible to get a fixed rate for some time *(Interview YCEA)*. They can be locked in for 1, 3, or 5-year terms *(Interview SRE).* Pennsylvania is the second-biggest natural gas producer in the US, and the state is therefore less concerned about its pricing *(Interview RII)*.

Electricity has variable pricing in the United States and can change every month *(Interview NL).* Pennsylvania, for its electricity, is part of the PJM grid, which is the wholesale electricity operator and determines the pricing by balancing the energy supply and demand (Huangpu, 2024). Because of legislation on safety requirements, a few central power plants will be closed between now and 2030. PJM predicts that by 2030, over 20% of current power generators, primarily coal and natural gas, will be retired (Huangpu, 2024). While there will be less supply, energy demand, for instance, from EVs and data centers, will increase in the coming years. Electricity is critical to the CEA project since the costs might increase substantially. Therefore, a fixed rate must be set for a predictable cost structure. In the financial analysis, sensitivity scenarios were used to give insight into how risky electricity price fluctuations are for the CEA project. It is possible to get a fixed rate for some time for electricity *(Interview YCEA)*. The most critical costs are thus investment costs including depreciation, electricity, and wages, which were added to the Business Model Canvas in Figure 6.1.

Revenue Streams

York State Fair and Susquehanna Real Estate questioned the margins, pricing model, and the revenues in York for selling crops *(Interview YSF & SRE).* The plan is to sell most of the produce to wholesale companies. However, "critical mass" (economies of scale) is needed to "afford" a wholesale price *(Interview YSF)*. Selling around 70% to 80% of the production to wholesale companies is recommended. Then possibly 20% can be sold to restaurants and 10% via direct sales *(Interview WUR)*. In the financial model, several different configurations were tested to be used for revenue streams. In addition, the fresh produce will be harvested, immediately sold, and not stored at the York State Fair *(Interview YSF)*. Only a tiny fraction can be sold directly at the farmers markets. A fixed rate could be established between CEA-produced food and customers, for example, wholesale companies and restaurants, since, compared to field-grown crops, CEA produce has a stable production (Moghimi & Asiabanpour, 2023). Direct selling at the farmers markets would still have variable pricing. In addition, the proximity to other cities allows fresh produce to be sold. Although prices do not seem to be higher in Pittsburgh, PA, or Washington, D.C., compared to York, which must be considered in the financial analysis (Giant Eagle, 2025; Giant Food, 2025; Giant Food Stores, 2025). Therefore, contracts with wholesale companies are essential for a stable price, while the prices will be variable for direct sales. Both factors were added to the Business Model Canvas in Figure 6.1.

Implications Business Model Canvas

In conclusion, the Business Model Canvas for the case which can be seen in Figure 6.1 consists of 9 different elements. The key partners include: York State Fair, York County Economic Alliance, York College, Priva, and the PA Department of Agriculture. The key activities relate to both the differentiation and experience business model. The key resources are: skilled employees, educational opportunities, the location of the CEA project being close to metropolitan areas, and having multiple crop types. The value propositions for the CEA project are that the lettuce is locally grown and that it improves the lack of fresh produce in York County and Pennsylvania. The essential sales channels include wholesale sales to Giant, selling to restaurants, and direct sales at the farmers markets or the York State Fairgrounds. In customer relationships, the key factors are short supply chains and having a "loyal audience." The customer segments are local elderly, young people, and more expensive cities and universities. Essential costs to consider are investment costs including depreciation, electricity costs, and wages. Lastly, essential revenue streams are contracts with wholesale companies for a stable price, and direct sales, where the prices will be variable. The question of (financial) viability of the CEA project remains, which will be explored in Chapter 6.2 by considering the commercial CEA facility where crops will be grown.

6.2 Financial Model

After the Business Model Canvas was developed for the case, it was used as input to create the financial model to assess the viability of the CEA project. Specifically, the findings of the cost structure, revenue streams, value propositions, and key resources in Chapter 6.1 were used as empirical data to demonstrate the financial model. While the CEA project will include educational and research activities that will bring additional revenue and costs, in the financial framework only a commercial vertical farm will be considered without educational aspects. This is done to limit the complexity of the research. The model was developed in Excel. It is titled: *Financial Model Tool Vertical Farming*. It can be used to determine if a vertical farm will be profitable based on its specific conditions. In the Excel sheet itself, it is explained how it can be used, which parameters are used, as well as data resources. In addition, scenarios were calculated based on variability in the data. The model calculates via metric units, but counterparts in customary units were also used since the CEA project is in the U.S. Data was used from resources in the U.S., the U.S. Government, York County, and resources in the Netherlands.

Model

In Chapter 4.2, it was found that electricity prices, labor costs, crop yields, the space used, and depreciation costs impact financial performance (Moghimi & Asiabanpour, 2023). Furthermore, sales prices and the wholesale price a grower gets impact financial performance (Song et al., 2024). These factors are therefore considered in the financial model. Furthermore, improvements on the following parameters could lead to higher profitability, which were considered in the sensitivity analysis: digitalization (engineers), scaling operations, labor efficiency, investment costs, yield, sales prices, wholesale prices, and electricity costs (Baumont de Oliveira et al., 2022; Song et al., 2024; Thomson, 2022). The different factors impacting profitability are described in more detail below. Thereafter, a "base scenario" was calculated with the most likely values for the parameters and a "third-year" scenario on the profitability in three years after the CEA project becomes operational (As indicated in Chapter 2.2, the projected horizon is 5 years). Due to the uncertainty in the values of the parameters, and to test the impact of the variability of the parameters in profitability, many different scenarios were calculated, which alter values in the parameters. The parameters of the financial model are described in more detail in the next section.

Sales Prices

To calculate sales prices, the lettuce prices need to be determined. The Giant in York, PA, which has three different locations in the city, was used as a reference for pricing since interviewees mentioned Giant as a potential wholesale company to collaborate with *(Interview SRE & PA)* (Giant Food Stores, 2025). Also, the possibility of selling crops in Pittsburgh (the second largest city in Pennsylvania) and Washington, D.C. (a nearby major metropolitan city) were tested for their sales prices. The sales prices, at least at the Giant Eagle in Washington D.C. and the Giant in Pittsburgh, are lower for butterhead and romaine lettuce than in York (Giant Eagle, 2025; Giant Food, 2025). Only Pittsburgh was calculated in the model as an alternative to test the impact of slightly lower average prices. Furthermore, romaine lettuce is sold at these companies as non-organic and organic, whilst butterhead is only sold as non-organic. Therefore, it was considered to sell romaine as non-organic or organic and butterhead as only non-organic in the model since otherwise no reliable price estimations could be made (the CEA project could potentially offer organic butterhead lettuce as an option to Giant which would bring them a unique offering). Since selling multiple crops increases the overall profitability as found in the literature review in Chapter 4, it was modeled that 50% romaine and 50% butterhead lettuce would be produced. Romaine can be organic or non-organic.

The profit margins could increase by selling to restaurants and direct sales *(Interview RII).* There are also options to sell produce directly at the farmers markets in York. Therefore, wholesale, selling to restaurants, and direct sales are all considered in different configurations, and how much is sold is spread between the three. Direct sales can bring you the highest pricing, restaurants, and wholesale *(Interview RII).* However, since there will not be a storage facility, most produce must be sold wholesale *(Interview YSF).* Furthermore, configurations where only slight portions are sold wholesale are also generally seen at other companies *(Interview WUR).* The configurations, where 100% of the production value is sold, were varied as follows:

- Configuration Base: Wholesale: 80%, Restaurants 10%, Direct 10%
- Configuration 2: Wholesale: 100%, Restaurants 0%, Direct 0%
- Configuration 3: Wholesale: 90%, Restaurants 0%, Direct 10%
- Configuration 4: Wholesale: 70%, Restaurants 20%, Direct 10%

The average price a grower gets for iceberg lettuce in the US was 34.3% of the retail price in 2019 (U.S. Department of Agriculture, 2020). There is no data from the USDA for romaine and butterhead lettuce, which are considered in the CEA project. While a premium price could lead to higher profitability, it was noted that one must be "realistic" about its pricing *(Interview RII)*. Therefore, different price levels were tested. The price the CEA Project receives is based on a percentage value of the sales price in the supermarket. The sale prices are expected to be higher for restaurants than wholesale, while the prices for direct sales could be the highest. The following price values as percentages of the sale prices in the Giant supermarket were used:

- Low-Price Value: Wholesale: 35%, Restaurants 60%, Direct 80%
- Mid-Price Value: Wholesale: 45%, Restaurants 70%, Direct 90%
- High-Price Value: Wholesale: 60%, Restaurants 80%, Direct 100%

Investment Costs & Depreciation

The CEA facility, as illustrated in the schematic overview in Figure 2.6 covers an area of 40,478 square meters (435,700 square feet). Of this area, it is estimated in the financial model that 33%, 50%, and 66% of ground floor space can be used for growing crops since space is needed for employees to harvest crops and also for equipment. A vertical farm of 1 square meter for lettuce costs 1000 euros (Vertical Farm Daily, 2024a). An internal model of Priva used around 500 USD per square meter for a high-tech greenhouse ground floor growing surface. However, it was also found that the investment cost per square meter could be 1500 USD *(Interview WUR*. Furthermore, depreciation and maintenance are considered. The investment costs are not specified in the model; most likely, different equipment has different lifetime years. For LEDs, 12 to 15 years when replacement is needed, is indicated on Google, but also a lifetime of 5 to 10 years was found (California Lightworks, 2020; Hortibiz, 2021). The model does not specify how much of the investment costs consist of LEDs and other equipment. Still, it is assumed that LEDs have the worst lifetime of the equipment and thus the highest depreciation, and that other investment costs have a lower depreciation. Therefore, the depreciation period was set to 15 years and was linear. In the sensitivity analysis, fewer depreciation years are tested. Maintenance was set to 0.5% of the investment costs based on an internal model by Priva. The number of vertical layers and how much of the total facility is used to grow crops also impact the investment costs (and yield). A single, 4, 6, and 12 layers were tested in the financial model (single layer is a high-tech greenhouse in practice instead of a vertical farm). In the base model, a 4-layer vertical farm was tested to reduce investment costs per square meter.

Energy Costs

A vertical farm can have a 90% reduction in water use, and for the U.S. specifically, water usage is 12 times lower compared to traditional farming (Graamans et al., 2018; Moghimi & Asiabanpour, 2023). The CEA facility incorporates the collection of rainwater to be used for the vertical farm. Therefore, it is assumed that water costs are minimal and thus are not considered in the model. Furthermore, natural gas costs have not been modeled in the energy costs since they only account for relatively small energy costs directly related to yield compared to electricity costs (Azzaretti & Carleton, 2023). Moreover, Pennsylvania is a natural gas-producing state, which implies pricing may not be as volatile as electricity prices could be in the future (Interview RII).

In the U.S., energy prices differ between residential, commercial, and industrial customers (U.S. Energy Information Administration, 2024). The electricity prices for Pennsylvania in September 2023 and 2024 were used in the financial model. For industry, the electricity price in cents USD per kWh was 7.73 in October 2024 and 7.63 in October 2023 (U.S. Energy Information Administration (EIA), 2024). This is lower than the U.S. average of 8.21 and 8.01, respectively. It is important to note that it was found that over time, energy costs decrease due to the learning process in a CEA facility (Azzaretti & Carleton, 2023). Therefore, energy use efficiency was considered in the model. Increasing electricity costs due to the PJM grid's decreasing supply is also considered in the model. The average energy use was 25.8 kWh per kg lettuce among 12 different CEA and vertical farms in the U.S. (Azzaretti & Carleton, 2023).

In Figure 6.2, the climate zone map, specifically considering building automation, can be seen, which is different from other climate zone maps of the United States (Azzaretti & Carleton, 2024). The studied CEA facilities & vertical farms in their report were located in the 4A, 5A, 6A, and 6B climate zones, which are showcased in Figure 6.2. Climate zones 4A, 5A, and 6A primarily concern the Midwest and Northeast states (from North Dakota to Maine and Kansas to Pennsylvania). The southern states of Kentucky, West Virginia,

Virginia, Maryland, and Delaware are also part of climate zones 4A, 5A, and 6A, while the Canadian border regions with Canada, Maine, Minnesota, and North Dakota, are not. Climate zone 6B is concerned primarily with Wyoming and Montana. Climate zone 4A is considered a mixed humid climate zone compared to cool humid for 5A, cold humid for 6A, and cold dry for 6B. York, PA is located in a 4A but relatively close to a 5A climate zone. This suggests that the energy use values in their report are climate zone-wise applicable to the location of the CEA project. This is important since energy usage depends on whether heating or cooling must be used, which depends on the climate zone. In the colder regions, more heating is needed in winter, thus increasing natural gas use (only slightly as heating in vertical farming is barely needed). In contrast, in the southern areas, more cooling is required in summer to compensate for the excess heat of LED lights, increasing electricity costs. The Dutch vertical farm Growy noted that it uses less than 10 kWh per kg lettuce in its vertical farm. (Vertical Farm Daily, 2024a). This value was also tested in the financial model.

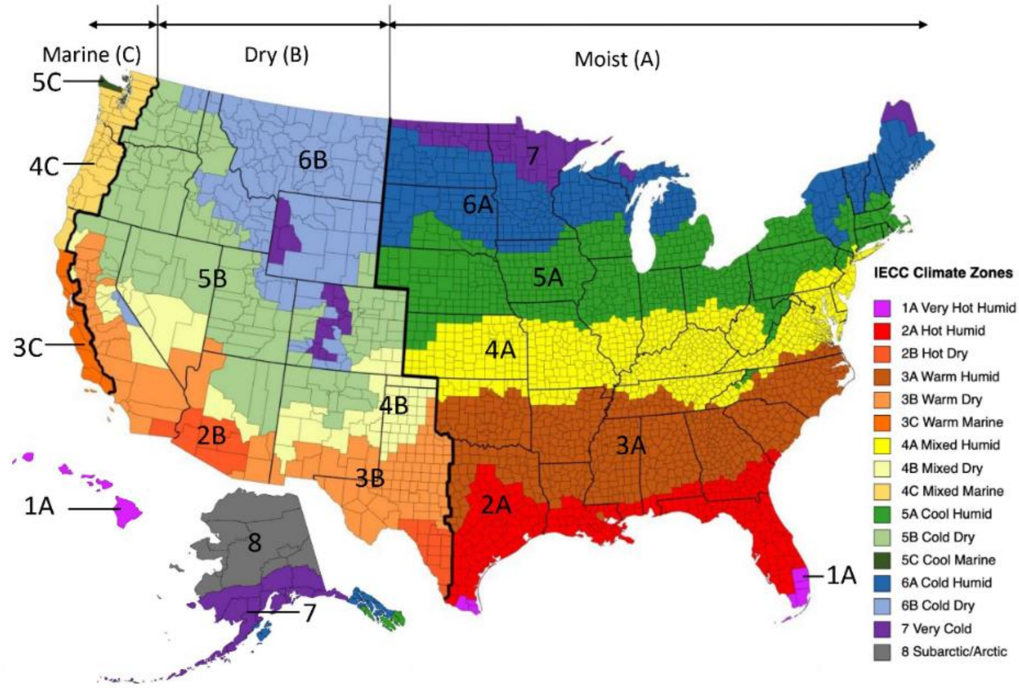

Figure 6.2: Climate Zone Map Building Automation in the United States (International Code Council, 2021)

Labor Costs

The labor needed to operate a vertical farm was one of the causes why vertical farms went bankrupt in the U.S., and thus is very important to profitability (Vertical Farm Daily, 2023a). For the financial model, it was assumed, based on internal models from Priva, that the workforce per 1 hectare of a vertical farm is structured as 10 growers, two head growers, and one manager. Head growers are assumed to have 50% more salary than growers. Furthermore, a salesperson is needed *(Interview YSF).* A salesperson, management, and engineers were modeled as being constant and not affected by the scale of operations. The costs of employees were based on the average salary per workforce group in York County (York County Economic Alliance, 2024a). Also, Pennsylvania's wage costs were tested in the model, which is, on average, a bit higher than those in York County. It is assumed that if the CEA project fails to meet labor demand, it will need to pay the Pennsylvania-level wages to attract more employees. If the facility is automated, it is assumed that only 50% of the number of growers and head growers are needed compared to when the facility is not automated based on Priva's internal models. However, employees with an engineering background will be required when the facility is automated. The efficiency of workers is reduced if they are less experienced. Therefore, other configurations including more employees per square hectare are also tested in the model. Another option for the CEA facility is to hire interns who could be both grower-related and engineering interns. It is assumed that they have an efficiency of 50% compared to their counterparts (growers and engineers), but their average wages are also approximated to be significantly lower (Indeed, 2023). All these different factors were tested in the scenario analysis.

