The transition towards sustainable food systems

– A study on the development of aquaponics and its market penetration in Sweden

Aleksej Tarasenka

Swedish University of Agricultural Sciences, SLU
Department of Molecular Sciences
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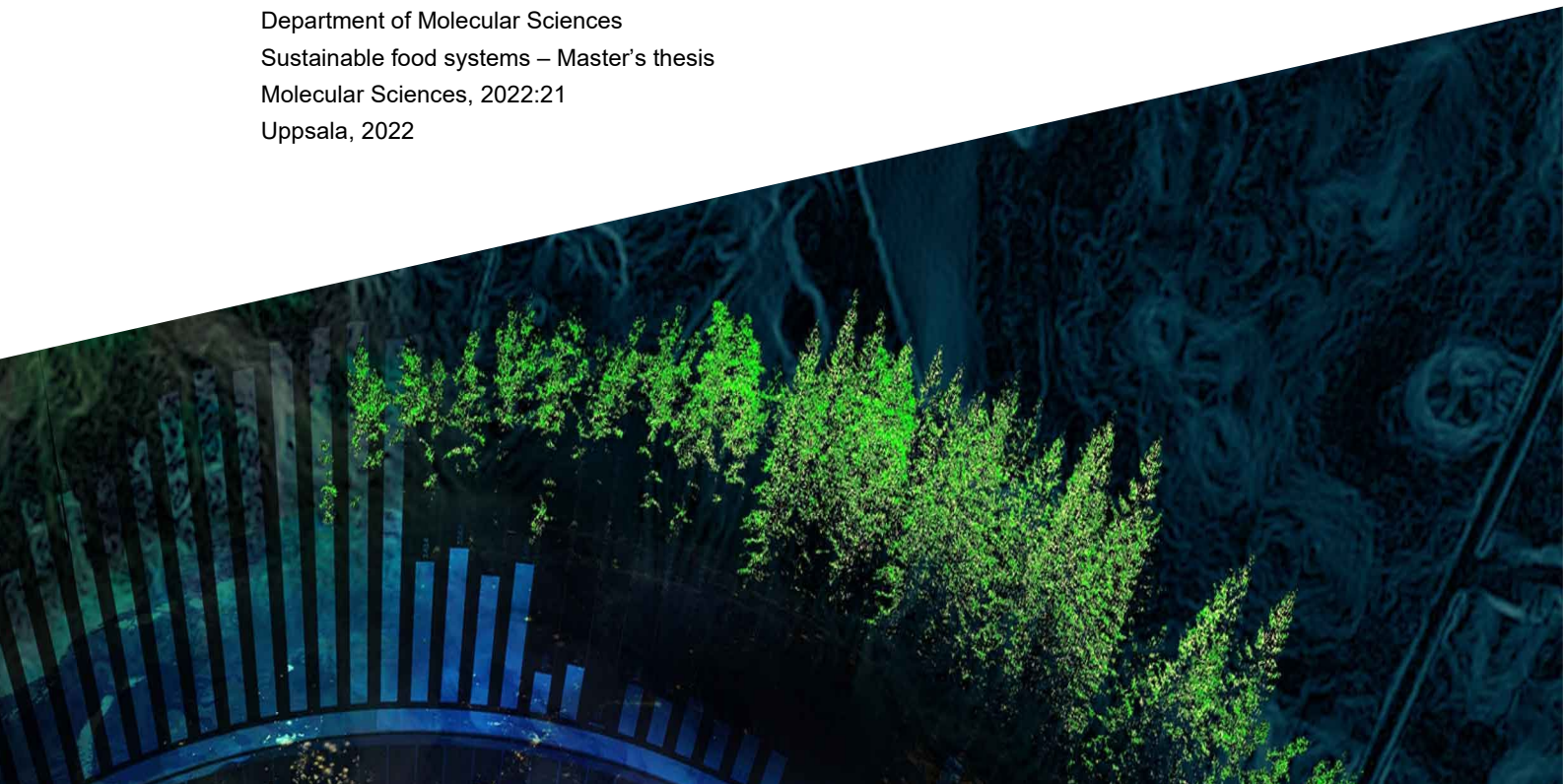

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Aleksej Tarasenka

Supervisor:	**Sara Spendrup, SLU, People and Society**
Assistant supervisor:	Sammar Khalli, SLU, Biosystem och teknologi
Examiner:	Fredrik Fernqvist, SLU, People and Society

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Swedish University of Agricultural Sciences
Department of Molecular Sciences

Abstract

A food system includes many processes and actors that interact at different levels to maintain human` access to food. As the need for the food increases due to population growth, the activities associated with obtaining the food led to pressure on the environment. Climate change, nitrogen and phosphorus flows, ocean acidification, biodiversity loss, and extinction of species are directly related to the agri-food system. Therefore, transforming food production in line with the principles of the SDGs is a major challenge for all of humanity. Aquaponics (AP) is an innovative method of food production that offers sustainability solutions and therefore may be an option for the agri-food transformation. The aim of this thesis was to understand the opportunities and barriers for AP development in Sweden and how AP may penetrate the mainstream market. A qualitative study was conducted with representatives of the Swedish agri-food system where the data was collected through semi-structured interviews and analyzed throw the theoretical lens of the multi-level perspective (MLP) and the concept of protective space. Results showed that there are possibilities as well as blocking mechanisms for the development of AP in Sweden concerning conventional fish and vegetable production. To leave the innovation space and integrate into the market, it is necessary to transform the regime by stretching the legislation and changing the norms and routine for the AP integrated system. Since the AP product fits the norms of the market and the consumers food culture, its further distribution depends on enlightenment and marketing strategies.

Keywords: *sustainability transition, transformation, MLP, protective space, niche-regime interaction, hydroponics, RAS*

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Abbreviations

AP	Aquaponics
HP	Hydroponics
RAS	Recirculating Aquaculture Systems
MLP	Multi-level perspective
LCA	Life Cycle Assessment

1. Introduction

The food has always been a central aspect in human activities on the planet. During the last century the technological breakthrough has allowed to produce an incredible amount of food with the help of fertilizers, genetic engineering, pesticides, and fuel-powered machinery.
However, the consequences of technological success in food production, as well as the development of international food trade, have made it clear that the production and consumption of food can be a part of socio-ecological instability (Fisher et al. 2016; Garnett et al. 2018). Food production and related to its activities put pressure on the planet's biosphere and lead to climate change, biodiversity loss and extinction of species, water pollution, land-system change, phosphorus and nitrogen imbalance (Steffen et al. 2015; Garnett 2018; Persson et al. 2022). Greenhouse gas emissions from food production are as high as approximately 20 percent of the global emissions that can jeopardize the achievement of the Paris Climate Agreement (Xu et al. 2021). The same study has shown that protein production from the livestock industry more than doubles CO_2 emissions compared to protein production from the plants. Overfishing in the seas and oceans threatens not only the extinction of many species, but also a huge CO_2 emission (Sumaila & Tai 2020). There are also many social problems that are connected to the food, among which nutritional imbalances, hunger, nutritional deficiencies, and obesity-related diseases (Willett et al. 2019).
The world's population continues to grow and by 2050 around 10 billion people will live on the planet according to the UN (2019). The humanity is looking for new pathways that will produce enough food for the entire planet while maintaining socio-ecological systems in the balance. For these purposes, the UN has developed 17 Sustainable Development Goals (SDG) within the Agenda 2030 that indicate directions for strategic planning (UN 2015). All those goals are directly or indirectly related to the food and therefore, in order to achieve them, a transformation of the global food system is necessary (Batini 2019; Rockström et al. 2020). Sweden has its own national food strategy for the transition to a sustainable food system with the main accent on the policy, the innovations and an increased food production (Rigeringskansliet 2016). Today, there are various innovative approaches, both social and technical, that are transforming the food system into a more sustainable one. One such innovation that could be a part of a fundamental changes is aquaponics.

2. Aquaponics background

The chapter describes AP technology, sustainability aspects of AP, market perspective, and state of art in the world. Furter, the preconditions of AP in Sweden are discussed. At the end of the chapter, the aim of the study is stated, and research questions are formulated.

2.1 Technology

Combination of growing fish and plants in one symbiotic system using wastewater from fish to fertilize plants has been known as a method of food production since antiquity. AP was coined in in the seventies to describe a technology that is part of a broader approach to food production known as integrated agri-aquaculture systems (IAAS) (Zajdband 2011, Gooley et al. 2003). AP is a combination of HP (HP, soilless controlled production of horticulture) and recirculating aquaculture systems (RAS) where the wastewater with ammonia convert to nutrients by bacteria and circulate between fish tanks and HP (H. Farhangi et al. 2020; Xiao et al. 2019; Danish et al. 2021; Lennard & Goddek 2019).

There are several design solutions for usage of this technology, however, technical features can greatly depend on both the environment and the purpose of the system usage. The scientists distinguishes four categories in the application of AP: open AP; domestic AP; demonstration AP and commercial large-scale & small-scale AP (Palm et al. 2018; Junge et al. 2017). Figure 1 demonstrates tree water management systems in AP that are described in the scientific literature: a) a coupled one-loop system, b) a simple decoupled system or c) a decoupled multi-loop system (Palm et al. 2019; Goddek et al. 2016; Monsees et al. 2017; Baganz et al. 2022; Lennard & Goddek 2019; Goddek et al. 2019).

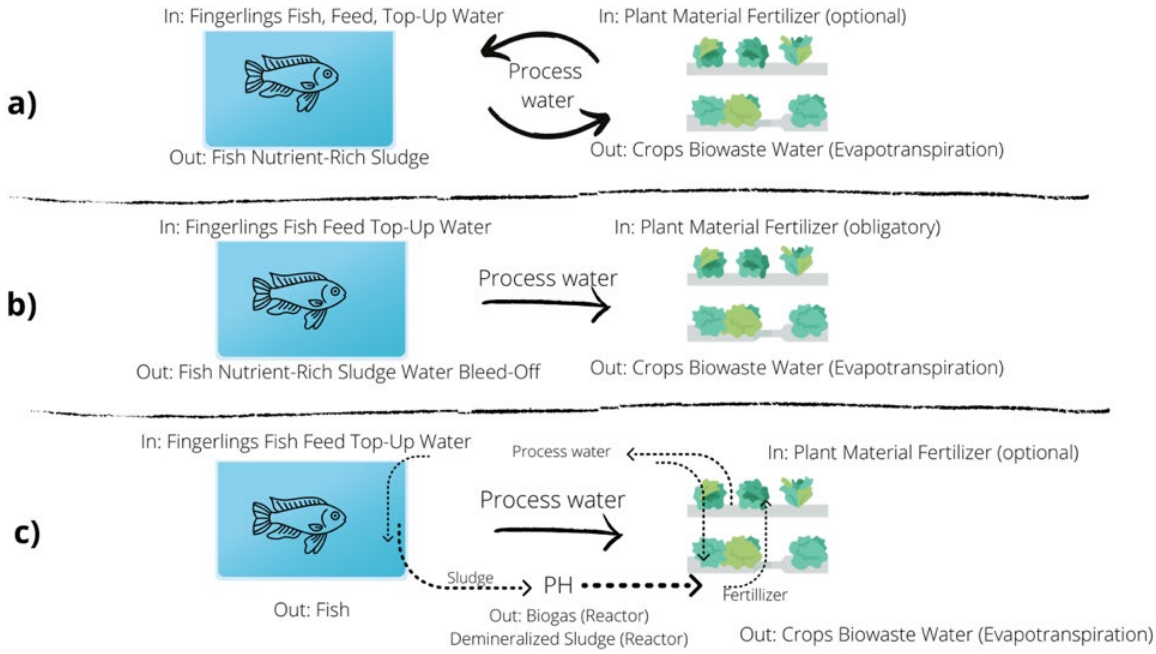

Figure 1 Three AP systems: (a) a traditional one-loop AP system, (b) a simple decoupled AP system, and (c) a decoupled multi-loop AP system. Every system shows input and input for water and waste products (adapted Goddek et al. 2019).

The coupled one-loop system is the traditional AP principle in which water circulates between utilities while removing the sludge. The simple decoupled system and decoupled multi-loop system represent a unidirectional water flow system with deferent level of technological complexity.
Despite the difference in the water management system, the metabolic products in form of nutrients from the fish tanks flow to the HP system (Goddek et al. 2019). Commercial systems which may include AP farming, semi-commercial AP systems or urban gardening may use both water management systems as is illustrated above, while breeding fish of different age groups and using an intensification production method (Palm et al. 2018). For the commercial production, are commonly used deep water/flow system and nutrient film method (NFT) types of plant cultivation (Colt et al. 2022; Palm et al. 2018). The Products from such commercial systems can be supplied in retail and wholesale.

2.2 Sustainability

AP technology is considered as sustainable food production that can help to reach at least five SDGs of UN: SDG2 - zero hunger; SDG7- energy for everyone and clean; SDG8 - both job satisfaction and economic growth; SDG12 - responsibility to create responsibility to use; SDG14 - protect the richness of the sea (Danish et al. 2021). If one look only at the RAS system, then according to conclusion of Ahmed and Turchini (2021) such production may be sustainable and can

undoubtedly be considered as meeting the SDG goals. Goddek et al. (2019) summarized that the balance of nutrients in the AP system, the flow of purified water back into the system, the use of energy, the large commercial systems and the productivity, and effectiveness of the supply chain are the main sustainability challenges for the technology. Other research says that it is premature to draw conclusions about the sustainability of AP, as the technology is in its developing phase and there is not enough data (König et al. 2018).

Environmental sustainability

The Life cycle assessment[1] (LCA) is widely used to determine what impact a given production has on the environment (Muralikrishna & Manickam 2017). Since the AP is the new production method that can be applied with different design solutions in different climates, the results of LCA assessments may vary accordingly, that can be seen in the review of Greenfeld et al. (2022). However, review written by Breitenstein & Hicks (2022) show that differences are not significant in different LCA studies and may be explainable. It is in line with the study of (Greenfeld et al. 2021) that show that pressure on the environment in AP is 50% less than in a separate systems.

The numbers of LCA studies show that the pressure on the environment can be reduced by using AP technology. The energy use per amount of fish protein and yield of plants produced in AP can be reduced, sometimes significantly, compared to other production methods (Atlason et al. 2017; Alkhalidi et al. 2020; Körner et al. 2021; Körner et al. 2017; Ghamkhar et al. 2020; Chen et al. 2020; Joyce et al. 2019). AP reduces the use of water and the use of fertilizers for HP, which reduces the pressure on ecological systems on the land and below the water (David et al. 2022; Yep & Zheng 2019; Monsees et al. 2019). Joyce et al. (2019) show that water usage in food production is lowest in RAS systems compering with any production of animal protein and hovering around 400 liters per kilogram of fish.

Given the fact that the quality of arable land is declining, AP and its derivatives could reduce pressure on arable land by producing more quality protein and nutrients in greenhouse systems (Prăvălie et al. 2021). Studies show that sustainability issues in applying AP often depends on factors such as production size, system design, climate, choice of fish and plants, fish food, fertility cycle and energy source (König et al. 2018; Breitenstein & Hicks 2022).

[1] LCA is an analytical method for evaluating how a manufacturing process, from resource extraction to product disposal, affects the environment. An assessment may include a "cradle to grave" assessment or only a certain stage of production, for example "from the cradle to the gate of the farm". The methodology complies with the international standard ISO 14040.

