Master thesis

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Technological Innovation System of hydroponics technology in Halland
A case study on functional weaknesses

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Binil Shah Usman Thorath and Josephine Palma Porto

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Abstract

Problem Discussion: The world population is increasing at a rate that the current food production capacity would not be able to sustain. In Sweden, only a small portion of the land area is used for cultivation and there is a high percentage of imports of food. Halland region is located in the southern part of Sweden has its arable land decreased between 2010 to 2020. This adds to the uncertainty of food production in the future in the region and in Sweden in general. Hydroponics combines food production and technology by using minimal space and resources. It is a technique of growing plants in water with nutrients. Despite being utilized in many countries around the world, hydroponics technology has not been widely adopted in the Halland region of Sweden.

Purpose: This thesis aims to analyze the functional weaknesses of the hydroponics industry in the region Halland by utilizing the technological innovation systems (TIS) framework. By analyzing the functional dynamics of actors, networks, and institutions, this thesis aims to explore the weaknesses within the functions, which can be a basis for innovation policies for the necessary stakeholders for the further diffusion of the industry in the Halland region.

Methodology: An in-depth qualitative case study was utilized in this study with a deductive approach. Authors have used the framework from Beregk (2008) to analyse the functional weakness of the TIS. And tested whether the theory stands true for a regional setting with little to no actor-network dynamics. A semi-structured interview using mostly video conferencing was done to collect data from respondents representing different actors within the technological innovations systems (TIS) framework.

Analysis: The data collected from the semi-structured interviews were analyzed using coding software and exported into an Excel sheet for ease of synthesizing the information. The primary data along with secondary sources was used to analyse the functional weaknesses. The data collected were assigned to each function to identify the patterns and come up with findings and conclusions.

Findings and Conclusions: An examination of the data reveals that, despite limited actor-network dynamics in the context, notable weaknesses have emerged within the Technology and Innovation System (TIS). These findings can serve as valuable insights for policymakers seeking to facilitate the wider adoption of this technology. This includes an insufficient development of knowledge within the region. Additionally, entrepreneurs face challenges in securing funding beyond the initial stages, which often leads them to employ trial-and-error approaches. This approach, while valuable for learning,
consumes significant time and capital resources, compounding uncertainty. Fortunately, being part of the European Union (EU) provides a distinct advantage for the region, as it enables a smooth flow of information and resources from EU counterparts. While the existing theory holds true within this context, there remains scope for further research. Further research for a distinct diffusion system analysis and greater clarity on defining the development of external positivity for an infant industry.

Keywords: Technological Innovation Systems (TIS), TIS Framework, Functions of TIS, Hydroponics technology, Halland Region of Sweden
Preface

First of all, we would like to thank our families for their support and encouragement during the writing of thesis. Secondly, we would like to thank our supervisor, Eugenia Perez Vico who has been steadfast in guiding us, always there to answer our questions, giving us constructive criticisms, and stirring us on the right direction when we lose our way. We also would like to thank the interview participants for their time and patience in sharing their insights that helped form this thesis in its entirety. Furthermore, we would like to thank our examiner, Deycy Janeth Sánchez for providing the comments and feedback that helped us do the final improvements of the thesis. Lastly, we would like to thank our professors and peers at Halmstad University for all the knowledge exchange, guidance, collaboration, and friendship.

Binil Shah Usman Thorath
Josephine Palma Porto
Halmstad, Sweden
31st October 2023
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1. Introduction

This chapter describes the context of the master thesis and explains the background and problematization that form the foundation of the study. This is followed by the purpose of the study and the research question. Towards the end of the chapter, a section is written to explain the delimitations of the study.

1.1 Background

The reports published by the United Nations projected that the world population will reach 9.7 billion by 2050 (World Population Prospects, 2017, 2022), which means that by 2050, humanity will have to produce 70% more food than now (De Clercq et al., 2018). The intense exploitation of land for food production is making it increasingly unsuitable in the future. The land has long been considered a finite resource, and 25% of the total farmland is rated as highly degraded (Organisation for Economic Co-operation and Development, 2012). The global water levels are highly stressed, and about 70% of the water used globally goes towards agriculture production (World Bank, 2022).

Sweden, located on the Scandinavian Peninsula, is one of the largest countries in Europe in terms of land area, using just 6.5% of their land for cultivation (Jordbruksverket, 2022). Agriculture is different in the north compared to the south, and Southern Sweden is responsible for most of the agriculture in Sweden. Figure 1 shows the agricultural land use in Sweden. This agricultural land has seen a steady reduction for the past 150 years due to the rise in population (SCB, 2020). The total land area decreased by 10.26% from 1990 to 2020 (Jordbruksverket, 2020). Sweden is also heavily dependent upon imports of food products from other countries, and imports have increased by 3%, a value of SEK 165 billion, from 2020 to 2021 (Strandberg & Lind, 2020).
Halland, one of the regions in the south of Sweden, is an important agricultural area that currently faces challenges. Regarding Sweden’s national strategy for climate adaptation, some of the prioritized challenges in Halland include the lack of water supply for agriculture and the negative impact of domestic food production (Edman, 2022). High harvest levels in the previous years have resulted in drought and sequentially decreased yields per hectare in Halland (Swedish Board of Agriculture, 2016). There is a steady decrease in the portion of arable land in the total land use. Halland has decreased arable land from 114,809 hectares in 2010 to 106,785 hectares by 2020 (SCB, 2022).

As the shortage of food and arable land is the reality of the future, international institutions, policymakers, scientists and innovators from their respective disciplines are investigating and making changes in the future of agriculture and food production in general. These encompass the analysis in digital agriculture (Lajoie-O’Malley et al., 2020), supply chain (Lezoche et al., 2020), and innovative urban agriculture (Armanda et al., 2019) analysis for the policy makers, equipping policymakers to make informed decisions regarding the future of agriculture. The traditional food production approach needs to be complemented, if not disrupted with innovative solutions that would sustain increased production with less resources. This includes crop improvement, more innovative use of water and fertilizers, the introduction of novel non-chemical approaches to crop protection and techniques and technologies from various disciplines, ranging from biotechnology and engineering (Beddington, 2010).

According to De Clercq (2018), hydroponics is one such technology that incorporates cross-industry technologies and applications to bring food
production to consumers with increasing efficiency and quality. Hydroponics is the art and science of cultivating crops in a soil-less manner. Using smart greenhouses equipped with technologies to control critical parameters for healthy plant physiology, hydroponics optimizes the use of water and chemicals to eliminate potentially hazardous waste and residuals (van Delden et al., 2021). Hydroponics can warrant a high volume yield and quality of food in the future (Velazquez-Gonzalez et al., 2022).

1.2 Problematization

Hydroponics has been increasingly utilized around the world. In China for example, as of 2010, the country had protected cultivation of 3,346,800 hectares; while Brazil had 22,000 hectares (Souza et al, 2019). The United States Department of Agriculture is working on extensive research and funding for the infusion of hydroponics in collaboration with their National Institute for Food and Agriculture, Agriculture Research Service and the Department of Energy (USDA, 2018). It is also becoming more and more popular in non-productive regions such as countries in the middle east region. In Saudi Arabia, one of the driest countries in the Arabian Peninsula, several agribusinesses have started using hydroponics systems with the aim of keeping pace with the kingdom’s soaring population and food requirements (Radwan, 2022). In Taiwan, there are extensive business models for hydroponics systems, such as the product used for their usage, like restaurants or corporations with more than 1000 employees (Kozai et al., 2016).

The agriculture sector in Halland is a prominent one. The total number of agricultural companies at 2020 who owns or leased arable land comes around 21% of the total agriculture companies in Sweden (Jordbruksverket, 2020). In recent times, heat waves, drought and floods have already reduced the agricultural production in Halland (Statistiska Centralbyrån, 2016). According to Edman (2022), Halland's agricultural and food sector is expected to be affected by climate change both via short-term exposure to extreme weather events, such as drought, torrential rain and sudden temperature changes, and of longer trends, such as changing average temperature. Halland is one of the six counties that has been assigned for increased preparedness in terms of food security (LRF, 2023). As previously mentioned, as the arable land is shrinking in Halland, and Halland will be accounted for 12 percentage of population growth by 2040 (SCB, 2021), increasing food production through conventional farming is unsustainable for Halland. This makes it crucial for Halland region to diffuse hydroponics technology in their farming sector with regards to their environmental challenges.
The Hydroponics industry as a whole consists of cutting-edge technologies, automation, and advanced techniques to optimize plant growth, water efficiency, nutrient delivery, and overall crop yield in a controlled environment. This often involves the use of sensors, data analytics, web platforms, software and mobile applications for the precise control over factors like temperature, humidity, light, and nutrient concentrations (Velazquez-Gonzalez et al., 2022). This requires a comprehensive and interconnected network of actors and networks, performing functions thus creating a system of innovations or Innovation system. Innovation system is defined as the systemic interactions between the various components of inventions, research, technical change, learning, and innovation (Soete et al., 2010). As the innovation system of hydroponics focuses on the development, diffusion, and utilization of technological innovations within the industry, the innovation system can be specified into a technological innovation system (TIS).

The original definition of Technological innovation system (TIS) is ‘a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology’ (Carlsson, 1991). Thus the main basis for defining a TIS is a focal technology (Bergek, 2019; Bergek et al., 2008; Carlsson, 2006; Carlsson et al., 2002) and a particular economic/industrial area (Bergek, 2019). Placing this into our empirical context, the focal technology being hydroponics and the area being the Halland region.

As hydroponics industry can be crucial for transition of conservative agriculture sector in Halland, authors try to provide a basis for innovative policy for the relevant stakeholders. For this assessment, a functional approach is used, instead of structural approach. The main reason is that the hydroponic industry is in the nursing stage in Halland and there is no defined structures formed yet. Structures focuses on established actors and networks, and this approach was prominent with the system failure approach, where the innovation system failure is related to the perceived weaknesses in the structural composition of the system (Klein Woolthuis et al., 2005). Also, the structural approach doesn’t take factor the influence of innovation process and how it effect the strength and weakness of actor-network (Bergek et al., 2008). By identifying and assessing each functions, authors can provide the areas of weakness and strength, which can be a basis for innovative policies by various stake holders. Bergek et. al. (2008) has identified seven functions from the previous literatures on functions of innovation systems, where they all have the general similar characteristics, which marks as the basis of functional dynamics approach and authors will be using this functions in the technological innovation systems framework to analyze the weaknesses in the functions. The analysis of the functions and identified weaknesses can help
the necessary stakeholders to formulate policies for the further diffusion of hydroponics industry in Halland.

The TIS framework using the functional approach has been used in many contexts. Most of the studies are concerned with sustainable industries, making it relevant in the field of sustainable innovation (Bergek, 2019). This includes wind energy innovation systems from various countries (Edsand, 2017; Furtado & Perrot, 2015; Gosens & Lu, 2014), electric car industries (Haley, 2014; Stephan et al., 2017) and various other renewable energy industries (Eleftheriadis & Anagnostopoulou, 2015; Goess et al., 2015; Negro et al., 2012; Tigabu et al., 2014). The literature in the field of TIS is mostly concerned with national or international implications. The wind turbine manufacturing industry of China (Gosens & Lu, 2014), the case of renewable energy in East Africa (Tigabu et al., 2014), the Norway’s oil and gas sector industry (Mäkitie et al., 2018), the Swedish biorefinery industry (Hellsmark et al., 2016), or the Swedish marine energy (Andersson et al., 2017) are some of the examples to be named.

To understand the literature base of the Technological Innovation Systems, the authors conducted a literature review. In a total of 165 articles, 84 articles are case studies where a technology is analysed in a national or international context. Certain articles compare the technological innovation systems between different countries or regions (Nevzorova & Karakaya, 2020; Quitzow, 2015; Vasseur et al., 2013). Most of these articles are concerned with analysing the success of case studies using TIS and modelling new frameworks and policies that could be used in different contexts (Furtado & Perrot, 2015; Hanson, 2018; Mäkitie et al., 2018). In the remaining articles, 48 articles are regarding the direct contributions to literature as frameworks (Edsand, 2019; Heirani et al., 2023; Ortt & Kamp, 2022) or towards the functions (Aldersey-Williams et al., 2020; Bening et al., 2015). Only three articles had a TIS analysis on a regional perspective within a country. A study on the renewable electricity in Nova Scotia, Canada (Haley, 2018) explores the already established transmission interconnections to study the integrating structural tensions. Another study was conducted in Nairobi, Kenya (van Welie et al., 2019), explores the already established sanitation value chains, to improve the innovation developments. The third article, explores the Natural gas and energy industry of China through their Sichuan-Chongqing gas province, which leads in China’s natural gas industry (Ma, 2017). The majority of the articles in Technological Innovation systems explores well-established industries, also in the limitation context of a National or global perspective.

As a master’s thesis, the authors has limited the scope of study to a province in Sweden, the Halland. This geographical limitation, added with the fact that the industry has not picked up yet in the region, the actor network functions
can be difficult to map as compared to the previous studies. This identifies as a notable research gap within the context of the aforementioned findings, where the predominant focus of Technological Innovation Systems (TIS) analysis centers on established industries at the national or international levels, but seldom extend their focus to regional or local contexts. This could either expose the weakness or the effectiveness of the use of TIS framework in analysing the data and policy formation in a limited geographical context for an industry in its budding stage.

1.3 Purpose

This thesis aims to analyze the functional weaknesses of hydroponics industry in the region Halland by utilizing the technological innovation systems (TIS) framework. By analyzing the functional dynamics of actors, networks, and institutions, this thesis aims to explore the weaknesses within the functions, which can be a basis for innovation policies for the necessary stakeholders for the further diffusion of the industry in Halland region.

This thesis is also intent to provide the validity of the TIS analysis in a regional or local setting for a budding industry where the actor-network functions are not quite developed.

1.4 Research Question

Hence, the research question that this thesis will answer is:

“What are the functional weaknesses of hydroponics industry’s technological innovation systems (TIS) in the Halland of Sweden?”

1.5 Delimitations

This thesis is focused on analyzing hydroponics in the Halland region of Sweden by utilizing the functional approach of technological innovation systems (TIS). As such, only essential technical aspects of hydroponics will be included. Furthermore, this study will not discuss about the sustainability aspects of hydroponics.

Due to the nature of hydroponics having complex specificities that are entirely different than the current agricultural practices, this study is limited to analysing the functional dynamics of hydroponics within the TIS framework. This study is limited to Halland region of Sweden, although some perspectives during primary data gathering will inevitably include the whole country of Sweden.
2. Theoretical Framework
In this chapter, the theoretical framework will be discussed in detail. The section starts with concept of Innovation systems, and various Innovation systems prevail in the literature. In innovation systems, the Technological Innovation systems is discussed in detail, as the topic of thesis is pertained to it. Within the TIS analysis, the structural approach is discussed in detail, as the analysis of the TIS is approached through the lens of functional view.

2.1 Innovation Systems
A innovation system can be defined as the group of components such as actors, networks and institutions, that works towards the overall functioning of the objective (Carlsson & Stankiewicz, 1991) and contributing to the overall developing, diffusing, and utilizing new products (goods and services) and processes (Bergek, 2002, 2019; Bergek et al., 2008; Carlsson & Stankiewicz, 1995; Galli & Teubal, 1997). An innovative system is a basis for policy action, and has been recognized and adopted by various international organizations (European Commission, 2023; Organisation For Economic Co-Operation And Development, 1997; United Nations Industrial Development Organization, 2023). The Innovation approach is a combination of both individual and collective act, where it encompasses individual firm dynamics as well as particular technology characteristics and adoption mechanisms (Hekkert et al., 2007).