Profitability

In Table 6.1, the configuration of the base model and the potential three-year model can be seen. For the facility's growing area size, investment costs are set at 1000 USD per square meter. While funding resources are not precisely known, venture capital has decreased substantially since the bankruptcies of many vertical farms in 2023 (Glasner, 2024). Therefore, to keep the CEA Project investment costs realistic relative to the possibilities at the York State Fair, it used only 33% of the ground floor space and a low (4-level) vertical farming height to keep the investment costs lower. Yield was projected to be at a base level without significant disruptions and first-year productivity. The wages were based on York County's average of 100% productivity, without interns and automation. Energy costs and usage are also based on the average prices in Pennsylvania and the average use of other CEA and Vertical Farms in the United States (Azzaretti & Carleton, 2023). For revenues, lettuce will be sold in York with 80% going to wholesale, 10% to restaurants, and 10% to direct sales. The price that the CEA facility receives was set to mediocre, and only non-organic produce will be sold.

Table 6.1: Configuration for Base Revenue Model & After Three Years

Parameters	Base Revenue Model	Three Years Model
CEA Ground floor Growing Area	33%	33%
Vertical Growing Layers Base	Low	Low
Investment	Mid	Mid
Depreciation	Low	Low
Productivity	100%	100%
Year & Type	First	Third
Type	No Automation	No Automation
Education	No Intern	No Intern
Productivity	100%	100%
Salary	York	York
Energy Productivity	Base	Base
Energy Costs	100%	100%
City	York	York
Configuration	Base	Base
Price Value	Mid	Mid
Type	Non-Organic	Non-Organic

The profitability of the vertical farm in the base model is showcased in Table 6.2. It can be seen that the business would be profitable for the base model. In Appendix DYork Information, it was found that for crop businesses between an asset value of 10M to 50M USD, the profit margin on average after tax is 6,5% (York County Economic Alliance, 2024a). In this case, the profit margin after tax is 9.3% indicating that the CEA Project would be more profitable than most of the competition in York County. In a realistic scenario, the business is unlikely to be profitable in the base model. Costs, such as energy costs in the facility (not production-related), rent to the York State Fair, IT support, shipping and delivery, branding, raw materials, and website development have not been accounted for. Depreciation is a significant factor impacting the costs, which aligns with the literature, due to the high investment costs of vertical farming and energy costs. In Figure 6.3, the cost structure for the base model is showcased, with depreciation and energy costs each accounting for over one-third of the total costs. Combined, they make up more than two-thirds of the total costs in a vertical farm.

The yield is projected to be almost twice as high in three years due to the learning process, while energy usage could be two times more efficient (Azzaretti & Carleton, 2023). Furthermore, the corporate tax in Pennsylvania will decrease in the coming years, and it is also projected that the federal corporate income tax will decrease from 21% to 15% under the Trump administration (Michel, 2025; York County Economic Alliance, 2024a). Based on these conditions, the profit margin will rise to more than 40% after taxes. A limitation would be that it is uncertain if the efficiency of growers will be the same as the yield, which was modeled by keeping the wage costs the same. However, if wage efficiency does not grow and increases almost twice to keep up with the higher yield, the profit would decrease from 8.5 million to 7 million USD, still leading to a profit. It can thus be concluded that while in the very short term (0-1 year), around break-even would be the most likely outcome, longer-term (3 to 5 years), the CEA Project would become profitable. More extensive cost research must be done for a complete financial projection.

Table 6.2: Profitability Vertical Farm CEA Project

	Base Revenue Model	*Scenario 1 (Three Years)*
Total Yield (Kg) / Year	1,758,178	3,366,724
Revenue Crops ($)	10,385,908	19,887,909
Total Revenue ($)	10,385,908	19,887,909
Energy Costs ($)	3,481,773	6,667,225
Wages ($)	1,713,100	1,713,100
Maintenance ($)	267,200	267,200
Depreciation ($)	3,562,670	3,562,670
Costs ($)	9,024,744	12,210,196
Profit Before Tax / Loss ($)	1,361,164	7,677,713
Taxes ($)	394,601	1,649,941
Profit / Loss ($)	966,563	6,027,773
Profit Margin After Tax	9.31%	30.31%
Investment Cost ($)	53,440,056	53,440,056
Payback Period (Years)	55.3	8.9

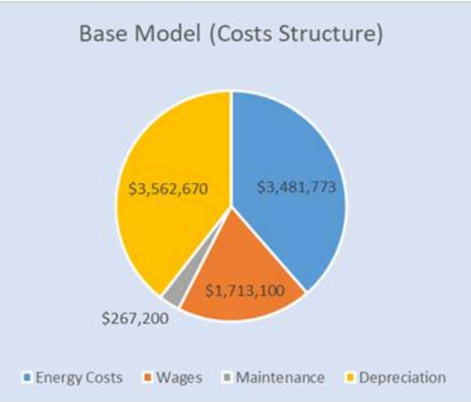

Figure 6.3: Base Model Cost Structure

Financial Model Review

Experts at Priva were asked to assess the financial model to evaluate its applicability. The respective protocol used for the model validation is presented in Appendix J. The experts have the following roles within Priva and/or Greengrounds.

- Expert 1: Director of Strategic Development
- Expert 2: Manager Indoor Growing
- Expert 3: Researcher, Food System Modelling

The respective experts' points of improvement are summarized below. Based on these recommendations, the model tool was changed or added as a limitation.

Improvement recommendations by Experts

Expert 1 (Notes translated from Dutch to English)

The model could be improved in user-friendliness. For one, it could showcase which parameters can be varied to alter the model, and two, which variables are related. This could explain what happens to other variables when one specific variable changes. Another important aspect is the use case, for example, for investors or governments. A model does not just exist to be “a model.” For them, the model data must be up-to-date and complete. The model should also be able to be used by people who are not as strong numerically. For example, icons can be used in a presentation to make it more insightful. This should also include the social aspects and the financial feasibility. At a higher level, it would be interesting to know how the model could provide insights into future scenarios, such as the increased viability of vertical farming if energy costs decrease.

Expert 2 (Notes translated from Dutch to English)

The recommendation correctly states that a fixed price for the produce is needed for stable revenues, it is commonly seen that the fixed cost is based on seasonality, where, for example, a grower gets a little bit of a better price in the winter compared to the summer. Another factor that is not considered is that if the facility size and thus growing area is more significant, less space is needed for equipment next to the growing surface area. This is because, for instance, equipment such as automation equipment or water irrigation units does not necessarily have to be two times the size if there is twice the growing area. Therefore, the percentage value of how much of a facility can be used depends on the facility size. In addition, since the goal is to identify the main drivers that affect the profitability, usability shall be improved by the ability to change all the parameters on one sheet. In addition, several inaccuracies in the results and their parameters were identified. Some data was also recognized as being realistic, and others were not. For example, the kWh/kg energy use was perceived to be realistic at 25.8 kWh/kg crop, but the 10 kWh/kg crop was. Depreciation could be much lower from 15 to 7 years, which aligns with the LED lights' timeline. Yield values of 100 kg/m2/year were seen in a non-commercial farm.

Expert 3

The “Lettuce Revenues” Excel sheet, while being correctly calculated, consists of an intermediate step that does not make as much sense as an alternative. For example, 80% of 1kg butterhead lettuce is sold via wholesale to a supermarket, and the price value in the supermarket is 10 USD. In comparison, vertical farming gets 35% of that price, and it was calculated that the grower thus gets 35% x 80% x 10 = 2.80 USD. This would hence be for 800 grams since the other 200 grams are sold via different ways. It would make more sense to calculate this price based on what you get via wholesale (3.50 USD), and only later calculate the average sales price combining wholesale, sales to restaurants, and direct sales. This way, the client can see that he needs to get 3.50 USD from selling via wholesale according to the model.

Financial Model Changes Based on Validation

Based on the expert validation the following changes were made to the model:

- The “Parameters” Excel sheet was expanded in the financial model to explain the variable interactions, make it more insightful, and showcase which parameters can be altered. Due to the model's setup, complete flexibility in changing parameters could not be achieved.
- Several results were visualized to make them more understandable for a larger audience. An extra sheet was explicitly created for visualizations of the results.
- Clarifying which data parameters could be changed based on other vertical farming locations
- Mistakes identified by the experts, such as incorrect formulas or values, were adjusted, which affected the results. Several alternative values such as depreciation being 7 years or yield being 100 kg/m2/year were added as alternative scenarios.
- The “Lettuce Revenues” Excel sheet was changed according to the recommendations of Expert 3.

Sensitivity Analysis

After the experts reviewed the model, a sensitivity analysis was conducted on several parameters to assess how variations in certain factors impact profitability. The parameters are grouped in the following categories: facility, investment costs, yield, wage costs, energy productivity and costs, and lettuce revenues. In Appendix I, different profitability scenarios are calculated per category based on the change in the different parameters. For instance, for the workforce, scenarios were calculated where the salaries are based on the Pennsylvania average instead of York County. In every case, only one parameter was changed. Combining different parameter configurations and determining which lead to the highest profitability would be more interesting. Due to time limitations and the model being in Excel and not in programming or simulation software, it would take considerable time to carry out this operation. Therefore, this sensitivity analysis is limited to the impact of parameters compared to the base model, whether it increases or decreases the profitability, and how much.

Yield

In Appendix I and Table I.11, the sensitivity analysis for different yield values is showcased. In the Expert 2 interview, it was noted that a non-commercial farm has a yield of 100 kg per square meter per year. This leads to a high profit margin, but since it has not been proven yet in a commercial vertical farm, it is questionable whether this can become possible in a commercial farm. It was found that in the case of workforce issues, which indicates only 60% of the yield can be captured, the business model would make a loss due to the decline in revenues. This shows the severe impact yield and the ability to harvest the yield has on the profitability. Therefore, workforce development must be thoroughly considered.

Workforce

In Appendix I and Table I.12, the sensitivity analysis of different workforce parameters can be seen. This also covers the profitability results in more detail. If the average wages are higher, the Pennsylvania average wage must be paid, which only slightly decreases the profitability. This indicates that paying higher wages is not much of a concern for the CEA Project. If due to lower productivity, more growers need to be hired, the profit margins decrease by 4% to about 5.3% compared to the base model. This implies that grower efficiency highly impacts financial performance and thus must be a priority in the CEA project. Moreover, if higher wages lead to better grower efficiency, it is an option that should be considered. Automation could increase profitability, while incorporating interns decreases profitability. This is because the efficiency of interns in replacing growers' tasks is a more significant decrease than their salary compared to growers, since the main functions of interns are educational activities and not replacing growers (the effects of efficiency increasing over time are neglected in this case). It must be noted that only employee costs were changed for automation, not investment costs. It must be considered that educational opportunities could decrease profitability, which was the preferred action in the stakeholder analysis in Chapter 5.

Energy

In Appendix I and Table I.13, the sensitivity results of variation in energy costs and energy use are showcased. In Pennsylvania, electricity might rise in the future due to the closures of power plants (Huangpu, 2024). When energy costs exceed 150% of the original costs, the vertical farm becomes marginally below break-even. If it is 300% compared to the original costs, the energy costs alone are higher than the sales revenues and likewise, the business model becomes highly unprofitable. If energy usage increases by 50%, the vertical farm makes a loss. There were instances of CEA facilities and vertical farms having this energy usage (Azzaretti & Carleton, 2023). If energy usage decreases to the value seen at Growy in the Netherlands, the profit margin doubles to almost 24%. This reinforces the literature highlighting the impact of energy costs on profitability. It is thus highly important that for a profitable business model, it can be assessed what future predictions of the electricity costs will be or ensure that energy costs are delivered at a fixed price for a certain number of years.

Revenue

In Appendix I and Table I.14, the sensitivity results of different lettuce sales revenues can be seen. If lettuce is sold in Pittsburgh instead of York while keeping the configuration the same, the average lettuce price per kilogram decreases from $4.77 to $4.16 (12.7% decrease). The profit margin in this scenario is only 0.20%; thus, it is about break-even. Still, considering additional costs are not accounted for, the business model will be unprofitable. If the average revenue prices are lower per kg of lettuce (e.g. 35% instead of 50% of sale price via wholesale), the business becomes unprofitable too. This means that sales prices are very volatile for the profitability of the vertical farm. Different configurations of selling lettuce to wholesale companies, restaurants, and direct sales were also tested. Selling only via wholesale channels makes the vertical farm unprofitable while having only 10% via direct sales and 90% to wholesale still keeps a profit margin of 6.19%. This indicates that it is necessary to have 10% direct sales at least, and preferably also restaurants to sell to. Already having only one of the lettuce types (50% of produce) sold as organic produce increases the profit margin to around 27%. Therefore, having an organic label can greatly improve profitability. The CEA project must start a conversation with potential sales markets to understand their revenues, since the margins are low enough, small changes can make vertical farming unprofitable.

Facility

Appendix I and Table I.15 show the sensitivity results of different production sizes. First, a scenario is calculated if more vertical layers are added. As wages are assumed to rise at half the rate of an extra vertical layer, it is assumed growers are more efficient when there are more vertical layers. The profitability margin increases to 11% with a larger asset size and total sales value. It was also calculated if only 1 layer and the investment costs of high-tech greenhouses were used. In this case, the profit margin is 15% and the CEA facility is thus more profitable than the base model. This could explain why vertical farming finds itself challenged for profitability. However, the three-year model has better profitability than the greenhouse scenario. This implies that longer-term vertical farming could be more profitable compared to greenhouses. As shown in Figure 6.3, wage costs do not contribute as much as energy and depreciation costs to the total costs. Employee efficiency improves with more vertical layers but is thus not as important to the total costs, which explains why a greenhouse performs financially relatively well compared to a vertical farm. Due to the facility size and the business environment, the potential lettuce production and thus company size is much smaller than for vertical farming. This means that higher profit margins are needed, as seen in Table D.8 in Appendix D. It shows that profit margins can be lower for companies with more asset size, which means vertical farming offsets the higher profit margin in greenhouses. Furthermore, increasing the area in the facility used for growing to 50% or 66% leads to higher profitability due to economies of scale in wage costs. These scenarios cannot be considered since the project's investment costs are very high. The location of the York State Fair potentially could have 16 hectares (40 acres) instead of 4 hectares (10 acres) of CEA facilities. In the future, these scenarios can be considered if the CEA project is ready for scaling up.