Social sustainability

AP makes it possible to produce high-quality protein and vegetables that meet both dietary requirements and the need to increase food production (Robaina et al. 2019; Zurbau et al. 2020; Kralik et al. 2022; Mchunu et al. 2017). Since AP can be used in both urban and rural areas, it reduces the risk of food deserts. It should be noted that automated AP systems make it possible to facilitate physical labour while at the same time providing employment to the local population (Yanes et al. 2020). The possibilities of producing food in controlled environments open up wide opportunities not only for business, but also for personal needs, which is analysed in the review Ragaveena et al. (2021). However, growing food for personal use is still only a dream, as can be inferred from Wirza & Nazir (2021) systematic review, which found only 66 studies in the past ten years highlighting urban applications of AP. Moreover, AP's workers of commercial firms require special skills to operate two different systems and in smaller plants with less automation, the labour becomes more intensive and must be paid accordingly (Turnšek et al. 2019). Despite difficulties and uncertainties on commercial side of production, demonstration models can have an educational orientation aimed at both advanced training and the general educational purposes in the educational institutions, schools, or universities (Milliken et al. 2022; Maucieri et al. 2018).

Economic sustainability

The commercial development of AP is also rather vague today, as there are quite a few large commercial enterprises that could be used as an example. Accordingly it is difficult to talk about the economic sustainability of AP today. Turnšek et al. (2019) examined the economic potential of AP in terms of aquaculture production, horticulture production and how the market see the AP. The findings said that consumer perception of AP food and issues in marketing no less important than the technological component.

The main expense in aquaculture side of AP is related to fish feed, energy consumption and labour (Morgenstern et al. 2016; Greenfeld et al. 2019). Production in hydroculture has approximately the same distribution of costs as AP has, however, instead of fish food in AP, seedlings are used in hydroculture. However, there are studies that show an economic profitability in such technology despite the high investment in equipment, if the potential of the system is used to the fullest (Quagrainie et al. 2018; Baganz et al. 2020). Studies have shown that the return on investment can stretch for more than eight years and only at a price comparable to the price of organic products. Greenfeld et al. (2019) come to the same conclusion in their literature review of economic profitability of AP, in the line with previously presented findings, that AP can be economically viable, however this depends on both retail prices and production scale. Moreover, researchers concluded that social benefits are directly correlated with the profitability of AP enterprises. However, interestingly enough, Turnšek et al.

(2019) highlighted that even if AP does not generate income, it does have a beneficial effect on the social dimension of sustainable development.

2.3 Market perspective

It is difficult to talk about economic sustainability before commercially successful enterprises with high turnover are created. However, market research, customer behaviour and their expectations will become increasingly important as technology improves. A number of studies conducted in Europe, South America, Australia and Israel with a survey of potential buyers have shown a willingness to buy AP products due to sustainability (Greenfeld et al. 2020; Suárez-Cáceres et al. 2021; Eichhorn & Meixner 2020). More than half of those surveyed knew about the technology before they answered on the survey. Greenfeld et al. (2019) highlighted the three most important components to take place on the market after technological success: the producer must be accept by the buyers, the consumers must accept the product, and external factors must be favourable, prices for instance. Baganz et al. (2020) conclude that consumer behavior is one of the most important points on the road to success, however infrastructure for distribution and availability of products on the shelves is also very important. Therefore, the products must be suitable for the market environment. Consumer acceptance, marketing and business model were identified by Turnsek et al. (2020) as crucial for an AP start-up and its success in European context, that confirms previous research.

Market prices, consumer behavior, channels for distribution and business model are according Silva Araújo et al. (2021) fundamentally important for product distribution, what is in line with previous studies.

Summing up the authors above, one can conclude that large systems are more economically profitable because the price of products can be lower, and this does not go against the classical economics of Adam Smith. Also, of great importance is how the client perceives the product, the manufacturer, the convenience of buying and his view on sustainability. Therefore, communication with consumers and product distribution patterns should be considered as a part of the successful development. And no less important observation is made regarding the business model, which is vital for success.

Legislation at EU level is not sufficiently developed to advance the commercialization of AP. If, for example, one sees the desire of customers to pay for sustainable food, then the inability to use organic certification for AP products may leave the product unclaimed for a certain part of the buyers. Since AP consists of two legally independent systems, this makes it difficult to obtain a business license. Streamlining the application process and obtaining a permit could help promote commercial development (Fruscella et al. 2021; Cammies et al. 2021).

2.4 State of the art in the world

The largest amount of research in the field of AP is carried out mainly in the USA, Europe and China, however the direction of research is quite different (Hao et al. 2020). If China is more focused on the applications of the Internet of things and biological control, whereas for example Europe is more focused on the multifunctionality of AP and the legislation of technology. At the same time, the number of scientific papers is higher in Europe than in the US, but there are more commercial enterprises in the US by 13 percent higher than in Europe. AP research on the African continent is extremely scarce, which is analyzed in the Obirikorang et al. (2021) review. The authors of the study mentioned only three AP commercial productions, two of which are in Egypt and one in Ghana. Despite the paucity of scientific papers and commercial distribution, market research indicates a positive attitude among potential buyers in Kenya (van Gorcum et al. 2019). Hao et al. (2020) highlights that despite the fair amount of research in Europe, little attention is paid to market, and marketing research.

2.5 Precondition for AP in Sweden

For the development of the industry to proceed in accordance with the challenges of our time, a food strategy was formulated at the national level. The National Food Strategy approved by the Swedish government in 2017 aims to make Sweden's food system sustainable, innovative, globally competitive, and attractive for business and investment (Livsmedelsstrategi 2017; Regeringskansliet 2017). The strategy is divided into three areas: rules and conditions; consumer and market; knowledge and innovation. Working in this direction requires the coordinated action of stakeholders, for which the Swedish Food Arena was created (Sweden Food Arena 2020). This platform serves for cooperation of stakeholders in research in the field of food innovations.

Innovation

Innovation in the food sector in Sweden ranks fourteenth among European countries, despite the fact that technological innovation in forestry, steal and cars manufacturing in Sweden is in second place in Europe (Beckeman et al. 2018). The Swedish innovation system is built on three blocks: knowledge of society, businesses and public administration (Sweden Food Arena 2021). The Sweden Food Arena, together with the Swedish government innovation agency Vinnova, outlines three areas in support and development of innovation in the food system. (Sweden Food Arena 2021). The first is the supporting and development of innovation and entrepreneurship, considering the existing industrial infrastructure and market needs. The second is the creating of a unique and competitive image

of Swedish food products. The third is organization of the food system as a single platform for all stakeholders who share a common vision of how innovations should develop to create a sustainable food system. This approach also contributes to the vision of how the whole food system can be rebuilt according to the "green" transition.

Sustainability

Sustainability in the food sector is broadcast by the public administration and anchored at the national level. In 2020, a study on sustainable food systems in Sweden was commissioned by the government (SJV 2021). Study defines sustainable food systems for work in Sweden and highlights closeness to FAO concepts and definitions.

Swedish Board of Agriculture and Swedish Agency for Marine and Water Management Agency had developed a sustainability aquaculture action plan. It focuses on the balance of aquatic ecosystems, social benefits and economic development (SJV 2021). Moreover, this plan is in line with the direction of the European strategy for the environmental assessment of aquaculture-related activities. (Hvitlock et al. 2021). The aim of the environmental assessment is to integrate environmental aspects into aquaculture development. The Federation of Swedish Farmers demonstrates that the development of the entire sector needs to be linked to sustainable development goals (LRF 2020). The National Fisheries Association adheres to the same line in matters of sustainable development.

The European Farm-to-fork strategy has much in common with the Swedish national strategy for sustainable development, but the Swedish strategy aims to increase production (Pia & Röös 2021; EU 2020).

Production and market perspective

Swedish food supply chain provide work for about 300 000 people. Sweden agriculture employs about 166 000 people whereas about 14 760 are employees in horticulture production and 543 people in aquaculture (SJV 2020).

This make possible to produce 9 900 ton fresh weight fish (SJV 2020). The number of pools was estimated at 278 by year 2020 with a total volume of 4,000 cubic meters. The number of RAS systems was estimated at 41 with a total volume of 5,000 cubic meters, that was highest numbers in national food fish production ever.

The number of companies growing vegetables in greenhouses was 329 by 2020 (SJV 2020). Greenhouses mainly grow cucumbers, tomatoes, herbs and lettuce. In 2020, 31,000 tons of cucumbers and 19,000 tomatoes were harvested, which is about 82 percent of the total greenhouse production and shows a constant annual increase. Lettuces were grown at 57 million, which is also more than usual, while the cultivation of pot salad has declined and became 40 million pots (SJV).

Statistics on how much is grown using HP and AP technologies is not available today. The AP products enter the market however in very small quantities. The high-tech AP company Agtira had 14,4 million SEK in turnover, which indicates growth compared to the previous year (Agtira 2022).

AP in Sweden

There is a certain interest in AP in Sweden, however it is more related to educational models and hobby activities (Junge et al. 2019). Several enterprises have a small-size or medium-sized commercial production and have been operating for several years. Studying AP in Sweden, Gregg & Jürgens (2019) conclude that there are certain legal barriers to the spread of commercial AP because the AP has to deal with two different food production regimes. Moreover, the study says that problem with development of AP is not about technics but rather economic.

2.6 Problem

The problem statement in this dissertation is formed by studying the available literature and trends that are formed at the level of public administration in the field of food system development. Currently, there is a gap in the understanding what AP needs to be integrated into the Swedish agri-food system and take a place on the market.

2.7 Aim and research questions

The master thesis aim is to investigate the development of AP technology in Sweden and shed light on how such technology and its products can be embedded into the Swedish agri-food system.

To understand the development and the processes of transition, the following research question were formulated:
How can AP technology escape the innovation field and be embedded in the Swedish agri-food system?

To answer the main research question, the two additional sub-questions w formulated:

a) *What are the opportunities and barriers to the development of AP technology considering the agri-food standards in fish and horticulture production in Sweden?*
b) *What conditions are necessary for the penetration of AP food into the market?*

3. Theoretical framework

Sustainability transition broadens our understanding of how the pressure on the ecological and socio-economical systems can be reduced or eliminated through transformation to more sustainable practices. This chapter describes the evolution of the theoretical approach to sustainability transitions and proposes a theory that seeks to explain such transitions.

3.1 Transition and sustainability

Transition is a process in which society radically changing or shifting from one state to another. According to the existing theories, there are large socio-technological systems that are somehow subject to transitions and changes. Sovacool and Hess (2017) have identified 96 theories and conceptual approaches in studies of socio-technical changes from more than 20 disciplines, among which the fourteen theories are mentioned most often in the scientific literature. These most common theories are designed to explain the emergence and spread of new technologies that are closely related to development of society.
The concept of sustainability transition in academia emerged as a response to the massive changes that were beginning to take place in society and the environment at the turn of the last decades of the twenty century (O'Riordan & Jäger 1996). The concept brings together two scientific multidisciplinary fields that had to go through the process of mutual integration (Loorbach et al. 2017). The first was the field of innovation research that developed from the technological research, innovation legislation and evolutionary economics (Kemp 1994; Rip & Kemp 1998). The second field was on sustainability science and a broad perspective of environmental studies (van den Bergh & Gowdy 2000; O'Riordan 2001). Loorbach et al. (2017) identified three approaches with different epistemological backgrounds in sustainability transition studies: *socio-institutional* approach includes labour, finance, or health care; *socio-ecological* approach studies biodiversity, fisheries, or forestry; and *socio-technical* approach usually focus on energy, mobility, or food.

3.2 Sustainability transition

The sustainability transition approach focuses on radical innovations that, at a multi-level dimension, transform large sociotechnical systems into more sustainable ones over a long period of time (Markard et al. 2012; Grin et al. 2010; Geels 2011). The transition approach is used by the scientists studying the sustainability transitions to conceptualize changes occurring at technological, economic, institutional and social levels (Rotmans et al. 2001).

The transition towards the sustainable development has its own specific characteristics that distinguish it from the historical transition. First of all, the purposefulness of such a transition can be singled out, since it is directly related to the solution of the environmental problems (Smith et al. 2005; Geels 2011). Since the goal is to improve the life of society, the main actors in such a transition are civil society and the state (Elzen et al. 2004). In this case, innovative technologies often do not have economic benefits since the price of production and the cost of the final product are inferior to competitors. Historically, transitions have occurred solely for the purpose of obtaining economic benefits from innovation. Therefore, private business cannot be involved in a sustainable transition without a clear economic benefit.

Secondly, sustainability often has indirect societal benefits that are difficult to determine at the start of a transition or when developing a strategy (Geels 2011). Therefore, for an individual user or business, production is not profitable because the price lags behind the quality. In this case, support is needed through subsidies, tax cuts or the development of new laws.

The third feature is that a sustainable transition should primarily affect those areas of the economy where the burden on the environment is the greatest (Geels 2011; Grin et al. 2010). Therefore, it should be applied to food production, energy, industrial production, or the retail sector. The patterns of eating behavior, such as the consumption of meat and dairy products could also be studied throw the prism of sustainability transition. It is difficult for sustainable innovation to penetrate such economically strong areas ruled by large companies. Since innovative start-ups are often more sustainable but do not have resources to provide the radical changes, support of big business is necessary.

There are number of characteristics that make the sustainability transition difficult in the research discourse: dimensions and co-evolution, multi-agent systems, change and stability, indeterminacy and openness, regulatory focus, extendedness in time processes, values, discuss and controversy (Köhler et al. 2019; Lachman 2013).

3.3 Food system transition

Socio-technical transitions and those innovative solutions that are the sphere of interest of scientists are considered today mainly under the lens of four conceptual frameworks (Markard et al. 2012; Köhler et al. 2019; STRN n.d.). These theories of sustainable transition, see Figure 2, are the most common in the analysis and management of the food system (El Bilali 2019; Loorbach et al. 2017).

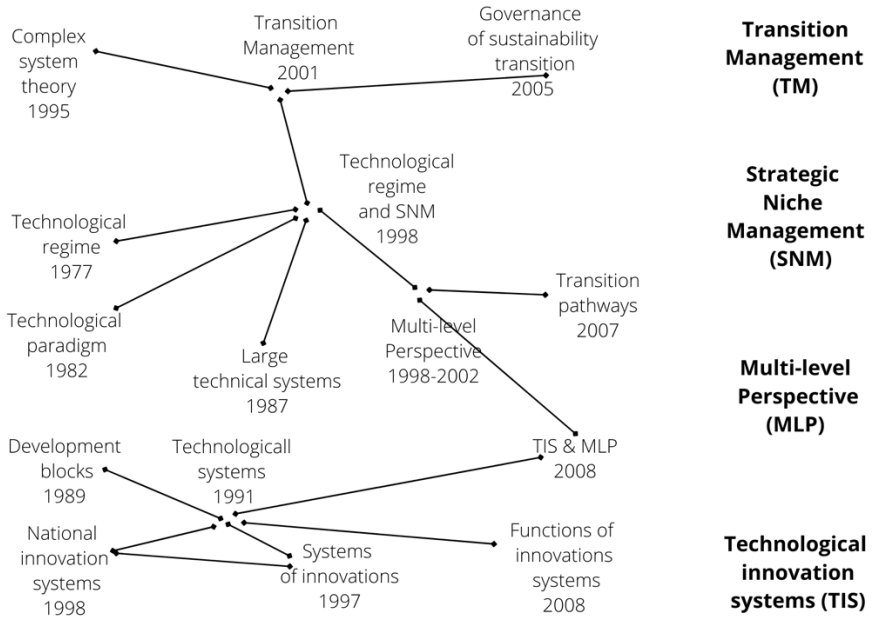

Figure 2 Map of key studies that led to the conceptualization of four theories in sustainability transition (Adapted from Markard et al. 2012).