An innovation system is a policy approach to fix failures in a system and strengthen the total innovation networks (Hekkert et al., 2020). This policy approach is focused primarily on the innovation for socio economic growth (Schot & Steinmueller, 2018). There are a different number of innovation systems concepts that has been put forward in the literature. National innovation system (Lyasnikov et al., 2014; Malerba & McKelvey, 2020; Nelson, 1993), regional innovation systems (Asheim et al., 2019; Chung, 2002; Lau & Lo, 2015), sectoral innovation system (Granstrand & Holgersson, 2020; Malerba, 2002), Mission oriented innovation systems (Hekkert et al., 2020) and Technological innovation system (Bergek, 2019; Bergek et al., 2008; Edsand, 2019; Hekkert et al., 2007; Walrave & Raven, 2016). As the name suggest the National and Regional Innovation systems focuses on a geographical area and Sectoral Innovation system focuses on an industry sector. Whereas the Technological innovation system focuses on the focal technology on a particular industrial/economic area (Bergek, 2019). These innovation systems approaches are developed differently, but they are also interrelated. i.e. a technology specific innovation system, i.e. TIS could operate at the national, regional and /or sectoral level (Esdand, 2019). The focus of the thesis will be Technological innovation system.
2.2 Technological Innovation Systems (TIS)

The definition of TIS is ‘a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or a set of infrastructures and involved in the generation, diffusion, and utilization of technology’ (Carlsson & Stankiewicz, 1991). As the definition talks about the generation, diffusion and utilization of the technology, it is important to understand the concept of technology. A technology is ‘a design for instrumental action that reduces the uncertainty in the cause-effect relationship involved in achieving a desired outcome’ (Rogers, 2003). So technology is the design or the tool to implement the innovation. This design for instrumental action can be either hardware, i.e. a tool or software, the information base. In relation with TIS, the technology can also be referred as the technical knowledge, either in general terms or in terms of knowledge embodied in the physical artifact (Bergek et al., 2008). In general, a technological innovation system is concerned around how new innovation systems emerge around technical innovations in order to support the development and diffusion of these innovations (Walrave & Raven, 2016).

As mentioned earlier the three components of a innovation system or a technological innovation systems are actors, network and institutions. The actor network and the institutional infrastructures are both dynamic (Bergek, 2019). When a novel TIS initially emerges, actors engage and create new network, and parallelly establishes or adopt new institutional frameworks (Jacobsson & Bergek, 2004). This structure matures overtime and became more stable. At the matured stage, the actors can still enter and exist, the institutional guidelines can change according to socio–economic factors, and changes in innovation collaboration patterns can lead to industry convergence (Bergek, 2019). Therefore, the TIS itself does not constitute as an industry, rather, it comprises the actors within an industry, the networks they establish, and the institutions that evolve throughout the processes.

2.3 Analyzing TIS: A Functional Approach

In a system view approach, the components of the system (actors, network and institutions) contribute to the ‘goal’ of the system, and this contribution is termed as a function (Bergek, 2002). Functions can act as an emergent property of an innovation, where it can shows the state of specific innovation system in a defined moment of time (Wieczorek & Hekker, 2012). Previously the innovation systems were analysed by perceiving the weakness in the structural composition of a system, but this analysis had many shortcomings in explaining innovation processes, and ultimately failing to show the strength or weakness of a particular actor-network. According to
Hekkert et.al (2007) there are three reasons for adopting the functional approach.

1. The functional approach perspective makes the comparison in terms of performance between innovation systems with different institutional set-ups more feasible.

2. The functional perspective permits a more systematic method of mapping determinants of innovations, increasing the analytical power of the innovation systems approach.

3. The functional perspective has the potential to deliver a clear set of policy targets as well as instruments to meet these targets.

Researches has mapped functions in different ways from the 90s. Evolutionary theory was used to define functions (McKelvey, 1997), functions were categorized as hard and soft functions (Galli & Teubal, 1997), and also functions where mapped by directly extrapolating from system modules (Liu & White, 2001). Johnson (2001) did a literature review to find the shared understanding of various functions and identified 8 system functions and later reduced to 5 functions in a later empirical work of the same author (Jacobsson et al., 2004) that to be served in an innovation systems. Through empirical application, additional literature studies and discussions amongst the scholars of innovation systems, the list has been revised and refined several times. From the total previous nine attempts of identifying the functions, Bergek et.al. (2008) has created the seven functions, by having a large agreement between the various different functional approaches. These identified functions, along with the functions identified by Hekkert et. al. (2007) are the currently dominating functions in the field that are used in the technological Innovation systems framework, where the former is based on the later (Bergek, 2019).

2.4 Technological Innovation Systems Framework

The Technological Innovations System approach is a widely applied framework for analyzing technology development in an innovation context (Markard, 2020). The framework is a scheme of analysis to identify the key policy issues related to the strength and weakness of an innovation systems by understanding how well the functions are fulfilled (Bergek et al., 2008). Through the framework the performance of the TIS is assessed, to identify
the shortcomings and to derive recommendations for the design of policies in support of a specific technology (Markard et al., 2015). Since its inception the framework has seen several conceptual developments, and has been used in many empirical contexts.

In this thesis’s empirical setting, inorder to analyse the technological innovation system of hydroponics in the Halland region, authors have adapted the functions as described by the Bergek. et. al (2008). The following figure illustrates the relationship between the components and functions as interpreted from Bergek, et al (2008), and the section that follows briefly explains each part.

![Diagram of Theoretical Framework](image)

*Figure 2: Theoretical Framework (adapted from Bergek, et al, 2008)*

### 2.4.1 Components

Carlsson and Stankiewicz (1991) take systems view of technological change, meaning that not one component, firm or innovations, taken individually, can explain economic change; instead, they must be viewed as part of a larger system, with various agents interacting with each other, and the institutions matter. As such, the components of an innovation system are the actors, networks and institutions contributing to the overall functions of developing, diffusing and utilizing new products and processes (Bergek, et al, 2008). To achieve success of an innovation systems specifically technological innovation systems, all the components must be in synergy. In this study, the components that affect the diffusion of hydroponics in Halland is identified.
2.4.1.1 Actors

In the diffusion of a technology under the lenses of technological innovation systems, the actors have the most impact throughout the system. The actors can be drivers or blockers of a technology based on how each of them responds to the technology. Their interpretations of technology will affect their opinion of the usefulness or even appropriateness of a certain technology (Monteiro Moretti, et al, 2023). As such, the success of the diffusion of a technology is highly dependent on the actors’ responses, perceptions, and interpretations of the technology. Moreover, the actors also drive the other components of technological innovation systems, i.e., networks and institutions. Where there are some resistance or negative perceptions in some actors, the networks and institutions will be highly affected. If the actors perceive the focal technology differently or even have contradictory perceptions at the technical level, the TIS encounters difficulties, and the diffusion of this technology are threatened as a result (Monteiro Moretti, et al, 2023).

2.4.1.2 Networks

As the saying goes, “no man is an island”; every human and organization on Earth needs to collaborate with each other to be able to prosper. In a practical sense, networking is interacting with other people or organizations to achieve a personal or professional goal. In the professional sense, people are encouraged to improve their network with other professionals, usually in the same field, to increase their chances of finding better opportunities.

The same concept applies to the diffusion of technology. One of the components of the TIS framework is the network which Musiolik, et al (2012) defined as an organizational structure with clearly identifiable members where firms and other organizations come together to achieve common aims or to solve specific tasks; and that from RBV perspective, formal networks can also be conceptualized as bundles of resources which are made available by the network members or which emerge in the network.

In the diffusion of hydroponics, network is a crucial component in order for the innovation system to flourish. For example, entrepreneurs would have to have a good network with other entrepreneurs in the field to be able to acquire much-needed resources such as equipment, supplies, knowledge, and financial resources. Within the actors component of TIS framework, it can be argued that entrepreneurs have the most significant responsibility of networking in order for a technology to be diffused. If the network within the entrepreneurs are good, it could be more accessible to foster a network with
other actors due to the existing network of other entrepreneurs. In the TIS perspective, networks rely not only on the organisational resources of their members but also on new resources developed at the network level, including network governance structures, trust among network members, a common understanding of the strategic goals or a good reputation of the network (Musiolik, et al, 2012).

2.4.1.3 Institutions

According to North (1994), institutions are humanly devised constraints that structure human interaction, and they are made up of formal constraints (e.g., rules, laws, constitutions), informal constraints (e.g., norms of behavior, conventions, self-imposed code of conducts), and their enforcement characteristics. As such, institutions, whether formal or informal, covers a wide range of influence in a diffusion of a technology.

In the TIS analysis of hydroponics in Halland, formal constraints can be the rules and regulations in the food production, and informal constraints can be the society’s perspective about the technology being so far away from the conventional way of farming. Institutions can drive the direction of an innovation, and it can differ between countries. For example, in an arid country where soil cultivation can be very challenging, government policies can be very supportive of the initiatives in the field of innovative solutions in agriculture, such as hydroponics. Meanwhile, this can be a different scenario in a country where it is deemed to have abundant soil for cultivation.

2.4.2 Functions

The analysis of the functional pattern of the TIS aims to ascertain to what extent the functions are currently filled; i.e., to analyze how the TIS is behaving in terms of a set of key processes (Bergek, et al, 2008). A number of functions have been explained by Bergek, et al (2008) to delineate the functional dynamics of a TIS, namely 1) knowledge development and diffusion, 2) influence in the direction of search, 3) entrepreneurial experimentation, 4) market formation, 5) legitimation, 6) resource mobilization, and 7) development of positive externalities. This thesis focuses on understanding each function of the TIS of hydroponics to fullfill the aim of exploring the challenges in the diffusion of hydroponics in the Halland region of Sweden. Many scholars have identified the effectiveness of the functional analysis in the TIS of a particular technology around the world (Oltander & Perez Vico, 2005; Hekkert, et al, 2007; Bergek, et al, 2008; Borges, et al, 2023). There are many ways that the TIS functions can be
analyzed in the certain technology. For example, Borges, et al (2023) conducted a quantitative analysis of the functions by developing survey questionnaires to find the current status of each function. In this thesis, the authors have conducted qualitative analysis through interviews with multiple actors to understand each function deeply.

The TIS functions described by Bergek, et al (2008) as they apply in the diffusion of hydroponics will be discussed in the following section.

### 2.4.2.1 Knowledge development and diffusion

According to Bergek, et al (2008), this function captures the breadth and depth of the current knowledge about the TIS, how that changes over time, and how the knowledge is diffused and combined in the system; and is generally placed at the heart of the TIS. The success of a TIS can be highly dependent on the knowledge of the technology. Knowledge can also affect the other functions within the TIS. For example, entrepreneurial experimentation can be affected by the level of knowledge that can be acquired from other actors. Furthermore, other actors can be a significant source of knowledge such as universities, in which case, collaboration between the universities and firms is necessary to continually improve the development of knowledge.

### 2.4.2.2 Influence in the direction of search

Some of the literature describes this function, pointing towards the effect of the government and public policies that support the TIS (Furtado, et al, 2020; Schiller, et al, 2020). However, Bergek, et al (2008) suggested that this function is not controlled by one organization and definitely not by the state (apart from the case regulations, etc.), but the strength is in the combined effect of different actors. It was further suggested that this function can be measured by qualitative factors of; 1) beliefs in growth potential, 2) incentives from factor/product prices, e.g., taxes and prices in the energy sector, 3) the extent of regulatory pressures, e.g., regulations on the minimum level of adoption and tax regimes, and 4) the articulation of interest by leading customers (Bergek, et al, 2008). In the authors’ definition of this function, it concerns the support of one or more organizations for the TIS to be able to succeed.
2.4.2.3 Entrepreneurial experimentation

According to Lindholm-Dahlstrand, et al (2019), the function of entrepreneurial experimentation is an essential mechanism for translating new knowledge into economic activity and growth created in innovation systems, but its role has been largely ignored in the literature. For a business idea to be successful, an entrepreneurial skill with a great deal of experimentation is required. The same applies to technology diffusion. One of the most important aspects is an entrepreneur willing to experiment with the right amount of technical and entrepreneurial knowledge. Ultimately, a TIS without vibrant experimentation will stagnate (Berget, et al, 2008). This proves that the literature recognizes the importance of an entrepreneurial mindset to enable a technology innovation.

2.4.2.4 Market formation

The market formation is described as typically passing through steps from a nursing over a bridging to a mass market, and each stage is associated with specific barriers and challenges (Dewald and Truffer, 2011). Bergek, et al (2008) defined the nursing market as a very early phase of a market formation while bridging the market allows for volumes to increase. In the TIS analysis, it is vital to understand at which stage the technology is in market formation. This is because the level of other functions in each market phase can vary significantly. For example, the knowledge development and diffusion in the nursing market can be limited, while it can be more abundant in the bridging market. Furthermore, resource mobilization in the bridging market can be largely available as compared to the nursing market.

2.4.2.5 Legitimation

In the political perspective, legitimacy is the conformity with the society's values and beliefs (Smith, 1970). Furthermore, legitimacy is formed through conscious actions by various organisations and individuals in a dynamic legitimation process, which eventually may help net TIS overcome its “liability of newness” (Bergek, et al, 2008). As one of the functions of the TIS framework, legitimation is focused on the society. The society’s perspective on a technology can affect other actors that make decisions, affecting other functional dynamics of the TIS. For example, government bodies and policymakers can support a technology diffusion or not, depending on the values and beliefs of the society on a certain technology.
2.4.2.6 Resource mobilization

Development and diffusion of most of the new technologies can be relatively resource intensive. In the TIS literature, it has been suggested that the mobilisation of financial resources is captured by looking at volume of seed and venture capital investment and asking core system actors if they have access to sufficient resources (Bergek, et al, 2008; Hekkert, et al, 2007; Karltorp, et al, 2017). Although financial resources can be seen as highlighted in the literature more than other resources, Bergek, et al (2008) also propose competence or human capital through education in specific scientific and technological fields, entrepreneurship, management, and finance; as well as complementary assets such as complementary products, services, and network infrastructure.

2.4.2.7 Development of positive externalities

This function is also called the creation of free utilities in other literature. According to Oltander and Perez Vico (2005) it identifies free utilities that have arisen from establishing a critical mass of actors within the system. It can be argued that the success of a TIS can be highly dependent on the development of positive externalities. This is because the sources of economies are external to firms, which include; 1) the emergence of pooled labour markets, 2) the emergence of specialized intermediate goods and service providers, and 3) information flows and knowledge spill-overs (Bergek, et al, 2008)
3. Empirical Context

This chapter will present the empirical context that is used in this study. Firstly, hydroponics will be introduced with brief history and its utilization around the world. A short but concise technical description about hydroponics is presented for the benefit of understanding the technology in general terms. Furthermore, the Halland region of Sweden will also be introduced as the area of to be analysed in this study.

3.1 Hydroponics

Hydroponics is the process of growing plants in a nutrient-enriched solution, without soil, and with or without the mechanical support of an inert medium such as perlite, gravel or other substrate (Gericke, 1945). Since Gericke first coined the word, hydroponics as a technology has been refined constantly due to the developments of scientific knowledge in the field of plant physiology. In this section, a brief description of components in relation to the plant physiology is described.