Investment & Depreciation

Appendix I and Table I.16 show the sensitivity results of variations in the investment costs and depreciation years (the number of years of decreasing value of the investment costs). Due to the high percentage of depreciation costs on the total costs, having lower or higher investment costs per square meter of the growing area substantially impacts profitability. This means that investment costs are important to consider in the business model as already indicated by the total cost structure in the base model in Figure 6.3. In the review by Expert 2, it was noted that LEDs could have a depreciation rate of 7 years or between 5 to 10 years (Hortibiz, 2021). The model does not specify what is included in the investment costs or the proportion allocated to LED equipment per square meter, but alternative depreciation periods have also been tested. In scenarios: 'Depreciation High' (depreciation from 15 to 7 years) and 'Depreciation Mid' (depreciation from 15 to 10 years) the vertical farm becomes severely unprofitable. Even though the costs of LEDs have decreased substantially over the last years (Freeing Energy, 2021). Since investment costs are very high, depreciation costs are important for viability.

Limitations of the Model

The financial model has several limitations. Some are due to uncertainty in parameters and were estimated. Others are to make the model less complex and easier to use. Also, the timeline of the research study led to prioritizing some aspects over others, for example, by only including the most essential costs found in the literature in the model. The various limitations in the financial model can be seen in Table 6.3. Users of the financial model must consider them in their analysis.

Table 6.3: Limitations Financial Model

Costs, such as energy costs in the facility (not production-related), rent to the York State Fair, IT support, shipping and delivery, branding, and other overhead costs have not been accounted for. While analyzing the profitability and profit margins that were accounted for, only guesses can be made about what, in a more realistic model, the costs would be. In addition, since the investment costs are not specified in more detail, the depreciation years are unknown. At the same time, it was found out that depreciation costs are very important to the cost structure in the model. Natural gas costs were not modeled in the energy costs since they only account for relatively small energy costs directly related to yield compared to electricity costs (Azzaretti & Carleton, 2023). Moreover, Pennsylvania is a natural gas-producing state, which implies pricing may not be as volatile as electricity prices could be in the future (Interview RII). Still, the model could be improved by having more reliable data on how much natural gas is used in the facility.
Price elasticity was found to impact the profitability of vertical farming (Song et al., 2024). The financial model did not consider this since it only looks at the profitability at a single moment and not over some time. Price elasticity could therefore not be added to the model. Seasonal price variation could not be added due to the inability of the model to consider multiple periods for profitability. Revenue prices of lettuce are assumed to have no seasonality and were based on the website of only one store. Lettuce production in the U.S. differs per month due to seasonal weather, for example, in Arizona and California (Weber, 2023). It is therefore highly unlikely that prices remain constant for a year. In the expert review, it was also found to be a factor in the price negotiation.
Depreciation was set to 15 years and linearly to investment costs. Furthermore, investment costs are modeled as constant and do not account for economies of scale if more production area is installed. The latter is not likely, which implies that larger facilities have improved profitability compared to the model. The impact on profitability could also be high since depreciation costs are relatively high in the overall total costs. Depreciation costs in general are not based on literature. 7 years was also mentioned as a possible depreciation in the expert validation
The model assumes that based on internal conversations within Priva, production increases via vertical layers lead to higher grower efficiency (about 50% in the model). This value was not based on literature. While wage costs do not have as much of an impact on profitability as depreciation and energy costs, it is still important to have more reliable data.
Only staff directly impacted by the yield (grower, intern grower, and head grower) are modeled to increase, when the growing area of lettuce increases. Overhead staff (management, salesmen, engineers, and intern engineers) do not relate to the lettuce cultivation area. While to some degree it is realistic that, for instance, a single salesman could sell twice as much if the yield is doubled, it is questionable and unlikely that no more overhead staff is needed after sufficient scale increases. Thus, the average wage costs would become higher if the scale of the lettuce production increases.
The model does not consider how much produce specific supermarkets are willing to buy. If production at the CEA facility is high enough, it is very unlikely that all produce can be sold in York County or even only the neighboring counties. Since cities such as Pittsburgh, PA, were found to have slightly lower prices, which did affect the profitability considerably, a more in-depth analysis of sales prices and lettuce sales must be done to better assess the business environment for the CEA project in York, PA.

Data in the model was based partly on Dutch resources, which might not be transferable to the case specifically. For instance, the employee size per hectare, yield data, and investment costs are based on Dutch models. While a vertical farm in theory is a closed environment and should have the same behavior not depending on the country or region, this will most likely not be the case in practice. Therefore, for example, lower efficiency among the workforce or lower and higher investment costs were tested to make the results more resilient against likely changes in the data. More reliable data must be used to assess the viability more accurately. Testing similar vertical farms with the same business environment and climate as the study case was impossible in this analysis.
A limitation of the model is that it is not convenient for a quick analysis. Ideally, as mentioned in the expert validation, one can change parameters on one sheet and immediately see the outcomes on the same sheet. Due to the many parameters and how the model was built, the combination of parameters affecting wages could already lead to 192 different variables, meaning that all options must be listed in a drop-down menu, which is not preferred. The model was built this way to accommodate more straightforward scenario analyses, but it makes it more complex for a quick study on profitability. Therefore, to improve the usability, it was chosen to link where the parameters can be altered and link some parameters directly in the sheet. Implementing variables on a single sheet was not done because this would only allow for making a single scenario and not for comparing different scenarios where alternative options could be compared.
A complexity is the use of two different measurement systems, which leads to double the use of different variable options if both are integrated on the same level. Since formulas are linked via the metric system, only the metric system is fully integrated.

6.3 Conclusion Sub-Question 4

This chapter was aimed to answer the following sub-question: *What business and financial model can be developed based on the study case?* A Business Model Canvas was made on the case, combining two business model types: the “differentiation” and the “experience” business model. The differentiation business model is concerned with focusing on products that are not yet offered. It was found that there is a lack of fresh produce in York County and the Northeast generally, and the CEA project could thus fill in this gap. The experience model concerns incorporating educational activities, which ties well with the stakeholder analysis, where it was found that having interns could lead to better alignment between the stakeholders. A financial model tool was made, and data specifically on the case was used to calculate profitability. While the base scenario suggests profitability already in the first year, it was found that costs not included in the model would most likely make the business model not profitable. In three years, however, the profit margin due to higher yield and energy savings could rise to such a significant level that profitability is likely. In the sensitivity analysis, many scenarios were tested where parameters in the facility's growing size, investment costs, energy costs, wages, and revenues were changed. It can be concluded that energy costs and revenues significantly impact profitability, especially since only relatively minor changes negatively affect the business model. In addition, the investment costs are high, which leads to high depreciation costs and reduces the potential growing size. Therefore, the CEA project must focus on establishing a fixed rate for the energy price and negotiating a stable wholesale price for its lettuce to shield itself from possible market changes. The model does contain significant limitations, which limit its usefulness as a definitive indicator of profitability. The concept of the Business Model Canvas in vertical farming and the financial model tool is used in Chapter 7, to support the making of a decision-support framework. This way it can also be used for future vertical farming projects.

7. Decision Support Framework

In Chapter 6, a Business Model Canvas was developed for the study case and the viability of the CEA project was analyzed. Furthermore, several different methods to analyze stakeholders involved in a vertical farming initiative were explained in Chapter 5. This chapter dives into how the methods and tools used in this research can form a framework that can be used in other projects in different business environments. Therefore, the question to be answered is: *How can stakeholder analysis methods and business model tools be combined in a decision-support framework?* The industry can use the framework to identify a suitable location for a vertical farm or assess which business model is appropriate for a vertical farming initiative. Public authorities could use the framework to asses if a vertical farming initiative is viable in their city/state and if needed what specific policies need to change to increase the viability of vertical farming in the region.

7.1 Framework

The decision support framework for vertical farming is showcased in Figure 7.1. The six stages represent the steps from left to right that must be taken. The steps are: “identify drivers,” “analyze business environment,” “analyze stakeholder alignment,” “develop business case,” “analyze viability,” and “implement vertical farm initiative.” The different stages are described in more detail below.

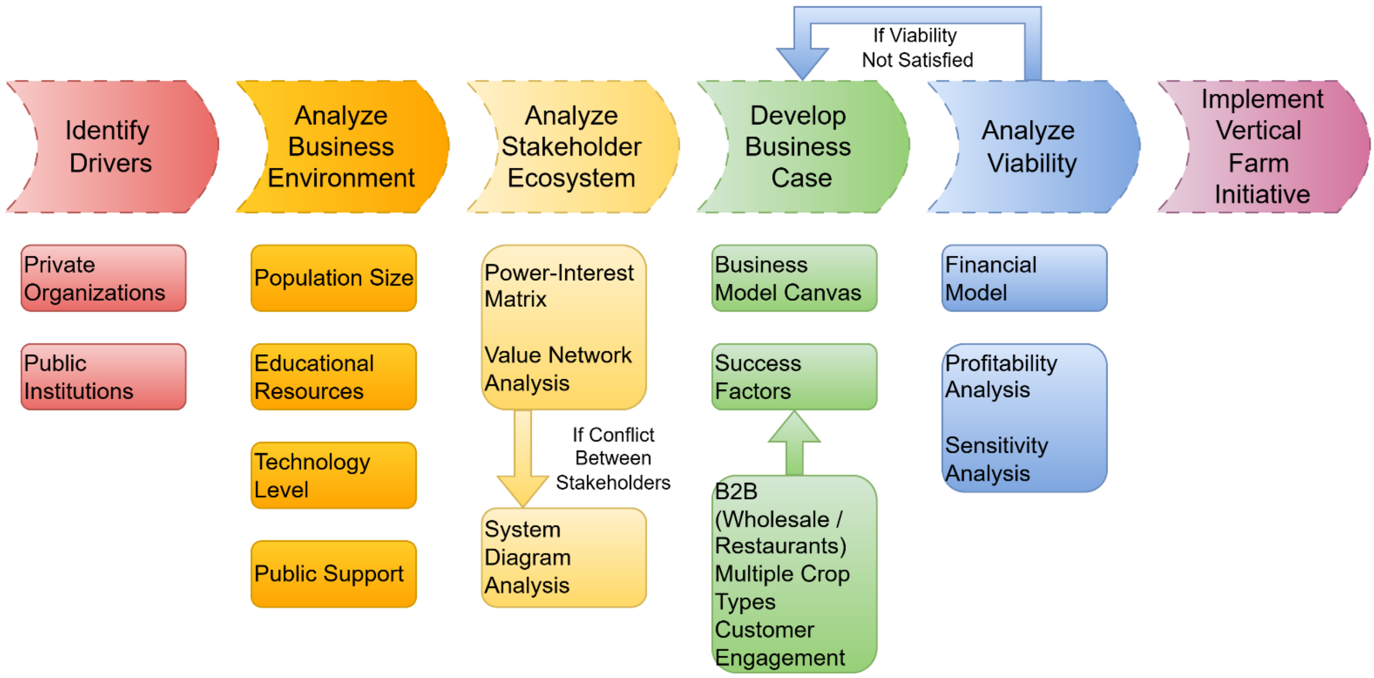

Figure 7.1: Decision Support Framework for a Vertical Farming Initiative

Identify Drivers

Vertical farming was found to be in most circumstances less financially viable than traditional farming, as described in Chapter 3. For a vertical farming initiative to be considered, there must be a driver from private organizations or public institutions. In the study case, a business driver was that the York State Fairgrounds is not as much used as the York State Fair wanted, and thus they need new financial resources while keeping the agricultural heritage. Another driver was the desire of local institutions to offer new high-paid/skilled job opportunities. At the same time, the PA Department of Agriculture wanted to increase the resiliency of agriculture in its state. Other drivers can be, for example, decreasing the reliance on food imports in favor of local production, such as in Singapore and the UAE, as can be found in Appendix E. In the U.S., as described in Chapter 1, the lack of fresh food in parts of the country can drive a vertical farming initiative. Furthermore, Rust Belt states (Illinois, Indiana, Michigan, Ohio, Pennsylvania, Wisconsin) due to their interesting business opportunities have seen growth in CEA, most likely since they have large population areas and have many former industrial areas, “brownfields” that can be used (Agritecture Consulting & CEAg World, 2024). Drivers create a window of opportunity for a vertical farming initiative.

Analyze Business Environment

The next stage consists of assessing the business environment where the vertical farm can be located. Four factors determine whether a vertical farm is desirable in that location and what type of resources can support the vertical farm. First, the population size of the urban environment and its periphery where the vertical farm could be located is essential. It was found in Chapter 4.2 that a vertical farm’s viability would increase when it is located in a city with a population size of at least 50,000 (Marczewska et al., 2023). In Chapter 6.1, it was found that since the study case is close to a large metropolitan area, the city where the vertical farm is located can be smaller than 50,000 to be viable. Second, a vertical farm's technology level depends on the business environment. For example, if more automation is desired, including robotics, can be an option, which entails a business environment where private companies are willing to invest in robotics development in the vertical farm. In addition, skilled and more expensive engineers would be needed in the vertical farm, which might or might not be available in the region. Another factor pressuring the technology level is the region's shortage of an agricultural workforce. It was found in Chapter 5.5 that automation can make a vertical farming more resilient to labor shortages. In the U.S., agriculture heavily relies on migrant labor, which might become under more pressure by the Trump Administration from 2025 and onwards (Gutierrez-Li, 2024).

Another resource vital to the vertical farm initiative is the educational opportunities that might be possible to offer. For example, there is the possibility of providing internships to agricultural students and students from other majors. This can potentially benefit the workforce in the long-run, but decrease profitability in the short-run as found in the financial model in Chapter 6.2. Lastly, while public institutions can drive a vertical farming initiative, it is also essential for public support to a project. It was found in Chapter 5.2, that public institutions can connect a vertical farming initiative to new stakeholders interested in the project, as the PA Department of Agriculture did in the case study.

Analyze Stakeholder Ecosystem

After examining the business environment, a stakeholder analysis must be done to explore the stakeholders' ecosystem for the vertical farming initiative. Interviews can be conducted to identify stakeholders' goals, roles, and concerns regarding the vertical farm initiative. First, their relative importance to the project can be determined by using a power-interest matrix. The stakeholders to consider decisive to a vertical farm’s success are the ones that have high power and high interest (Buser, 2024). This implies that their interests are of higher concern and must be preferred compared to stakeholders with low power/low interest. This was examined for the study case in Chapter 5.3. Next, a value network analysis must be done to identify how the stakeholders interact and what value they exchange with each other (Allee, 2008). This can indicate which partners are more collaborative with each other and which are not.