The technological innovation systems (TIS) is one of the core approach that uses of Sustainability Transitions Research Network (STRN) and used as an integrated theory in MLP (Markard & Truffer 2008; Coenen et al. 2012). TIS was formed for policy makers to analyse the technological systems at an early stage of their development and recently is used to identify obstacles and prerequisites for development for one specific technology (Hekkert et al. 2007; Bergek et al. 2008). However, TIS approach was not chosen for this research because it does not explain the diffusion of innovation into the mainstream market, and it does not have the well-developed concept of protected space as in SNM approach (Smith & Raven 2012; Geels 2011).

Transition management (TM) is the concept that the management of innovation in the socio-technological paradigm requires active intervention and management (Smith et al. 2005; Kauffman & Macready 1995). The theory combines work on technological transitions with theories of large, complex systems. This approach suggests a model that could be applied in practice in order to move to sustainable trajectories.

The strategic niche management (SNM) has been developed as an analytical policy tool within MLP approach to conceptualize technological innovations at the experimental stage of the development (Hoogma 2002; Schot & Geels 2008; Kemp et al. 1998). The SNM has developed understanding of how an innovation emerges and matures in a so-called "protective space"(Rip & Kemp 1998; Smith 2007; Wieczorek & Hekkert 2012). Smith and Raven (2012) develops the concept of protective space in more detail which led them to propose the new understanding of how innovation interplay with the broader social context, escapes the protective space and leads to the transformation or the regime.

The MLP (MLP) is one of those fourteen more spread theories mentioned by Sovacool and Hess (2017) and only one that have been developed to analyze the broad context of technological innovations and dynamics of processes between technical dimensions, actors and rules within the socio-technical systems (Markard et al. 2012; Sovacool & Hess 2017; Lachman 2013; Köhler et al. 2019; El Bilali 2019; STRN n.d.).
This theory has a co-evolutionary nature, interdisciplinary approach and are closely intertwined with the different fields of social sciences, that allows them to be used to analyze innovation and sustainability transition in food systems. The socio-ecological problems faced by society has led to an increase in research using these theories and their mutual integration in the agri-food sector. (El Bilali 2019; Geels 2011).
In this thesis, the *MLP* (MLP) framework (2.4) is used for analyzing of the interaction between socio-technical levels, where AP acts as an innovative technology and the agri-food system as an its antagonist (Geels 2002). The conceptual approach of the *protective space* (2.5) analyses the development process of AP in an innovative niche and its wider interplay with agri-food regime (Smith & Raven 2012).
Conceptual integration is needed to answer the main research question and the sub-questions through understanding the potential of AP at the current level of development and possible expansion within the existing agri-food system (STRN 2022).

3.3.1 MLP

MLP framework conceptualize a model of the long-term, complex socio-technical systems and operates with concepts that are divided into three levels: *socio-technical landscape* as macro-level*, socio-technical regime* as meso-level *and niche-innovations* as micro-level (Geels 2002; Rip & Kemp 1998; Smith et al. 2010). The framework has a nested hierarchy, which is built on interaction and dynamics between levels and how amenable each level is for the reconfiguration by the impact of other levels or by endogenous factors (Rotmans et al. 2001; Geels 2004).

Socio-technical landscape performs on macro-level of the hierarchy and depicts a plexus of exogenous slowly flowing processes and events in socio-ecological systems (Geels 2002; Rip & Kemp 1998;). Exogenous event that influence and form the landscape are climate change, wars, economics developing, political development, cultural values, demographic changes etc. (Geels 2002). The landscape is highly stable; however, it can pressure the regime by environment problems for instance and influence niche-innovations by expectations (Geels & Schot 2007).

Socio-technical regime performs on the meso-level of the hierarchy and represents the technical systems, actors and rules/institutions (Geels 2004; Geels 2020). Dynamics within a regime are driven by interactions between actors and rules, actors change the rules, and the rules form the context for the actors' activities. The sets of rules are semi-consistent and related to each other that makes coordination of actions in a social system tightly intertwined (Scott 2014; Geels 2004; Geels 2005). A change in one rule leads to a change in another, and the consistency of the rules is a condition for regime stability (Smith et al. 2010). Industry, policy, science, technology, culture, market and users' preferences are multiple domains that exist on interrelated rules that by coordination form agri-food regime for instance (Geels 2004; Holtz et al. 2008; Leeuwis et al. 2021).The regime is locked-in and sufficiently stabled, however can change the configuration either for the influence of incremental innovations or to entering the innovation from the micro level (Geels 2011; Penna & Geels 2015; Unruh 2000; Geels 2004). Generating incremental innovation on the regime level allows incumbent technological firms to smoothly adjust rules and users' preferences (Lachman 2013). The diffusion of innovation may require significant changes in the complex regime configuration (Geels 2004). The regime, over a long period of time can infiltrate into the landscape affecting social and cultural narratives. Moreover, the regime influences the niche with its vision, which can create conditions for the development of innovation. Also, the regime under the landscape's press creates the prerequisites for the penetration of innovation into the regime.

An example can be given to demonstrate how the agri-food regime is formed. Buying fish or greens in the store, the customer demonstrates both the user's preferences on the market and the culture perception of food that are imbanded in the *cultural* and *market, users' preferences regimes*. The production and transportation of food are related to *policy, industry, and technology regime.* Industrial production, scientific work, government's work on regulation is deeply intertwined and their activities are well coordinated. When an innovation appears, a certain restructuring of this entire complex system will be required, which will lead to a loss of profit for the incumbent firms.

Niche-innovations is an incubation place or a protected space on the micro-level that appears due to the interaction between different actors interested in a

particular promising sustainability innovation (Kemp et al. 1998b; Schot 1998 p.193; Smith & Raven 2012). This interaction is driven by the expectations emanating from the landscape and the vision or believes that is projected by actors from the mainstream regime. The protected space is a technological niche for the innovation where learning processes take place between users and manufacturers. Technological niches are extremely unstable in their development and depend on many external factors, what may delay the development of innovations for a long period of time.

If interactions between actors from regime and niche are successful, the highly instable technological niche becomes a more stable market niche (Schot & Geels 2007; Raven 2006). There is also a breakthrough type of niche. Such a technological innovation does not need a protective space if the regime with which it competes is in decline. Geels and Schot (2007) highlight the necessary conditions for a technological innovation to leave the market niche and break into the mainstream market, the authors identify the following conditions: learning processes should be stabilized in the accomplished design, powerful actors are included in the network of supporters, the price/quality ratio has improved, innovation occupies at least five percent of the market niche.

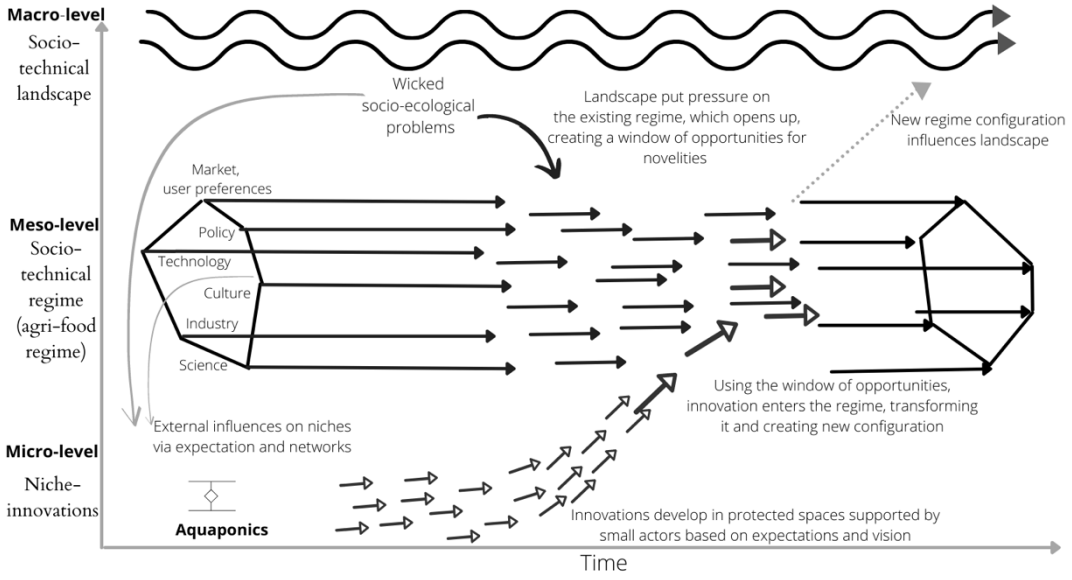

Figure 3 MLP: three levels depict an interaction and dynamic within socio-technical system (adapted Geels 2002).

MLP theory defines transition as switching from one socio-technical regime to another (Smith et al. 2010). Switching regimes is associated with socio-ecological tension in the landscape, which causes pressure on the regime and destabilize it (Geels & Schot 2007; Driel & Schot 2005; Geels 2002). Landscape pressure on the regime can be associated with agrarian practices and overuse of aquatic food leading to socio-political and environmental tension(Geels 2002; Geels & Penna

2015). By the pressure on the regime, the landscape requires changing food production to a more sustainable one. Simultaneously, the landscape translates the expectation into the niche-innovation level that is associated with the demand for an innovative solution of the environment problem, what can be AP for example (Geels & Schot 2007). Under pressure from the landscape, a *window of opportunity* opens up in the regime, thus providing a possibility for an innovation to infiltrate into the regime and transform it, if the window of opportunity is not exploited, the innovation gets stuck in protected space (Rip & Kemp 1998; Geels 2004). The right timing of interaction between the levels is a prerequisite for all this momentum, otherwise the innovation may miss the window of opportunity and get stuck in the niche-innovations.

3.3.2 Protective space

Sustainability transition processes may be controlled hence more predictable, even though a sustainability transition is not a linear process, but a loopback one. The strategic niche management (SNM) is a research model and policy tool that suggests that technological innovations could emerge, develop and interact with the regime in a controlled environment, a technological niche (Kemp et al. 1998). For the further analyses will be used the protective space concept, which was formulated first within the SNM. There is a discussion in the academic environment about the development of a theoretical foundation for a protective space. Therefore, the protective space is applied as theoretical approach for the development of niche-innovation.

A technological niche can be understood as a domain where an experiment is conducted, in which, with the participation of various kinds of actors, the features of the technology, costs and responses of the first adapters are studied (Hoogma 2002). To move from a technological niche to a market niche, and from a market niche to the mainstream market, the innovation need the potential for competition and user's acceptance (Geels and Schot 2007). Protective spaces have received a broader understanding in the literature, which has led to the conceptualization of features and processes that occur along the path to transition (Smith & Raven 2012). The protection, the maturation process and the process of embedding in the regime can be understood through these three features: *shielding, nurturing and empowering* (Verhees et al. 2012; Raven et al. 2016; Smith & Raven 2012).

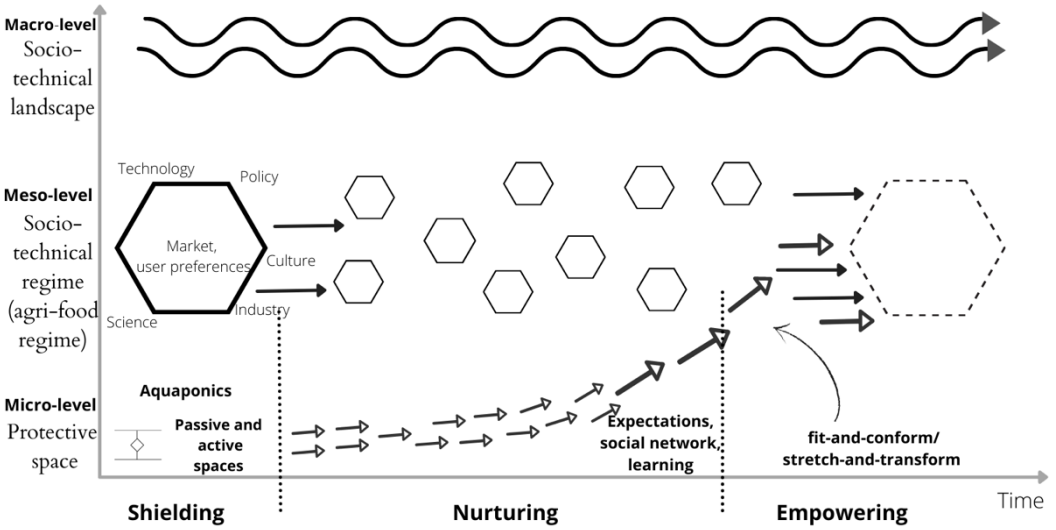

Figure 4 Protective space: shielding, nurturing, empowering (inspired by Geels 2002 and Smith & Raven 2012).

As shown in Figure 4, *shielding* is a process that allow the innovation to withstand pressure from a dominant environment or regime that can be detrimental to an experiment or start-up (Smith & Raven 2012). The pressure of the regime on the niche comes from the different domains of the regime, cultural, economic, political, etc (Geels 2004). Accordingly, a niche needs multi-level protection. This protection may be provided by the local community, private investors, or local political leadership. Shielding can be passive space when the original niches are at a relative distance from the infrastructure and the market, in a relative geographical distance (Raven et al. 2016). A farmer can try new types of production, a little AP facility, and sell small quantities of vegetables through alternative regional REKO- associations[2]. Active space protection extends to incubators or start-ups run by large agri-food firms that are extensions of R&D departments. SNM tool may be the active space protection for an experiment (Kemp et al. 1998). Raven et al. (2016) conclude that technology proponents tend to use passive spaces first before moving on to the strategic creation of active spaces.

Nurturing is a process for developing of innovations that became possible when shielding is formed, regardless of whether it is an active or a passive protected space (Smith & Raven 2012; Schot & Geels 2008). Nurturing focus on the social inclusion in launching and development of the technological innovation through expectation, learning and a support of the social network (Schot & Geels 2008; Grin 2020; Raven 2005; Kemp et al. 1998).

[2] REKO is an alternative, local, online, or physical food market in Sweden.

The processes that occur during cultivation take place in two dimensions, in a local niche, directly in the technological process itself and in a global niche consisting of community and actors from regime (Geels & Raven 2006; Geels & Deuten 2006). These processes allow to develop the system structures and define functions.

Empowering is a process when a niche innovation gradually goes through a stage of shielding, which makes protected space redundant because innovation needs a wider distribution and the ability to openly compete in the market. Innovation during nurturing develops in such a way that it gradually fits into the environment for which it was prepared (Smith & Raven 2012; Raven et al. 2016). This feature is called *fit-and-conform*.

Another feature of the empowering in niche-innovation may be the institutionalization of the features of those practices that are necessary for the application of innovation. This involves the transformation of the regime by having the regime reckon with the establishment of new norms and routines. The niche begins to expand and change the environment in a way that is favorable for the niche. This development is called *stretch-and-transform* (Smith & Raven 2012; Raven et al. 2016; Mylan et al. 2019).

4. Method

This chapter explains: 4.1 The logic of inquiry; 4.2 Method and procedure of data collection; 4.3 Method and procedure of data analyses; 4.4 Data reliability and validity; 4.5 Ethical consideration; 4.6 Delimitation.

4.1 The logic of inquiry

Philosophical view in scientific research is necessary for understanding the principles of theoretical thinking, developing methods of cognition, developing reflection and self-awareness for understanding the material world (Moon & Blackman 2014; Spirkin 1983). In science, there are three paradigms of inquiry, the first of which is ontology, which studies being or what exists in the world or a type of reality (Howell 2012). The second branch is epistemology, which focuses on the study of knowledge or how an investigator may understand reality. The third is methodological framework, which guide the researcher to produce knowledge by collecting data and formulating the conclusions that he or she was able to collect during the study.