Possibly one of the first recognized works published about hydroponics is the of Dr. William F. Gericke, who first coined the word hydroponics which is derived from the Greek and means literally “water working”, and defined it as the art and science of growing crops without soil and its application (Gericke, 1940). Most of the literature in this field is focused on the improvement, such as the amount of nutrients used and other technical specifications. However, the rate of diffusion has not been explored. As such, the authors have relied on secondary data from worldwide. According to Souza, et al (2019), It is increasingly relevant in the global agricultural scenario and is commonly found in areas with difficult access to soil; in China for example, as of 2010, the country had protected cultivation of 3,346,800 hectares in 2010 while Brazil had 22,000 hectares. Furthermore, in Saudi Arabia, one of the driest countries in the Arabian Peninsula, several agribusinesses have started using hydroponic systems to keep pace with the kingdom’s soaring population and food requirements (Radwan, 2022).

Even with the perceived slow diffusion rate, particularly in the focus of this thesis, the Halland region of Sweden, there is a strong body of literature focused on the specifications such as nutrient solution analysis technologies used, use of wastewater many other aspects. Most of the literature is a case study in a single test environment. However, there is currently little to no literature about the analysis of hydroponics in an innovation systems perspective, which is why this study is significant and would contribute to both theoretical and empirical body of knowledge.
**Substrates**

Substrate is the physical medium that substitutes soil to support plants by the stem and keep them under appropriate growing conditions by providing an aseptic environment with good aeration and adequate contact with the nutrient solution (Savvas et al., 2018). One of the major properties of a substrate is to have a good water retention capacity, while ensuring sufficient aeration to the roots (Khan et al., 2021). Some of the substrates available in the market include Perlite, vermiculite, sand, rockwool, coconut coir, peat moss, pumice etc. The farmers/entrepreneurs chose the substrate according to the requirement, by comparing the advantages and disadvantages of each material. Several studies have been conducted regarding the social, economical and environmental impact of each substrates (Rogers, 2017; Savvas et al., 2018; Vinci & Rapa, 2019).

**Nutrient Solution**

In hydroponics, plants are cultivated in highly oxygenated, nutrient-enriched water, which is treated beforehand with the process of reverse osmosis. The nutrient solution can be static, continuously aerated, continuously flowing, or delivered to the plants' root through mist (Jones Jr, 2004). The plant's required nutrients are classified into macro and micronutrients according to their quantity requirements for the plant to grow. Macro nutrients include Carbon (C), Hydrogen (H), Oxygen (O₂), Sulfur (S), Phosphorus (P), Calcium (Ca), Magnesium (Mg), Potassium (K) and Nitrogen (N). The micronutrient includes Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Boron (B), Chlorine (Cl), Cobalt (Co) and Molybdenum (Mo), and they are required in small amounts. Different plants require different combination and quantities of nutrient solutions. The nutrient solution's lifetime is of utmost importance for plant growth and health, and this will depend upon the timely adjustment of pH, electrical conductivity and water level (Velazquez-Gonzalez et al., 2022).

**Chemical properties critical for hydroponic farming**

pH as a chemical property of a nutrient solution that describes weather the solution is acidic or basic. The pH ranges varies for the nutrient solution depending upon the plant species (Othman et al., 2019). Almost all hydroponic plant species grow optimally in a pH range between 5 -7, i.e. slightly acidic (Lu & Shimamura, 2018). The pH keeps getting varied during the harvest period due to the chemical composition of the particles, the ratio of media components in the mix, and irrigation and fertilizer practices (Khan et al., 2021). Extensive studies have been done on finding and managing the
optimum pH value for many plant species. pH value also varies regarding the substrate used for the plant growth.

Electrical conductivity estimates the total concentration of ions in a solution (Velazquez-Gonzalez et al., 2022). Electrical conductivity indicates the salinity of the soil. Salinity can vary according to weather the system is closed or open. In a closed hydroponic system, where the nutrient solution is re-circulated and re-used, there is higher salt accumulation in the growing substrate (Othman et al., 2019). Excessive salinity can increase the solution's electrical conductivity, reducing crop growth and yield. So it is essential to keep the electrical conductivity within a target range because it significantly affects the growth and crop quality (Sonneveld & Voogt, 2009).

**Abiotic factors critical for hydroponics farming**

Light is an essential factor that influences plant growth by affecting photosynthesis, photorespiration and photoperiodism (Khan et al., 2021). Loss of light or providing lights in an indoor space is a significant concern in hydroponics farming. Countries situated above the artic circle have a major loss of light year around, which can lead to the poor growth of plant (Challa & Schapendonk, 1984; Moon & Lee, 1980). It is found out that plants benefit more from lower light intensities, which is distributed uniformly throughout the year (Aikman, 1989).

Temperature plays an essential role in vegetative growth, cluster development, fruit setting, fruit development, fruit ripening and fruit quality (Khan et al., 2021). There are studies in regard to temperature distribution concerning plant growth and quality. Several studies have been conducted in regard to the difference in day and night temperature and their effect on plant yield (Khan et al., 2021; Myster & Moe, 1995; Shimizu, 2007) as well as how a temperature inside a controlled polyhouse or indoor farming is far efficient than open field temperature in terms of shoot length and yield (Ganesan, 2002).

Carbon dioxide concentration is directly proportional to the rate of photosynthesis. In the atmosphere, there are significantly less concentration of CO₂ and providing more CO₂ can increase the rate of photosynthesis until limited by another independent factor (Boretti & Florentine, 2019).

Relative humidity is another abiotic factor that can affect the yield and efficiency of plant growth. The relative humidity is something that can be controlled on an indoor farm. Low ambient humidity can cause limited growth and increased water consumption (Michell & Hoff, 1977), whereas a rise in air humidity stimulates growth (Bunce, 1984).

Having the two major components, the chemical properties and abiotic factors required for the hydroponic system, there are several techniques by which a
hydroponic farm can be designed. Figure 3 shows a simplified version of how a closed hydroponic system works.

![Figure 3: A simplified version of how a closed hydroponic system works. Source: (Velazquez-Gonzalez et al., 2022)](image)

3.2 Halland Region of Sweden

Halland County is a west Swedish coastal county in Götaland. Primarily an agriculture County, Halland faces several challenges in agriculture. Regarding Sweden's national strategy for climate adaptation, some of the prioritized challenges in Halland county include the lack of water supply for agriculture and the negative impact of domestic food production (Edman, 2022). High harvest levels in the previous years have resulted in drought and sequentially decreased yields per hectare in Halland (Swedish Board of Agriculture, 2016). There is a steady decrease in the portion of arable land in the total land use. Halland county has decreased arable land from 114,809 hectares in 2010 to 106,785 hectares by 2020 (SCB, 2022). These challenges faced by Halland county could be addressed and mitigated by the diffusion of hydroponic agriculture. Using optimum water levels and with the method of vertical farming, Hydroponics have the potential to mitigate the environmental concerns of Halland. Halland has an active Food Programme, which is a regional initiative for the National Food Strategy. The major aim of the food programme is to put the food industry of Halland to be forefront
of Sweden and have global recognition (Hallands Län, 2021). The project started in 2016, with Region Halland and the County Administrative Board of Halland in charge of responsibility. The food programme is focused on thematical areas such as Innovation, market, local food and food tourism. Diffusion of Hydroponics in Halland can significantly enhance Halland's food situation in terms of the thematical areas discussed before.

The initial research shows that the hydroponics industry is not diffused in Halland compared to Europe's other food-producing hubs. There is little to no data about hydroponics farming on the official statistics website of Sweden or in Jordbruksverket, the Swedish Board of Agriculture. On the other hand, many parts of the world have witnessed the increased adoption of hydroponics as an industry, urban co-operative farming method, or household farming method. The USA has a thriving hydroponic industry with 1.8% annual growth on average between 2018-2023, with a market size of $807.9 million as of 2023 (IBISWorld, 2023). Japan, one of the pioneers in combining hydroponics with technology, has started the "plant factory with artificial light and/or solar light" project by the Ministry of Agriculture in collaboration with the Ministry of Economy, Trade and Industry (Kozai et al., 2016). Urban agriculture with closed plant factories using hydroponics is an emerging business opportunity in Europe, especially in the Netherlands, Spain, Belgium and Italy. The Netherlands is considered the most advanced country regarding plant factories and protected glasshouse cultivation in the EU (Kozai et al., 2016).

Given that the utilization of hydroponics technology in Halland or all over Sweden is not as widespread as in other regions globally, the aim of this study is to investigate the reasons behind this slow diffusion. Technology innovation system (TIS) is a socio-technical system focused on the development, diffusion and use of particular technology in terms of knowledge, product or both (Bergek et al., 2008). The authors chose TIS because an innovation system is an analytical construct, i.e., a tool to illustrate and understand system dynamics even if the system is non-existent or emerging with very weak interaction between components (Bergek et al., 2008). Thus, this tool fits in the context of Halland, where the presence of hydroponics as a technology is weak and underdeveloped.
4 Method

In this section, the methodology conducted to complete this study will be presented. The research approach will be discussed, followed by the methodological choice, research design, research techniques and procedures, quality of the research, and lastly, the ethical considerations.

4.1 Research Approach

Deductive Approach

According to various different business research literatures, there are two main approaches to conduct business research. These are inductive and deductive approach (Blomkvist & Hallin, 2015; Bryman & Bell, 2015; Saunders et al., 2019). An inductive approach is when a problem is identified, and an empirical study is conducted, and subsequently making use of the theory inorder to develop a better understanding of the findings (Blomkvist & Hallin, 2015). In inductive, a phenomenon is explored and a conceptual framework is generated to understand this phenomena (Saunders et al., 2019). In deductive approach, a hypothesis is formulated based on the theories, and design a study to see whether these hypotheses can be verified or falsified (Blomkvist & Hallin, 2015). In deductive, the research starts with theory, and a research strategy is designed to test this theory (Saunders et al., 2019).

Therefore, this study is using an deductive approach, as the research starts with the theory, i.e. Technological innovation systems, a research strategy is is designed to check the theory, if the hypothesis can be verified or falsified.

The authors are conducting an analysis of hydroponic industry in Halland region by utilizing the Technological innovation systems perspective. Authors are using the existing functional framework from Beregk (2008) to understand the functional weakness in the area. As authors are concerned about the functional weaknesses of the industry in a specific region within the context of national, are also raising concerns regarding the useability of the theory, as the industry’s state of being novel and uncertainty. These concerns have shaped an hypothesis of whether using the analysis could be effect in this context. As theory, authors have gone through the literature and established the premise of the context, to be true with the theory of the Technological Innovation Systems. This is in line with Saunders et al. (2019), that in deductive inference, when the premise is true, the conclusion must be true as well. Currently, the inference drawn is that, despite the absence of prior TIS analysis for a particular region, especially within a nascent industry characterized by uncertainty, the theory shows TIS has the potential to
provide a valuable assessment of the state of this innovation system from a national perspective. By using an existing literature, the above mentioned testable proposition was deduced in order to test the theory. This is in line with Blaikie (2010) who contributed the six sequential steps through which the deductive approach will progress. This will be followed by examining the premises with existing theories, collecting appropriate data to measure the concepts, and analyzing the results, checking whether it is consistent with the premise or not (Blaikie, 2010).

4.2 Qualitative Research

The research methods are differentiated between quantitative and qualitative research. The main difference between the two methods are primarily concerned by the method of data collection and data analysis (Saunders et al., 2019). A quantitative is where the research is describe the general, whereas the qualitative research concentrates on explaining details (Hyde, 2000). Our study employs a qualitative research strategy to explore the functional weakness of the technological innovation systems of hydroponics in Halland county. The main reason for choosing a qualitative research method is as the purpose of the research is to look into individual actors, institutions and networks created in the process. As individual actors need to be analysed differently, the qualitative research is suitable as capturing rich perspectives of individuals or organizations within their contextual setting (Creswell & Creswell, 2018). The empirical problem is to assess the functional weaknesses within the hydroponics industry in Halland County, with the goal of enabling policymakers to implement the requisite policy measures to address these shortcomings. To understand the functional weaknesses, the actors point of view could provide rich and contextual data. This is in line with Bryman and Bell (2015) perspective, qualitative research necessitates researchers to be immersed in the participants environment, closely engaging with it to acquire a contextual understanding. According to Yin (2016), a qualitative research also captures the viewpoints and perspectives of individuals involved in the study, aiming to extract significance from real-life events while overcoming the researchers' own biases or opinions. As such, a qualitative methodology using semi-structured interview during data gathering helped the authors to capture rich information that can help this study to contribute empirically and theoretically.

The following figure and explanation of each steps shows the qualitative research process followed by the authors to achieve the purpose of this study.
Establishing purpose and research question

During the idea generation on what to focus on, the main driver was the authors’ curiosity about hydroponics not being diffused in Sweden, in Halland in particular, where many other countries have adopted it. Further research and through guidance from our supervisor lead us to technological innovation systems (TIS) as a fitting theoretical framework to establish the research. Through analysis of the problem statement and the theoretical frameworks, the purpose of the study was established and the research question finalized, which guided us throughout the research process.

Selecting subjects based on the theoretical framework

Due to the nature of the research, analysing multiple actors, the subjects were carefully selected based on the theoretical framework. As seen in Figure 5, Framework for empirical data gathering, it was identified that five actors needed to be studied to be able to analyse the functional dynamics of the TIS of hydroponics in Halland, namely; 1) government / policy makers, 2)
universities, 3) customers, 4) non-government institutions, and 5) companies. Once the actors were identified, the authors contacted representatives from each segment.

Data collection from semi-structure interviews

Once the target participants were contacted, the interviews were scheduled and conducted. The data collection was done through semi-structure interviews with representatives from each actor segment based on the theoretical framework. The interview questions vary based on the role of the actors’ representation in the TIS framework. The interviews were conducted digitally and recorded with each respondent’s consent. Interview transcriptions were also saved for the credibility of the data and accuracy of data analysis and findings.

Data analysis and interpretation

The data collected from semi-structured interviews in the form of transcriptions transferred into a coding software called QDA Miner Lite. The software made it easy for the authors to group thoughts into the aspects of each functions of the TIS Framework. Once all the data where processed in the software, the coded items were exported into an Excel sheet that became a basis of data analysis and interpretation. For reporting purposes and for the readers’ ease of understanding, tables were created detailing the findings in each functions. It also became easier for the authors to find the connections between the aspects of each functions and write about the findings.

Conclusions and discussions

Based on the findings from the data collected through semi-structure interviews, discussions and conclusions were written. These parts linked the findings from the data gathered to the empirical and theoretical problem at the beginning of the study. Ultimately, the authors were able to offer managerial and theoretical implications in relation to the study conducted. Avenues for further research was also written on the last part of the document.
4.3 Research Design

The research design of this thesis is an in-depth case study. According to Bryman and Bell (2015), a basic case study entails the detailed and intensive analysis of a single case, and can be a single organization, a single location, a person, or a single event. In this study, the case in focus will be the TIS functions of hydroponics in a single location which is the Halland region of Sweden. Stake (1995) noted that case study research is concerned with the complexity and particular nature of the case in question. The case of the functional dynamics of TIS of hydroponics in Halland region of Sweden has a high complexity due to the newness of this innovation in this region. The system involves many actors that need to be studied to be able to understand the functional weaknesses that exist. Furthermore, according to Yin (2009), a case study is an “empirical inquiry that investigates a contemporary phenomenon in depth and within its real-time context, especially when the boundaries between phenomenon and context are not clearly evident” (p. 18). This study conducted an in depth investigation of the current state of hydroponics to identify the functional weaknesses that causes the slow diffusion in Halland.