If it is found in the interviews that specific goals could potentially lead to conflict between stakeholders, a system diagram analysis must be done. In the system diagram, actions (means) available to the vertical farm can be assessed in whether they positively or negatively affect stakeholders’ concerns. In addition, external factors can be added that may impact the causal relations in the system diagram as can be seen in Figure 5.3 in Chapter 5.4. The best possible action(s) should be chosen to solve or mitigate the potential stakeholder conflict and to find alignment between the stakeholders. This is where the power-interest matrix becomes vital since the goals of the more essential stakeholders must be preferred above the less important ones if it is impossible to satisfy all stakeholders’ objectives.

Develop Business Case

The business case must be developed after the stakeholder ecosystem is explored and the potential concerns have been satisfied. A Business Model Canvas can be used to identify the components essential to the business model in a visualized framework. The Business Model Canvas consists of 9 elements: Key Resources, Key Activities, Key Partnerships, Customer Segments, Customer Relationships, Sales Channels, Value Propositions, Revenue Streams, and Cost Structure (Osterwalder & Pigneur, 2010). A crucial element is the "key activities" which define the type of business model(s). In Chapter 4.1, six types of business models are identified that can be used. Table 4.4 also specifies the drivers and challenges for every business model. These need to be considered to ensure the type of business model suits the business environment and the stakeholders involved. In addition, in Chapter 6.2, success factors critical to the viability of vertical farming were identified. The following factors lead to increased business performance: B2B (wholesale and/or restaurants), multiple crop types, multiple revenue streams, and customer engagement (Marczewska et al., 2023).

Analyze Viability

When the business case has been developed with the support of a business model, the viability must be assessed to identify if the vertical farm can be profitable and how resilient its profitability is to different scenarios. A financial model was developed that can be used to calculate the profitability. Its applicability to the study case can be found in Chapter 6.2. In Chapter 4.2, it was found what the crucial costs are to consider for a vertical farm. This includes: labor, electricity, investment, and energy costs. Other parameters that affect profitability are the scale of the vertical farm, yield, and revenue prices. These factors are included in the financial model tool and the data can be altered to fit a specific vertical farming initiative. The tool is also made so that parameters can be changed to test which configurations lead to better or worse profitability or what profitability might be after a few years. The tool also possesses limitations which are summarized in Table 6.3.

Next to assessing the profitability in the "base scenario", a sensitivity analysis must be done to test how the viability performs under different scenarios. For example, in the case study, based on concerns about rising electricity prices in the future, different electricity pricing was tested to examine how the vertical farm initiative performs under these circumstances. The resiliency of the vertical farm can thus be assessed by identifying potential concerns and determining key areas to focus on for future-proofing its viability. If the viability of the vertical farm is not likely or profitability in the sensitivity analysis is assessed as too uncertain, one could reconsider the business case and choose a different business model if possible. When the viability of the vertical farm is evaluated positively, all stages are satisfied. The vertical farming initiative can be implemented.

7.2 Implications Decision-Support Framework

The aim was to answer the following research question: *How can stakeholder analysis methods and business model tools be combined in a decision-support framework?* The stakeholder analysis methods used in Chapter 5 were generalized and incorporated into the "analyze stakeholder ecosystem" stage. This includes a power-interest matrix to determine the stakeholders' relative importance. In addition, a value network analysis should visualize what value stakeholders exchange with each other. If misalignment between stakeholders is found, a system diagram analysis must be done to explore the project owner's options to ensure the goals of at least the most critical stakeholders can be met in the vertical farming initiative. Other vital methods that have been included in the framework are the Business Model Canvas and the financial model tool developed in Chapter 6. These methods and tools substantiated the decision support framework, which consists of the following six stages: "identify drivers," "analyze business environment," "analyze stakeholder ecosystem," "develop business case," "analyze viability," and "implement vertical farm initiative."

8. Conclusion

This study aimed to develop a framework for assessing the viability of vertical farming. A vertical farming initiative in York, Pennsylvania, was used as a case study to create the framework. First, the sub-questions are repeated to support answering the main research question. Thereafter, the societal contribution of this research and the academic reflection are given. Lastly, the limitations and future suggestions are summarized based on the limitations.

Sub-Questions

Sub-Question 1: What is the current economic landscape of vertical farming?
In Chapter 3, the economic landscape of vertical farming in 2024 was examined. It was found in the literature that whilst vertical farming has several advantages and disadvantages compared to traditional farming, the disadvantages are economically more impactful. Due to its circular environment, vertical farming significantly reduces water and pesticide use, while yield is higher and production is stable year-round. Other advantages are possible social and educational benefits and more efficient land use. However, disadvantages including high electricity costs, labor costs, and investment costs were found to impact the viability of vertical farming to a much larger extent. This also significantly contributed to multiple bankruptcies of vertical farms in the U.S. in 2022 and 2023. It was found that this was mostly related to a failed business model where the technology aspects in a vertical farming were preferred above focusing on growing crops. This meant that despite perceived business drivers favoring vertical farming, the business model must be assessed to determine the viability.

Sub-Question 2: What business models can be used for vertical farming?
A literature review determined which business models can support a vertical farm initiative in Chapter 4. Six different business models were found, each with specific advantages and disadvantages. This includes the: “differentiation,” “diversification,” “experience,” “specialization,” “shared economy,” and “low cost” business model. The “differentiation” business model focuses on niche products, and the “diversification” business model focuses on small buyers with close consumer relationships. Both were found to be the best-performing business models in urban farming, while the experience business model has the most challenges (Pölling, Sroka, et al., 2017). Furthermore, business drivers for urban farming include short supply chains and direct sales. In contrast, challenges to urban farming include the difficulty of managing supply and demand and scaling up a farm. Additionally, parameters that lead to better business performance in vertical farms were found. Risk factors to the business model also need to be considered in a vertical farming initiative.

Sub-Question 3: How can the stakeholder ecosystem for the vertical farming case be developed?
Several stakeholder analysis methods were used in Chapter 5 to develop the stakeholder ecosystem for the study case. It was discovered in the interviews that stakeholder goals could lead to conflicts in workforce development. Where the ARM Institute was concerned about robotics development, which entails employing engineers, the PA Department of Agriculture wanted to focus on the agricultural workforce. Overall profitability, focusing on unit economics, including lower workforce costs, was the concern of the CEA project. Focusing on education in the CEA project would be the best action to satisfy the most critical stakeholders in favor of hiring local workers. If budget allows, robotics needs to be implemented to make the CEA project more resilient to external factors that might impact the workforce. The power-interest matrix was beneficial in identifying that the York County Economic Alliance, York State Fair, Susquehanna Real Estate, and PA Department of Agriculture were the most critical stakeholders to consider. The value network analysis contributed to identifying the roles of stakeholders concerned about workforce development.

Sub-Question 4: What business and financial model can be developed based on the study case?
A business case was developed in Chapter 6, which consisted of a business model analysis and a financial model tool. A Business Model Canvas was used to visualize the business model for the case. The Business Model Canvas combined the “differentiation” business model by offering crop types not produced locally and

the “experience” business model by providing educational opportunities. In calculating the viability, only the commercial production of crops was considered. A financial model was made to assess the viability of the vertical farm. It was found that profitability is unlikely in the first year of operation. Still, in 3 years, profitability would be likely because of improved yield and energy efficiency due to the learning process. The cost structure indicated that depreciation costs due to high investment costs are more than 1/3 of the total costs, and electricity costs are also more than 1/3 of the total costs. This aligns with the literature on the cost structure in vertical farming in Chapters 3.1 and 4.2, which indicate the importance of investment and energy costs. However, depreciation costs were not specifically found to be an essential factor, which was found in this research to be the most crucial factor in impacting profitability. On the other hand, labor costs were found to be less critical to the business model as stated in the literature. From the sensitivity analysis, it can be concluded that variations in electricity prices, investment costs, and depreciation, significantly impact the profitability of the study case. In addition, revenue price variations heavily affect profitability.

Sub-Question 5: How can stakeholder analysis methods and business model tools be combined in a decision-support framework?
A decision support framework was made in Chapter 7. Empirical data on the study case were used in Chapter 5 for the stakeholder analysis and in Chapter 6 for the business and financial model. The stakeholder analysis methods encompassed a power-interest matrix, a value network analysis, and a system diagram analysis. This supports the identification of the stakeholders' importance and roles. To understand the business model, a Business Model Canvas can be developed, where its viability can be assessed by the financial model tool developed in Chapter 6. The complete decision support framework consists of the following six stages: “identify drivers,” “analyze business environment,” “analyze stakeholder alignment,” “develop business case,” “analyze viability,” and “implement vertical farm initiative.”

Main Research Question

Which decision support framework can support the assessment of the viability of vertical farming?
The decision support framework for determining the viability of a vertical farm consists of several stages that must be satisfied. First, a “(business) driver” must be the main reason a vertical farm initiative is considered. It can be from a private organization or a public institution. Next, the business environment needs to be examined, including population size, technological level, educational opportunities, and public support. This is important as it gives an idea of the environment where the vertical farm initiative would operate and what opportunities or challenges may support forming the business case. Then a stakeholder analysis must be carried out, which consists of determining the interests, roles, and concerns of every stakeholder in the project. Critical is to find out if stakeholders align or have opposing goals, which may lead to conflicts in what the vertical farming initiative should encompass. After this, the business case for the project can be formed with the support of a Business Model Canvas. The Business Model Canvas visualizes nine different elements of a business model. Lastly, the viability must be assessed using the financial model tool developed in this research. Next to profitability, the viability includes a sensitivity analysis to examine the effects of different scenarios and future projections. If viability is satisfied, one can execute the vertical farming initiative.

Societal Contribution

Several factors, such as the rise of the global population and climate change, indicate that our traditional farming methods might not be sufficient in the future. While vertical farming was expected to contribute to our food production substantially, bankruptcies among major vertical farming companies in 2022 and 2023 have showcased the opposite. Policymakers can use the decision support framework developed in this study to identify possible bottlenecks for vertical farming in specific locations. It also could help future vertical farming projects pinpoint where the focus must be for viability. For example, if from the decision-support framework, it becomes clear that a vertical farming operation in a particular area cannot be profitable only due to too high energy costs, it can specifically address this issue to the public authorities, and negotiate a fixed or lower price for a few years. Therefore, this study helps industry and policymakers since it develops proof of the obstacles. A vertical farm can now seek funding dedicated explicitly to the obstacle.

This research used empirical data from a case to develop the decision support framework. Stakeholders in the project had several concerns, the most important being whether the CEA project could be viable. Based on the commercial operation, while financial prospects will likely be below the break-even point in the first year, profitability is likely due to increased yield and energy efficiency from the third year. Furthermore, stakeholders were unsure what the CEA project could look like and what, for example, the revenue model could be. The stakeholders can use the Business Model Canvas developed in Figure 6.1 as guidelines for the CEA project. The scenario analyses found that the vertical farm would be very volatile in terms of changes in the lettuce revenues and electricity prices. Therefore, extensive research on the lettuce prices should be conducted, and strong relationships should be built with wholesale companies to ensure a stable crop price. For a profitable sales model, 20% of the produce must be sold to restaurants and via direct sales, for instance, at the farmers market. In addition, since electricity costs might rise significantly in Pennsylvania shortly, it is suggested to reach out to the PA Department of Energy to have fixed rates for some time. To align the stakeholders, incorporating educational facilities in the vertical farm satisfied the most critical stakeholders. Preferably, automation via robotics should be integrated to cope better with possible external factors such as difficulties in hiring growers.

Academic Contribution

This research provided a decision support framework for vertical farming initiatives. Stakeholder analysis methods and business/financial model tools were integrated into this framework. The decision framework aims to provide private organizations and public institutions a tool to analyze whether a vertical farm in a specific business environment would be viable. Moreover, it can indicate what business model should be used based on the business environment, and if it is viable using the financial model. Also, analysis methods that evaluate the stakeholder ecosystem are incorporated in the framework. While economic aspects of vertical farming have been examined in the literature, a comprehensive framework on implementing a vertical farming initiative built on data-driven results has not been done before. This includes the use of stakeholders analysis methods in a vertical farming initiative. In addition, this study contributes to the aftermath of the bankruptcies of multiple large vertical farms in the U.S. in 2022 and 2023, after which the need for assessing the viability of possible business models developed.

In line with the literature, investment and energy costs were found to impact the cost structure of vertical farming strongly. However, labor costs were found to be less impactful on the costs than was found in the literature. Also, the sensitivity analysis showcased that scenarios concerned with labor costs were not as impactful as scenarios where the investment, energy costs, and revenue prices were varied. This might be due to labor costs being generally less expensive in Pennsylvania than other states in the U.S., or the fact that the workforce was not adequately modeled. Therefore, testing the model would be interesting to determine if workforce costs are also less impactful for other vertical farming projects. Direct sales are seen in the literature as an important driver for urban farming. In contrast, B2B sales supposedly lead to better business performance in vertical farming literature. The financial analysis in Chapter 6.2 found that both are true and a combination of the two, in line with having a “multiple revenue stream,” leads to higher profitability.

Limitations

A significant limitation is that the decision support framework was not validated, including the applicability of the stakeholder methods and the Business Model Canvas. Since only one case was used in this research, the framework was developed and iterated, considering a single case. Therefore, it is questionable how applicable the decision support framework is for other vertical farming initiatives. Furthermore, it limits the reliability of the results found for the case. Three experts were asked to review the financial model following a review protocol. Several changes were made accordingly, but the financial model includes significant limitations. In Table 6.3, the limitations in the model are more thoroughly explained. They are mostly related to a lack of reliable data, time limitations leading to a simplified model, and limited usability for new projects. In addition, the sensitivity analysis only considered changing one parameter in the scenarios. Important conclusions may have been missed by not combining and changing different parameters simultaneously, which could better indicate the optimal parameter configurations to maximize profitability. Due to the model being in Excel and not in programming software, time limitations, and the desire to limit the complexity, this was not executed.

Another limitation of the research is that the results found have limited value for stakeholders. First, only the commercial operation of the CEA project was considered. The facility's economic impact might be much more significant than just the commercial operation as pictured in this study, which might convince other stakeholders to take a role when they realize that the value created also could apply to them. Second, due to the case being an ongoing project, changes were seen during and after data collection. In November and December 2024, interviews were held with most of the (important) stakeholders involved. As of March 2025, new stakeholders have been involved in the project while some stakeholders' roles have changed. Due to a limited time frame and to keep the research feasible, it was decided not to include information gathered after the data collection period. Also, not every stakeholder included in the analysis was interviewed and their role was based on other interviewees and online resources. Their concerns and their role in the project were thus not verified. This means the stakeholder analysis in Chapter 5, was not a complete picture taken in December 2024. The methods used for data collection were: direct observations, open-ended Interviews, and documents. While this should make the findings more robust, there was almost no overlap between the data collection methods and their use cases. For example, data collected for the stakeholder analysis was only based on interviews. The study case was visited, and discussions between stakeholders were observed, but because the stakeholder analysis was already completed, this information could not be implemented. The data collection methods could thus also not be checked for their differences and similarities. Therefore, the data collected is not as "robust" and comprehensive as intended initially before the research was conducted.