The *ontological* approach of this study suggests that reality can be explained to some extent by scientific theory, but the nature of the observed phenomena remains beyond the reach of full understanding.(Moon & Blackman 2014; Howell 2012). Hence, between the two poles of naïve realism and relativism, the choice of an ontological approach towards structural realism was chosen because the study focuses on social actors.

Epistemology operates with aspects of reliability and methods in the acquisition of knowledge and the volume of this knowledge (Moon & Blackman 2014). Epistemology influences which direction research takes in an attempt to discover what we call knowledge. Objectivism and subjectivism are the two poles of the epistemological approach. In this study, the constructivism is used, which involves the creation of meaning through the knowledge that is already available and the acquisition of new knowledge through personal experience due to communication with social actors.

Methodology approach suggests that research can have quantitative, qualitative or mixed nature of data collection for subsequent knowledge extraction (Creswell & Creswell 2018; Robson & McCartan 2016). Since this thesis aimed to explore the

subject of AP, which is little studied, the choice was made in favor of a qualitative study. This approach was chosen in order to understand the context and phenomena occurring in the social world created by the communication and interaction of social actors. Social phenomena and their meanings are in constant reformulation by social actors therefore qualitative studies is more appropriated in this case. AP is a new sustainable method of production therefore processes and actions that support development and market penetration can be understood through communication with stakeholders.

4.2 Methods and Procedure of Data Collection

The study is built by collecting data from various sources. Firstly, secondary data obtained as a result of familiarization with the available scientific literature and publications from public institutions were studied. Secondly, data were obtained from the primary sources through semi-structured interviews.

4.2.1 Literature review

Robson & McCartan (2016) highlighted that to understand the problem, determine the direction of the research and formulate the research questions, a literature study is necessary. The literature search was carried out according to given criteria such as English language, year of publication since 2017 for AP and without any limits for the theory part, database which included Scopus, Web of Science, Google Scholar. Keywords and different combinations of them were AP, sustainability, RAS, and HP to search for literature of AP. Reviewing literature for the theory part were used following key words: MLP, sustainability, transition, transformation, SNM, niche, regime, food, aquaculture. In addition to the search query for the selected parameters, the snowball technique was used.
To understand how innovation and sustainability are considered by government agencies and professional associations when formulating a development strategy in the food sector, publications and reports from these organizations were studied. These include Swedish Board of Agriculture, Swedes, Swedish University of Agricultural Sciences, Federation of Swedish Farmers, Swedish Agency for Marine and Water Management, National Fish Association, EU.

4.2.2 Semi-structured interviews

For this study, companies that have a commercial focus, are pioneers in the technological development of AP in Sweden and are represented in a market niche were selected. In addition, in order to answer the research questions, experts with knowledge and experience in the food system and representing the agri-food

regime were selected. Participants were selected according to Geels's (2002) MLP theory, described in the Theory chapter 3.3.1.
To get answers on the research questions semi-structured interviews were done with representants of business, government organization, agri-food experts, researcher, and retail, see Table 1. A semi-structured interview allows to see a broader view of the theme of research, since the questions are open-ended, and the respondents are not limited in their responses. The questions for each interview were designed according to a theoretical framework where the participants could express how they see AP in relation to the food system in Sweden.

Table 1 The stakeholders within the agri- food system

Respondents	**Medium**	**Length/min**	**Date**
Entrepreneur A (Niche innovation)	Zoom	60	2022-02-16
Entrepreneur B (Niche innovation)	Zoom	40	2022-02-21
Fish expert, National fisheries association	Zoom	35	2022-03-11
Researcher, Swedish University of Agricultural Sciences	Zoom	65	2022-03-10
Horticulture expert, The Federation of Swedish Farmers	Zoom	40	2022-03-17
Authority, Swedish Board of Agriculture	Zoom	35	2022-03-21
Shopkeeper, ICA	Zoom	35	2022-03-16

4.3 Methods and Procedure of Data Analysis

Thematic coding analysis is a frequently used approach in text interpretation in qualitative research (Robson & McCartan 2016). Such an analysis makes it possible to identify patterns of similarities and differences in data by encoding the data and then identifying themes (Ahuvia 2001; Neuendorf 2018).
Since the study was based on an already existing theory, it was expected to find certain themes and, accordingly, codes (units of meaning) that would correspond to the themes. To identify themes, categories, similarities, or other patterns that may seem relevant to the study were examined. The data received by the interview was transcribed and carefully studied. Coding could include whole sentences, phrase or a word that explain a behavior, meaning or connection to the theme. Then the integration and synthesis of the results was carried out to understand the correspondence with the theory and literary review.

4.4 Data reliability and validity

The reliability of qualitative research can be difficult to test. Despite this, the reliability of the research methods should be in the focus (Robson & McCartan 2016). Good research always strives to measure or test what was intended to be measured or investigated at the beginning of the study. Therefore, the results of the study should correlate with reality. How the data was obtained and how they were analyzed is one indicator that the study can be credible. In this study, interviews were conducted according to procedures. The questions were asked in the language in which it was convenient to answer, English or Swedish. The interviews were recorded, later transcribed, and checked again with the original. The questions were sent in advance and the participants had time to think about the answers, which reduces the likelihood of reporting erroneous information. The data were collected from participants that are not directly dependent on each other, indicating that the responses were not biased. In this study, the literature was used from reliable sources, namely from the official websites of organizations and scientific databases. Since the field of study is new, the goal was to get as much information as possible to fill in the gaps in the topic.

4.5 Ethical Consideration

When collecting data during the interview, it is necessary to take into account the ethical side of the study (Creswell & Creswell 2018). The necessary ethical standards were observed during the study. Attention was drawn to the opinion, anonymity, and impartiality of all interview participants. Before the beginning of the interview, the respondent was informed about the author of the study, its goals, and the subsequent use of the data. The respondents were notified that the interviews would be recorded, and data can be withdrawn by him/her before the publication of the thesis. Each participant signed a document on participation in the interview and the use of data in this scientific work.

4.6 Delimitation

The study involved actors in the Swedish food system and explored initiatives for innovation and sustainability. Since the food system is very complex and has many horizontal connections on deferent levels, it is necessary to consider the delimitations of the stakeholders who were interviewed because of the available time. The study included two AP representatives who were selected for their commercial level activities and who do AP in different geographical regions. In addition, fish and horticulture sub-regimes were chosen as AP competes directly with these sub-regimes in the agri-food system.

5. Results

The results chapter presents empirical data obtained from semi-structured interviews. The questions in the interviews were formulated through predefined topics that sought to bring the researcher closer to answering the research questions. Each topic consisted of questions that were formulated according to a theoretical framework. The socio-technological regimes in Giles' (2002) theory of MLP was interpreted as agri-food sub-regimes. These six sub-regimes have been projected onto the Swedish agri-food system. Therefore, stakeholders in the number of six people are representatives of the agri-food sub regimes. The representatives of AP are niche actors, according to Giles' theory (2002) of MLP, Kemp et al. (1998) theory of SNM and Smith & Raven (2012) concept of *protective space*.

5.1 Stakeholders within the agri-food system

AP entrepreneurs is a category of stakeholders that has a vision of what food production should look like. They are the creators of the business model, the use of new technology, the search for funding, the creation and dissemination of knowledge about use of technology and functioning of the symbiotic systems. They occupy an innovative niche in a large socio-technological system. In this study, two AP representatives were interviewed. They have been in the business for several years and occupy a small part of a niche market.

Shopkeepers are a representative actors of food system that has established logistic of food and are aware of food standards. They are managers of retail stores and are directly connected with producers of fish and vegetables. Retail sector has a key position in the food system, as it can influence both the range of products in supermarket and the choice of the buyers. In this study a shopkeeper of an ICA grocery store was interviewed.

Scientists play a key role in innovation research, especially in assessing sustainability and applying some innovations along with other stakeholders. Scientists work closely with business, governments, and non-profit organizations. In this study a researcher who is an employee at Swedish University of

Agricultural Sciences was interviewed. He is the international expert in the field of AP and is engaged in AP research in Sweden.

Authorities are a key link in innovation processes and are in close cooperation with business and scientific research. Innovation usually comes with legal hurdles that need to be revised to accommodate new production practices or novel food. This organization is also responsible for sustainable development strategy in Sweden. In this study, one of the representatives of the Swedish Board of Agriculture who has relation to aquaculture was interviewed.

Fisheries association is dedicated to promoting the most important issues for members regarding the fishing industry in Sweden. The organization is in close cooperation with the authorities and other organizations that have an interest in the industry. The organization includes about 165 companies that are included in the value chain. In this study, one of the representatives of the National fisheries association was interviewed.

Horticulture association is a branch organization that protects the interests of entrepreneurs engaged in horticulture. The main goals of the organization are to promote the interests of the members of the organization, create the necessary conditions for competitiveness and profitability for the members of the organization. The interview for this study was conducted with one of the representatives of the Federation of Swedish Farmers who is also involved in the production process and is an owner of the horticulture business.

5.2 Thematic map analyses

The thematic map shows themes and sub-themes that were formulated during the coding process of data obtained during the interviews with the stakeholders, see Table 2.

Table 2 Thematic map analyses

Themes	**Sustainability factors and the premises for an innovative food production in AP**	**AP and its implementation in food production**	**Market condition and consumer behaviours regarding AP**
Sub-themes	Scientific view on sustainability in AP	Technology development and AP	Cultural perception of AP
	Legislation and its premises for AP	Industry awareness of AP	Market and users' attitude towards AP food

The sub-themes are related to the multi-level agri-food regime which consists of such dimensions as science, policy, technology, industry, culture, market, and consumer preferences.

5.3 Sustainability factors and the premises for an innovative food production in AP

This theme highlights the sustainability issues faced by AP, the problems that could be solved by AP and knowledge that are needed for the development of niche innovation. It also highlights the legislation and its impact on the development of AP.

5.3.1 Scientific view on sustainability in AP

Innovative high-tech food production requires careful study and understanding of how sustainable such production may be. The main parameters of sustainable production in AP according to entrepreneur B are the absence of fertilizers and local production that shortens the deliver, see Table 3. Entrepreneur B said, *"I think overall there is much more awareness of local crop sustainability and climate impact of food production."* However, in AP the fish feed should be considered seriously, because it has a huge impact on the environment. Entrepreneur also talked about their research on how to get mealworm into fish and mussel feed from the Baltic Sea. This work is underway both with universities and with insect farms. She also believes that AP required more energy for running facilities that is an issue because of price.

Table 3 Results obtained according to the sub-theme "Scientific view on sustainability in AP".

Stakeholders	**Quotes**
Entrepreneur B	*"I think overall there is much more awareness of local crop sustainability and climate impact of food production."*
Researcher	"*So, this is where the aquaponic is very important. One can use those metabolic products of fish as fertilizers not only in the greenhouse but on the land as well."*
Entrepreneur A	*"It's different with growing fish, so that's the aspect that is that we grow fish on the land, and it is smart from environmental perspective because is closer to consumers."*
Horticulture expert	*"We have nutrient leakage from plants and things like that, but we also have a lot of rules that govern this, but you can always go further in sustainability work."*
Authority	*"In addition, we see that quotas for wild-caught fish are decreasing."*

Fish expert	*"Herring is caught a lot, but it goes to Denmark and becomes food in such large feed factories."*
Shopkeeper	*"I read some figure that 75% of world wheat production takes place in Russia and Ukraine. I think it would benefit locally produced food."*

Researcher said that universities are working closely with AP initiatives. The help lies both in the technological configuration and in the development of a sustainable approach to production in different dimensions. The representative of the academy also paid a great attention to the fish feed. Fishmeal is made from fish that are in the maturation stage. Such a catch destroys the fish ecology, which leads to a decrease in the fish catch in general. Thus, by expanding aquaculture, we are destroying the ecosystem of the sea and ocean.
However, feed is an issue not only in terms of the environment, but also has social factors. Since fish food is produced mainly in poor countries, its production is very cheap due to slave labor. Researcher expressed the hope that one day Sweden will stop using feed obtained through slave labor. He said, *"Slavery is a very big issue. The Asian companies were not used the insect larvae for feed because it's expensive."* Other aspect of sustainability is that raising fish in open water leads to water pollution through fecal excretion and unbalanced feeding. Researcher said that because of the extensive lake system in Sweden, there is an increase in the accumulation of feed at the bottom of the fish farm.
Growing plants in soil without fertilizer is rare. The use of fertilizers ultimately leads to eutrophication and consequently changes in water quality. However, researcher think if one brings aquaponic to the farms it helps to get fertilizer. He said "*So this is where the aquaponic is very important. One can use those metabolic products of fish as fertilizers not only in the greenhouse but on the land as well."*

Researcher also believes that the war in Eastern Europe will affect the use of fuel and fertilizers in food production, as well as the provision of the world market with grain. Since it is the two countries in the conflict, Russia and Ukraine that are deeply involved in the world food system.
Entrepreneur A said that the main factor in doing business, in addition to the economic component, is local production, which is due to the awareness of environmental problems. Entrepreneur said, *"It's different with growing fish, so that's the aspect that is that we grow fish on the land, and it is smart from environmental perspective because is closer to consumers."* He is convinced that from a climate perspective it is very smart not to bring food from far away.

The expert in horticulture notes also active cooperation with scientists from universities, mainly from of the Swedish University of Agricultural Science.

Especially there was a dedicated platform, the Swedish food arena, where the entire food chain is represented. The expert in horticulture says that in general the changes will affect how we do open field cultivation. First, this will be due to a decrease in chemical preparations from weeds, crop rotation and spring drought. He said, *"We have nutrient leakage from plants and things like that, but we also have a lot of rules that govern this, but you can always go further in sustainability work."* The expert mentioned that they are implementing an interesting garden project called "Circular Bioeconomy in Horticulture". Moreover, the expert linked climate problems to the energy used in growing food. Mainly, it is about fossil fuels that are used in agriculture and horticulture.
The expert also thinks that the geopolitical changes associated with the war in Eastern Europe are already affecting the food system, through the disruption of the supply of food, fertilizer, and fuel. This is also accompanied by rising prices.

Authority also raised the issue of fish feed when it comes to sustainability in aquaculture, and she thinks that this problem has always been presented in aquaculture.
She sees a special feature of innovation in food production in the fact that technologies copy natural processes, which mainly reduces the burden on nature and makes ecosystems more resilient. Innovations allow employment to be brought to sparsely populated areas, which is a hot topic in Sweden. Such industries could make many places attractive, which would reduce the outflow of people and even attract new residents. A differentiated food system also matters, and different types of production ensure sustainability in access to food and food security. Moreover, the authority sees the issues with biodiversity in the sea that is linked with food security because of wild-caught. She said, *"In addition, we see that quotas for wild-caught fish are decreasing."* She is convinced that if we want to have a stable supply of fish, then we must rethink which food chains provide financial returns in the long term.
She is confident that the geopolitical changes associated with the war in Eastern Europe will affect the entire food system and may be more significant than during the pandemic.

Fish expert talked about the organization's collaboration with scientists and named universities such as the University of Gothenburg and Chalmer University. The collaboration is around innovation where the focus lies on seafood at the Blue Food platform, a hub for the future of seafood. The expert raises an issue in the field of fish food, which is consistent with the views of other stakeholders. The point is that the caught fish should go to feed people, and not to produce feed for fish, as is the case in the Baltic region. He said, *"Herring is caught a lot, but it goes to Denmark and becomes food in such large feed factories."* The expert is convinced that it is far away from a sustainable approach.