4.4 Interview as a Research Method

In a participant-observer scenario within qualitative research, interviewing is one of the primary research methods (Yin, 2016). The authors will be using qualitative interviews for data collections from various participants to analyse the functional weakness of the technological innovation systems of hydroponics industry in Halland. The intent of using qualitative interview is that, as it is a useful method that contrary to a formal questionnaire will allow having access to the individual’s attitude and values (Byrne, 2004). This is essential for our study as it is crucial to discern the functional weakness of the innovation system by taking into account the varying values and attitudes of the actors involved. A qualitative interview will be used, as a structured interview doesn’t work with a diverse pool of actors where the functions and networks are different in each cases. This is in line with Yin (2016) as the researcher will have an implicit agenda of study questions and the questions will differ according to the context and setting of each interview. As such, the interview questions vary according to the actors’ role in the TIS framework. As the role of the actors in the TIS framework is very different from each other, the interview questions needed to be adapted each time the category of the actors changes. Through this approach, the authors could capture all the needed data from the respondents, and ultimately examine the case in detail. By personally talking to the participants, the authors were able to fully understand what is the current condition of hydroponics in Halland. The data
gathered provide detailed information for the intended purpose and
oftentimes, further information that can help the study derive an accurate
conclusion.

4.4.1 Interview Questions

To be able to assess the functional dynamics of the TIS of hydroponics in
Halland, the participants where asked questions based on their roles in the
TIS and according to the functions that the authors think are relevant. The
following table shows the interview questions asked to the participants and
the aim for questioning based on the TIS framework.

<table>
<thead>
<tr>
<th>Aim of the questioning</th>
<th>Non-government organization</th>
<th>Government / Policymakers</th>
<th>University</th>
<th>Companies / Entrepreneurs</th>
</tr>
</thead>
<tbody>
<tr>
<td>The role of the actor in the TIS of hydroponics, and their perspective about the technology</td>
<td>What do you think about hydroponics as an industry sector in Halland? In your opinion, what are the challenges in establishing hydroponics in Halland?</td>
<td>What do you think is the role of the kommun in the innovative solutions in agriculture? What do you think about hydroponics here in Halland. Would you consider it as innovative solution in agriculture?</td>
<td>What do you think about the knowledge in this field of agriculture?</td>
<td>What do you think about hydroponics here in Halland. Would you consider it as innovative solution in agriculture?</td>
</tr>
<tr>
<td>Function 1: Knowledge development and diffusion</td>
<td>What do you think about the knowledge in this field of agriculture?</td>
<td>What do you think about the knowledge in this field of agriculture?</td>
<td>What do you think about the knowledge in this field of agriculture?</td>
<td>What do you think about the knowledge in this field of agriculture?</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

32
| Function 2: Influence in the direction of search | How supportive is the government in Halland in terms of agriculture? If the business venture is sustainable, how does the government see this? Is there some support from the government, if so, in what way? | Could there be any rewards or incentives for entrepreneurs to start hydroponics farming in Halland? | Could there be any rewards or incentives for entrepreneurs to start hydroponics farming in Halland? | Have there been any rewards or incentives for entrepreneurs to start hydroponics farming in Halland? |
| Function 3: Entrepreneurial experimentation | Are the entrepreneurs interested in investing into hydroponics here in Halland? | Are there enough entrepreneurs in Halland who are willing to start hydroponics farming business in the region? | Are there enough entrepreneurs in Halland who are willing to start hydroponics farming business in the region? | How is the competition in this business? |
| Function 4: Market formation | If an entrepreneur is to start a hydroponic farming business, is there a market for the produce? | If an entrepreneur is to start a hydroponic farming business, is there a market for the produce? | If an entrepreneur is to start a hydroponic farming business, is there a market for the produce? | Is there a market for the hydroponics produced food? |
| Function 5: Legitimation | What do you think is the society’s perspective towards hydroponics in Halland? Are there regulations that could affect the diffusion of hydroponics in Halland? | What do you think is the society’s perspective towards hydroponics in Halland? Are there regulations that could affect the diffusion of hydroponics in Halland? | What do you think is the society’s perspective towards hydroponics in Halland? Are there regulations that could affect hydroponics business owners in Halland? | What do you think is the society’s perspective towards hydroponics in Halland? Are there regulations that could affect hydroponics business owners in Halland? |
### Table 1: Interview questions towards participants and aim of the questions

Before the interviews were conducted, interviewee’s role in the TIS of hydroponics in Halland has already been identified. The relevant questions to be asked to the participants had to be thought through, to understand the functional dynamics related to the participant, and to ensure that the interview will be valuable for the purpose of the study. Some questions were asked to a certain participant only and not the others. For example, an entrepreneur was asked about the competition within the industry, while the other participants were not asked the same question. By doing this approach, each functions were specifically examined through the participants who represents the actors within the TIS.

The first interview with a representative from a non-government organization was not aligned with the aforementioned guideline because during the time of the interview, the theoretical framework has not be firmly established yet. The main purpose of the interview was to request for inputs on who and where we can find more information about the topic. The authors’ intention was to conduct a snowball sampling which according to Bell, et al (2019), is an approach where a researcher makes initial contact with a small group of people who are relevant to the research topic and then uses these to establish contacts with others.
The other questions included in the questionnaire that do not match the functions within the framework are intended to enquire more information that could be relevant to the topic. It is also the authors’ intention to find some ideas that could be outside of the framework but can potentially lead to new discoveries during the study. As it is a semi-structure interview, some discussion lead to other questions and further discussions that could enrich the data gathering for the study.

4.4.2 Details of interviews

<table>
<thead>
<tr>
<th>Name</th>
<th>Representative From</th>
<th>Date of Interview</th>
<th>Time</th>
<th>Duration</th>
<th>Mode of Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erik-Wilhelm Graef Behm</td>
<td>Invest in Halland</td>
<td>2023-01-24</td>
<td>10.00 – 11.00</td>
<td>60 minutes</td>
<td>Face-to-face</td>
</tr>
<tr>
<td>Marie Mattsson</td>
<td>Halmstad University</td>
<td>2023-02-27</td>
<td>16.00 – 16.50</td>
<td>50 minutes</td>
<td>Via Zoom</td>
</tr>
<tr>
<td>Paul Klinteby</td>
<td>Falkenberg kommun</td>
<td>2023-03-01</td>
<td>13.15 – 14.15</td>
<td>60 minutes</td>
<td>Via Zoom</td>
</tr>
<tr>
<td>David Andersson</td>
<td>Region Halland</td>
<td>2023-03-01</td>
<td>13.15 – 14.15</td>
<td>60 minutes</td>
<td>Via Zoom</td>
</tr>
<tr>
<td>Graham Clark</td>
<td>Greeny Grow AB</td>
<td>2023-03-14</td>
<td>16.30 – 17.30</td>
<td>60 minutes</td>
<td>Via Zoom</td>
</tr>
<tr>
<td>Harrie Rademaekers</td>
<td>FutuFarm AB</td>
<td>2023-03-15</td>
<td>16.00 – 16.40</td>
<td>40 minutes</td>
<td>Via Zoom</td>
</tr>
<tr>
<td>Christer Tilk</td>
<td>Grow Pipes AB</td>
<td>2023-04-25</td>
<td>13.00 – 13.55</td>
<td>55 minutes</td>
<td>Via Zoom</td>
</tr>
<tr>
<td>Elin Windfäll</td>
<td>Lantbrukarnas Riksförbund - LRF</td>
<td>2023-05-05</td>
<td>10.30 – 11.15</td>
<td>45 minutes</td>
<td>Via Zoom</td>
</tr>
</tbody>
</table>

Table 2: Details of the interview

4.4.3 Significance of the interviews

These interviews were important for the study due to the roles they play in the TIS of hydroponics. Each of the interviewees represented a certain area that has a major impact in the components such as network, institutions and actors, and how they affect the functional dynamics of the technological innovation systems. Invest in Halland is an important actor as they could be a contributor to the influence on the direction of search, as well as market formation functions. Halmstad University is an important actor, specifically in the function of knowledge development and diffusion. Falkenberg kommun can be a representation of the other kommuns within the Halland region, and is specifically important in the function of legitimation. Furthermore, Region Halland is also an important actor specifically in the legitimacy of current legislation as well as the development of positive externalities, as it represents the government side of actors. Greeny Grow AB and FutuFarm AB gave insights about all of the functions with first hand experience from entrepreneurs themselves. Additionally, Grow Pipes AB
contributes to all of the functions but is particularly important in the
development of positive externalities. Lastly, Lantbrukarnas Riksförbund is
also a very important actor because they represent a group of hydroponics
farmers, and could give insight on most, if not all functions.

4.4.4 Digital Interviews (Zoom)

To gather data with ease and efficiently, 7 out of 8 interviews were conducted
digitally through the Zoom software. Due to the nature of the interviewees
and the authors being from different cities around Sweden, a recorded digital
meeting is the easiest and most efficient way of conducting the interviews.
After the global pandemic from early 2020 to around the middle of 2022,
people worldwide have become accustomed to meeting at a distance through
the help of technology. Due to people's openness to video calling technologies
nowadays, the authors managed to conduct the interviews as if it was face-to-
face; and were able to collect all the valuable data that would answer the
research question. Through the Zoom software, a meeting can be scheduled
and the software will create a weblink. The weblink will then be shared to the
participants in the interview. By clicking the weblink on the scheduled time
of the interview, participants will be linked to a single window in the
computer where everyone can see each other and talk. The software have a
function to record the meeting and the recording can be saved in the computer
after the meeting is completed.

4.4.5 Consent to record

Before the start of data gathering, the authors decided that the best way to
capture the data accurately is to record the interviews. During all the recorded
interviews, the authors asked the respondents if they agreed to record the
interview. Of all the interviews, all the respondents agreed to record the
meeting. On the first interview with the representative from Invest in Halland,
there was an audio recording through a mobile application that also
transcribes. During the video interviews with other respondents, the videos
were saved, as well as the transcriptions of the interviews.

4.4.6 Transcriptions

During the interviews, a transcription software is also ran so that the authors
can have a transcription right after the meeting. The transcriptions are saved
and used for the coding and the data analysis for this study. This method
helped in the accuracy of data and all the details from the interview being
captured to ensure that important information relevant to the study is not lost.
The transcriptions also helped in the validation of the conclusion, as well as
for better discussions. It became a rich source of information for framing the
analysis, conclusions, and discussions.
4.5 Participants

To accomplish the aim of the study, the sampling of actors that represents different areas of the society that has an impact to the TIS of hydroponics are selected. To be generalized, the data gathering focus on the point of views of government / policymakers, universities, customers, non-government organizations, and companies. As a result of this sample, eight participants were interviewed. Each of the representing organizations are presented in this section.

Figure 5 represents an illustration of desired participants for data gathering for this study.

![Figure 5: Framework for data gathering](image)

4.5.1 Universities

**Halmstad University**

Halmstad University is a university in Halmstad, a city in Halland region of Sweden. The university was established in 1983 and since then, innovation and collaboration with society have characterised the university’s education and research (Halmstad University, 2023). In this paper, the authors interviewed one of professors in Halmstad University in the School of Business, Innovation and Sustainability, Professor Marie Mattsson; to gather
some insights about hydroponics. To gather data, the authors conducted a semi-structured interview for 50 minutes. During the interview, the authors endeavored to cover most aspects of the TIS functions that applies to university as one of the main actors in the TIS framework.

4.5.2. Government/Policy makers

Region Halland

Region Halland is a crucial organization in the TIS of hydroponics due to its role in the region. It is an organization governed by the elected politicians in the regional council and is responsible for health and medical care as well as development and growth in the region (Region Halland, 2023). The interview with the representative from Region Halland was conducted digitally along with another representative from Falkenberg Kommun. The aim of the interview was to gain insights about TIS of hydroponics in Halland region from the government’s perspective. The semi-structured interview was conducted digitally and lasted 65 minutes; was able to achieve the aim of the interview, and the authors gathered data that will help answer the research question.

Falkenberg kommun

Falkenberg Kommun is one of the municipalities in the Halland region of Sweden. Its is located along the coast and E6 highway, north of the capital city Halmstad. A representative from the municipality was interviewed along with the representative from Region Halland. The interview was conducted digitally and lasted 65 minutes. Similar to the interview with the representative from Region Halland, the authors were able to achieve the aim of the interview, and had many insights about the role of the municipality in the diffusion of an innovative technology in agriculture.

4.5.3 Non-government Organizations

Invest in Halland

The first interview conducted for this paper was with a representative from Invest in Halland, a non-profit, regional investment promotion agency located
in Halmstad, and their purpose is to attract international investments to the region and develop Halland as a business destination (Invest in Halland, n.d.). The interview was conducted face-to-face and ran through for about one hour. The authors’ aim for selecting Invest in Halland as the first interview is to gather the respondent’s insight about hydroponics in Halland and, at the same time to seek advice on possible contacts to develop the research topic. The respondent provided valuable input about the current status of the technology in Halland and was also able to connect the authors with two other respondents.

**Lantbrukarnas Riksförbund - LRF**

Another one of the non-government institutions that was interviewed for this thesis the Federations of Swedish Farmers, LRF. LRF is a politically independent business and interest organization for people and companies in the green industries, and they contribute to the development of companies and entrepreneurs based on land, forests, gardens and the rural environment so that they can realize their ambitions for growth, profitability and attractiveness (LRF, 2023). The interview ran for 45 minutes and was conducted digitally. The interview aims to gather information on the perspective of an association of Swedish farmers to understand the current situation in the agriculture sector on a national level as well as to know farmers’ perspectives about hydroponics as another way of food production.

**4.5.4. Companies**

**Greeny Grow**

Greeny Grow is an indoor hydroponic farm founded by Graham Clark and his wife, Pia Clark, aiming to deliver high-quality, locally produced products grown without soil (Greeny Grow AB, n.d.). The company is located in Frillesås, in the municipality of Kungsbacka, the northernmost part of Halland county, and directly produces in the greenhouse and delivers to the customers. During the identification of actors within the TIS of hydroponics, Greeny Grow AB was found to be a company that would best fit to have an insight from the perspective of companies and entrepreneurs. The semi-structure interview was conducted digitally and lasted 57 minutes. As summary, the interview provided valuable primary data for the authors to evaluate the condition of the hydroponics technology in Halland in many aspects.
**FutuFarm**

FutuFarm is a hydroponics solution provider in Halmstad, the capital of Halland region. The company develop solutions for urban farming in the Nordic region through modern food technology and smart solutions, and they do this by working together with food tech partners, Freight Farms as well as actors in agriculture, cultivation expertise, business, community building, academia, and public sector (FutuFarm, n.d.). The authors interviewed the owner of FutuFarm through digital means, which lasted about 40 minutes. The primary data gathered provided a different perspective on the entrepreneur/company segment. The business model of FutuFarm and different from Greeny Grow, but nevertheless an important actor in the diffusion of hydroponics in Halland. The authors were able to see from a multiple perspective because FutuFarm serves as an entrepreneur, as well as part of external economies.

**Grow Pipes**

The authors also interviewed an equipment supplier company to understand the innovation system perspective around hydroponics. Grow Pipes is a company the produces pipes for vertical growing hydroponics solutions. Their product GROWPIPES is a patented, highly space-efficient, economically sustainable, and user-friendly vertical hydroponic system focusing on building farms requiring minimal water use for efficient cultivation (GROWPIPES, 2023). The interview was conducted digitally and ran for about an hour. The aim of the interview is to know about the development of external economies around the hydroponics innovation system.

**4.6 Data Analysis**

During the interviews, a transcription software is also ran so that the authors can have a transcription right after the meeting. The transcriptions are saved and used for the coding and the data analysis for this study. This method helped in the accuracy of data and all the details from the interview being captured to ensure that important information relevant to the study is not lost. The transcriptions also helped in the validation of the conclusion, as well as for better discussions. It became a rich source of information for framing the analysis, conclusions, and discussions.