Also, a limitation is that the Business Model Canvas and financial model analysis did not include factors that may be important for vertical farming and its viability. Viability was only focused on financial profitability and not on secondary effects. For example, sustainability factors are an essential aspect of vertical farming but are not considered in the research or applied in the Business Model Canvas. In Chapter 3, it was found that vertical farming may be more sustainable than traditional farming, depending on whether renewable resources produce the electricity used in the vertical farm initiative. Moreover, business model types might impact sustainability differently. Other factors that limit the usefulness are that in the financial analysis, only the commercial operation of a vertical farm was considered. The calculations did not consider other factors important to viability, including specific government policies.

Future Research

Validation will increase the reliability and applicability of the decision support framework. First, the framework can be applied to other case studies with real-world vertical farm initiatives. Since this research was based on a project in the United States, specifically in Pennsylvania, verifying whether it applies to other projects in the U.S. and globally would be interesting. An important aspect would be the financial model, which was based on data for the case study and did not consider other input. One could implement different data to assess the viability of a vertical farming initiative. For example, in Europe, where energy costs are generally higher, and in non-western countries, in which wages are significantly lower.

To increase the usefulness of the case study results, the decision support framework should be expanded beyond only the commercial operation. For example, it could include the educational aspects in the CEA project. Education can have many more benefits besides the impact on the vertical farming operation in terms of interns. It could attract young and talented people to the York region, benefiting local businesses and public institutions and increasing its attractiveness. Furthermore, the decision support framework could be expanded to one that can be used also to monitor stakeholder involvement. Ideas, partners, or funding change when an ongoing case is studied. Enhancing the framework to an interactive model allows new information to be added without restarting the analysis, thus nullifying any progress made. This would benefit the study case where new stakeholders got involved. Furthermore, the business environment changed due to a new federal administration taking office in the United States. Tariffs and new policies on migration by the new federal U.S. government were expected and imposed. As of March 2025, the effects for agriculture remain unclear, but it would be interesting to explore the impact of the policies on agriculture in the next several years.

Furthermore, the Business Model Canvas can be expanded to include non-financial factors impacting viability and sustainability. For example, when possible revenue streams are determined, the environmental impact of these decisions can be considered, which may lead to decision-making favoring local consumers to decrease the distance traveled and lowering carbon dioxide emissions. In Chapter 1, it was found that reducing food loss is essential for the EU. Including food waste reduction in the Business Model Canvas would be interesting by comparing vertical farming to traditional farming. The UAE and Singapore value reducing their food imports as described in Appendix E. For vertical farming initiatives in these countries, the Business Model Canvas can be improved by analyzing which produce is imported from foreign countries in the highest percentage. In the case study, it was found that there is a lack of crops grown in the Northeast, which is why, to a large degree, it is imported from California. Due to the travel distance, there is food waste during the transportation, and it is less fresh when it arrives. These factors could lead to different decision-making, where the value of the vertical farm is not purely created by financial incentives. For example, in the EU, produce might be chosen for a vertical farm that is, on average, wasted the most during transportation, and in Singapore, crops can be selected based on their reliance on imports from foreign countries. These factors could enhance the viability of vertical farming to a much broader scope.

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Appendix

A. Glossary

Table A.1: Glossary Table

Concept	Abbreviation	Meaning
Aeroponics		*"Growing plants in an air/mist environment with no soil. Technique created by the National Aeronautics and Space Administration (NASA) in the 1990s, as a result of their interest in finding effective ways to grow plants in space"* (Saxena et al., 2024, p.5).
Agriculture Technology	Agritech	*"Agricultural technology uses data technologies, combining AI, robotics, and biotech, along with local and global data on livestock, food species, disease state, soil conditions, weather patterns, and more, to improve agricultural productivity and sustainability while reducing emissions"* (The University of Edinburgh, 2024, What is Agritech?).
Aquaponics		*"Integrating fish and plants in one ecosystem"* (Saxena et al., 2024, p.5).
Business Case		*"Provides justification for undertaking a project, programme or portfolio. It evaluates the benefit, cost and risk of alternative options and provides a rationale for the preferred solution"* (Murray-Webster, 2019).
Business Model		*"A business model describes the rationale of how an organization creates, delivers, and captures value"* (Osterwalder & Pigneur, 2010, p.14).
Business Model Canvas		*"The Business Model Canvas is a shared language for describing, visualizing, assessing, and changing business models. It is focused on design and innovation, in particular by using visual thinking which stimulates a holistic approach and storytelling"* (Fielt, 2013, p.93)
Controlled Environmental Agriculture	CEA	*"Growing of crops while controlling certain aspects of the environment including lighting, temperature, humidity, irrigation, fertigation, and other factors that influence plant physiological responses"* (Agritecture & CEAg World, 2025, p.9).
Hydroponics		*"Growing plants in nutrient results without using soil. The factory roots are immersed in the nutrient solution"* (Saxena et al., 2024, p.5).
Indoor Farming / Indoor Growing		*"Crop production that utilizes artificial lighting instead of sunlight. This can include rooms, warehouses, factories, and other converted indoor spaces"* (Agritecture & CEAg World, 2025, p.9).
Pennsylvania	PA	Middle Atlantic state in the U.S. includes two metropolitan areas Philadelphia and Pittsburgh (Willard Miller & Thompson, 2025).
Stakeholder		*"persons, groups, or organizations that are affected by the project, interested in the project, and/or able to affect the project"* (Buser, 2024, section 3.3).
Traditional Farming / Agriculture		*"Horizontal agriculture on the surface of the land"* (Khalil & Wahhab, 2020, p.2).
Unit Economics		*"Direct revenues and costs of a particular business measured on a per-unit basis, where a unit can be any quantifiable item that brings value to the business"* (Paddle, 2025, What are unit economics?).
Urban Farming / Agriculture		*"The practice of cultivating crops, livestock, or types of food in an urban environment"* (Unity Environmental University, 2024, What Is Urban Farming?).
Vertical Farming		*"Crop production that uses the vertical space in a farm facility and has multiple planes of production. Plants can be stacked horizontally or in tall towers"* (Agritecture & CEAg World, 2025, p.9).

B. Vertical Farming vs Other Terminologies

Urban Farming / Urban Agriculture

Urban Farming is defined in several ways. In the Book: Urban Farming in Sustainable City Development by Grochulska-Salak (2019, Abstract), it is defined as: *"building development for the production of plants for the needs of the local community*." According to Unity Environmental University, it is defined as "*the practice of cultivating crops, livestock, or types of food in an urban environment*" (Unity Environmental University, 2024, What Is Urban Farming?). There are four benefits: locally raised products, community, redevelopment, and density. A similar terminology is urban agriculture, which is defined as producing food within a city or in the periphery of a city (Wageningen University & Research, 2025b). Something is defined as urban farming if it incorporates at least the following factors: be located around or within urban areas, contain food production, and be part of the urban environment in a social, economic, and ecological context (Müller et al., 2022). The following six different types of urban agriculture were identified (Müller et al., 2022).

- Urban Farm = Commercial outdoor or indoor food production in an urban or peri-urban environment.
- Community Park = Food production in a public space with additional activities and services.
- DIY Garden/Farm = Food production in a public space where owners are households or associations.
- Zero Acreage Farm (ZFarming) = Rooftop farming, green walls, and indoor farms, which have in common to use space efficiently (Specht et al., 2014; Specht et al., 2015).
- Social Farm = Combine urban agriculture and health or social services.
- Community Garden = The Main activity is forming a community besides food production.

Vertical Farming

Vertical farming is defined as *"the activity of growing crops in many layers, one above the other, inside a building or under the ground, often in a specially controlled environment"* (Cambridge Dictionary, 2024, vertical farming). While vertical farming is usually referred to in an urban and indoor environment, there is not a single agreed definition (Jaeger, 2024). A significant advantage of vertical farming is the increased density, which is achieved by efficiently using expensive space in an urban environment. Several methods can be used for food production in a controlled environment, and a combination of techniques can supplement each other, but it increases the complexity of a vertical farm. Vertical farming can thus combine indoor growing practices in an urbanized environment. While humans, due to a lack of space in cities, have started building in the sky (skyscrapers), farming has never adopted this strategy to a considerable level (yet). There are three more advanced methods of indoor growing and one, soil-based, which has its origins in traditional outside farming (Wong et al., 2020).

The **hydroponics** indoor growing technique was already developed before the Second World War, and is the practice where plants are grown without soil, but just water, which also includes other nutrients needed for the plants, leading to higher yields (Hydroponics Europe, 2023). This is the most used vertical farming technique (Birkby, 2016). Another one is **aeroponics,** where plants are grown in an air environment with misty water, and without soil (Barth, 2018). This technique was developed by NASA, which sought methods to grow plants in space in the 1990s (Birkby, 2016). It is more water and nutrient-efficient than hydroponics and aquaponics, but is less commercially practiced yet (Moghimi & Asiabanpour, 2023). In 2019, this was rated as the second most popular growing method with a 20% market share (Wong et al., 2020). **Aquaponics** is a technique where fish are grown in a vertical farm, aiming to create an ecosystem where plants and fish complement each other (Birkby, 2016). This highly technical method is mostly only used in smaller pilot farms due to its complexity. In addition, it takes more time to start such a farm since it takes time to create a stable ecosystem (Wong et al., 2020). Vertical farming has been practiced in the following forms in Europe (Butturini & Marcelis, 2019).

- Plant factory with artificial light (PFAL) = vertical farm in an industrial environment
- Container farm = shipping container
- In-store farm = vertical farm located next to consumption place (supermarkets or restaurants)

- Appliance farm = indoor growing systems for households or offices

Indoor Growing / Indoor Farming

Another term that was used in vertical farming is indoor growing. Indoor growing is defined as: *"the practice of locating high-performance agriculture in buildings to exploit the synergies between the building environment and agriculture"* (Specht et al., 2014, p.36). This term seems to be used mainly by companies when searching on Google. In Scopus, when the title is set to indoor AND growing, 44 documents show up. When the title is set to urban farming, more than 500 documents can be found, and for vertical farming, it corresponds to 325 papers. Vertical farming can be seen as indoor growing but on multiple levels.

PFAL (Plant Factory with Artificial Lighting)

The last term equivalent to vertical farming is the abbreviation PFAL: Plant Factory with Artificial Lighting. PFALs are characterized as: "*farming systems based on the control of all environmental factors that can affect plant growth, including temperature, relative humidity, light, and CO2*" (Appolloni et al., 2020, p.66). It can be seen as indoor growing by using artificial lighting, and no additional solar light (which indoor growing & farming can refer to) (Kozai et al., 2016). PFAL can be divided into commercial larger-scale production or m-PFALs (mini PFALs). These are smaller units and can be used by households, offices, or restaurants (Yuliarini et al., 2020). PFAL therefore refers to more significant industrial-scale production (Jaeger, 2024).

C. Interviews

In Table C.2, an overview of the organizations interviewed for this research can be seen. Due to privacy reasons, the names are not specified. A separate document was made, consisting of summaries of all interviews. These summaries are based on notes taken and/or interview transcripts. Whenever information from an interviewee is referred to, it is indicated by: *(Interview, Abbr.)*. Several interviews were held with multiple respondents from the same institution due to different expertise. In January 2024, there was a meeting between the following stakeholders: York State Fair, Susquehanna Real Estate, Priva, Borlaug, and York County Economic Alliance. In text, it is referred to as: *Stakeholder meeting January 2024*. In this meeting, the CEA project ideas and possibilities were more formalized. These stakeholders were interviewed first. Interviewees were asked if they knew of other potentially relevant organizations or institutions for this research. In addition, Priva's relationships were used to speak to institutions involved in CEA in the U.S. or concerned with the viability of vertical farming *(Interview NL, GG, WUR)*.

Table C.2: Overview Interviews

Institutional Name	Abbr.	Role of Interviewee	Number of Interviewees	Date of interview	Reference in Text
Borlaug	BG	President & CEO	1	12/4/2024	Interview BG
Embassy Washington, D.C. Agriculture, Fisheries, Food Security and Nature (The Netherlands)	NL	LVVN Council / Agricultural Officer	2	12/4/2024	Interview NL
Susquehanna Real Estate	SRE	President & CEO / Project Consultant	2	12/5/2024	Interview SRE
Greengrounds	GG	CEO	1	12/10/2024	Interview GG
Resource Innovation Institute (RII)	RII	Marketing & Membership Director / Engineering Operations Manager / Resource Efficiency Engineer	3	12/11/2024	Interview RII
Problem Owner	PO	Project Leader	1	12/12/2024	Interview PO
York College	YC	Assistant Vice President for External Relations and Executive Director of York College's Knowledge Park and J.D. Brown Center for Entrepreneurship / Executive Director, Center for Community Engagement	2	12/19/2024	Interview YC
York State Fair	YSF	CEO	1	12/19/2024	Interview YSF
York County Economic Alliance	YCEA	President & CEO	1	12/23/2024	Interview YCEA
PA Department of Agriculture	PA	Director of Conservation and Innovation	1	12/23/2024	Interview PA
Wageningen University & Research	WUR	Sector Expert Horticulture	1	1/8/2025	Interview WUR

D. York Information

York County

The use of land is showcased for York County in Figure D.1. The City of York has residential areas, but much of York County consists of agricultural land, implying competition from traditional agriculture. York County is also characterized as "still very much an agricultural county" *(Interview SRE)*. Furthermore, York County is very protective of its land. Farmland is also considered necessary, and local support is needed to maintain it. Moreover, Pennsylvania has a complicated political structure in different counties and cities *(Interview SRE)*. In York County, there are 72 different municipal governments and school districts, and in Pennsylvania, there are around 1600 different municipal governments. From 2012 to 2022, the real GDP annual growth rate in Pennsylvania has been following the trend of the United States closely, but always a few percentiles lower as can be seen in Figure D.2 (York County Economic Alliance, 2024b). York County is not always very progressive and does not appreciate change ("resistance to change") very much *(Interview YSF).* Pennsylvania can be characterized as representative of the U.S. *(Interview PO).* The rural area is conservative, but it does have big cities which are liberal. In addition, all four seasons in Pennsylvania's climate make it a representative testing ground for CEA. Pittsburgh has a high-tech industry, while Harrisburg (the capital) has a large manufacturing and agriculture sector. After its steel industry left, Pittsburgh has been focusing on robotics *(Interview PO).*

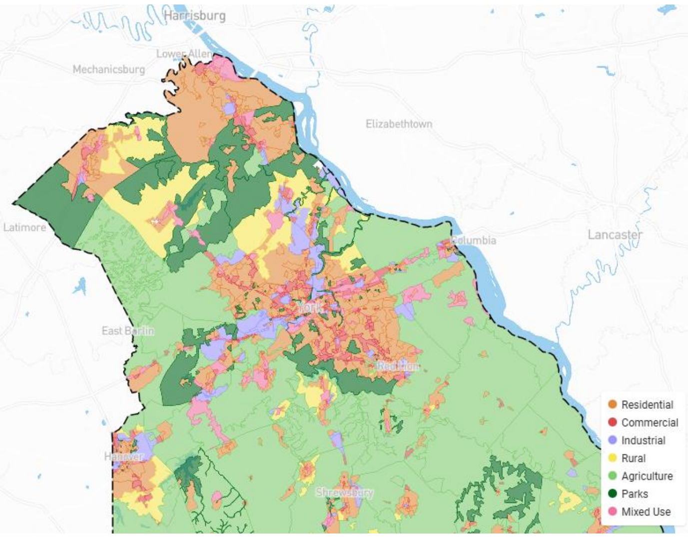

Figure D.1: Land Uses per category in York County (York County Economic Alliance, 2024a)

Figure D.2: Real GDP Annual Growth, York, PA, US (York County Economic Alliance, 2024a)

Population

The City of York is part of York County (York County Economic Alliance, 2023). The population in York (city) has remained relatively stable over the last decades. In 1990, it was 42,192, then decreased to 40,862 in 2000. In 2010 and 2021, it grew to 43,718 and 44,692, respectively, and the population is expected to reach 44,398 by 2030 (York County Economic Alliance, 2023). York County's population changed significantly in comparison. In 1990, it had a population of 339,574 and increased to 454,605 in 2021 (York County Economic Alliance, 2023). It is expected to reach 504,958 by 2030. York County has two major cities, population-wise *(Interview SRE)*. However, surrounding townships and boroughs in York have much larger populations. While York has a population of around 45,000, the surrounding areas are around five times more populated. There is more housing development and an unmet demand for 300 to 400 houses in residential areas *(Interview SRE)*. The industry moved out of the city, and nowadays the city dynamic entails local services and retail, similar to Lancaster. The median age is 40.8 years and in December 2022 the labor force was 239,000 people with 231,000 people employed meaning 7,800 people were unemployed and an unemployment rate of 3.3% (York County Economic Alliance, 2023).