In addition, there is concern about environmental sustainability associated with the release of nutrients into the sea, which was already mentioned above in one of the interviews with the scientist. The expert also believes that fish quotas are a driver for sustainable innovative solutions.
He says, like other experts, that the geopolitical changes associated with the war in Europe will have serious consequences for the food system. Seventy percent of the fish consumed in Sweden comes from abroad. A large quantity of fish is exported from Russia and there may be a shortage. Therefore, the development of local production is a very topical issue. He also mentioned that from a sustainability standpoint, you need to think about how the fish is processed for filleting, as there is a need to reduce food losses.

Shopkeeper notes that buyer's interest in locally grown products is growing in comparison with five years earlier. He pointed also out the digitalization of business model and the trend to buy food online what does the purchase more environment friendly. Regarding the geopolitical tension he said *"I read some figure that 75% of world wheat production takes place in Russia and Ukraine. I think it would benefit locally produced food."* The shopkeeper believes that global events such as a pandemic or a large-scale war will lead to a reshaping of supply chains and food production will be more local, which will increase the self-sufficiency of society.

Opportunities and difficulties for AP

The AP potential to solve environmental issues, see Table 4, explain the involvement of scientists in this field and their collaboration with other stakeholders (Entrepreneur A & B, expert in horticulture, fish expert, authority, researcher).

Table 4 The contributing factors and barriers derived from results of the sub-theme "Scientific view on sustainability in AP".

Contributing factors for development	**Barriers for development**
Shorter delivery	Energy use
No need for fertilizers	Issues with fish feed, both on social level and environmental level
Less use of water	
Less leakage of nutrients	
Collaboration with scientists	
Food security	
Quotas for fishing	

There is some interest from sub agri-food regimes to RAS technology and bio circular systems what can be concluded from ongoing projects in this field (Expert in horticulture, fish expert). Moreover, geopolitical tension is a factor that

will further favor local food production and cultivation to ensure food security (Entrepreneur A & B, expert in horticulture, fish expert, authority, shopkeeper, researcher). However, there are challenges in providing sustainable feed for fish, both from environmental and social perspectives (Entrepreneur A & B, expert in horticulture, fish expert, authority, researcher).

5.3.2 Legislation and its premises for AP

As for regulations and laws, entrepreneurs consider them to be lagging behind AP, which creates certain confusion in the organization of production. Entrepreneur A believes that some rules need to be revised for growing fish while others are about HP, see Table 5. Regarding the RAS system, the main obstacle is the standards of animal welfare. Entrepreneur A think that regulations contradict production technologies, for example, those that require windows in a room where fish is grown. He said, *"The laws in Sweden are not created for growing fish on the ground."*

Table 5 Results obtained according to the sub- theme "Legislation and its premises for AP".

Stakeholders	**Quotes**
Entrepreneur A	*" The laws in Sweden are not created for growing fish on the ground."*
Entrepreneur B	*"The Swedish laws are actually not that good when it comes to circular food production."*
Researcher	*"An AP company in Sweden needs support in terms of environmental law."*
Authority	*"Will you prove your sustainability with certificates, or are we moving towards a system where consumers value more locally produced raw materials? Then maybe not as important to discuss the eco-certification."*
Horticulture expert	*"There are challenges to working with plant protection products that come in the wrong place because of legislation."*
Fish expert	*"I think it should be political will. The existing regulations that put sticks in the wheel, but you should be able to stay in production. The regulations must change."*

Another feature of the legislation imperfection is, according to entrepreneur A, the fact that AP production cannot be certified as ecological, and this rule is valid throughout the European Union. The entrepreneur does not see any benefit for the environment in such a law, but the law only shows a romanticized idea that vegetable products should grow in the ground. Entrepreneur thinks that legislation

is a bit hostile to technology and AP. It is a biological cycle that can be connected, and which is ingenious, but it also involves quite a lot of technology.

Entrepreneur B agreed with the other AP representative about the issues in the legislation that make it difficult to develop innovative food production in AP. Entrepreneur B said, *"The Swedish laws are actually not that good when it comes to circular food production."* This is a large cycle and local authorities are often very reluctant to give the permits. Entrepreneur had in mind that finding a space and converting unused buildings for production with AP technology faces bureaucratic obstacles. Entrepreneur also thinks that it is a conundrum that aquaponic products cannot be eco-certified, even though production is very environmentally friendly, without pesticides and artificial nutrients.

However, restaurants where products are sold do not focus on certification, it is more important for them that they themselves know about the production method and that the food is produced locally. Entrepreneur thinks that now there is almost more interest in locally grown than organically grown because organic often comes from a long way.

Researcher said that the laws that regulate food production in Sweden are aimed primarily at protecting the environment. He believes that companies starting in AP need support from the state and, accordingly, the development of the necessary laws that would meet today's technological development. Researcher said, *"An AP company in Sweden needs support in terms of environmental law."* He explained this by saying that environmental laws are formulated in such a way that they are an obstacle for AP. The state is very interested in the development of aquaculture and its derivatives, so now the legislation is being developed in order to give way to innovations in this industry. Moreover, the production of organic products should be increased, which is an important direction in the development of a sustainable agri-food system. Scientist said that sustainability is dictated by government policy. European food law states that 30% of food must be organic by 2030 and this is part of the strategy in Sweden. Companies will still think about profit, but since the law pushed them to the path of sustainability, they will follow it.

Authority also said that the development of aquaculture is a priority topic for the government. As for the AP, such production is within the framework of the aquaculture action plan and the national food strategy. Authority think that the question is how exactly or what form will be in future food production. She said *"Will you prove your sustainability with certificates, or are we moving towards a system where consumers value more locally produced raw materials? Then maybe not as important to discuss the eco-certification."* If we develop the theme of eco-certification, then the concept of sustainability can be very relative.

Technological systems to produce food are based on circularity but at the same time it is not a natural habitat for fish.
This view is generally consistent with what entrepreneur B said about the relative value of certification and the manager of retail store had same understanding of value of eco-certification. The authorities are aware of the innovations that precede the rules and there is an understanding that this is an obstacle. But this is a normal phenomenon, the official said, mentioning that with all this, support for innovation is present at all levels. Also in the interview, the official mentioned 639 million crowns that were allocated for the development of aquaculture.
The authority think that the legislation or regulations related to sustainability may be interpreted differently by different actors. For example, lobbies for conventional production may consider certain production to be sustainable, at least in comparison to how it used to be. But despite this, producers and branch organizations are trying to meet the standards laid down in the regulations and laws.

Expert in horticulture said that Sweden has very strict laws regarding sustainability compared to other countries. In crop production, there are many problems with plant protection if chemicals are applied too much or in the wrong place. This also applies to the leakage of fertilizers. However, in Sweden there are many laws on how to reduce such a process. Expert said, *"There are challenges to working with plant protection products that come in the wrong place because of legislation."* There are a lot of rules that govern plant nutrient leakage, but one can always go further in sustainability work.
Expert also notes that all horticultural products in Sweden that are sold to large retail chains undergo certification called IP-standard[3] or Svenskt Sigill-standard[4]. Such certificates have different levels and reflect the features of how a particular product was produced in terms of sustainability. The expert agreed also with the authority when he said that the risk of the rules is that there may be so many of them that there is no room for production. He said that before introducing this or that rule, you need to understand whether there is a real problem.

Fish expert believes that the rules and laws that exist today cannot be prerequisites for the development of RAS systems or AP in Sweden. Expert thinks that the rules are not adapted to new technologies and new opportunities for innovators in

[3] IP-standard is based on ISO 17067 and accepted by Swedac (Swedish Authority for Accreditation). It defines how food and flowers have to be produced to meet higher food safety, better animal care, reduced environmental impact and healthier working conditions. IP-marking is used for products with the lower requirement.

[4] Svenskt Sigill mark is for products that meet the stringent requirements and are certified according to the IP standard's Sigill.

this field, even though the industry sees such development as more sustainable than conventional aquaculture or fish harvesting.
This opinion largely converges with what entrepreneurs think. Fish expert said about an example of one RAS project they are working on to rise the salmon in Bohuslän. He said that during the construction of a facility they must face many difficulties regarding standards. Entrepreneur B had similar difficulties when they build the facility for AP. The fish expert said that the conversation with politicians is constantly about the need to create conditions for growing fish on the ground and form legislation for this. He said that they got the response from officials many times that RAS systems sounds good and that it is positive. And expert added *"I think it should be political will. The existing regulations that put sticks in the wheel, but you should be able to stay in production. The regulations must change."*

Opportunities and difficulties for AP

AP may conflict with current laws and regulations, see Table 6, because the AP production differs from conventional production (Entrepreneur A & B, fish expert).

Table 6 The contributing factors and barriers derived from results of the sub-theme "Legislation and its premises for AP".

Contributing factors for development	**Barriers for development**
The legislation is strict regarding plant protection	Laws of animal welfare does not consider the features of technology
Aquaculture is included into the national strategy	Different interpretation of sustainability
	Eco-certification
	Bureaucracy
	To many regulations that confront the idea of combining the different systems of production

In addition, unnecessary bureaucratic delays hinder the opening of new places for production (Entrepreneur B, fish expert). Products made in AP cannot be eco-certified (Entrepreneur A & B). However, if you look at the strategy of the state and the adopted laws, you can see no coincidence. Business mentioned the difficulties with eco-certification of environmentally friendly food, and at the same time, the state has an intention to increase the percentage of eco-certified products. AP obviously is a part of a strategy for developing sustainable food systems and food innovation at the national and EU levels (Entrepreneur B, authority).

5.4 AP and its implementation in food production

This theme highlights how stakeholders and AP entrepreneurs see the development of technological innovation in food production and the interplay of new technology with the food industry. The interviews showed that all actors were aware of the technological alternatives for growing fish and vegetables. The asked questions were about development of AP, RAS systems and HP. The respondents said that they had seen such products on store shelves, and everyone had tasted one of these products once upon in time.

5.4.1 Technology development and AP

AP is an interesting activity for people with different professional backgrounds. Entrepreneurs said that in this business specialists in the field of engineering, programmers, biologists, and plant growers intersect. Since the system is in constant development, research and observations are often carried out by the entrepreneurs themselves. Entrepreneur B said that when they started to develop the idea of creating their own AP production, they received a lot of knowledge from people who understand this. Including knowledge was obtained in different countries, such as the USA and the Netherlands. All the people involved in AP were happy to share their knowledge on how to grow vegetables and fish in a closed system, about sensors and how to measure everything. However, when it comes to AP, much is at the theoretical level, especially when it comes to academic knowledge, and it is not enough with practical solutions.
Entrepreneur B is engaged in research in AP and all useful information is posted on the blog for review. The company has carried out an environmental impact assessment of AP production at the initial stage of development and plans to repeat the study with the support of the Swedish University of Agricultural Science. Entrepreneur B sees a positive development in the formal training of AP´s engineers, see Table 7. For example, it was mentioned that 250 applications were submitted for an AP course designed for 25 people. Entrepreneur B said*, "There is a new engineering course in Norrtälje for aquaponic engineering and they had 10 times more applicants than they had places."*

Table 7 Results obtained according to the sub- theme "Technology development and AP".

Stakeholders	**Quotes**
Entrepreneur B	*"There is a new engineering course in Norrtälje for aquaponic engineering and they had 10 times more applicants than they had places."* *"Everyone wants to invest in an app on the phone, but very few people think that food is actually terribly interesting."*

Entrepreneur A	"*Yes, they began to move from hobby projects to commercial companies, but this did not happen. It hasn't gone commercial yet, but at least some companies have."* *"There are not many manufacturers that you can buy systems from."*
Authority	"*It is of course very welcome with innovations, and it is something that you try to support in several places."*
Shopkeeper	*"As for the HP school, I was in early and talked to those who started the idea and built a farm in the basement."*
Horticulture expert	*"We have a gap between the industry when there is a huge development of automation and digitization in the manufacturing industry and those who do what they know nothing about food production and those who do food production do not engage in technology development or the manufacturing industry."* *"It is that it is very difficult to raise capital to build greenhouses. The banks are not very positive."*
Researcher	*"... to get a special integrated system for agriculture, they must buy from Denmark."*
Fish expert	"*We also have food fish producers who raise fish in Sweden, and they are very good producers*. *And it is a limited scale in Sweden now still and we would like to see more even conventional aquaculture."*

Entrepreneur A said that the exchange of opinions and experiences was more relevant at an early stage in the development of the company. After the company becomes more economically independent, its openness decreases due to secrecy. However, contacts with universities and trade association remain. Entrepreneur A also sees some development in technology over the past five years, which is confirmed by the fact that much more people are trying commercial production compared to hobby production. Entrepreneur A said "*Yes, they began to move from hobby projects to commercial companies, but this did not happen. It hasn't gone commercial yet, but at least some companies have."* Entrepreneur mentioned also Southern folk high school that opened courses in the AP's engineering. Despite the growing interest, the entrepreneur B sees a problem in attracting funding to AP, which stops the technological development in this area. The entrepreneur said, *"Everyone wants to invest in an app on the phone, but very few people think that food is actually terribly interesting."* She added that there is a lot of people who are interested in the technology. The company participate in conferences about food and food technology and there are many indicators that Sweden wants to be ahead in the food tech market.

Authority said that aquaculture is one of the central questions of food system development strategy on the national level, which is also indicated by the

provisions included in the reports that was publicized by The Swedish Board of Agriculture. Authority compared the situation with aquaculture in recent years, which makes it clear that the state is more involved in the question of development of the innovations and aquaculture on the land is a very interesting direction. Authority says, "*It is of course very welcome with innovations, and it is something that you try to support in several places."* She mentioned that it possible to get funds that one can apply for. There are also regional actors who support innovations in a slightly earlier stage, in the development phase.

Shopkeeper realized also how food production is changing and becoming more technological and digital over time. He mentioned that he is planning to install a HP setup inside in the store. The interviewee also noted that their store chain is following the development of technologies that allow produce the food in the store itself. The shopkeeper said, *"As for the HP school, I was in early and talked to those who started the idea and built a farm in the basement."* However, it did not go as it was intended at the beginning and the project was restarted and solutions was customized.

Despite the growing vegetable production, horticulture expert said that it is problematic to inbuild high technology into food production. Here's what expert in horticulture says about it: *"We have a gap between the industry when there is a huge development of automation and digitization in the manufacturing industry and those who do what they know nothing about food production and those who do food production do not engage in technology development or the manufacturing industry."* He highlighted that technical solutions are not moved between industries.
However, conventional greenhouse cultivation is carried out with the help of automation, especially for production in large greenhouses and on large areas. There are two systems for such cultivation and expert in horticulture said that it is possible to maintain a suitable climate in a greenhouse with already established technology. To support automation and develop technologies, investments are needed that are difficult to get from banks, which agrees with the opinion of entrepreneur B. Horticulture expert said *"It is that it is very difficult to raise capital to build greenhouses. The banks are not very positive."*

The fact that technological systems for AP still must develop is also confirmed by the words of one of the entrepreneurs. Entrepreneur A said, "*There are not many manufacturers that you can buy systems from."* Many people must make their own systems, and the technology and systems need to mature. At the same time, the company owns one technological patent for AP production and at the time of this study, the company has applied for another one. As for investments, the

entrepreneur A used support from the EU fund, however, it was intended for the general development of agricultural activities and not specifically for AP.