According to Bell, et al (2019), computer assisted qualitative data analysis software, or CAQDAS allows the analyst to code text while working at the
computer and to retrieve the coded text; and its emergence is one of the most notable developments in qualitative research. For this study, data analysis was conducted using QDA Miner Lite which is designed to manage and analyze unstructured textual data from interviews. Since the data for this thesis was gathered through semi-structured interviews, this software fits the data analysis of the thesis.

The transcript of the semi-structured interviews was uploaded in QDA Miner Lite, and after reading and rereading, a coding frame was established. The coding frame was created in regard to the functions of the TIS framework, as explained in the article Bergek et. al. (2008), which consists of seven categories. Each category represents a function of the TIS framework, with several codes that identified with the concepts of that particular function. The codes are modified from the article Bergek et. al (2008) in regard to the theme of the thesis. First, different types of knowledge can be distinguished between design, market, scientific, and technological knowledge; and between different sources such as R&D. Second, the function of influenced in the direction of search is a combined strength of belief in growth potential, change landscape, growth in other countries, and incentives and/or pressure to enter. Third, to be able to assess if there is a vibrant experimentation, the number of new entrants and diversification and breadth of technologies used and the character of the complementary technologies employed needs to be assessed. On the market formation function, the phase of the market whether it be nursing, bridging, or mature, should be assessed, as well as identifying who are the users of the technological innovation. In the function of legitimation can be analyzed by assessing the legitimacy among the society and current legislation. Furthermore, the function of resource mobilization can be assessed by understanding the the volume of human resources, capital, seed and venture capital, and complementary assets. Lastly, the extent of the development of positive externalities can be assessed through the entry of new firms, emergence of labour market, information flows, and the emergence of specialized intermediate goods and services.

The coding frame is given the following table:
<table>
<thead>
<tr>
<th>Category</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge Development and Diffusion</td>
<td>Design knowledge</td>
</tr>
<tr>
<td></td>
<td>Market knowledge</td>
</tr>
<tr>
<td></td>
<td>Knowledge between different sources i.e. R&amp;D</td>
</tr>
<tr>
<td></td>
<td>Scientific knowledge</td>
</tr>
<tr>
<td></td>
<td>Technological knowledge</td>
</tr>
<tr>
<td>Influence in the Direction of Search</td>
<td>Beliefs in growth potential</td>
</tr>
<tr>
<td></td>
<td>Change in landscape</td>
</tr>
<tr>
<td></td>
<td>Growth in other countries</td>
</tr>
<tr>
<td></td>
<td>Incentives and/or pressure to enter</td>
</tr>
<tr>
<td>Entrepreneurial Experimentation</td>
<td>Breadth of technologies used and the character of the complementary technologies employed</td>
</tr>
<tr>
<td></td>
<td>Number of new entrants and diversification</td>
</tr>
<tr>
<td>Market Formation</td>
<td>Identifying users</td>
</tr>
<tr>
<td></td>
<td>The phase of the market</td>
</tr>
<tr>
<td>Legitimation</td>
<td>Legitimacy among the society</td>
</tr>
<tr>
<td></td>
<td>Legitimacy in current legislation</td>
</tr>
<tr>
<td>Resource Mobilization</td>
<td>Volume and quality of human resources</td>
</tr>
</tbody>
</table>
### Table 2: Coding structure

Table 2: Coding structure

It is to be noted however that the adaptation of codes from Bergek, et al (2008) is modified based on the topic and the data gathered. There are other factors suggested in the article that affects the functions, but are not related to this study.

Ultimately, the reason for the coding structure is to have a more specific description within each function and so that the authors can better categorize the primary data gathered through semi-structure interview. It is also a way of clarifying the intended meaning of each function for ease of analyzing the data. These codes are also crucial in drawing conclusions for this study.

### 4.7 Quality of Research

According to Bryman and Bell (2015), in order to ensure quality of research in qualitative studies, it is important to build trustworthiness through such criteria as credibility, transferability, dependability and confirmability.

#### 4.7.1 Credibility

Credibility parallels to internal validity and pertains to the extent to which the research findings are reliable, indicating weather the researchers have arrived at accurate conclusions (Bryman & Bell, 2015). An extensive time was spent on reading upon the technology of hydroponics inorder to understand and justify its effect on future food production. An extensive systematic literature
review was conducted to find the areas where the TIS framework was used, and how the framework had provided the results in such cases. Moreover, a desk research was done to see the amount of hydroponics companies in Sweden, and the installation of hydroponics technology in different settings around Sweden. This has made the interview discussions more significant and substantial. This includes a better understanding of the importance of each answers and follow up those answers with more probing questions (Saunders et al., 2019). The individuals selected as interviewees hold significant credibility, including government and non-governmental officials, founders of different companies and representative from academia.

4.7.2 Transferability

Transferability parallels external validity and refers to the extent to which the research findings are generalizable across other settings and contexts (Bryman & Bell, 2015). Qualitative studies are usually employed in small groups or specific settings. Therefore an ample size of data was provided about the topic in order to allow the reader to consider the case in different context. The thesis was started with the idea in mind that the comparison of the condition of hydroponic technology in Halland county with other pioneering locations in the field. The framework of TIS can be used to analyse the same with other location and the state of the technology in it. The analysis and data findings will be presented in a comprehensive manner to enhance the reader’s ability to apply the study to a different scenario. This aligns with Nowell et. al (2017) which asks for providing thick descriptions, so that those who seeks to transfer the findings to their own site can judge transferability.

4.7.3 Dependability

Dependability parallels reliability and refers to the extent to which the research can be reproduced or replicated, resulting in a similar outcome (Bryman & Bell, 2015). In order to determine the dependability of research, the work if repeated, in the same context, with the same methods and with the same participants, similar results would be obtained (Shenton, 2004). This was achieved in this thesis by transparency. Transparency was upheld through the diligent recording of all actions taken and providing a clear and detailed description of the research process, procedures, and steps. This was accomplished by maintaining a well-documented chain of evidence in data collection and organizing working documents systematically throughout the data analysis process. This aligns with Shenton (2004), inorder to address the dependability issue more directly, the processes within the study should be
reported in detail, thereby enabling a future researcher to repeat the work, if not necessarily to gain the same results.

4.7.4 Confirmability

Confirmability parallels objectivity and assures that the findings of the study are based not on the researcher’s characteristics and preferences of the researcher, but on the results of the experiences and ideas of the informants (Shenton, 2004). A detailed methodological description on the data gathering process was given to enable the reader to determine how far the data and constructs emerging from it may be accepted, as suggested in Shenton (2004). It is vital to avoid personal beliefs or biases that could impact the research’s performance and therefore the researchers in this study endeavored to maintain objectivity by thoroughly describing the methodology steps, thematic analysis, coding procedures, and the resulting findings.

4.8 Ethical Consideration

To uphold research ethics, prior to recording the conversations, explicit consent was sought from all interviewees. Follow up email was sent to every respondents to ask permission to use their name and description in the thesis. In data analysis, exact quote from the respondents were used to make sure that the quotes where not misused, and in some cases the contexts of the quotes were explained, so that they were not misinterpreted. In order to avoid the issue of lack of informed consent, adequate information about the thesis was provided to the interviewees, regarding research topic, research purpose and questions, the interview process, the use of data, and why the participant is needed in this study. Equipped with this information, the participants were able to make an informed choice regarding their participation in the research.
5 Findings based on data

In this chapter, the findings from data gathered through the semi-structured interviews are discussed. Each function of the TIS framework is correlated with the participants’ responses during the interviews organized in an Excel sheet. A summary of findings is presented at the end of the chapter along with an illustration for ease of identification.

5.1 Data results on knowledge development and diffusion

“there’s always need for more knowledge and continued contact between the farmers and universities for innovation” - LRF

The global knowledge pertaining to hydroponic techniques, design, and product advancements is significant, and this trend has made its way into Halland, contributing to the knowledge development in the TIS.

FutuFarm’s business model imported the whole system from the US in a container and deliver it the system to the customers with technical knowledge and expertise as well as support in monitoring the farm through a cloud server. As its founder stated that:

"The whole farm is made in the US, and delivered here in Sweden. Everybody asks us, why don’t you build your own system? Well, not necessarily. You don’t have to reinvent the wheel. That’s a great system. Let’s bring it over here and it’s much faster".

The founder of Grow Pipes while talking about how he started in the field stated that:

“We wanted to study vertical farming and we started vertical farming for six months. And then we went on renting a small place in Gothenburg. And then we started to do like a pilot scale production. And we started to import different kinds of hydroponic systems available on the market in those days, many of them were American. Many of them came with high price tags.”

While knowledge development on a global scale is noteworthy in the global level, it has not diffused significantly within the TIS in Halland. This knowledge development is typically articulated through research projects and various collaborative programs, often involving partnerships with universities and diverse initiatives. There was a general agreement between the interviewees that there is a lack of knowledge that can be accessed within the country.

The representative from LRF stated that:

"The Swedish greenhouse growers don’t rely on the knowledge of universities in Sweden, they go to the big science fairs in Europe or the USA and hire counselors from Europe."

The founder of GrowPipes stated that:

"There’s a university in Hamburg with a lot of students building systems with our pipes, but (with) their framing, ...and then we exchanged some idea so
they come with some ideas that sometimes are good ideas. So yes, I like it very much the way of exchanging ideas to move ahead."

The general collaborative programs for the actors of TIS is mainly from outside the country. The geographical location of Sweden being closer to the countries where hydroponics is more developed, such as Netherlands and Spain could also be the reason for this knowledge sharing and collaboration with universities and other institutions within Europe.

But there are also several occasions where actors the authors interviewed has contacted and collaborated with several universities and with each other in Sweden and within Halland. LRF sites that the majority of the collaboration happens with the Sveriges lantbruksuniversitet (SLU), the Agriculture University of Sweden. GrowPipes also stated the following about collaboration with a university in Halland:

"Three years ago, there was a program at Halmstad University where there were students who wanted to do a setup and proposing a design. I was in the middle of negotiating and looking at the proper design. It was an interesting concept, but it was a lot longer. So, I supported Halmstad University in that sense. I was there for meetings and their graduation. But then we have come so far with our prototype so I took that route instead."

Among the participants, the knowledge development within Halland arises from the trial-and-error experiences of the local entrepreneurs themselves. In all of the three participants who are entrepreneurs in the field of hydroponics, only Greeny Grow is the one who is doing hydroponics as a core business function. As stated by the founder of Greeny Grow:

"I think we need more knowledge because the entrepreneurs that have started, a lot of it is trial and error. I know from talking to (some other entrepreneur in the field) they've gone through a few issues. They build their own system. A lot of that was really due to the fact that the building they were is was old carpentry building. So they produce their own bespoke system. And as you know yourself, if you build something you're not sure that it's going to work, and you always want to make it better. (for example), yeah, that's one of the problems or we can change this and change that. And before you know where you are, you spent several million kronor."

The founder of Greeny Grow elaborated on how he himself was doing trial and error on his operations and further stated that:

"We fitted in Grow Pipes and we bought the microgreens system from a company called Instant Green. The focus at that time was to make things as simple as possible. So we laugh as much as possible because there's a lot of experimentation. In order to get the fertilizer right to get the lights right, to get the test right. And we think we've got the test right on to solid dates. We still need to get a crisp solid that gives us a good taste and has a good shelf life. We're looking at all kinds of things at the moment."

The founder of GrowPipes is in agreement to this as he stated:

"I got to know a person in South Africa who had been doing hydroponics cultivation for more than 50 years and he was representing a system in those days. And we imported a number of these sections made them to a number of
towers, and it was much better than we had previously experienced with any other system. (there) was still some problems. They were not molded in one piece. You had to glue them together. Yes, there were some leakage problems, but still it was much better than we previously experienced. So then the weeks after receiving them and seeing that this is nice, this is neat."

The significant disadvantage of trials and errors is that it is resource intensive in terms of time and capital. As the representative from Falkenberg kommun stated:

“you can do a lot of trial and error this but it's sort of capital intensive. We have this case now for looking at a company asking for funds, just to scale to where they would need to be. And finally, its a lot of money, you need to sell quite a lot of lettuce. If you consider the margins you wind up with so much farm land and the greenhouses.”

In summary, the global influence of design and product knowledge, has spurred the initiation of hydroponics in Halland. However, there is a deficiency in this regard, as the diffusion of knowledge is limited, and university collaborations, both in Sweden and particularly in Halland, are not as robust as those conducted with external partners. The primary source of internal knowledge development largely relies on the trial-and-error methods employed by local entrepreneurs, although this approach may demand significant time and capital investment.

5.2 Data results on influence in the direction of search

“Food, good food. This got to be a problem in the Future. Maybe we can get involved in that. Somehow. To look at the future of food” – Futufarm on starting the company.

According to Bergek (2019), influence of the search refers to mechanisms that influence in what direction firms and other actors look for new opportunities and to what problems and solutions they apply their resources. Actors start to explore new opportunities or technologies and diversify into new fields because of crises in their current industries or markets. In this context, the growing concern of climate change and food security has given the influence in search for new opportunities and technologies.

One of main agreements between the actors interviewed for this study is that there is a significant belief in a new technology like hydroponics due to the changing landscape in food production. A representative from Region Halland stated that:

"Overall hydroponic system have the potential to address some of the challenges facing traditional agriculture, such as land and water scarcity. So that is what we wanted to explore. How can you get a better output if you can have the same neutral desert and they can get a better output from hydroponics system than a greenhouse for instance or an open air farm?"

The founder of FutuFarm strongly stressed the importance of the future of food production and stated that:
“I met an old friend and he said, well, we should probably do something with food, good food. This got to be a problem in the future. Maybe we can get involved in that, somehow. To look at the future of food. What is probably going to happen? And then during this period when we were sort of brainstorming this on what to can get involved with, I got an email from a friend in Los Angeles who sent me a short video clip of a guy walking into a container where you're able to grow lettuce, salad, herbs, things like that.”

The founder of FutuFarm expressed his concerned about the future of food supply in Sweden, as currently a large portion of the food supply are imported from other countries such as Spain. He stated that:

"also there will come a day, not right now but a couple of years when Spain will say, hey, we cannot send you any more ship, we need (them) ourselves."

In addition to the above primary data, our secondary research found a similar result. For example, RI.SE (n.d.), the Research Institute of Sweden stated that:

“Sweden is dependent on imports to cover the population’s food needs. The provision of food constitutes a complex system in which the availability of food can be rapidly affected when something unforeseen happens.”

Due to the belief of this potential food crisis in the future, many companies in Halland have been influenced by the growth in other countries. This has prompted entrepreneurs in Halland to be influenced by these developments and embark on establishing and growing industries in the region.

The founder of FutuFarm stated that:

"The company in the US that we are working mostly with this is called Freight Farms. They construct containers where you can very easily start a farm. Now we are supporting companies, selling systems, instantly installing systems, helping them build their business plan."

This means that due to the abundance of technical knowledge in the US, some entrepreneurs in Halland such as the founder of FutuFarm was able to buy the technology and process.

Furthermore, the founder of Greeny Grow stated that:

“I first came across hydroponics in the 1980s when I was in Saudi Arabia. We grew wheat on roads, grass under irrigation. Everything came from a center irrigation system. And the soil was terrible. It was basically sand. It (hydroponics) worked brilliantly. We were getting 10 tonnes to the hectare of wheat. It was fantastic. So I’ve kept my eye on it.”

This shows that entrepreneurs first gain knowledge from other countries where either hydroponics has already been diffused or there is a lot of technical knowledge available.