Location & Infrastructure

York's location in the Northeast of the U.S. makes it in a range of 800km (500 miles) from 40% of the U.S. population and 60% of Canada's population. In Table D.3, the approximate distance to other cities can be seen. The geography of York is favorable for agriculture since around 50 million people can be reached quickly *(Interview YSF).* This is also why York County has many warehouses and truck traffic. Nearby cities, Lancaster is similar to York, where it is agriculturally focused, while Harrisburg is more government-focused since it is the state capital *(Interview SRE)*. Two of the ten largest employers in York County are two retailers: Walmart and Giant Foods Stores. Nearby airports are Harrisburg International Airport (HIA) and Baltimore-Washington International Thurgood Marshall Airport (BWI). Several rail services, such as CSX Transportation, Inc. (CSXT) and East Penn Railroad, LLC (ESPN), are present. York is no longer connected to the Pennsylvanian Rail Network, which is a "lost opportunity" for York *(Interview SRE)*.

Table D.3: Distances From York, Pennsylvania (York County Economic Alliance, 2024a)

City	Distance (Kilometers)	Distance (Miles)
Baltimore, MD	89	55
Boston, MA	624	388
Chicago, IL	1072	666
Columbus, OH	621	386
Harrisburg, PA	53	33
New York, NY	304	189
Newark, NJ	264	164
Norfolk, VA	426	265
Philadelphia, PA	140	87
Pittsburgh, PA	351	218
Raleigh, NC	542	337
Washington, DC	140	87

Climate

Table D.4, the climate of York County can be seen. Specifically for building automation (including CEA), York County has a mixed humid climate zone, which is the average of the United States (International Code Council, 2021)Although a larger part of Pennsylvania has a calm and humid climate zone, if the CEA project in York is to be expanded into other regions, most of Pennsylvania, including Pittsburgh and the eastern part of West Virginia, will have slightly different CEA climate models. This can impact energy costs and the type of crops. Harrisburg and the whole state of Maryland and Kentucky have the same climate zone as York County.

Table D.4: Average Temperature and Precipitation in York County

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature in Celsius (°C)	-1.7	1.7	7.0	10.4	18.0	22.3	25.1	24.6	19.8	11.3	7.9	1.3
Average Temperature in Fahrenheit (°F)	29.0	35.1	44.6	50.7	64.4	72.2	77.1	76.3	67.7	52.3	46.3	34.4
Precipitation (centimeters)	3.86	3.91	2.69	8.51	8.79	5.13	7.14	7.04	6.65	5.97	5.00	9.58
Precipitation (inches)	1.52	1.54	1.06	3.35	3.46	2.02	2.81	2.77	2.62	2.35	1.97	3.77

Wages

The average income per capita is $35,623, which is just higher than the required annual income before taxes to afford the cost of living ($35,224) (York County Economic Alliance, 2024a). In Table D.5 and Table D.6, the average wages in York and Pennsylvania per occupational group and industry sector can be seen, where only the ones potentially relevant to the case were selected (York County Economic Alliance, 2024a). For CEA, workers in the following occupational groups are also needed next to growers (farmers): Computer and Mathematical, Building and Grounds Cleaning and Maintenance, Sales and Related, Office and Administrative Support.

Table D.5: Average Wages Per Occupational Group in 2021 for York County & Pennsylvania (York County Economic Alliance, 2024a)

Major Occupational Group	Average York County Wage	Average Pennsylvania Wage
Management	$113,890	$126,450
Business and Financial Operations	$77,820	$80,280
Computer and Mathematical	$86,330	$94,730
Education, Training, and Library	$62,170	$66,040
Food Preparation and Serving Related	$28,180	$29,460
Building and Grounds Cleaning and Maintenance	$33,310	$34,860
Sales and Related	$42,240	$47,010
Office and Administrative Support	$42,890	$44,850
Farming, Fishing, and Forestry	$39,010	$39,290

Table D.6: Wage by Industry Sector in 2021 for York County & Pennsylvania (York County Economic Alliance, 2024a)

Industry Sector	Number of Establishments	Number of Employees	County Wage	Pennsylvania Wage
Agriculture, Forestry, Fishing and Hunting	84	725	$32,432	$42,543
Wholesale Trade	416	6,137	$73,758	$95,505
Retail Trade	1,145	20,527	$33,472	$36,323
Accommodation and Food Services	762	13,311	$19,987	$23,614

Consumers

In Figure D.3, the total number of consumers can be seen, which can be targeted by businesses in York County *(York County Economic Alliance, 2024a)*. When individual and household income, age, and household type are not specified in smaller ranges, there are 1,348,316 potential consumers.

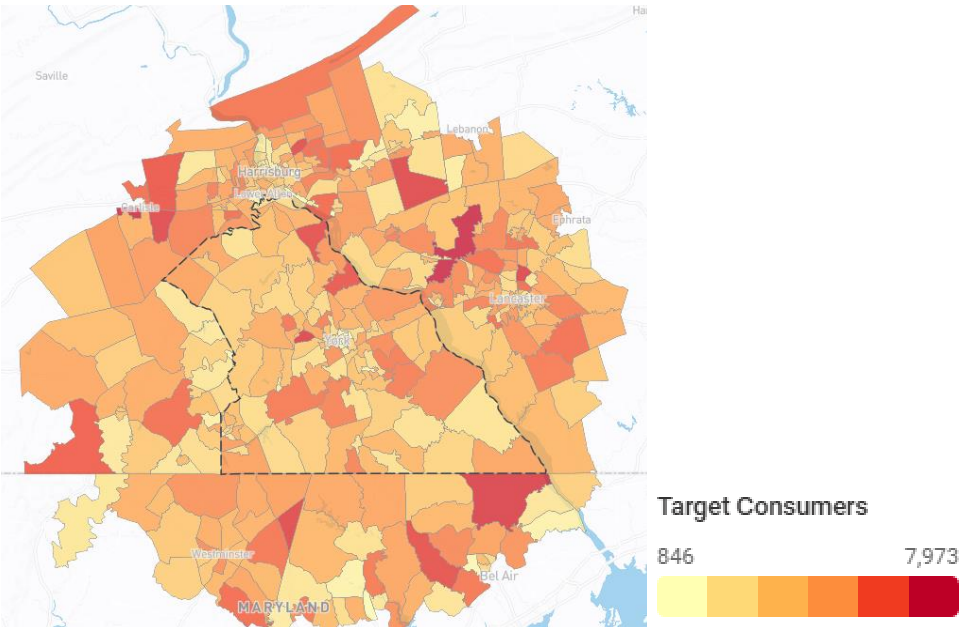

Figure D.3: Total number of potential consumers 1,348,316 (Darker areas more consumers) (York County Economic Alliance, 2024a)

Wholesale Companies

In the greater York area, there are 26 fresh produce wholesalers (distribute fresh fruits, vegetables, spices, and herbs) and a total of 136 in Pennsylvania in 2021, and they were decreasing in numbers over the years from 177 in 2013 (York County Economic Alliance, 2024b). In Figure D.4, the location of the 26 fresh produce wholesale companies can be seen around York. In Figure D.5, the location of the 186 food wholesale companies can be seen around York.

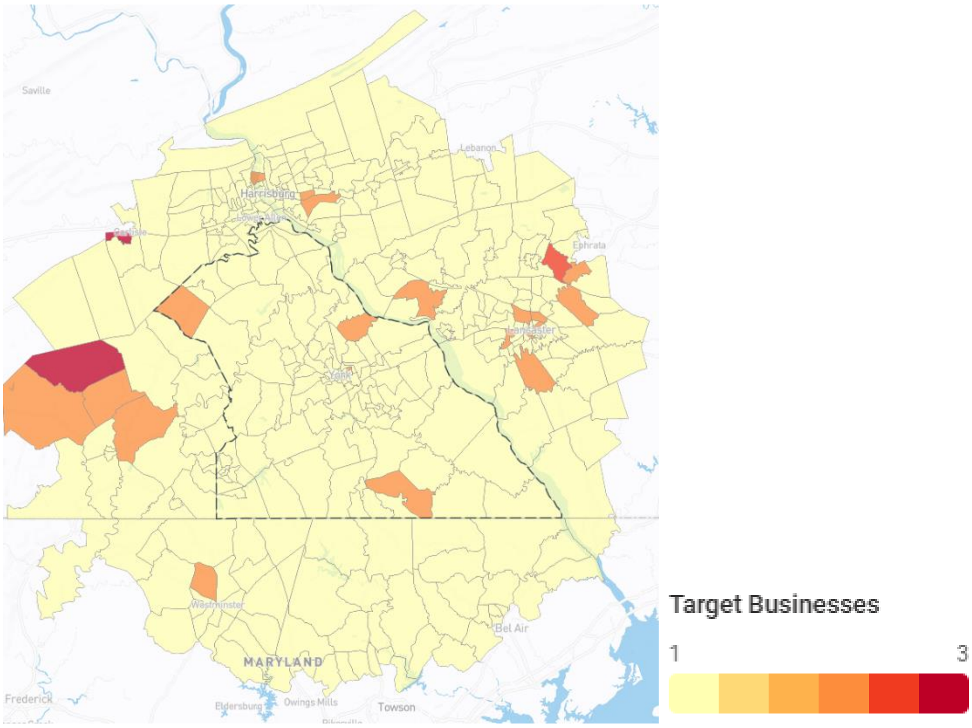

Figure D.4: Fresh Produce Wholesalers (York County Economic Alliance, 2024a)

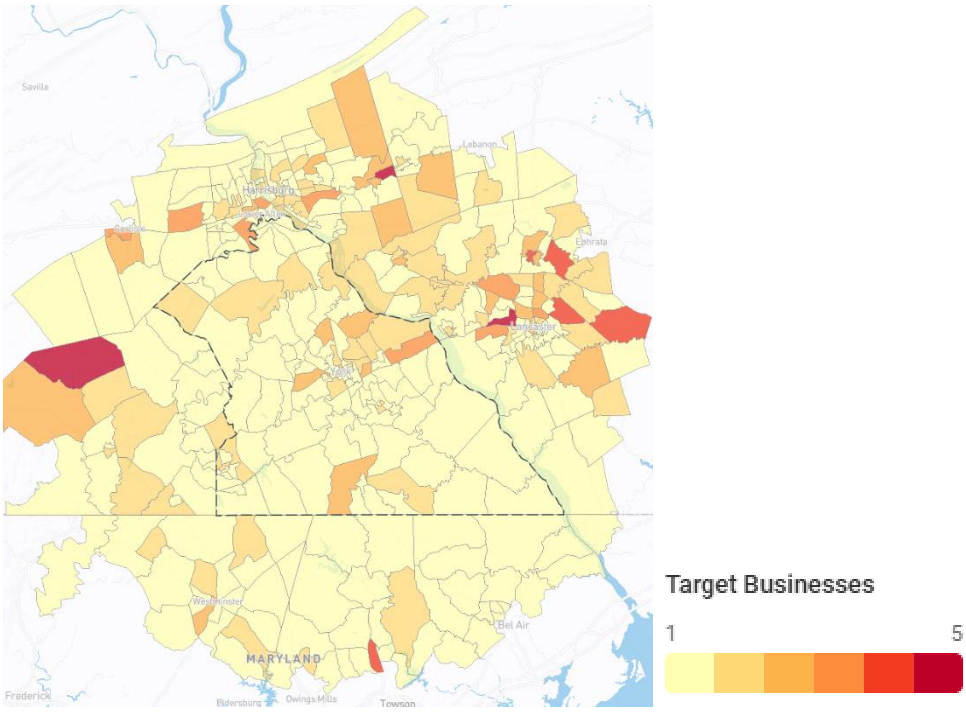

Figure D.5: Food Wholesalers (York County Economic Alliance, 2024a)

Agriculture

The latest report on agricultural data in the U.S. was published in 2022 by the USDA (U.S. Department of Agriculture, 2022). In 2022, there were 1929 farms in York County with a total market value of agricultural products sold of 389 million dollars. Of the sales, the share of crops was 46% meaning $178 million in sales value. In Table D.7, the market value of agricultural products sold in York County can be seen. Interestingly, 12% of farmers sell directly to consumers, and 22% hire farm labor. In addition, 95% of farms are family-owned.

In Figure D.6, the spread of 550 total agricultural businesses can be seen in York County and the area around it (York County Economic Alliance, 2024a). Closer to York and Harrisburg, there are not many agricultural farms. Lancaster is an exemption with a high-density area of 14% of all total farming businesses that can be seen on the map. Important to note is that 2 percent of Pennsylvania farms were certified to produce organically (Econsult Solutons Inc., 2021). Pennsylvania is the largest mushroom-producing state in the U.S., with $612 million in sales value (46% of the total). Vegetable sales value is relatively low, ranking the lowest in market sale size compared to other crop groups. York County has a more significant market value in greenhouses and floriculture. In York, there are three active farmers markets. However, it is still a bit of a food desert *(Interview YC)*.