However, this is an exception to the rule since the opinion of experts about the gap in technology in the production of AP is shared by a representative of science. Researcher said that Sweden is at late start and it's not because Swedish technology is behind in general. Engineering technology in Sweden is very good and it is possible to build airplanes and other high-tech things. However, he said that *"... to get a special integrated system for agriculture, they must buy from Denmark."*

Fish expert does not see much increase in AP or RAS systems in recent years. However, despite the projected increase in consumption leading to more conventional aquaculture, the organization supports the production of fish in RAS systems. The fish expert said "*We also have food fish producers who raise fish in Sweden, and they are very good producers*. *And it is a limited scale in Sweden now still and we would like to see more even conventional aquaculture."* Expert highlighted that today, production in Sweden is very limited compared to, for example, Norway

Despite the development of technology, Sweden still lags the countries of Southeast Asia and Nordics countries (Researcher, authority, fish expert). The opinion of the researcher regarding the development of AP technology in Sweden is indicative and he said "*Sweden is slow relative to Asia simply because there is no population pressure. Sweden technology is behind you because you have enough food".*

Opportunities and difficulties for AP

Considering the experience and opinions of the respondents, see Table 8, may be concluded that technologies for agri-food production are not sufficiently present in Sweden (entrepreneur A & B, expert in horticulture, researcher).

Table 8 The contributing factors and barriers derived from the results of sub-theme "Technology development and AP".

Contributing factors for development	**Barriers for development**
The education places for engineering	The lack of investment from the private actors
The interest in the commercial production	The lack of integrated systems on the Swedish market
The investment from the official side	

The interest from official side on national level to the innovations in food sector	Swedish technologies do not "see" the food sector
The patents	Lobby of conventional producers

There is a network for the transfer of experience and knowledge however business secrecy may limit the synthesis of experience (entrepreneur A & B). There is only one patent today in AP sector. However, it seems that the interest in AP is growing, and different actors want to try the AP on the commercial scale (entrepreneur A & B, fish expert, authority). Lack of funding from private actors slows down the process of AP development (entrepreneur A & B, expert in horticulture). At the same time, there is support for funding from the state side, although it is not specifically aimed at AP (entrepreneur A, fish expert, authority). Conventional aquaculture and horticulture may be a barrier for development of AP because of lobby (expert in horticulture, fish expert).

5.4.2 Industry awareness of AP

Entrepreneurs agree that AP cannot be built into the fish and vegetable industrial production because those standards that exist today do not leave room for the technological implementation of AP. Entrepreneur A think that it will be a few more years before we can talk about an industry with many suppliers of food that is produced in AP.

Entrepreneur B thinks that the AP may be implemented only step by step, see Table 9, and she said, "*I think it's a long way off. It will become part of a mixture of technologies and vertical growing or HP. It is a complex ecosystem."* She added that you must have a lot of different types of knowledge to make it tick. However, everyone who visits the facility, from top chefs to investors think that this is the future.

Table 9 Results obtained according to the sub-theme "Industry awareness of AP".

Stakeholders	**Quotes**
Entrepreneur B	"*I think it's a long way off. It will become part of a mixture of technologies and vertical growing or HP. It is a complex ecosystem."* "W*hen you scale up for that, then you run into a lot of problems."*
Entrepreneur A	*"If you build a large facility, then this may be contrary to the idea of local food, since you will have to deal with delivery over long distances."*
Shopkeeper	*"If I would start to produce it in this way, I would contact the quality managers in the centralized network and ask questions about it."*
Horticulture expert	*"Technological slowness does not contribute to the development of the industry"*

Fish expert	*"Yes, still small scale when it comes to RAS so the more the problems should be solved."*
Authority	*"There are waste heat facilities that you could use and could have, and this type of heated ground aquaculture system."*

Entrepreneur A also highlighted that lack of specialists in AP will be an obstacle to get more commercial facility. However, the forecasts of entrepreneur B are more optimistic for the future, who predicts a sufficient influx of young professionals.

Entrepreneur B explains the difficulties of implementing into industry standards by the fact that in AP certain difficulties arise when increasing production. Expert also believes that those who start AP naively believe that the systems will work regardless of the size of the production. She thinks that it is not a problem to make it work in hobby activities and those who have a small tub with fish and a little salad on a very small scale can grow without any problem and she added, "*When you scale up for that, then you run into a lot of problems."*

Entrepreneur A said, *"If you build a large facility, then this may be contrary to the idea of local food, since you will have to deal with delivery over long distances."* He also believes that regardless the size of facility is required the same workforce per square meter.

Shopkeeper does not yet fully understand how such innovative production as AP will fit into the food industry. While a grocery retailer is installing HP in its retail space, the regulations remain unclear. The shopkeeper store said, *"If I would start to produce it in this way, I would contact the quality managers in the centralized network and ask questions about it."* Also, he would make sure the supplier respects the rules and things that exist.

Expert in horticulture sees the difficulty in integrating AP into the industry because of the technical side of it, which has little interest from lifelong conventional growers who are about to retire. The expert said that he sees the problem in specialists, which is similar to the opinion of the entrepreneur A. Without this, it is difficult to talk about the development of new technology in general. The expert said, *"Technological slowness does not contribute to the development of the industry".* He added that this may be individual and it's hard to understand at an industry level because there are always those who are very far ahead, and then there are always those who are so far behind, and then the majority is in the middle. For example, when something was introduced enough, then the vast majority caught on and we can talk about reshaping.

He thinks that the development of the industry or the integration of AP into the industry largely depends on the young farmers who will replace the retired farmers horticulture expert thinks. In addition, to make production better and more efficient, investments are needed, which in the end are difficult to obtain if the economic benefit is not clear. The expert in horticulture said also that greenhouses in Sweden are in poor condition, and it is urgent to build new ones, but investments are not easy to come by. All this leads to the fact that for example Dutch tomatoes are more competitive in the market because of the price.

The expert in the fish industry believes that some of the companies that are currently raising fish in RAS systems or in AP have the potential to become part of the industry. However, like Entrepreneur A, the expert believes that a serious limitation in order to become part of the industry is the volume of production in the first place. Regulations that limit the expansion of industrial production and cultivation were also named. Expert in the fish industry *says "Yes, still small scale when it comes to RAS so the more the problems should be solved."* The industry organization lobbies issues related to increasing fish production, which is dictated not only by economic growth, but also by the request that comes from politicians and authorities. Expert said that we must find new ways to produce fish in Sweden and they do a lot of lobbying as an industry organization. Authority sees opportunities for integrating AP and RAS systems into an existing industry or abandoned places of the postindustrial time. Authority mentioned sparsely populated areas and unused facilities where it is possible to organize production. She also added, *"There are waste heat facilities that you could use and could have, and this type of heated ground aquaculture system."* There are some open systems that fit well into watercourses with good through drainage. Then there are kind of sparsely populated areas where we might have unused production facilities or production with waste heat that could be reclaimed and could have, and this type of heated land aquaculture system. However, when we are talking about a pandemic, then when restaurants and tourist places did not work, then fish producers in aquaculture who worked directly with restaurants had nowhere to supply fish. Since shops only take fillets. She explained it by that Swedish buyer do not buy uncleaned fish. Therefore, the processing industry is not ready yet.

Opportunities and difficulties for AP

To date, AP cannot be integrated into the agri-food industry because there is not enough production capacity, see Table 10, problematization of scaling up and the complexity of the production process requires more specialists in this niche of production (entrepreneur A & B, expert in horticulture, fish expert, shopkeeper).

Table 10 The contributing factors and barriers derived from results of the sub-theme "Industry awareness of AP".

Contributing factors for development	**Barriers for development**
The economic benefits by increasing the production	Not enough large producers
The need of rebuild the older greenhouses	A complexity of the system
The energy usage from other industries	The lack of specialists at the moment
The possibility to use the postindustrial buildings	The lack of connection to the processing industry
The workplaces can be organized everywhere	Problematic to scale up
	The longer delivery if scaling up
	Unclear how to build in and maintain in the shopping centers

There are also difficulties in the processing industry in terms of filleting (entrepreneur A, authority). AP is less interesting for older growers but at the same time greenhouses in the country need a makeover. There is a potential to use the buildings of other industries and to receive energy return from other industries (entrepreneur B, authority, expert in horticulture).

5.5 Market condition and consumer behaviours regarding AP

This theme highlights the culture attitude of buyers towards products grown by AP and the attitude towards the technology itself. Consumer behavior and market resistance are also considered.

5.5.1 Cultural perception of AP

Food produced in AP is not an innovation and these products has always been part of the daily diet in Sweden. On the one hand, entrepreneurs do not see a gap in the cultural perception of such food products because it is familiar food, on the other hand, the production itself may cause a certain dissonance in the perception of food, see Table 10. Entrepreneur A said *"However, the big problem lies precisely in the cultivation of fish. There is some controversy around this, and I have had reporters wondering what it all looks like."* He added that the reporters wanted to dig a little deeper to see how it's going because the cultivation of fish on the land is perceived differently. Entrepreneur A believes that if people live near an AP plant, visit it and

see, for example, fish in closed containers, then this raises questions about the well-being of animals. According to the entrepreneur, this aspect should be given more attention when one is considering starting AP, because people do not understand what it means animal well-being in production process.

Table 11 Results obtained according to the sub-theme "Cultural perception of AP".

Stakeholders	**Quotes**
Entrepreneur A	*"However, the big problem lies precisely in the cultivation of fish. There is some controversy around this, and I have hade reporters wondering what it all looks like."*
Entrepreneur B	*"The varieties of farmed fish also fit into the cultural setting of the buyer if fish does not seem exotic."*
Researcher	*"There is a general preference by the older people to take a naturally caught fish. They want something natural."*
Authority	*"This can be tricky if you want to have a lot of tropical fish in your production and you think it should go to the domestic market."*
Shopkeeper	*"I think that it is the information and education issue. There may be some resistance to food that you do not know."*
Horticulture expert	*"People know that the cucumber is grown in such rock wool or pumice stone, we have done that since the 60s, so it is not like something new."*
Fish expert	*"I do not think there are problems that the fish are grown in land-based facilities. But there is the problem that there are other species."*

Entrepreneur B said, *"The varieties of farmed fish also fit into the cultural setting of the buyer if fish does not seem exotic."* The entrepreneur mentioned Tilapia which requires a special approach to cultivation and does not look very attractive in the eyes of the buyer. This entrepreneur also draws attention to the fact that people pay more attention not to the final product, but to the technology itself.

Researcher believes that AP and its products may conflict with the mainstream food culture. Firstly, it concerns the fact that meat consumption significantly exceeds fish consumption. Researcher said that Swedish people eat more meat than fish. Secondly, people tend to separate food into natural and artificial. Researcher said *"There is a general preference by the older people to take a naturally caught fish. They want something natural."*

Authority thinks that one should proceed from the fact that there is a small group of people who want to try something new and a large group of those who get used to unfamiliar products for a long time. She also thinks that it might be easier to move on to products that are similar to what we had before. However, she added, *"This can be tricky if you want to have a lot of tropical fish in your production*

and you think it should go to the domestic market." On the other side it is not a problem if it is exported.
Authority said that one really must consider what is the cultural heritage in Sweden with lettuce and tomato and other vegetables. When the authority talks about her own feelings, then in her perception with such products there should be no difficulties from the point of view of cultural setting.

Shopkeeper believes that there may be questions about products that are not traditionally grown, but such contradictions can be eliminated. The shopkeeper said *"I think that it is the information and education issue. There may be some resistance to food that you do not know."* However, he added that if you can be transparent and clear, it shouldn't be a problem with food from AP. Shopkeeper does not see any cultural conflict with such products or any opposition from buyers' side.

Expert in horticulture believes that not many people think about how fish is produced. As for vegetables produced in HP, this approach has been known for a long time and there is no cultural confrontation here. Expert said, *"People know that the cucumber is grown in such rock wool or pumice stone, we have done that since the 60s, so it is not like something new."* On the other hand, people are skeptical about what is produced artificially or with the addition of something artificial that can influence the choice, the expert added. He is convinced that the way fish are raised on land is unlikely to conflict with the buyer's cultural perception of how it should be.

Fish expert said that consumers are quite conservative and new varieties of fish are not popular and exotic varieties of fish or unfamiliar varieties can be ignored by buyers. The expert said *"I do not think there are problems that the fish are grown in land-based facilities. But there is the problem that there are other species."*

Opportunities and difficulties for AP

Vegetables and fish have historically been a cultural part, see Table 12, of the Swedish diet (entrepreneur A & B, fish expert, authority, shopkeeper, expert in horticulture).

Table 12 The contributing factors and barriers derived from results of the sub-theme "Cultural perception of AP".

Contributing factors for development	**Barriers for development**
Familiarity with food produced in AP	Unfamiliarity with the technology
Familiarity with the production of greens in the greenhouses	Exotic species may be a repulsive factor
	It does not fit the meaning of "natural" food

	Time spent on enlightenment of a consumer
	Unclear about animal well-being
	The significance of meat

However, the meat is more popular and even may have a stronger cultural fundament (researcher). Exotic fish species may be rejected because of unfamiliarity with cooking and taste factors (entrepreneur B, fish expert, authority). The ignorance of buyers about the production technology and the division of food into that which is grown in natural conditions and non-natural ones can be a factor of rejection (researcher, expert in horticulture).

5.5.2 Market and users' attitude towards AP food

Entrepreneur A said that their products are of very high quality and can seriously compete on store shelves with products grown by other methods. However, many buyers have no idea about AP, which potentially could increase the demand for such products at least for the target group. The company focus on the group of customers who think about the environment and is ready to pay the higher price for food that is grown within the concept of sustainability. These consumers care about the quality of the products, prefer locally produced food or those who usually buy organic food, see Table 13. The company sell food through wholesalers because is easier for company handle the delivery. Entrepreneur A said about target group *"Those who understand the principle and believe that it is equivalent to organic. And of course, those who want to grow locally who want something that is not have been transported long distances."* However, this is a minority of the total number of buyers. However, in general entrepreneur think that most customers are guided by the price when buying food.

Table 13 Results obtained according to the sub-theme "Market and users' attitude towards AP food".

Stakeholders	**Quotes**
Entrepreneur A	*"Those who understand the principle and believe that it is equivalent to organic. And of course, those who want to grow locally who want something that is not have been transported long distances."*
Entrepreneur B	*"We get a lot of people who buy from us and come back. It's a good marketing tool for us. And people became more familiar with technology as well."* *"They wouldn't be competitive. No, I think unless the supermarkets change their strategy of selling things as cheaply as possible. It would really not be possible."*
Researcher	*"You must get a famous cook. Well, this is a famous cook will prepare some fille while someone wear a blindfold*."

Authority	*"And you can see all these reports and so on. They are soaring and it would have been stupid if Sweden had not kept up with that development."*
Shopkeeper	*"I also think I feel a very clear tendency among customers, that they want to buy locally grown and that is important for consumers."* *"On the subject of price, I would probably like to say that in grocery trading, price is always important, but not necessarily low price."*
Horticulture expert	*"If you look at a ten-year period, more Swedes choose Swedish-produced and Swedish-produced take market shares."*
Fish expert	*"There are many people who pay attention to that (WWF) guide and these labels."*

Entrepreneur B said that the sale through REKO market is very good for business. This serves as a marketing tool and helping to educate customers about the production process and get feedback on the product, which is important for development. Entrepreneur B said *"We get a lot of people, who buy from us and come back. It's a good marketing tool for us. And people became more familiar with technology as well."* She also believes that the quality of products is very high. This applies to both taste and keeping quality during transport and storage. As for competition on supermarket shelves, she thinks it's hard to achieve. This is explained by the fact that supermarkets have a strategy to sell as cheaply as possible, thereby earning more on cheaper products. Entrepreneur said, *"They wouldn't be competitive. No, I think unless the supermarkets change their strategy of selling things as cheaply as possible. It would really not be possible."* Entrepreneur believes that when food is produced sustainably, a completely different approach is needed in the organization of sales and, accordingly, in pricing. Entrepreneur said that if cheap cucumbers and tomatoes are shipped from Spain and the Netherlands, local AP products cannot fit into the supermarket business model. That is why their distribution channels are restaurants, conferences, and local food markets. These actors are aware about environmental issues and prefer to buy local produced food.