To support this companies, the government and other institution are providing incentives. This is in accordance to the Beregek (2008)’s viewpoint that there must be sufficient incentives for the organizations to be induced in the industry. According to the founder of Grow Pipes:
"We have a green loan, so that's a nice support that we have. ...through the European community they have the possibility to lend out under their umbrella, which needs to be for companies working in the green technology sector. Then I had to take a course in the US which was interesting and fun. And then the interest rate is lower.”

The support from the government was confirmed by the representative from Invest in Halland and stated that:

“We have several (examples of support from the government). First of all, the Swedish government together with our organization could give soft loans and invest in companies. This is specifically for sustainable business, as long as it's not illegal or inappropriate.”

However, the pressure to enter the industry is considerably high and can hinder other entrepreneurs from entering the industry.

As an example, a representative from Halmstad University stated that:

"And also the price. Can they sell these locally grown vegetables from the hydroponic system? I mean, to the same price as the imported vegetables. So then there's a factor about the price competition with imported products that could be much, much cheaper or something.”

However, there are pressures to enter the industry in Halland, one of which is related to regulatory concerns, as exemplified by the statements of the founder of greeny grow:

"Regulation is definitely one of them (challenges in the industry). We are classed as a greenhouse which sees us get the the worst possible classification and all their classifications in terms of risk until the EU wakes up to the fact that indoor farming is going to be part of the future. It's not the total answer and it never will be but it's part of the future.”

The representative from Halmstad University concerned about the price competition between locally developed hydroponic produce and the imported goods.

“there’s a factor about the price competition with imported products that could be much, much cheaper or something”

The concern of competing with the imported food price can cause new players not to enter the industry. Furthermore, as the respondent from LRF mentioned,

“one of the problems is that you need to find one segment, either you need to be as big as so you can compete with Netherlands or Spain or Morocco, or to be small and specialized where you have your own shop and do everything your own. It is very very difficult to survive in the middle segment.”

To summarize the function of influence in the direction of search, the data shows that there is significant belief in hydroponics due to the changing landscape in food production, particularly due to the concern of future of food supply in Halland and in Sweden in general. As a result of this belief, many entrepreneurs have been influenced by the growth of hydroponics from other countries. For example, some entrepreneurs were inspired by the potential of
the technology in other countries, while others opt to buy the process and equipments. To support the entrepreneurs in their endeavours, the government and other institutions are providing incentives in the form of green loans. Nonetheless, there are two notable weaknesses in the aspect of influence regarding the direction of search. First, it pertains to government regulation. The hydroponics industry is not officially classified separately from traditional greenhouses, and the incentives they receive are grouped under the broader category of green loans, available for various eco-friendly practices. The absence of official recognition of hydroponics as a distinct industry by the Swedish government is apparent. Second, there is the issue of price competition, with questions arising about the ability of locally produced hydroponics to compete with significant imports from other countries.

5.3 Data results on entrepreneurial experimentation

“Now apart from the pipes, we are looking at framing, cost-effective framing” – GrowPipes

A positive enthusiasm was seen among the companies where, as new entrants actively taking part in the process of experimentation. Grow Pipes mentions they are in a continuous development are currently in their first prototype and have plans for making additional changes for it. Grow Pipes also thinks about diversifying as they are going to focus on whole framing of the facility along with their product and act as the whole hydroponic system installers in the future.

Greeny Grow on the other hand, had issues with packaging and how it affected the shelf life. They are currently testing between various packaging methods to find which one will have more shelflife, marketing and visually appealing. Many established firms around Sweden are trying to diversify their products. IKEA store in Malmo started growing greens for their Bistro and restaurant in hydroponics system as a way to produce sustainable salad (Ingka, 2021). This was later adopted in various IKEA stores around the world. The example for diversification in Halland is the ICA store in Halmstad University. ICA has installed a hydroponics system to provide fresh vegetables and herbs with the help of FutuFarm, one of this thesis’s interviewee.

“There is a lot of jute in India and Bangladesh, and this.. is made of Jute” – GrowPipes

In regard to the breadth of technologies used, there were many positive feedbacks from the interviewees. Grow Pipes are experimenting with complementary technologies such as using Jute as the alternative for plastics. FutuFarm, who has installed farms in various countries, monitors and adjust parameters for optimum production quality from Halland. FutuFarm has installed camera in one of the farms in Cyprus, and receives live feed 24/7. Greeny Grow uses the hydroponic systems developed by the GrowPipes, the supplier actor in our interviewee list. The horticulture specialist from LRF, the farmers association of Sweden, confirmed the interest of entrepreneurial experimentation by stating that
“our producers always like technology. If we do some trip (field trip) or something, everyone wants to look at whatever technology we can find”.

A lot of entrepreneurial experimentations within the industry is through trials and error experimentations with new technologies, applications, and strategies by the entrepreneurs themselves. In relation to this study, it has been found that there is a significant degree of uncertainty being experienced by the entrepreneurs. In terms of reducing uncertainty through trial and error, the founder of Greeny Grow was struggling with packaging the could lead to the best shelf life and stated:

“We sold our living solid (lettuce) in paper bags which were coated. We buy them from a company that produces them in Germany and the solid socks inside the paper bag. They look fantastic. Yeah, they look brilliant. We put a plastic condom over the roots of plastic with an elastic band and we injected water into the condom bag. But we're only getting about five days shelf life. Times isn't enough. And a lot of the supermarkets didn't particularly like it. So one supermarket asked us to check out clam shells which are very common in America. So we started to look at clam shells and today we sell 50% clam shells, 50% paper bags.”

As previously discussed in the context of knowledge development, the trial-and-error approach can be both time-consuming and capital-intensive. The founder of Greeny Grow elaborated by stating that:

“And as you know yourself, if you build something you're not sure that it's going to work, and you always want to make it better. ...or we can change this and change that. And before you know where you are, you spent several million kronor.”

Another findings related to the function of entrepreneurial experimentation based on the primary data collected is that there is lack of complementary technologies within Halland region. For example, the founder of Greeny Grow is using Grow Pipes which is located in Gothenburg because the technology that he needed for his system is not produced in Halland.

“We use the Swedish system called Grow Pipes produced in Gothenburg area and they cobbled together a bit like Lego and they were quite well for us in this facility. So we have four frames with a total of 2312 positions for solid. We will put in our homemade NTF system. As soon as we get the reorganization and things moved around completed.”

Furthermore, in the perspective of another entrepreneur, the founder of FutuFarm, eventhough some of the technologies or required materials are produced in Halland, some are produced in other cities.

“And we also apart from doing all the technical stuff, we also sell grow plugs which are the products that you grow your plant your seeds. And we produce nutrients for the plants. So we produce that in Halland, and other microbes, we produce in Stockholm.”

The absence of required technology and or equipment’s needed for hydroponics increases the uncertainty the entrepreneurs face. This demands that the entrepreneurs seek the technologies in other parts of Sweden or in other countries.
Lastly, and possibly the one that would be the hardest challenge to overcome is the limited number of new entrants in the hydroponics industry in Halland. Earlier in this study, we noted that Halland is primarily an agriculture region in Sweden. A representative from Halmstad University, when asked about comparison between traditional farmers and entrepreneurs who might be interested in hydroponics stated that:

“I think it's not easy to compare. I mean, if you're interested in farming if you're interested in being a farmer, I think it's very different from starting a company in hydroponics, because of course, it's good if you have some knowledge about what kind of crops are suitable and what kind of light do they need, what kind of nutrients do they need, but still, it's an entrepreneurial thing to start up something like this. To put together a system that could work. And it's very different from being a traditional farmer. So it would be hard to compare in terms of intrapreneurial interest with traditional farming and hydroponic farming. I think it's two very different things. Of course there are farmers that are very innovative and they find new solutions to things. But I don't think it's a natural thing for a farmer to start growing crops hydroponically.”

This suggests that conventional farmers, despite having the necessary space and resources to embark on a hydroponics venture, may be hesitant to enter the hydroponics industry, even when they are already engaged in the same domain, which is food production.

In summary, the data results reveal that three main factors significantly influence this function. The first factor is the high level of uncertainty experienced by entrepreneurs. This uncertainty stems from a lack of readily available knowledge, forcing entrepreneurs to rely on trial and error, ultimately straining their resources. The second factor is the absence of complementary technologies within the region. Finally, the third factor is the limited number of new entrants in the industry. Notably, the first factor, which is the uncertainty among entrepreneurs due to knowledge limitations, and the second factor, the absence of contemporary technologies within Halland, collectively contribute to the third factor: the restricted influx of new entrants into the industry.

### 5.4 Data results on market formation

“And for hydroponics. This is a small area. I think that counts. Small and young” – InvestinHalland

In the TIS framework, market formation is described as typically passing through the steps from a nursing over a bridging to a mass market (Jacobsson and Bergek, 2004). This function is an important part of the framework because it analyses the market to which the industry is currently positioned. During the primary data gathering, there is a general agreement within the respondents about the phase of the market as well as identified users for the hydroponics industry.
Nursing phase is the very early phase of the market formation (Bergek, et al, 2008). The first interview during primary data gathering alluded to this finding as the representative from Invest in Halland stated the hydroponics industry in Halland is small and young. The founder of Greeney agrees to this and stated:

“As far as I know, it is in many ways in its infancy. I don’t think there are many larger commercial operations in Halland.”

And finally, the founder of FutuFarm also supported this and stated:

“...its not big at all. Just a few activators. I can tell you why its not there. When we started, we were very early. We were a little bit emotional about it. But this type of food disruption I would say has to be driven by entrepreneurs. But eventually, it is the big players who has to commit.”

In many ways, the Hydroponics industry is in its infancy in Halland. The nursing phases (Bergek, et al, 2008) of the hydroponic industry was a general understanding among all the interviewees. Graham from Greeny Grows noted that other than FutuFarm, there is no information for him of other players in the hydroponics industry in Halland. According to the LRF horticulture division representative, Helsingborg in Skane has many distribution channels and haulage companies, making it a perfect place for any horticulture and greenhouse companies to be operated from and near Helsingborg. Ninety percent of Sweden’s food supply passes through the Helsingborg region, and Helsingborg is considered Sweden's food logistics 39 hub (Helsingborgs Hamn, 2022). Skane had 187 greenhouses by 2017, compared to 46 in Halland (SCB, 2017). This gives the pressure for market formation development in Halland compared to Skane. Harrie from FutuFarm agrees that:

“95% of all fruit and Greens we import to Sweden comes to one harbour. Okay, lands in one place. It's in Helsingborg.”

This factor may be a contributing reason for the stagnant development of Halland's market, as the nearby and easily accessible region of Helsingborg offers a more favorable environment for establishing a robust hydroponics industrial hub.

Another findings about this function is the identified users for hydroponics industry. Based on the primary data collected, there is a significant market for produce from hydroponics. Both companies agrees (Greeny Grow & FutuFarm) agree that their market is targeted at people looking for healthy, sustainable, diversified food solutions. Graham of Greeny Grow states that:

“Our lettuce isn’t dead. It’s alive. Every lettuce we sale is alive. You take it home, you take off the plastic condom, you set it in a glass or a cup of water and it keeps growing”.

ICA Maxi Halmstad, who has installed a hydroponic container by FutuFarm, claims that they offer healthier, crisper, and fresher store-grown crops, which is sustainable (ICA, 2019). Graham shared an incident where a supermarket displayed their product differently to focus the sustainability quality, giving them more sales even when the price was charged more.

The representative from Halmstad University who is an environmental advocate stated:
“I think we are ready to buy, since there are obvious advantage with this. I mean, I would rather buy salad from hydroponic system in Halland, compared to salad that comes from maybe far away from south of Spain of wherever. Because it’s more sustainable with a locally grown vegetable in a hydroponic system compared to to these vegetables that has been transported from a very long distance.”

The founder of FutuFarm echoed the same and said:

“Its now starting to pay off all the work we’ve done. So now we see a lot of interest.”

Finally, the founder of Greeney Grow also thinks the same about the market for hydroponically produced food and said:

“if we look at the microgreens we produce see there are 1600 restaurants in Gothenburg more than 700 in Malmö and we're not counting the bit in between. So you know, that's 2300 restaurants and most restaurants today use microgreens.”

Overall, this function is highlighted by two factors, namely the phase of the market and the identified users. Based on the primary data gathered, it can be determined that the phase of the market is in the nursing phase which is a very early phase. There is also Helsingborg, with its established food logistics infrastructure, holds a distinct advantage over Halland County in its potential to become a hub for the hydroponics industry. Furthermore, in terms of identified users, the data shows that there is significant interest in the public for hydroponically produced food.

5.5 Data results on legitimation

“future food in Halland shall be the Blue Technologies. Let's see. It should be tech that used in the food industry, food tech and new proteins” - InvestinHalland

For the function of legitimation, the authors analyzed the data gathered by separating the responses between the legitimacy among the society and legitimacy in the current legislation as adapted from Bergek, et al (2008). According to Markard, et al (2016), legitimacy is crucial for firms, industries, and technologies to emerge, expand and survive because it is the basis of securing resource flows and maintaining support.

There was a higher legitimacy within the relevant institutions on the future of food in Halland, and general understanding on working towards them. David and Paul too agrees to that and they are working on an ecosystem for innovative new technologies in the field of agriculture in Halland. Legitimacy can be linked in many concepts related to innovation such as sustainability. For example, when talking about social acceptance of hydroponics produce, Marie Mattsson from Halmstad University stated that:
“we are aware of the climate impact from long distance transport of food stuff, and also we are maybe a little bit suspicious about how things are grown.”

Furthermore, Marie Mattsson also stated that

“I would rather buy 40 hydroponically produced salad rather than the one from far away like Spain”.

It is worth noting that Marie Mattsson is a professor in the School of Business, Innovation and Sustainability, and have published papers about circular economy, greenhouse gas emissions, and biogas production among others (Halmstad University, 2023). Greeny Grow founder interacts with customers on a regular basis and stated that customers are buying and that he gets a positive feedback from customers as well as the media.

There was also a heterogenous opinion between the interviewees about hydroponics. The representative from Region Halland and Falkenberg kommun feels strongly about how the food are grown in the natural environment and have concerns about the nutrient content of the hydroponically produced food. Moreover, hydroponics may not be seen as one of the best ways to contribute to tackling environmental challenges as indicated during the interview with the representative from Falkenberg kommun.

“I wouldn't say lettuce or hydroponics or herbs is the lowest hanging fruit from saving the climate. But it's one piece of the puzzle.”

Some people in the society feels strongly about how things are naturally grown. David Andersson from Region Halland stated that:

“Regenerative farming soil-based systems yields better products because they let the plant be a plant. They let the plant become one with its ecosystem that has evolved for billions of years... Whereas (in) hydroponics, you dip its toes in the water and pours in a basically an industrial cocktail of chemicals”

Additionally, the founder of Greeny Grow stated that one of the the challenges they have in Halland is to overcome the resistance of traditional farmers, who sees hydroponics as hocus pocus.

“biggest challenges we have in Halland is to overcome the resistance of traditional farmers”

In terms of legitimacy in current legislation, there are three conditions that affects the legitimation function of the TIS, as was learned from the interviews. The first one is the difficulty in having certified as ecological for hydroponically produced food. As stated by FutuFarm founder, anything that does not grow in Earth is cannot be labeled ecologically. This can have a negative impact on the customer perception because some people might prefer to buy ecological food.