Table D.7: Market Value of Agricultural Products Sold in York County (U.S. Department of Agriculture, 2022)

	Sales ($1,000)	Rank in State	Counties Producing Item
Total	388,567	6	67
Crops	***178,329***	***4***	***67***
Grains, oilseeds, dry beans, dry peas	114,023	2	65
Tobacco	1,453	3	14
Cotton and cottonseed	-	-	-
Vegetables, melons, potatoes, sweet potatoes	7,228	7	67
Fruits, tree nuts, berries	8,217	6	67
Nursery, greenhouse, floriculture, sod	34,001	6	66
Cultivated Christmas trees, short rotation woody crops	2,295	3	62
Other crops and hay	11,114	8	67
Livestock, poultry, and products	***210,238***	***8***	***67***
Poultry and eggs	100,105	8	67
Cattle and calves	48,913	2	66
Milk from cows	32,746	19	62
Hogs and pigs	20,557	12	64
Sheep, goats, wool, mohair, milk	527	10	64
Horses, ponies, mules, burros, donkeys	4,473	4	63
Aquaculture	556	14	56
Other animals and animal products	2,361	4	66

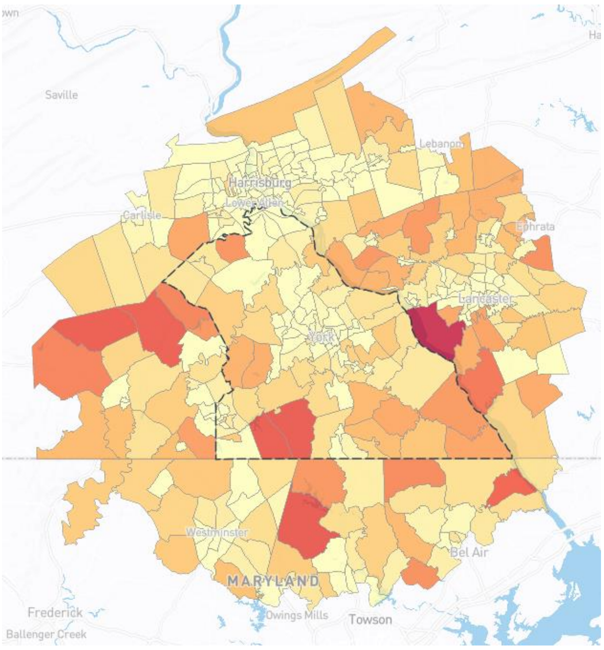

Figure D.6: 550 Agricultural businesses (Darker color more percentage of total businesses) (York County Economic Alliance, 2024a)

Crops

In Pennsylvania, there are almost 15,000 people in crop production in 2021. This rose from 12,500 in 2017. In the United States, employment in crop production remained relatively stable between 2017 and 2021, with around 550,000 workers. In York County and surrounding areas, there are 397 crop-production businesses which can be seen in Figure D.7 (York County Economic Alliance, 2024a). There is a total of 1,026 in Pennsylvania. It can be seen that the area around York does not have many crop-production businesses. The average wages after 2016 have followed the average annual salaries of the United States, as seen in Figure D.8.

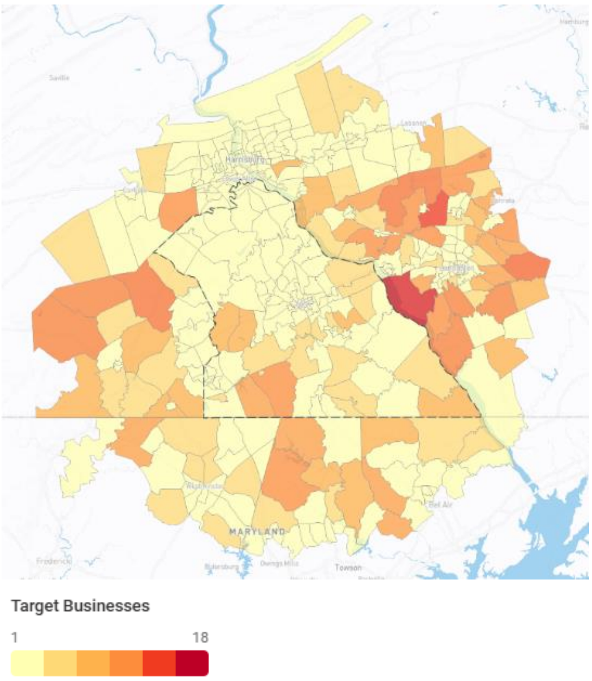

Figure D.8: Average Annual Wages Crop Production (York County Economic Alliance, 2024a)

Figure D.7: Crop Production businesses (York County Economic Alliance, 2024a)

The profit margin pre-income tax is 15% and after income tax 14.4% when the business has an asset size between $1k and $500k as showcased in Table D.8. With a business size between $500k and $1M, the profit margin decreases to 12.1% and 11.6% respectively. With a business size between $1M and $5M, the profit margin decreases to 8.8% and 8.1% respectively. With a business size between $5M and $10M, the profit margin decreases to 8.8% and 8.1% respectively. The corporate net income tax rate in Pennsylvania is 8.49% but is projected to decline to 4.99% during the next several years (York County Economic Alliance, 2024a).

- Gross Profit Margin: Indicates the percentage of revenue that remains after covering the cost of goods sold (COGS)
- Return on Assets: An Indicator of the profitability of a business compared to the asset value.
- Cost of Goods Sold to Sales Ratio: The cost of goods sold (COGS) to sales ratio indicates the percentage of sales revenue to pay for expenses that fluctuate with the sales.

Table D.8: Profit Margins for Crop Production (York County Economic Alliance, 2024a)

Asset Size	**Profit Margin (pre income tax)**	**Profit Margin (after income tax)**
$1k - $500k	15.0%	14.4%
$500k – $1M	12.1%	11.6%
$1M – $5M	8.8%	8.1%
$5M - $10M	8.3%	7.6%
$10M - $25M	7.0%	6.5%
$25M – $50M	7.1%	6.6%

Asset Size	Gross Profit Margin:	Return on Assets	Cost of Goods Sold to Sales Ratio
$1k - $500k	0.9	0.4	0.2
$500k – $1M	0.9	0.2	0.2
$1M – $5M	0.7	0.1	0.4
$5M - $10M	0.7	0.1	0.4
$10M - $25M	0.5	0.1	0.5
$25M – $50M	0.4	0.1	0.6

E. Public support for vertical farming

Singapore & The UAE

Singapore set a goal ("30 by 30") in 2019 that by 2030, 30% of food consumed must be produced in Singapore itself, which was 10% in 2019 (Wood et al., 2020). Singapore has less than 1% of land available for farming (Ministerie van Landbouw, 2023). In 2022, the market value of urban farming in Singapore was 152 million USD. As part of supporting this goal, Singapore issued 30 million USD to support local farming (V. Liu, 2020). The indoor farm company Archisen produces 100 tons of vegetables every year (Milan Urban Food Policy Pact, 2023). Locally produced eggs increased significantly after the announcement in 2019, however, vegetables and seafood saw their local production decrease from 2019 to 2023 (Tham, 2024). Citizens were particularly price sensitive, and locally produced food could not compete in price, although more positive marketing for local food could improve sales. In addition, Singapore lacks a history of farming and, therefore, lacks industry support (Tham, 2024).

The UAE imports more than 85% of its food and is therefore almost as vulnerable as Singapore for food resilience (Cairns, 2024). The UAE has aimed to become the world's best country on the Global Food Security Index by 2051, and in the top 10 in 2021. One strategy to achieve this is by increasing local production to 50% of total consumption (The Arab Gulf States Institute in Washington, 2024; UAE, 2024). In 2024, the largest vertical farming project to date was announced by GigaFarm, which should be complete by 2026 and will be located at an airport. The goal is to produce 3 million kilograms of crops annually, up to 1% of food consumed in the UAE. Due to low energy costs, food produced is mostly by vertical farms, including the different growing techniques or rooftop farming in the UAE (Sharma et al., 2024).

North America

In the United States on a federal level, several CEA funding options are available through government agencies such as the National Institute of Food & Agriculture (Reichard, 2023). However, most federal grant options do not specifically outline vertical farming as the primary focus. Since 2018, urban agriculture has been officially recognized by the U.S. Department of Agriculture (USDA), and more than 50 million USD has been given out in grants for urban farming, including indoor farming (Senate Committee On Agriculture Nutrition & Forestry, 2023). New York City, as an effort to improve the availability of fresh food, also emphasized the possibilities of vertical farming in its city, including the creation of a specific urban agricultural office in 2021: Mayor's Office of Urban Agriculture (NYC Urban Agriculture, 2024). Next to the federal government, individual states also provide opportunities for funds.

In Canada, grants are offered for vertical farms, such as by: Agriculture and Agri-Food Canada (Vertical Farm Daily, 2024b). Since it cannot be directly linked to vertical farming, its impact is unclear (Vertical Farm Daily, 2024b). On a state level, Ontario, Alberta, British Columbia, and Quebec support vertical farming, for instance, through the Alberta Investment Growth Fund, where a vertical farm receives $15 million in funds annually (Coleman, 2023). In a roadmap for the development of vertical farming in Canada, it was proposed that for policy interventions the following steps could improve the growth of vertical farming: access to clean energy, incorporating vertical farming into the workforce, local economic policies, and increasing public awareness of vertical farming through education and exposure (Carolina et al., 2024).

Europe

The Dutch government actively supports Topsector Agri & Food, aiming to bring together research, business, and policymakers (Topsector Agri & Food, 2024). The government also launched a plan of action to make the Netherlands a global leader in circular agriculture in 2030 (Ministry of Agriculture Nature and Food Quality of the Netherlands, 2019). Data on how much funds are directly supporting vertical farming is lacking. Wageningen University & Research (WUR) is globally top-ranked in agricultural sciences and therefore is a large contributor to vertical farming (Wageningen University & Research, 2025b).

The National government of the UK, as part of their vision in agritech, had planned to invest more than 150 million pounds as support (Government UK, 2013). In the end, it ended up being less than 100 million pounds as of 2024 (Development Tracker GOV.UK, 2024). How much this has contributed to indoor growing and vertical farming is unclear.

Asia

Japan is a leading country in vertical farming and has primarily focused on lettuce production (Takeshima & Joshi, 2019). In Japan, the possibility of natural disasters such as floods and tsunamis has promoted increasing vertical farming (Monma et al., 2015). In 2017, Japan produced 66% of its food locally compared to its consumption level (J. Liu et al., 2022). The government of Japan has been supporting vertical farming since 2008 (Jones, 2017). More than 50% of indoor farms in Japan have received funding from the government through loans or subsidies. The indoor growing company, Spread, only became profitable in 2013 after receiving support from its start in 2008.

Sustainable agriculture policies were announced by China, such as in the 14th Five-Year Plan (English.GOV.CN, 2021). Cities in China, such as Shanghai, have been actively supporting vertical farming, for instance, the Sunqiao Urban Agricultural District, which is a project to create a district in Shanghai that incorporates vertical farming (AgritechTomorrow, 2024). Specific funding that directly leads to vertical farming development is unknown. China recently built the largest robotics-operated vertical farm (Zhe, 2023).

F. Market Size of Vertical Farming

Statista estimated that in 2013, the global market was 400 million USD and in 2016, 1.5 billion USD (Takeshima & Joshi, 2019). In comparison, by Grand View Research, the vertical farming market size was only estimated to be just over 1 billion (1.02) USD in 2019. In 2022, it was already estimated to be 5.6 billion USD, which shows the substantial growth of vertical farming in the last decade (Statista, 2023). It is projected to increase to 10 billion USD in 2025 and more than 30 billion USD in 2032. However, according to Fortune Business Insights, vertical farming is expected to grow to more than 50 billion USD in 2032, which is also supported by Precedence Research, which projects 55.11 billion USD in 2032 (Precedence Research, 2024). For 2023, according to the vertical market size, it had a value of 5.7 billion USD, Fortune Business Insights, and is expected to grow to 6.92 billion USD in 2024 (Fortune Business Insights, 2024). This is relatively in line with Precedence Research, which valued the market size of vertical farming to be 5.85 billion USD in 2023 and estimates 7.51 billion USD for 2024 (Precedence Research, 2024). On Markets and Markets, the vertical farming market was valued at 5.6 billion USD in 2024 (MarketsandMarkets, 2024). Unlike the setbacks of Vertical Farming in 2023, there is consensus that the market will grow in the coming years despite significant differences between sources for specific years. For North America, the market size is approximately 2.33 / 2.34 billion USD in 2023 (Fortune Business Insights, 2024). In 2023, the North American market accounted for around 40% of the global vertical farming market size. For the US specifically, it was valued at 1.64 billion USD in 2023, projected to be 2.11 billion USD in 2024, and USD 15.73 billion in 2032. It is projected that North America, with the US and Canada, is approximated to contribute to vertical farms' growth the most (Fortune Business Insights, 2024).

G. Literature Review Urban & Vertical Farming

In Table G.9, an overview of the literature on urban and vertical farming business models is showcased. The first column represents the respective authors, and the second column describes how the source was found. The concept and study field were also added. Furthermore, interesting findings in the sources for this specific literature review were included. The literature review can be found in Chapter 4.

Table G.9: Overview of literature on urban & vertical farming business models

Source	Search	Concept	Field	Interesting Findings
Urban Farming				
(Sroka et al., 2023)	Scopus: TITLE (urban AND farming AND business AND model)	Success Factors and Barriers and Threats to peri-urban Farms	Peri-urban farms	Despite using different business models, urban farms use the exact solutions except for specialization. The experience business model has the most significant barriers.
(Pölling, Sroka, et al., 2017)	Scopus: TITLE (urban AND farming AND business AND model)	Analysis of the economic performance of farms based on business model type	Farms around the Ruhr area	Urban-adjusted farms have better economic prospects than non-urban-adjusted farms. Differentiation and diversification were better performing as business models economically than specialization
(Pölling, Prados, et al., 2017)	Scopus: TITLE (urban AND farming AND business AND model)	Analysis of different classifications of urban farm business models	50 urban farms in Germany, Italy, and Spain	Due to the lack of space in urban environments, differentiation and diversification business models are more prevalent than low-cost business models. Most urban farms focus on short supply chains.
(Pölling, 2016)	Scopus: TITLE (urban AND farming AND business AND model)	Identify similarities and differences between urban farms	21 urban farms in Nordrhein-Westfalen	Diversified and differentiated business models have the most substantial ties with the urban environment. Diversified farms invest the most in social services and personal contact with customers.
(Wiśniewska-Paluszak et al., 2023)	Scopus: (Urban Farming OR Agriculture) AND (Business Pricing OR Model)	Analysis of business models used by urban farms	In-depth interviews and participant observation on urban farms in Poland and Italy	Three different business strategies were identified: service-oriented, product-oriented, and land-use-oriented
(Saint-Ges, 2021)	Scopus: (Urban Farming OR Agriculture) AND (Business Pricing OR Model)	Analysis of business models used by urban farms	Survey of 25 market and productive organizations	Key success factors are: partnerships with the community, providing education services, a wide variety of customers via short marketing cycles
(Pölling et al., 2016)	Scopus: (Urban Farming OR Agriculture) AND (Business Pricing OR Model)	Spatial analysis of urban farming characteristics	Urban farms in the Ruhr area (geo-statistical and interviews used for data collection)	Urban farms use a mixture of three different business models: low-cost specialization, differentiation, and diversification
(Richardson et al., 2024)	Scopus: (Urban Farming OR Agriculture) AND (Revenue Streams)	Analysis of urban farmers' needs and challenges in the Northeastern United States	A survey among 394 urban growers primarily from the Northeastern United States	Most significant barriers to urban agriculture are related to the availability of land, labor, and economic viability