Researcher believes that the older generation is more price sensitive and prefers to buy fish that was caught in open water. The middle generation and their children will buy AP products if they are enlightened in this topic. To take a place in the market niche, AP products need campaigns and establishing of marketing channels that can introduce the products to wider groups of buyers. The researcher think that it is good to do campaigns with food from AP and probably it is a good idea to organize cooking for example. He said*, "You must get a famous cook. Well, this is a famous cook will prepare some fille while someone wear a blindfold*."

Researcher believes that the Swedish legislation helps to shape the market and fill it with food that is grown in a sustainable way. Since the population of Sweden is richer, people are willing to pay for ecological products or those products that are produced according to sustainability principles. He also mentioned the need for education in the diet itself when it is necessary to switch from read meat consumption to fish. Researcher believes that right now the Swedish market is not a big market because the people don't eat a lot of fish.
However, regarding export, the scientist sees a huge potential, especially in the direction of the Japan fish market. The fact that Norway is the main supplier of salmon to Japan is explained by the fact that, firstly, fish is used in national cuisine, in sushi. And secondly, there are no parasites in such fish, which makes it very popular.

Authority said that aquaculture is becoming more and more economically attractive, and sales of food made in Sweden are increasing. Authority said that because of growing population aquaculture products are increasing all over the world. She added, *"And you can see all these reports and so on. They are soaring and it would have been stupid if Sweden had not kept up with that development."*

Shopkeeper said that consumer attitudes have changed a lot about where products are made. There are more and more buyers who want to buy locally produced, as close as possible to their place of residence. Shopkeeper said
"I also think I feel a very clear tendency among customers, that they want to buy locally grown and that is important for consumers." He thinks that it's more important now than it was five years ago. He also said that organic products have also become more in demand, but in comparison, locally produced products dominate the consumer basket. The shopkeeper said that he is ready to sell food produced in AP in the store if it is economically justified and is in consumer demand. He explained it by an inner city rent per square meter and that must be a very high degree of refinement per square meter for it to work. However, he said that before there is demand, it is necessary to show the buyer that such a product is available, especially if it is of high quality and sustainably produced. He also believes that to better understand what sustainable products are, buyers need to be more enlightened in such matters.
As for the prices of products, the retailer believes that not everything is so unambiguous. This is not to say that everyone wants to buy only cheaper. In many ways, this depends on socio-economic factors. He said, *"On the subject of price, I would probably like to say that in grocery trading, price is always important, but not necessarily low price."* In addition, he said that it must be affordable, and they invest in affordability through local, qualitative, and sustainable production. He thinks also that the store can influence the choice of the buyer, but it is necessary

that there is information about the product, about how it is produced. This is also the task of both the manufacturer and the supplier.
He believes it is certain that AP products can compete with conventionally produced foo. However, when a consumer stand in front of the shelf in the grocery store and must choose which basil should you take, conventionally grown or hydroponically grown, the product should be provided with information from the grocery store or from suppliers.

Expert in horticulture sees the problem in having to compete with import of food that are produced with lower price and without concept of sustainability in mind. However, despite this, the expert notes that there have been serious changes in the behavior of buyers, and they are increasingly choosing products produced locally. He said, *"If you look at a ten-year period, more Swedes choose Swedish-produced and Swedish-produced take market shares."*

Fish expert noted that more and more buyers are choosing fish that are produced sustainably and is certified. Also, the expert talked about the fish that is included in the list of WWF and fish species that are red listed in the fish guide. *"There are many people who pay attention to that guide and these labels",* he said.

Opportunities and difficulties for AP

Food grown in AP can compete with other food, see Table 14, because it is not inferior in taste and quality (entrepreneur A & B, shopkeeper).

Table 14 The contributing factors and barriers derived from results of the sub- theme "Market and users' attitude towards AP food".

Contributing factors for development	**Barriers for development**
Locally produced	The price
Acceptance of the retail sector	The limited target group
The export is possible	The time spent on the marketing and the campaigns
Presence on the niche market	
Possibility to compete by the taste and the quality	

Consumer interest in sustainable and local food is growing, however the target group is limited (entrepreneur A & B, shopkeeper, expert in horticulture, fish expert, authority). For distribution, enlightenment, marketing, and campaigns are needed to sell the food produced in AP (entrepreneur B, shopkeeper, researcher). The high price is not a significant barrier for people who are interested in sustainable food, but it is an issue for some wider social group (researcher,

shopkeeper). Consumer demand is growing for local food produced in a sustainable way. There is a huge potential for export as the quality of the products improves (researcher, authority).

5.6 Results summary

The table shows the main prerequisites and barriers that were identified during the thematic analysis of the results obtained under the interviews with stakeholders.

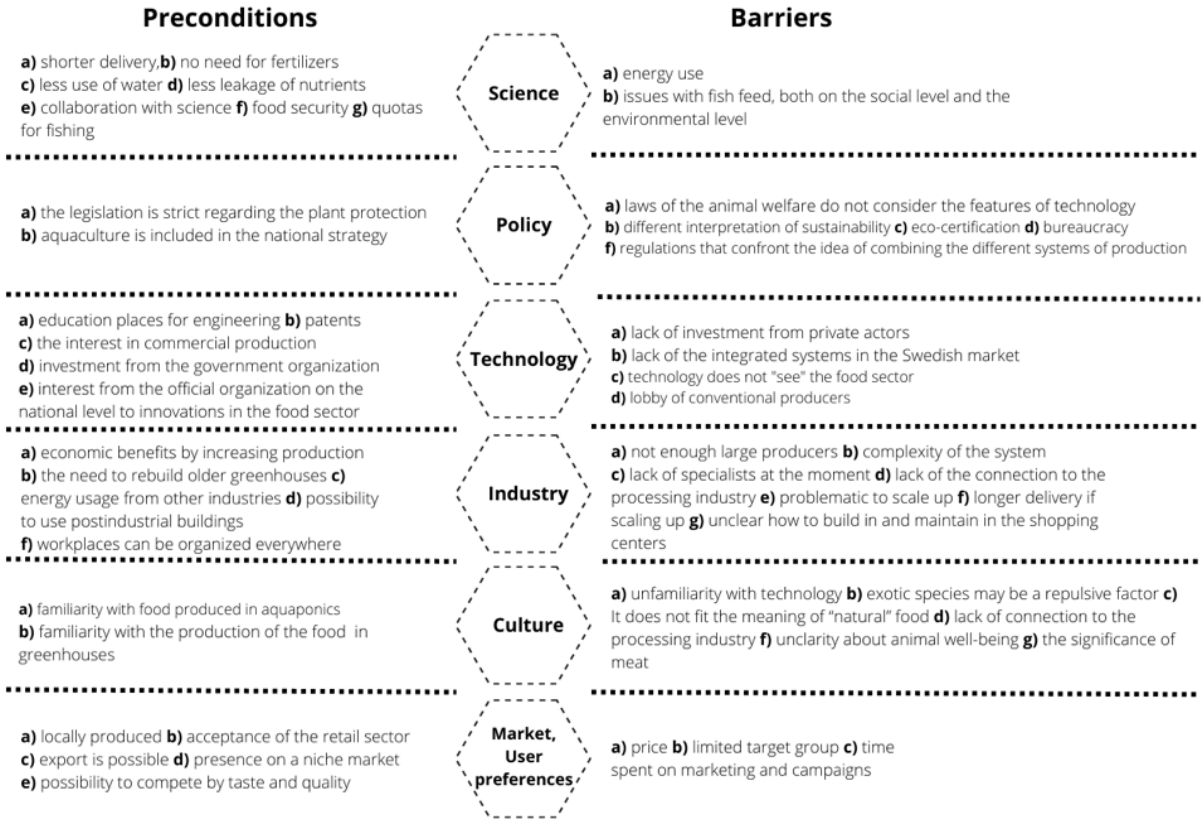

Figure 5 Preconditions and barriers for AP

Each sub-regime has its own characteristics of interaction with the AP, which was revealed during the processing of the results. However, it was not always obvious in which sub-theme to place unit of meaning. Therefore, the general context of the units of meaning was taken into account.

6. Analysis and discussion

AP is an innovative solution that can be part of a sustainable transition in the agri-food sector to reduce pressure on the environment, improve food security and increase food production for both domestic consumption and for export. The aim of this study was to determine *"How can AP technology escape the innovation field and be embedded in the Swedish agri-food system?"*
To do this, it was necessary to answer the two sub-questions: a) *What are the opportunities and barriers to the development of AP technology considering the agri-food standards in fish and horticulture production in Sweden?* and b) *What conditions are necessary for the penetration of AP food into the market?*
To escape the innovation niche and fit into the regime, AP needs to go through three stages of protective spaces within the theory of MLP. The literature research has shown that the theory of MLP and the concept of protective spaces has gained acceptance in the study of sustainable transitions in the agri-food sector (El Bilali 2019; Loorbach et al. 2017; Mylan et al. 2019).

6.1 Socio-technical landscape

Socio-technical landscape performs on macro-level and consist of a plexus of exogenous slowly flowing processes and events in socio-ecological systems (Geels 2002; Rip & Kemp 1998). These socio-ecological systems fundamentally determine the development of society and changes in them occur over a long period of time. For such changes to begin, external pressure is needed, which can be expressed in an environmental threat, a large-scale war, a pandemic, economic or political development and migration.
The environmental and geo-political problems that are accumulating in the landscape destabilize it and the landscape begins to put pressure on the agri-food regime within fishing, conventional aquaculture, and horticulture, thus indicating that conventional food production must become more sustainable and independent of export. At the same time, the landscape directs its expectations about sustainability solutions towards the meso-level or innovative niche. This expectation creates a desire among hobby-enthusiasts to try a new sustainable mode of production as an experiment.

The stakeholders are aware of the negative processes in environment and understand the root cause of these phenomena. The use of fossil fuels for transporting food, catching fish, and growing vegetables releases greenhouse gases into the atmosphere and consequently affects climate change. These negative pressure on the environment is lower in AP separate systems, that was shown i previous LCA studies of AP (Greenfeld et al. 2021; Breitenstein & Hicks 2022).
Fish farming in open water, the use of chemical fertilizers and chemical plant protection products leads to biogeochemical pollution and affects biodiversity. According to previous studies, AP could slow down the negative consequences of food production (Atlason et al. 2017; Alkhalidi et al. 2020; Körner et al. 2021; Körner et al. 2017; Ghamkhar et al. 2020; Chen et al. 2020; Joyce et al. 2019). Overfishing is destroying the ecosystem in the Baltic Sea and leads to the extermination of species, and this is similar with conclusions of Sumaila and Tai (2020). The previous studies also showed that AP reduces the use of fertilizers which reduces the pressure on ecological systems on the land and below the water (David et al. 2022; Yep & Zheng 2019; Monsees et al. 2019).
The interviewees did not mention the reduction of water use, however, in previous studies, a significant reduction was found, since water is constantly circulating in the system (Joyce et al. 2019).
In the dimension of landscape, pressure may be caused by the geopolitical processes that began with the war in Eastern Europe. Both Russia and Ukraine are important links in both the global food system and food trade in general. The war leads directly to the disruption of food supplies to Sweden, both in the case of fish, and indirectly through the overpricing of energy for food production and transportation. One more example is the pandemic COVID 19 that affected the whole society and showed that local food production should be rethought. Therefore, food security is the very serious aspect that follows from geopolitical instability. Yanes et al. (2020) concluded in their review that the technological solutions used in AP are excellent solutions for local production, considering environmental problems in the agri-food system. Ragaveena et al. (2021) concluded that the possibilities of producing food in controlled environments open wide opportunities not only for business, but also for personal needs.

6.2 Socio-technical regimes

Socio-technical regime performs on the meso-level of the hierarchy and represents the technical systems, the actors, and rules/institutions Geels 2004; Geels 2020). The fish industry and horticulture industry are the sub-regimes in the Swedish agri-food regime, and they interplay with market sub-regime, technology sub-regime, policy sub-regime, culture sub-regime and science sub-regime.

According to the theory, agri-food regime should be subject to landscape pressure, since the conventional cultivation of vegetables and fish has a negative impact on the environment (Geels 2002). The policy sub-regime is tailored to serve the agri-food regime and vice versa, the horticulture and aquaculture sub-regimes activities affect the legislation. It shows interplay between the sub-regimes, and it also shows system strength. Therefore, despite the strictness of regulations regarding sustainability, innovation cannot be in line with the policy sub-regime, even despite all its advantages in sustainable food production. In addition, excessive bureaucracy can delay the development process. The interesting is that sustainability may be interpreted differently what make the regime more resilient for transformation. This allows regimes to gradually reconfigure the production method and grow food more sustainably, that is in line with legislation. This is also facilitated by the availability of the necessary technologies, which are used, for example, in greenhouses, aquaculture or fishing. The food from the conventional production is built into the market and meet the expectation of the buyer regarding the price and culture meaning. The fish sub-regime and horticulture sub-regime as well as the retail sector, are involved in various projects related to the sustainable cultivation of vegetables or fish often with support of universities.

Summing up the results obtained by data analysis of the industry, one may conclude that the industry has no prerequisites for the fast transformation but rather for a slow evolution. Moreover, combination of two different mode of production remain invisible for the legislations. Conventional horticulture as well as aquaculture in open water or fisheries, have their own established equipment and it can be a certain obstacle to the development and spreading of AP integrated systems.

This indicates the stability of the agri-food regime even though there are factors that do not meet the principles of sustainability. Moreover, interest in sustainability is seen only from the side of the policy sub-regimes, the business wants to change only under pressure of legislation. Despite on the national sustainable food strategy, there are not any subsides that are created specifically for AP. Moreover, it is very difficult to attract venture capital in AP`s startups. The socio-technical regime in MLP framework does not include a financial dimension. It is likely that the financial sub-regime should be taken into account in order to reflect the fuller dynamics between levels. The results showed that funding has a deterrent to development.

Given that landscape pressure on the regime it opens a window of opportunity for innovation into the regime, the question remains how significant the negative effects of conventional food production should be. Therefore, the *expectation* directed to the micro level mainly comes from the policy regime, even because legislation causes difficulty in the creation and development of AP.

The example of sustainably grown food failing eco-certification also demonstrates a strong regime structure. This is in line with research made by Gregg and Jürgens (2019) in Sweden that showed the legislation as one of the most important obstacles for AP. Fruscella et al. (2021) and Cammies et al. (2021) highlighted that EU legislation is not formed for AP, since AP consists of two legally independent systems, this makes it difficult to obtain a business license. Moreover, if a customer wants to pay for sustainable food, then the inability to use organic certification for AP products may leave the product unclaimed. Even though the actors talk about the contradictions in the legislation and bureaucracy, the study of official documents and strategies at the national level and EU level showed interest of the state in developing the sustainable food system, supporting innovation in agri-food sector and aquaculture (Pia & Röös 2021; EU 2020; SJV 2022; Livsmedelsstrategi 2017; Regeringskansliet 2017; Sweden Food Arena 2021).

6.3 Niche-innovations

According to the conceptualization of the protective spaces, AP may develop through three stages, going through an evolutionary process. Technical innovations originate in hobbies or experiments in a *shielding* phase, where they need a *passive* or an *active protection* from the dominant regimes (Kemp et al. 1998; Smith & Raven 2012; Raven et al. 2016). The difficulty for the passive protection is the inaccessibility of technology and the lack of knowledge. Interest in the topic of sustainable development is the best driver to start such a project. Representatives of the sub-regimes have stated that they are experimenting with HP and a RAS system, which is an example of active protection on R&D department level. The results show that hobby AP may have some difficulties to transfer to a commercial level due to limited access to the necessary equipment, which characterizes the isolation of the technological sub-regime. The difficulties to get access to hi-tech equipment highlighted by König et al. (2018) in their research about AP. One of the companies that was interviewed said that they made integrated system itself, which had allowed to obtain a strong potential in this area and move to next stage of development. Junge et al. (2019) in their research showed that in Sweden AP almost does not go beyond hobby or training centers, despite a certain interest. Also, one of the obstacles for a start-up is the lack of funding from private investors. However, such a start-up may receive funding from public funds, which are allocated both at the national level and at the EU level, which may be a *passive protection* of innovation.