“regulations is definitely one of the challenges because we’re classified as a greenhouse by the Ministry of Agriculture, which sees us get the worst possible classification.” – Greeny Grow

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Graham believes that hydroponic indoor farming needs their own classification and regulation, as a greenhouse can include indoor farming with soil. Greeny Grow follows strict hygiene requirements and grows plant in a sterilised non-soil, highly controlled growing environment. This shows the requirement of a new classification for hydroponic farming. This was further cemented by the fact that, the LRF horticulture representative asked the authors “what do you mean with hydroponics?” in order to understand how the current term is used in the context of horticulture, as the authors explain, the LRF representative confirmed that “yes, that is what we have in the greenhouses nowadays. I mean, all the greenhouses in Sweden, i mean, almost all of them, the big ones, cucumber and tomato are grown in that system.”

So the authors understand that hydroponics farming in general is called and categorized under greenhouse farming, and this can be a disadvantage and a part of lesser legitimacy from the current legislation. This classification completely disagrees with greeny grows and futufarm, who are specialized in indoor farming, and rather than having sunlight, they rely on modern artificial lights and can be used all year long.

Based on the above analysis, it is found that even with the varied societal opinions about hydroponics, there is significant strength in this area of legitimization within the public. The debate about whether hydroponically grown produce is healthy or not continues to weigh on the minds of certain representatives. Nevertheless, there are significant shortcomings in the legitimacy of current legislation, primarily stemming from the inability to comprehend modern hydroponics as a technological innovation. It remains categorized under traditional greenhouse farming, which does not accurately represent its unique characteristics.

5.6 Data results on resource mobilization

“the big issue we have is finding finance. We finance everything ourselves.” – Greeny Grow

There are several examples of companies receiving funds and supports from various organizations like Vinnova and Almi. FutuFarm and Grow Pipes has had grants from Vinnova. Vinnova is the Swedish innovation agency, and their mission is to strengthen Sweden’s innovative capacity and contribute to sustainable growth (Vinnova, 2023). Moreover, Grow Pipes and Greeny Grow has also had green loans from Almi, which is Sweden’s most active developer (Almi, n.d).

"(there was) good support from Almi, ...for innovation that we had because everything in terms of solid production hangs from the roof, we design special frame so we can slide them closer or further apart. But I don't have the cash to pay for the equipment first and then claim the money back." – Greeny Grow.

However, there is a general agreement between the interviewees about the challenge in financial resources. The challenges surrounding financial resources can affect the function entrepreneurial experimentation as was mentioned by the representative from Falkenberg kommun, who says that
“one can do a lot of trial and error, but it is also capital intensive”. He also pointed out about the amount of initial investment in terms of equipment’s, nutrients, electricity, etc., to be able to put up a hydroponics operations; and at the end, the grower would sell something that people are expecting to be cheap. The founder of Greeny Grow echoed a similar opinion who stated that the big issue they have is finding finance, and said that once they have enough financial resources to scale up, they will change from the manual system they currently have to an automated system. For most of the interviews, the companies and LRF all stated that there are available funding for companies working in green technologies. However, this seems to be happening only during start up phase. Once the companies have established and ready to scale up, it is then become challenging in the financial aspects.

Companies also agreed that there is a lack of European Union level funding, and outside seed or venture capitals. Producing in hydroponics system can be capital intensive and it is a major challenge for the growers that they have to compete in price with bigger players with better economies of scale. This is possibly the reason why as a representative from LRF concluded that:

“It's very, very difficult to survive in the middle segment. So you play the real big companies or you need to go very small and very specific.”

The companies and organizations were generally satisfied with the current status of human resources in Halland. During the interviews, it was learned that there are some strengths particularly in the aspect of human resources. The founder of Grow Pipes was able to quickly develop the solution due mainly to the skills and dedication of the people he is working with, from the design and improvement, to manufacturing.

“we obviously (have) the right people, because there is every plastic detail. There's a lot of work. There's a lot of knowledge on top. So I'm happy that I'm working with the right people.”

FutuFarms agrees that there are several technical knowledge people that can work in the industry, stating themselves as technical providers.

In terms of complementary assets, there seems to be some available resources in Halland and in Sweden in general. However, the majority of the resources are still coming from abroad, particularly in countries where the industry is much wider. Greeny Grow gets the seeds from Poland and Spain, and the growing medium from Dutch manufacturers. FutuFarm produces the nutrient solution in Halland. Grow Pipes, had their layout, design, and production of their food graded plastic pipes for the hydroponic system was done in Molndal. LRF had a different perspective in complimentary asset, where she compared the purity of water resources in Sweden to be better than in Holland (Netherlands) and a question to be asked ourselves, that “how can we make better use of this?”

Based on the aforementioned analysis of the gathered data, it is evident that while there are certain strengths within this function, there are also notable weaknesses that have an impact on the entire Technology and Innovation System (TIS) in Halland. The aspect of financial resource mobilization presents an interesting dynamic where companies can secure initial funding
as start-ups. However, obtaining funds for diversification poses challenges. Moreover, external funding sources such as the EU or other venture and seed funds have not provided substantial financial support. On a more positive note, there is a favorable assessment of the current human resources and the acquisition of complementary assets, even if they originate from outside Halland or Sweden.

5.7 Data results on development of positive externalities

“this sounds very interesting because we're used to doing a number of different plastic for doors and so on, but we'd like to do a good plastic, something that would change the world” – GrowPipes about the plastic company that designed and constructed their product

The development of positive externalities is possibly one of the indications that a technological innovation has diffused to a certain country or region. According to Musiolik and Markard (2011), positive externalities in innovation systems are conceptualized as side effects of an accumulation of actors and ‘critical mass’, and an emergence of specific labour markets, dedicated service providers or knowledge spill-overs is explained by an enlargement of the actor base or co-location effects.

For a TIS to be able to flourish, a growth in the industry is necessary, which means that other entrepreneurs will have to enter the industry either directly or indirectly. For example, one of the interviewees for this thesis is a supplier of a specialised equipment that will enable to increase the efficiency of the technology. Grow Pipes designed and patented specialized growing pipes that would increase the yield, and decrease leakage during the growing time. They've partnered with a manufacturer specializing in plastic doors to create a customized hydroponic pipe, and it's proving to be highly effective. With Grow Pipes' technology knowledge, interested entrepreneurs might be encouraged to enter the industry. As a new entrant, Grow Pipes may have resolved at least one of the initial uncertainties with respect to technologies (Bergek, et al, 2008). Established firms in Halland such as FutuFarm and Greeny Grow too had contributed to the knowledge development as they contribute to new business model innovations, marketing and design knowledge. Eric from InvestInHalland affirms that the Hydroponics knowledge flow is in the learning phase:

"We are very active in agriculture and food. But we are still learning. So we might not have the right ideas and theories and methods yet. We're in a learning phase.”

It is also observed that there is a scarcity of new entrants at the present moment. During the interview with the founder of Grow Pipes, it was mentioned that there had been no inquiries from other companies in Halland, apart from Greeny Grow, which is also a participant in this study. The limited number of new entrants creates challenges for companies aiming to achieve their full potential.

"(I)have not receive any other inquiries from any other (companies) in Halland.” – Greeny Grow.
New entrants in hydroponics TIS can act like a domino effect towards a positive direction. As such, it will affect other functions within the TIS. By resolving at least some of the uncertainties in respect to technologies and markets, they can strengthen the functions' influence on the direction of search and market formation; they can also legitimate the new TIS, and strengthen the political power of advocacy coalitions (Bergek, et al, 2008). This may not be the case yet, when putting Halland in context. When asked if Grow Pipes is getting a lot of interest from Halland, the answer was that he did not receive any other enquiries from other entrepreneurs in Halland other than that of Greeny Grow, the other interviewed actor in this thesis. However, according to LRF, they have 400 members growing in hydroponics system, most of which are around Helsingborg. When asked why most growers are are around Helsingborg, LRF answered

“because it’s close to the distribution..., and some historical reason that they started”.

As previously mentioned, Helsingborg already boasts a strong foundation in food logistics, which could be influencing the development of the hydroponics industry in Halland.

The aspects of emergence of labour market seems to have a conflicting opinion within the participants. The representative of the LRF said that:

“Do you think that there are enough resources here in Sweden, in terms of human resources, the equipment's the technology that they need, here? No, no there's not and that's the reason why they go abroad for all of these things.”

In contrast, FutuFarm and InvestInHalland express a strong confidence in the labour force available in Sweden and specifically in Halland. FutuFarm stated that:

“in Halmstad, or in general in Sweden, we have a lot of technical technical people from Asia to electricians to and a lot of stuff”.

However, it is important to note that LRF talk about the proficiency in plant physiology and horticulture, while the other participants are focused on the technological aspects of knowledge.

Regarding the rise of specialized intermediate goods and services, Grow Pipes, one of the participants in this study, falls within this category. They are producing specialized products designed for use in hydroponic systems. Greeny Grow incorporates Grow Pipes' products in their facility. Greeny Grow states that:

"They circulate fertilizer infused water around the solid production systems. And we use the Swedish system called Grow Pipes produced in Gothenburg area and they cobbled together a bit like Lego and they were quite well for us in this facility."

However, it remains that there are still limited number of firms that could form a network and strengthen the TIS of hydroponics in Halland. Additionally, another strength of the aspect of emergency of specialized intermediate good and services is that universities are in continuous search for new innovations that could complement hydroponics. The representative
from LRF stated that they regularly receive requests from universities to let them demonstrate new technologies to the growers.

"I got an email from two former students, who asked me, Okay, we have a drone, big drone that are used to spread out the biological pesticides, you know that there's small microorganisms and they can spread it with this drone. So can we please come in and show this to growers?"

In summary, the development of positive externalities is closely tied to the overall growth of various functions. However, due to significant weaknesses in these functions, the progress in developing positive externalities remains stagnant. The exchange of information from foreign sources is at a moderate level, primarily driven by knowledge development and dissemination activities. In the local context, the Technological Innovation System (TIS) is still in its early stages, which means that the information flow is in a continuous learning phase.

One notable challenge is the absence of new entrants that could stimulate the overall growth of positive externalities. When it comes to the labor market, companies express confidence in finding technologically proficient workers in Sweden and Halland. However, for specialists in plant physiology and nutrient management, there remains a reliance on foreign talent.

The initial production of specialized goods and intermediates takes the form of Growpipes, which supply the necessary pipes for hydroponic farming. Moreover, through collaborations with Greeny Grows and FutuFarm, Growpipes has contributed to initial knowledge in areas such as business models, product development, marketing, and design.

6. Summary of Findings

<table>
<thead>
<tr>
<th>Functions</th>
<th>Summary</th>
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<tr>
<td>Knowledge Development and Diffusion</td>
<td>• The global knowledge pertaining hydroponics has penetrated to Halland, helping for the initial setup, but there is a lack of knowledge that can be accessed within the country.</td>
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<td></td>
<td>• Major knowledge development within Halland relies on trial-and-error method. This demands significant time and capital investment.</td>
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| Influence in the Direction of Search | • Strong societal and governmental faith in the future of food drives greater participation in hydroponics.  
• The expansion of hydroponics in foreign nations motivates entrepreneurs to initiate ventures in Halland.  
• Government-backed green loans and a supportive attitude toward startups also steer the search in this direction.  
• Conflating hydroponics with greenhouse farming, rather than recognizing it as a distinct agricultural form, may considered as a pressure to enter the market. |
|---|---|
| Entrepreneurial Experimentation | • High level of uncertainty experienced by entrepreneurs, due to the lack of readily available knowledge, often resorting to trial-and-error experiments to overcome it.  
• The unavailability of complementary technologies in the region compounds the challenges.  
• The combined effect of these factors results in a limited number of new entrants into the market. |
| Market Formation | • The market is currently in its infancy stage.  
• Helsingborg, renowned as a food logistics hub, enjoys a distinct advantage in fostering further growth in hydroponic farming.  
• When it comes to identifying potential users, there is a significant demand for locally grown, sustainable produce. |
| Legitimation | • There is a mixed response when it comes to the quality of the product. To address this, increased awareness and deeper studies are necessary to inform society about whether hydroponically grown products offer superior quality.  
• Current legislation's inability to provide a distinct classification for modern hydroponics farming, instead grouping it within the broader category of greenhouse farming. |
| Resource Mobilization | • Initial funding is secured through green loans or startup assistance, but acquiring additional funds for further investments or diversification proves to be challenging.  
|                       | • Scarcity of venture or seed funds, and a notable absence of EU funding  
|                       | • Favourable perception on human resource mobilization.  
|                       | • A positive perspective on the acquisition of complementary assets, largely sourced from within the EU.  |

| Development of Positive Externalities | • Overall, the development of positive externalities is hampered by deficiencies in various other functions.  
|                                     | • While information flows effectively from foreign sources, internal knowledge sharing is notably limited.  
|                                     | • In the labour market, there is a substantial pool of technology skills within Sweden and Halland. However, when it comes to expertise in nutrient management or plant physiology, both the labour pool and information flow primarily originate from other countries.  
|                                     | • Growpipes has played a crucial role by providing specialized goods and intermediaries for the initial stages of hydroponics farming. However, apart from Growpipes, there is a noticeable deficiency in this area.  |

Table 4: Summary of Findings

7. Discussions

The purpose of this thesis is to understand the functional weakness of hydroponics industry’s technological innovation systems (TIS) in the Halland of Sweden based on the article by Bergek, et al (2008). The authors used a deductive research approach, having a case study on the Halland county in Sweden.

The research question of the thesis is “What are the functional weaknesses of hydroponics industry’s technological innovation systems (TIS) in the Halland of Sweden?”
The authors have delved into the components of TIS which includes actors, networks and institutions; and the functions that includes knowledge development and diffusion, influence on the direction of search, entrepreneurial experimentation, market formation, legitimation, resource mobilization, and development of positive externalities (Carlsson, et al, 2002; Bergek, et al, 2008). In this study, the authors concentrated on functional dynamics to gain insight into the weaknesses within the system.

In the Halland region, the Technological Innovation System (TIS) for hydroponics technology is currently in its infancy. The establishment of modern farming using hydroponics technology marks its initial phase, yet progress appears to be stagnant. Nevertheless, there are notable efforts aimed at disseminating the technology throughout Halland. Along with the efforts, the challenges faced by such initiatives were also recognized.

Knowledge development and the flow of information emerged as one of the primary challenges blocking the further diffusion of hydroponics technology in Halland. The issue of insufficient local knowledge in Sweden or Halland featured prominently as a key obstacle across several functions. Majority of the knowledge comes from outside the country. While there is a substantial pool of global technological and plant physiology knowledge, the knowledge development within the country is stagnant. Collaborations between universities in the field of hydroponics are relatively few, with the primary partnership established with the Swedish University of Agricultural Sciences (SLU). The SLU is actively engaged in urban horticulture programs, wherein they employ controlled farming techniques incorporating hydroponics technology (Sveriges Lantbruksuniversitet, 2021). The research by the entrepreneurs are mostly of trial-and-error methods. As this is a capital and time incentive method, this has implications in various functions of the TIS. This situation contributes to a heightened level of uncertainty among entrepreneurs, undermining the function of entrepreneurial experimentation by hampering the influx of new entrants and curtails the development of positive externalities, effectively limiting the entry of new firms into the field.