(Appolloni et al., 2022)	Scopus: (Vertical Farming) AND (Business OR Pricing Model)	Summarization of the current status of urban agriculture	Theoretical overview of urban agriculture economic viability and business models	Identification of six different types of business models and their success factors and challenges
(Martin & Bustamante, 2021)	Scopus: TITLE (vertical AND farming AND business AND model)	Analyze new business models for urban farming	Small-scale automated urban (vertical) farms	Identification of barriers to urban farming business models and aspects of value delivery and sales channels
Vertical Farming				
(Thomson, 2022)	Scopus: TITLE (vertical AND farming AND business AND model)	Exploratory research on new technology-based firms in vertical farming	36 different organizations' input from interviews in vertical farming in Europe & North America	Framework on how value can be increased by learning from efficiency and novelty drivers
(Marczewska et al., 2023)	Scopus: TITLE (vertical AND farming AND business AND model)	Identification of successful Business model elements	31 global vertical farms	Location, Customer Engagement, Location, Multiple revenue streams, and crop types increase vertical farms' performance
(Moghimi & Asiabanpour, 2023)	Snowballing & Scopus: TITLE (vertical AND farming AND value AND proposition)	The economic prospect of vertical farming in different urban environments	Theoretical study on 7 cities in the US	Cities in the US with lower energy costs have better financial prospects but still underperform in traditional farming
(Baumont de Oliveira et al., 2022)	Scopus: (vertical AND farming AND revenue AND streams)	Analysis of two different vertical farms' economic viability	Two cases: a small-scale UK farm and a theoretical Japanese larger-scale	Financial risks for vertical farms and risk modeling for vertical farms
(Ion, 2022)	Google Search (business model framework vertical farming)	Analysis of costs and profitability of vertical farming	Literature study and theoretical financial analysis	Theoretical mushrooms financial analysis, which is estimated to be profitable
(Avgoustaki & Xydis, 2020)	(Vertical Farming) AND (Revenue Streams)	Comparison of traditional farming with greenhouses and indoor vertical farming	Literature-based study on current technology vertical farming	Potential benefits of optimizing electricity costs by using different time zones in a day
(Moghimi et al., 2020)	Scopus: TITLE (vertical AND farming AND financial)	Framework for financial analysis of vertical farm	Literature-based study	Parameters for a financial analysis of vertical farming
(Kozai, 2019)	Scopus: (PFAL) AND (business AND model OR pricing)	Perspectives of PFAL in Japan, Taiwan, China, Thailand, and North America	Literature-based study	B2C sales are more profitable than B2B sales. Focus on locally produced and product presentation

H. Financial Model Parameter Description

Table H.10: Parameters Financial Model

Facility	Options							Parameter Options
CEA Ground floor Growing Area	66%	50%	33%					3
Vertical Growing Layers Base	Base	Low	High	Greenhouse				4
Total Growing Area								12
Investment Costs (per square meter)	Options							
Investment	High	Mid	Low					3
Depreciation	High	Mid	Low					3
*Investment Options (*Total Growing Area)*								36
Yield	Options							
Efficiency	100%	60%						2
Productivity	First	Dutch	Second	Third				4
Yield Options								8
Wage Costs	Options							
Automation	No Automation	Automation						2
Education	No Interns	Interns						2
Productivity	100%	67%						2
Salary	York	Pa						2
*Wage Options (*Total Growing Area)*								192
Energy Productivity & Costs	Options							
Energy Productivity	Base	Low	Mid	High	NL	Extreme	Improve	7
Energy Costs	100%	50%	75%	125%	150%	200%	300%	7
Energy Options								49
Lettuce Revenues	Options							
City	York	Pittsburgh						2
Configuration	Base	2	3	4				4
Price Value	Low	Mid	High					3
Type	Non-Organic	Organic						5
Revenue Options								120

I. Sensitivity Results

Table I.11: Sensitivity Results Yield

	Non Commercial Yield	Workforce Issues (Productivity)
Total Yield (Kg) / Year	5,344,006	1,054,907
Revenue Crops	$ 31,568,110	$ 6,231,545
Total Revenue	$ 31,568,110	$ 6,231,545
Energy Costs	$ 10,582,898	$ 2,089,064
Wages	$ 1,713,100	$ 1,713,100
Maintenance	$ 267,200	$ 267,200
Depreciation	$ 3,562,670	$ 3,562,670
Total Costs	$ 16,125,868	$ 7,632,035
Profit Before Tax / Loss	$ 15,442,242	$ (1,400,490)
Taxes	$ 4,476,706	$ -
Profit / Loss	$ 10,965,536	$ (1,400,490)
Profit Margin	34.74%	0.00%
Investment Costs	$ 53,440,056	$ 53,440,056
Payback Period	4.9	
	Yield	
Parameters	Non-Commercial Yield	Workforce Issues (Productivity)
Productivity	100%	60%
Year & Type	Non-Commercial	First

Table I.12: Sensitivity Results Workforce

	Pennsylvania Workforce	Workforce Productivity	Automation	Interns
Total Yield (Kg) / Year	1,758,178	1,758,178	1,758,178	1,758,178
Revenue Crops	$ 10,385,908	$ 10,385,908	$ 10,385,908	$ 10,385,908
Total Revenue	$ 10,385,908	$ 10,385,908	$ 10,385,908	$ 10,385,908
Energy Costs	$ 3,481,773	$ 3,481,773	$ 3,481,773	$ 3,481,773
Wages	$ 1,739,040	$ 2,298,250	$ 1,038,735	$ 1,791,120
Maintenance	$ 267,200	$ 267,200	$ 267,200	$ 267,200
Depreciation	$ 3,562,670	$ 3,562,670	$ 3,562,670	$ 3,562,670
Total Costs	$ 9,050,684	$ 9,609,894	$ 8,350,379	$ 9,102,764
Profit Before Tax / Loss	$ 1,335,224	$ 776,014	$ 2,035,529	$ 1,283,144
Taxes	$ 387,081	$ 224,967	$ 590,100	$ 371,983
Profit / Loss	$ 948,143	$ 551,048	$ 1,445,429	$ 911,161
Profit Margin	9.13%	5.31%	13.92%	8.77%
Investment Costs	$ 53,440,056	$ 53,440,056	$ 53,440,056	$ 53,440,056
Payback Period	56.4	97.0	37.0	58.7
	Workforce			
Parameters	Pennsylvania Workforce	Workforce Productivity	Automation	Interns
Type	No Automation	No Automation	Automation	No Automation
Education	No Intern	No Intern	No Intern	Interns
Productivity	100%	67%	100%	100%
Salary	PA	York	York	York

Table I.13: Sensitivity Results Energy

	High Energy Costs	Extreme Energy Costs	Low Energy Use	High Energy Use
Total Yield (Kg) / Year	1,758,178	1,758,178	1,758,178	1,758,178
Revenue Crops	$ 10,385,908	$ 10,385,908	$ 10,385,908	$ 10,385,908
Total Revenue	$ 10,385,908	$ 10,385,908	$ 10,385,908	$ 10,385,908
Energy Costs	$ 5,222,660	$ 10,445,320	$ 1,347,204	$ 5,222,660
Wages	$ 1,713,100	$ 1,713,100	$ 1,713,100	$ 1,713,100
Maintenance	$ 267,200	$ 267,200	$ 267,200	$ 267,200
Depreciation	$ 3,562,670	$ 3,562,670	$ 3,562,670	$ 3,562,670
Total Costs	$ 10,765,631	$ 15,988,291	$ 6,890,174	$ 10,765,631
Profit Before Tax / Loss	$ (379,722)	$ (5,602,382)	$ 3,495,734	$ (379,722)
Taxes	$ -	$ -	$ 1,013,413	$ -
Profit / Loss	$ (379,722)	$ (5,602,382)	$ 2,482,321	$ (379,722)
Profit Margin	0.00%	0.00%	23.90%	0.00%
Investment Costs	$ 53,440,056	$ 53,440,056	$ 53,440,056	$ 53,440,056
Payback Period			21.5	
	Energy			
Parameters	High Energy Costs	Extreme Energy Costs	Low Energy Use	High Energy Use
Energy Productivity	Base	Base	NL	High
Energy Costs	150%	300%	100%	100%

Table I.14: Sensitivity Results Revenues

	Pittsburgh Prices	Configuration 2	Configuration 3	Configuration 4	Low Prices	Organic
Total Yield (Kg) / Year	1,758,178	1,758,178	1,758,178	1,758,178	1,758,178	1,758,178
Revenue Crops	$ 9,049,962	$ 8,987,805	$ 9,886,586	$ 10,885,231	$ 8,388,618	$ 14,591,470
Total Revenue	$ 9,049,962	$ 8,987,805	$ 9,886,586	$ 10,885,231	$ 8,388,618	$ 14,591,470
Energy Costs	$ 3,481,773	$ 3,481,773	$ 3,481,773	$ 3,481,773	$ 3,481,773	$ 3,481,773
Wages	$ 1,713,100	$ 1,713,100	$ 1,713,100	$ 1,713,100	$ 1,713,100	$ 1,713,100
Maintenance	$ 267,200	$ 267,200	$ 267,200	$ 267,200	$ 267,200	$ 267,200
Depreciation	$ 3,562,670	$ 3,562,670	$ 3,562,670	$ 3,562,670	$ 3,562,670	$ 3,562,670
Total Costs	$ 9,024,744	$ 9,024,744	$ 9,024,744	$ 9,024,744	$ 9,024,744	$ 9,024,744
Profit Before Tax / Loss	$ 25,218	$ (36,939)	$ 861,842	$ 1,860,487	$ (636,126)	$ 5,566,726
Taxes	$ 7,311	$ -	$ 249,848	$ 539,355	$ -	$ 1,613,794
Profit / Loss	$ 17,907	$ (36,939)	$ 611,994	$ 1,321,132	$ (636,126)	$ 3,952,932
Profit Margin	0.20%	0.00%	6.19%	12.14%	0.00%	27.09%
Investment Costs	$ 53,440,056	$ 53,440,056	$ 53,440,056	$ 53,440,056	$ 53,440,056	$ 53,440,056
Payback Period	2984.3		87.3	40.5		13.5
	Revenues					
Parameters	Pittsburgh Prices	Configuration 2	Configuration 3	Configuration 4	Low Prices	Organic
City	Pittsburgh	York	York	York	York	York
Configuration	Base	2	3	4	Base	Base
Price Value	Mid	Mid	Mid	Mid	Low	Mid

Type	Non-Organic	Non-Organic	Non-Organic	Non-Organic	Non-Organic	Organic

Table I.15: Sensitivity Results Facility

	High Vertical Farm	Greenhouse	66% Growing Area	50% Growing Area
Total Yield (Kg) / Year	5,274,534	439,544	3,516,356	2,663,906
Revenue Crops	$ 31,157,725	$ 2,596,477	$ 20,771,816	$ 15,736,225
Total Revenue	$ 31,157,725	$ 2,596,477	$ 20,771,816	$ 15,736,225
Energy Costs	$ 10,445,320	$ 870,443	$ 6,963,547	$ 5,275,414
Wages	$ 4,248,750	$ 698,840	$ 2,220,230	$ 2,727,360
Maintenance	$ 801,601	$ 33,400	$ 534,401	$ 404,849
Depreciation	$ 10,688,011	$ 445,334	$ 7,125,341	$ 5,397,985
Total Costs	$ 26,183,682	$ 2,048,017	$ 16,843,518	$ 13,805,608
Profit Before Tax / Loss	$ 4,974,043	$ 548,460	$ 3,928,298	$ 1,930,616
Taxes	$ 1,441,975	$ 158,999	$ 1,138,814	$ 559,686
Profit / Loss	$ 3,532,068	$ 389,461	$ 2,789,485	$ 1,370,930
Profit Margin	11.34%	15.00%	13.43%	8.71%
Investment Costs	$ 160,320,168	$ 6,680,007	$ 106,880,112	$ 80,969,782
Payback Period	45.4	17.2	38.3	59.1
	Facility			
Parameters	High Vertical Farm	Greenhouse	66% Growing Area	50% Growing Area
CEA Ground floor Growing Area	33%	33%	66%	50%
Vertical Growing Layers Base	High	Greenhouse	Low	Low
Investment	Mid	Low	Mid	Mid

Table I.16: Sensitivity Results Investment & Depreciation

	Low Investment M2	High Investment M2	Depreciation High	Depreciation Mid
Total Yield (Kg) / Year	1,758,178	1,758,178	3,516,356	2,663,906
Revenue Crops	$ 10,385,908	$ 10,385,908	$ 20,771,816	$ 15,736,225
Total Revenue	$ 10,385,908	$ 10,385,908	$ 20,771,816	$ 15,736,225
Energy Costs	$ 3,481,773	$ 3,481,773	$ 6,963,547	$ 5,275,414
Wages	$ 1,713,100	$ 1,713,100	$ 2,220,230	$ 2,727,360
Maintenance	$ 133,600	$ 400,800	$ 534,401	$ 404,849
Depreciation	$ 1,781,335	$ 5,344,006	$ 15,268,587	$ 8,096,978
Total Costs	$ 7,109,809	$ 10,939,679	$ 24,986,765	$ 16,504,601
Profit Before Tax / Loss	$ 3,276,100	$ (553,771)	$ (4,214,948)	$ (768,377)
Taxes	$ 949,741	$ -	$ -	$ -
Profit / Loss	$ 2,326,358	$ (553,771)	$ (4,214,948)	$ (768,377)
Profit Margin	22.40%	0.00%	0.00%	0.00%
Investment Costs	$ 26,720,028	$ 80,160,084	$ 106,880,112	$ 80,969,782
Payback Period	11.5			
	Investment & Depreciation			
Parameters	Low Investment M2	High Investment M2	Depreciation High	Depreciation Mid
Investment	Low	High	Mid	Mid
Depreciation	Low	Low	High	Mid

J. Expert Validation Protocol

Expert Assessment - Financial Model VF

Dear Expert,

You are invited to assess the: *'Financial Model Tool Vertical Farming'* developed by: Yassine Mouhdad. This is part of the master's thesis: *Viability Assessment of Vertical Farming: A Decision Support Framework with a Case Study on York, Pennsylvania*. The master's thesis is part of the Engineering & Policy Analysis program at the University of Technology Delft. The project is in collaboration with TU Delft and Priva. The following supervisors are part of the Committee for the master's thesis.

- *Chair:* *Dr. J. Ubacht, section ICT* *TU Delft*
- *1st supervisor:* *Dr. J. Ubacht, section ICT* *TU Delft*
- *2nd supervisor:* *Dr.ir. J.N. Quist, section E&I* *TU Delft*
- *Company supervisor:* *Dr.ir. Jan Westra* *Priva B.V.*

Experts must assess the financial model of the master's thesis to increase its validity. Therefore, you are asked to answer the following questions with your insights on the financial model. The Financial Model Tool will be called 'tool' in the questions.

1. Is the tool clear to use or does it need improvement in explanation and user-friendliness?
2. Are the most important factors of Vertical Farming and a Business Model included in this tool?
3. Are the choices made, such as the relations between the variables and data appropriate? (considering the model tries to represent as much as possible a real-life situation)
4. Is the tool fit for purpose based on the description in the Excel Worksheet?
5. What are the advantages and disadvantages of the model considering its purpose?

Thank you for your valuable time!

Yassine Mouhdad