The growing concerns of food security and future of food have a significant impact on the current legislation and in the society. The Swedish government has implemented diverse food programs and designates Halland county as a region facing prioritized challenges related to the negative effects of domestic food production (Edman, 2022). This significantly influences the direction of the search. As a result, it has prompted initial incentives from various stakeholders, including initial funding in the form of green loans or startup loans from organizations like Vinnova and Almi. Despite the availability of initial funding, securing financing for further diversification proves to be a challenge. Moreover, there is a notable absence of widespread venture capital funding from domestic sources and a scarcity of general EU funding. This weakness has a detrimental impact on numerous functions, including knowledge development, resource mobilization, and the development of positive externalities. The constraint on available funds hampers further research within the country and diminishes opportunities for diversification. Moreover, this exerts a negative influence on the incentive to enter the market.
As previously discussed, the current legislation and societal norms offer increased legitimacy to locally produced sustainable food. However, regarding societal perspectives, the interviewees hold mixed opinions on the sustainability and quality of produce grown through hydroponic technology. The representative from Halmstad University, an accomplished expert in agriculture and a professor of environmental science, endorses the quality and sustainability of food production using hydroponic techniques. This viewpoint finds support among other industry professionals experienced in hydroponics technology. Conversely, the representatives from Falkenberg Kommun hold a differing stance on hydroponically grown foods, expressing skepticism about their nutritional quality compared to conventional farming methods. Such reservations may be shared by many, highlighting the need for additional research and awareness in Halland to address concerns about the nutritional quality of hydroponically cultivated produce.

Despite government support for future food and sustainable growth, there is a lack of recognition for hydroponics technology as a distinct form of agricultural practice. Hydroponics currently lacks a clear categorization and is often grouped under greenhouse farming, which can lead to confusion, as traditional greenhouse farming may still rely on soil-based cultivation. It is essential to classify hydroponics as a separate and distinct farming technology, especially considering its use of modern technologies like Artificial Intelligence, Big Data Analysis, and the Internet of Things. This reclassification could differentiate hydroponics from traditional agriculture, potentially creating a unique market for this innovative farming method.

Regarding the available resources, both companies and government representatives express a high level of confidence in the technological expertise of the labor force in Sweden and Halland. However, the LRF representative raised a distinct concern about the availability of human resources, specifically in the areas of nutrient management and plant physiology. This issue is attributed to the broader challenge of knowledge development, as many specialized horticultural skills require seeking consultants and collaborations from outside the country.

Regarding other physical resources and complementary assets, while there may be shortages within Sweden or Halland, many essential supplies such as seeds and nutrient solutions are sourced from within the EU. The efficient transportation and logistics networks within EU member countries mitigate this as a significant weakness. This attribute can also be linked to knowledge development, as there is a smoother exchange of knowledge within the EU countries.

Hydroponic technology is still in its early stages in Halland, and two significant challenges impede its market growth in the region. The primary challenge is price competition. Imported produce from other EU countries often comes at significantly lower prices than sustainably and locally produced hydroponic goods. To address this, companies can differentiate themselves within their market segments, innovate their marketing strategies, and identify the right target customers for their produce. The second major challenge is the industrial area of Helsingborg. Helsingborg, a port city in Skåne geographically close to the Halland region, serves as a major entry
point for imported food. Approximately 90% of food supplies pass through the Helsingborg region, establishing it as a vital food logistics hub. This logistical advantage could incentivize entrepreneurs to establish their companies there rather than in Halland, due to the strategic location facilitating access to a broader market.

8. Conclusions

In this thesis, the authors conducted an evaluation of the functional weaknesses within the technological innovation systems (TIS) of the hydroponics industry in Halland, Sweden. The aim of this assessment is to provide valuable insights for policymakers to address barriers and facilitate the widespread adoption of this technology in the region.

Hydroponics technology is still in its infancy in Halland, and the existing weaknesses in its functions are hindering its progress and preventing it from advancing. Entrepreneurs are confronted with a significant degree of uncertainty. All of the functions exhibit weaknesses, and these weaknesses are interconnected, perpetuating one another. The lack of knowledge development available within the country or Halland, limited legitimization of hydroponics as a distinct category, challenges in accessing loans and support beyond the initial stages, price competition with imported food products, and the scarcity of EU funding and venture capital, all collectively create barriers for new firms and entrants seeking to enter the market. Helsingborg, located in close proximity to Halland, offers more favorable conditions for market formation.

On a positive note, Sweden's membership in the EU has allowed a significant advantage, ensuring a smooth flow of information and resources. The freedom of movement within the Schengen countries has enabled access to valuable information through university collaborations, interaction with specialists, and other channels. Furthermore, this has simplified the acquisition of complementary assets and resources from various EU countries, fostering an environment of collaboration and resource sharing. Leveraging these advantages, in conjunction with addressing the functional weaknesses, could drive the further diffusion of hydroponics technology in Halland.

8.1 Managerial Implications

The thesis uncovers the functional weaknesses within the technological innovation system (TIS) of hydroponics technology in the Halland region. Its objective is to provide policymakers with insights into the identified weaknesses across the key functions of the TIS, allowing them to address these issues effectively. Collaborative efforts with universities in Sweden and Halland can be enhanced by placing a greater emphasis on research and development concerning the future of food. Notably, Halmstad University in Halland is involved in a research project focusing on Business Development in Green Industries, encompassing two programs, namely "Future Agriculture" and "Green Innovation." (Högskolan i Halmstad, 2021).
Initiatives like these have the potential to significantly contribute to knowledge development in the field of future food, and subsequently towards hydroponics technology.

A county with a rich agricultural history, recently Halland has seen notable growth in IT and other technological industries. In recognition of its achievements, Halland was named the Export Region of the Year in 2021, highlighting its efforts to create optimal conditions for local companies to expand into international markets through collaborative efforts with regional agencies. (Region Halland, 2021). Several regional agencies offer potential benefits for future food research and marketing collaborations. Organizations such as Envolve Earth, InvestinHalland, Hallands Matgille, and Hushållningssällskapet are among the agencies with which entrepreneurs and policymakers can engage to make a meaningful impact in advancing hydroponics technology (Invest in Halland, n.d.).

8.2 Theoretical implications

Analyzing a technological innovation system (TIS) in its infant stage, such as hydroponics technology in Halland, presented considerable challenges. With a limited number of actors and numerous undefined networks, creating a comprehensive overview was a demanding task. Additionally, due to the small number of actors, close interactions and collaborations were common among them. When analyzing various TIS, differences arise in how the functions are defined, operationalized, and how individual functions are measured (Bergek, 2019). Some of the observations made during the analysis of this thesis are as follows:

In diffusion oriented TIS analyses, knowledge development is often focused on adaptation of technologies from other countries (Agbemabiese et al., 2012; Blum et al., 2015; Edsand, 2017). This is in line and similar to the case study of Halland, where since the technology is in infant stage, most of the knowledge development is focused on adaptation of technologies from other countries like the USA and prominent hydroponics players from the EU. Since the knowledge development within the country is limited, entrepreneurs resort processes of uncertainty reduction through trial-and-error experimentation with new technologies, design new business models and strategies. This is in line with Rosenberg (1976), where “all technological problems cannot be solved through formal R&D, but some have to be worked out through real-world experiments at different scale.” However, by employing the trial-and-error approach within the Halland case study, authors found that this method consumes both time and capital, ultimately resulting in heightened levels of uncertainty.

Concerning resource mobilization, as indicated by Bergek (2019), most TISs rely on financial resources primarily derived from public funding sources, both at the national and international levels. Typically, these funds are allocated for long durations (Andersson et al., 2017). However, in the case of Halland, public funds for adoption are provided in the form of low-interest loans and credits, but they come with shorter terms due to the current legislation's lack of legitimization. This also results in limited EU funding for
the hydroponics technology in Halland. Nevertheless, the provision of low-interest loans and credits for adoption and startup purposes aligns with the practices observed in other TISs in the adoption stage (Blum et al., 2015; Gebreeyesus & Sonobe, 2012; Gosens & Lu, 2014).

According to Bergek (2019), legitimization can be of two interpretations. The first one being legitimation of the focal technology, and the second one is legitimation of the industry supplying the focal technology. In the case of hydroponics, the hydroponics technology has been in used for centuries around the globe, and still used in many horticulture farming in Halland. This legitimacy is questioned as the new problem of future food and food security arises, where there is a need of maximum output from minimum settings. This is where the hydroponics technology combined with new modern technology (IoT, AI and big data analysis) comes into the picture. This calls for a new interpretation of legitimation, where an existing working technology is metamorphized into a new form of focal technology, which redefines the industry.

Defining the development of positive externalities presented the most significant challenge in the case study. Given the early stage of the TIS, positive externalities are typically yet to emerge, and there is limited evidence regarding the mechanisms driving this particular function (Bergek, 2019). The scarcity of data, owing to the early stage of the case study, introduced confusion in effectively defining most of the functions. Functions such as market formation and the development of positive externalities proved challenging in describing and identifying weaknesses. Bergek (2019) addresses the issue of how examining the role of experimental learning affects uncertainty. In the Halland case study, it has seen that due to the lack of additional funding after the initial stage, the experimental learning has compounded for more uncertainty.

In conclusion, significant weaknesses could be identified using the TIS analysis, and even there was ambiguity in defining weaknesses into particular functions. This stands that the theory of TIS proved to be true for a budding industry in a regional setting, where the actor-network functions are not quite developed. Due to the budding nature of the industry, there was trouble distinguishing weaknesses in the functions such as market formation, and development of positive externalities. This might calls for a different analysis system for a budding industry with little to no actor-network interactions. This is in line with the suggestion of Bergek (2019), where the author calls for a distinction between innovation systems and diffusion systems.

8.3 Future Research

The area of research was limited to Halland region of Sweden due to the time constraints as a masters thesis. There is a future scope of analyzing the diffusion of hydroponics technology in the national level, i.e. Sweden. This study has a particular focus on the small segment of hydroponics companies because there is no larger companies in Halland. It would be valuable to conduct future studies with the larger hydroponics companies in other parts of Sweden. There is also a scope of researching the future of food production in indoor plant factories, especially in Scandinavian countries where the
availability of sunlight is limited all year. This research haven’t considered the sustainability factor of hydroponics. There is future scope of conducting research in the sustainability factor of hydroponics.

In regard to the theory of Technological Innovation System (TIS), there is great ambiguity while analysing a budding industry in a localized area. Future research could explore the possibility of establishing a distinct diffusion system for analysis and focus on achieving greater clarity in defining the development of positive externalities for an infant industry.
References


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Appendices

Appendix 1

Semi Structured Interview Questions

Representative from Invest in Halland

1. What is the mechanism of Invest in Halland? How is the relationship with the government? Also, how do you collect data, and how do you provide assistance to new business ventures.
2. How supportive is the government in Halland in terms of agriculture?
3. If the business venture is sustainable, how does the government sees this? Is there some support from the government, if so, in what way?
4. What do you think about hydroponics as an industry sector in Halland? Are the entrepreneurs interested in investing into hydroponics here in Halland?
5. In your opinion, what are the challenges in establishing hydroponics in Halland?
6. Is there any association we can talk to, to find out more? Anyone from the government?
7. Can you provide list of hydroponic companies that we can get in touch with here in Halland?

Representative from Halmstad University

1. Please tell us about your field of expertise and about your project with Halmstad University.
2. What do you think are the challenges in the agriculture in Halland?
3. What do you think is the role of the university in the innovative solutions in agriculture
4. What do you think about hydroponics here in Halland. Would you consider it as innovative solution in agriculture?
5. What do you think are the collaborations required for hydroponics to be successful in Halland? Do you know someone we can talk to, to know more about this topic?
6. What do you think about the knowledge in this field of agriculture?
7. Could there be any rewards or incentives for entrepreneurs to start hydroponics farming in Halland?
8. Are there enough entrepreneurs in Halland who are willing to start hydroponics farming business in the region?
9. If an entrepreneur is to start a hydroponic farming business, is there a market for the produce?
10. What do you think is the society’s perspective towards hydroponics in Halland?
11. Are there regulations that could affect the diffusion of hydroponics in Halland?
12. Is there funding from the government or other organizations in Halland for hydroponics farming.
13. Are there available resources around Halland for hydroponics farming? For example, technical resources, supply of equipment, human resources.

Representative from Falkenberg Kommun and Region Halland (respondents preferred to be interviewed together)

1. Please tell us about your field of expertise and about your current projects in agriculture
2. What do you think are the challenges in the agriculture in Halland?
3. What do you think is the role of the kommun in the innovative solutions in agriculture?
4. What do you think about hydroponics here in Halland. Would you consider it as innovative solution in agriculture?
5. What do you think are the collaborations required for hydroponics to be successful in Halland? Do you know someone we can talk to, to know more about this topic?
6. What do you think about the knowledge in this field of agriculture?
7. Could there be any rewards or incentives for entrepreneurs to start hydroponics farming in Halland?
8. Are there enough entrepreneurs in Halland who are willing to start hydroponics farming business in the region?
9. If an entrepreneur is to start a hydroponic farming business, is there a market for the produce?
10. What do you think is the society’s perspective towards hydroponics in Halland?
11. Are there regulations that could affect the diffusion of hydroponics in Halland?
12. Is there funding from the government or other organizations in Halland for hydroponics farming.
13. Are there available resources around Halland for hydroponics farming? For example, technical resources, supply of equipment, human resources.
**Greeny Grow and Futu Farm (interviewed separately)**

1. What do you think are the challenges in the agriculture in Halland?
2. What do you think about hydroponics here in Halland. Would you consider it as innovative solution in agriculture?
3. What are the challenges you are facing in this business?
4. What do you think are the collaborations required for hydroponics to be successful in Halland? What are the value chains, who are the actors?
5. What do you think about the knowledge in this field of agriculture?
6. Have there been any rewards or incentives for entrepreneurs to start hydroponics farming in Halland?
7. Is there a market for the hydroponics produced food?
8. How is the competition in this business?
9. What do you think is the society’s perspective towards hydroponics in Halland?
10. Are there regulations that could affect hydroponics business owners in Halland?
11. Is there funding from the government or other organizations in Halland for hydroponics farming.
12. Are there available resources around Halland for hydroponics farming? For example, technical resources, supply of equipment, human resources. Where and how do you buy equipments, nutrients, seeds, etc.

**Grow Pipes**

1. Can you tell us about the company and the products.
2. What is the inspiration to start this company
3. How do you develop your products? Do you collaborate with other companies from other region in Sweden or countries, or do you collaborate with universities, etc.
4. Who are your target customers? Do you have a considerable amount of customers, and from which regions
5. What do you think about hydroponics in Halland.
6. Do you have many customers from Halland?
7. Is there a tax implications for your customers who are from other regions?
8. Do you think that new innovations such as Grow Pipes encourage new entrepreneurs to enter into the business of hydroponics?
9. How do you sell your products to the companies, how do these companies find you?
10. Do you get funding from any government or non-government institutions?
LRF

1. Can you tell us about the LRF’s core functions.
2. Please tell us about current projects that you are involved with the members of LRF.
3. What do you think are the challenges in the agriculture in Sweden?
4. Are there any innovative solutions in agriculture that are introduced to the members of LRF? If so, where are those innovations coming from?
5. What do you think is the role of a farmers’ association such as LRF, in the innovative solutions in agriculture?
6. What do you think about hydroponics? Would you consider it as innovative solution in agriculture?
7. What do you think are the collaborations required for hydroponics to be successful in Sweden?
8. What do you think about the knowledge in this field of agriculture? Do you think there are enough knowledge currently?
9. Within LRF, do you know of some members who are currently interested in starting a hydroponics farming business.
10. If an entrepreneur is to start a hydroponic farming business, do you think that there is a market for their produce?
11. What do you think is the society’s perspective towards hydroponics in Sweden?
12. Do you know of any regulations that could affect the diffusion of hydroponics in Sweden?
13. Do you know if there is any funding from the government or other organizations to support potential or current hydroponics farmers.
14. Are there available resources in Sweden for hydroponics farming? For example, technical resources, supply of equipment, human resources.