Difficulties with the expansion of production arise at the level of the *nurturing* and are associated primarily with the complexity of the process, lack of specialists

and the ambiguity of how to integrate into the current food industry. Latest studies also highlighted difficulties with integration into industry because of problems with large commercial systems and productivity, complex of the systems and lack of qualified workers (Turnšek et al. 2019; König et al. 2018; Breitenstein & Hicks 2022). According to the theory, at the phase of *nurturing*, knowledge is disseminated, and social networks are formed, which expand due to expectations from the potential of innovation (Schot & Geels 2008; Grin 2020; Raven 2005; Kemp et al. 1998). Horticulture sub-regime sees no potential for AP as those working in the industry often approach retirement age and they do not want to change they mode of production and the innovation should be establish by other actors first. The government places certain hopes on such innovations and sees their integration into other industries, which requires additional knowledge and involvement of many stakeholders. Similarly, the fish industry sees opportunities to incorporate AP or RAS systems as there is a need to expand the market.

Previous studies showed that AP may be economically profitable if the system is used to the fullest, despite the high investment (Quagrainie et al. 2018; Baganz et al. 2020). The emergence of courses related to AP and the training of engineers are indicators of the willingness to protect innovations and the form a technological niche with the support of regional authorities. The emergence and spread of AP courses, the interest of citizens, collaboration with university and the support of the state form a space for the *nurturing* of innovation, as expectations of social actors begin to grow (Smith & Raven 2012; Schot & Geels 2008). The research written about education in this field emphasized that even in the face of economic uncertainty, the organization of training centers is an important condition for the development of technology (Milliken et al. 2022; Maucieri et al. 2018).

In the third phase, *empowering,* AP product tries to take a place in the market and compete with other food when a window of opportunity opens in the regime, due to landscape pressure.
The culture is one of sub-regime in the theory of MLP that may resist the innovation (Geels 2004; Geels 2020). Since AP produces a very traditional food and symbolic meaning is part of this food, one may assume that the cultural perception of a familiar variety of fish or vegetable should not be characterized by cultural dissonance. The theory said that a product may *fit-and-comfort* to the market (Smith & Raven 2012). However, exotic fish species can be dismissed as lacking any symbolic meaning or cultural code. The food production in AP may not be acceptable by byers due to the "unnatural" production. The previous studies shown that the producer must be accept by the buyers, the consumers must accept the product, and external factors must be favourable (Baganz et al. 2020).

Consequently, with gradual development, the fish from AP can be fitted into the cultural acceptance of the buyer.
The results also show that meat is part of a culture regime, and its symbolic significance can reduce the value of the fish diet. According to the theory, AP is at the stage of *empowering* where it tries to communicate with buyers and penetrate a niche market (Smith & Raven 2012; Raven et al. 2016).
According to the theory, an innovative product can be built into a market niche during the *empowerment* phase (Smith & Raven 2012; Raven et al. 2016). The results showed that AP products can compete to some extent with conventionally produced food, as may gradually *fit-and- conform* the shopping trolley because taste and look are good, and the food meets the demands and standards of the market. The food already is presented in market niche and is distributed throw REKO, city´s restaurants and a wholesaler.
However, the way of production itself does not correspond to either the market's standards or the buyer's ideas about how food should be produced. Therefore, it shows the need for a restructuring of the institutionalized features that, according to the theory, can *stretch-and-transform* the regime (Smith & Raven 2012; Raven et al. 2016; Mylan et al. 2019). The results corelates with previous research which showed that marketing, availability, and enlightenment are very important to take a place on the shelve (Baganz et al. 2020; Turnsek et al. 2020).
In addition to the above circumstances the learning process of AP is not stabilized, there are not powerful actors who wants to invest into AP, the prices cannot compete with imported food and innovation does not occupy more than five percent of the market niche. Therefore, according to Geels and Schot (2007) it is to early talk about the market penetration yet.

6.4 Limitations

This study was limited due to the following factors: limited number of study participants and semi-structured online interview.
The number of participants can be increased and supplemented. For example, representatives of the media, buyers and non-profit organizations were not represented in this study. In addition, those actors that were interviewed could be duplicated to create an additional dimension in opinion.
A semi-structured interview conducted online has its limitations because the psychological connection was not possibly established enough during the interviews, and the moment to ask the right additional question could be missed.

6.5 Further research

It would be of most interest to study the buyer's behavior and attitudes to AP within the REKO market and buyers within the mainstream market. In addition, it remains an important question how educational activities in a supermarket could affect the attitude of the buyers towards AP, especially the group of people who prefer to buy "natural" food.

7. Conclusion

Regarding all the above, it can be concluded that there is potential for the AP development, however the technology needs support.
AP can be considered as a more sustainable alternative to conventional food production and allows to grow vegetables and fish locally.
The development of this technology corresponds to the direction in which the development strategy of the food system in Sweden is being formed. The food system must be sustainable, innovative, and competitive.
The study showed that there is a pressure on the conventional food production primarily due to environmental concerns. This has an impact on the agri-food regime which is trying to respond to this pressure and adjust to. AP does not yet have the potential to use the window of opportunity and transform the regime yet. The study identified both the main barriers to the innovation and the prerequisites for that. A bridge between the technology and agri-food system has to be found. AP should be supported at the legislative and institutional level by creating a legal framework that would be more consistent with the combination of fish and horticulture production. This will allow stretch and transform the regime at the institutional level with by changing the industrial agri-food norms and establish new routines within production approaches. The transformation of regulations and the establishment of new routine for aquaponics production can win the trust of consumers. Such a transformation could make consumers more accepting of AP food, because culturally and qualitatively, AP products can fit and comfort into the market. However, further distribution of food produced in AP on the market depends on marketing and enlightenment of consumers.

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Popular science summary

Newspapers and televisions reports are increasingly talking about the weather anomalies that entail the infrastructure destruction due to floods or forest fires. We hear constantly about the glaciers melting both on the tops of mountains and in places as far away as the Arctic. According to scientists, all these negative processes in nature are caused by human activity and point to the climate change. The food production negatively affects the climate and the planet the flora and fauna. However, as the world's population increases, we need to produce even more food, which will lead to even serious consequences.

For all the inhabitants of the Earth to have enough food in the future without destroying the environment by the production of food, humanity can use technical innovations for food production that copy the ecological systems and keep the nature in balance. One of these technical solutions can be AP, which allows to grow fish on farms or in urban areas by placing it in containers. At the same time, fish metabolic products can be used as fertilizers for growing vegetables.

To understand how such food production can become more popular and how food grown in this way can spread in the market, some interviews were conducted with the food experts. The processing of the results obtained during the interviews showed that the development of AP can be hampered during development, mainly due to insufficient investment, limited access to technical devices and shortage of specialists. However, if these barriers are overcome, then AP can produce qualitative and tasty food with less negative impact on the environment.

The technical side of production is followed by the release of food on store shelves and the market. The production method is unfamiliar and may cause wariness or distrust from both the retailer and the buyer. Therefore, the legislative framework for such production should change so that it begins to comply with the industrial norms and be identified with everyday production routine. Since fish and vegetables are common foods in terms of culture, such products can be accepted in the market, and they correspond to the consumer's ideas about food. However, in order to expand the target group, the fish and vegetables from AP need to be presented as safe and natural food, which can be done through the enlightenment and the marketing.

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Appendix

Appendix 1. Interview questions to the AP representants

1.What is your role in the company (organization)?
2. What do you think about the development in AP over the past five years in Sweden? What could be the reason for the emergence and interest in such technology?
3.How ready is AP to become the industry standard today in Sweden?
4.What kind of support for the development of the enterprise do you receive from external actors, investors, large companies, government agencies or the local population?
5.Could you describe what your interaction with other AP initiatives looks like? Collaborations, exchange of experience, workshops, educational and technical materials?
6. Do you think AP can conflict with society's cultural settings towards food and how it is produced? For instance, fish is common in Sweden but not exotic species, or tomatoes grow in sludge water may feel strange for consumers?
7. Do you think AP fits into the market infrastructure?
8.How do you sell your products? Which intermediaries are involved between you and the end customer?
9.Do you think AP products are competitive on store shelves today?
10.Who is a potential buyer of your products? Do you think that such products should have special certification? How do you asses the quality of products?
11.Are you assessing the environmental and social pressures that such production has? LCA assessment for example?
12.Do you see potential for expanding production? In your opinion, is it better to have a smaller production but dispersed, or just a few but large enterprises?
13.AP deals with two different agri-food regimes: fish and plants. Could you identify what opposition each regime has against the spread of AP?
14.What do you see as the main obstacles to the development of AP today?
15.Is there anything else you would like to share that has not been covered?
16.Could you advise me who else I could talk to about AP and market with?

Appendix 2. Interview questions to the researcher

1.What role do you have in the organization?
2. How would you describe the development of AP in Sweden over the past five years?
3. What factors do you think affect the development of AP? Social, economic, environmental.
4. What support does AP' company receive from other stakeholders today? From business, government.
5.Are there enough resources for research in AP today?
6.Who is most interested in such research? Why are they interested?

7.What interest to AP have large companies in the fishing industry? Do you see any lobby in conventional aquaculture?
8. What interest to AP have large companies in horticultural business?
9. Given the combination of the right factors, can AP be a sustainable production from an economic perspective? Environmental perspective? Social perspective?
10. How ready is the agri-food industry for sustainable technological change in food production? If we look at RAS, HP and AP.
11.Does it matter to customers how a product is made? By AP, HP, or aquaculture?
12.What can guide consumers when choosing such a product?
13. What is needed to penetrate a mainstream market with such products? Can AP products be imbedded in mainstream market today?
14.What do you see as the main obstacles to the development of AP today? Market, laws, technical support, lack of specialists?
15. Would you like to add anything regarding to development of AP?
16. Could you recommend some research articles in AP field that were done in Swedish context?

Appendix 3. Interview questions to the fish expert

1. What role do you have in the organization?
2. Do you know about Recycling Aquatic Systems (RAS)?
3. Do you know about AP?
4. How do you view the development of conventional aquaculture in Sweden over the past five years? Or the RAS development?
5. What factors do you think affect the development of aquaculture or RAS?
Can there be any kind of trigger that can affect the development of Recirculating Aquatic Systems? Climate change, for example.
6. How can the geopolitical situation (war in Ukraine) affect the development of innovations in food production?
7. Can you tell us what the future development of fish production looks like?
8. How do you view sustainable technological innovations in relation to your industry? Can they change the business models that exist today?
9. To what extent do current production standards in fisheries and aquaculture allow to include AP or RAS in industrial production?
10. How did the industry view the development of sustainable production using innovative technology?
AP or RAS for example? What is needed for this? What obstacles do you see in the introduction of new technology?
11 Is their state support for innovative solutions in fish production? Is there interest from large companies in sustainable production in aquaculture or fisheries?
12 Is there any support for your activities from investors and other food system experts? Does the industry collaborate with researchers?
13 Do you feel that your business today is protected and strengthened by political structures and financial institutions?
14 Is there any pressure on the business to change today's production to a more sustainable production?
15 Do you feel any changes in the attitude towards conventional products on the market? Do you feel that consumers behave differently now in the past when they have a choice between sustainable and conventional products on the store shelf?

16 Are there any recent changes in legislation that impose a framework on aquaculture and drive it in a certain direction?
17. Can fish produced in RAS or AP be less sought after by consumers due to cultural characteristics? For example, a consumer may think that fish must be caught in open water.
18. Do you want to add something regarding fish production?

Appendix 4. Interview questions to the authority

1. What role do you have in the organization?
2. Do you know about AP? Do you know anyone who works with AP? Have you ever bought such a product?
3. Why does a government agency show interest in aquaculture and want to develop it?
4. How would you describe the development of aquaculture and agriculture in Sweden over the past five years?
5. How do you define AP today - agriculture, aquaculture or something else?
6.What factors influence the development of aquaculture and agriculture? Social, economic, environmental.
7. Do you see how aquaculture / agriculture can be developed in the future?
8. To what extent is it possible for AP to be incorporated into production standards applicable to fish farming and plant-based farming?
9. What can hinder the development and integration of such an innovation into the standard of food production? What difficulties may be associated with entering the market for such products?
10. What support is there today for an innovative food company from the state? How open is the food system to radical innovations?
11. What pressure is there today on conventional food production? Given that there is a strategy for a sustainable transition?
12. Can it be said that there are lobby groups or other actors whose activities aim to support conventional fisheries, aquaculture and agriculture without regard to sustainability?
13. Aquaculture takes a negligible share of the fish products sold in Sweden? How likely is it that AP products will be accepted by buyers in a broader market context, given the culture and consumer behavior?
14. Could it be possible to certify AP to show a consumer its sustainability benefits over another primary production?

Appendix 5. Interview questions to the shopkeeper

1. What role do you have in the organization?
2. How would you describe the development of the food sector in Sweden over the past five years? Why are these changes taking place?
3. Is there any pressure on the food sector today to change production and influence consumption? What is it connected to?
4. Do you know about innovative methods for food production? Do you know about HP, AP or recycled aquatic systems (RAS)?
5. Do you have such products in the store? If the answer is no, would you like to have such products in the store?
6. Can it be said that there is a serious lobbying activity in support of conventional food production in Sweden?
7. How important is it to market sustainable food in stores?

8. How important is organic certification for a customer who is interested in sustainability development? AP is a sustainable production but it is not possible to eco-certify such food today.
9. Is the price the most important factor for the customer? If not the price, what is the deciding factor when choosing food in the store?
10. How do customers perceive food that is not produced in a traditional way? For example, fish produced in the countryside or cucumbers grown in water? Could there be a cultural resistance to such foods?
11. Do you think the demand for locally produced food will grow?
12. How can the geopolitical situation (the war in Ukraine) affect the food chain and locally produced food?
13.What impact does ICA have on accelerating the spread of local products on the market?
14. Can products such as fish and vegetables produced in AP be built into the standards that exist today?
15. Do you know about support for innovative food companies or for sustainable agriculture from the side of large companies, the state, financial structures?
16. Could we say that AP or HP can compete with conventionally produced foods today?

Appendix 6. Interview questions to the horticulture expert

1. What role do you have in the organization?
2. How do you view the development of horticulture in Sweden over the past five years?
3. What factors do you think affect the development of vegetable cultivation in greenhouses?
Was there any kind of trigger that influenced the development of greenhouse cultivation?
4. Can you tell us what the future development of agriculture looks like?
5. How do you view technical innovations in relation to your industry? Can they change business model?
6. Do you know what AP is? And HP?
7. To what extent do current production standards in horticulture allow to include HP or AP?
8. How does the industry view the development of sustainable production using innovative technology?
AP for example? What is needed for this? What obstacles do you see in the introduction of new technology?
9. Is there state support for innovative solutions in food production? Is there interest from other actors (companies that have conventional production) for sustainable production in the horticultural industry?
10. Is there any support for your activities from investors and other food system experts?
11. Do you feel that your business today is protected and strengthened by political structures, financial institutions and other actors?
12 Is there any pressure on the horticultural industry to change the business model to a more sustainable one?
13 Do you feel any changes in the attitude towards conventional products on the market? Do you feel that consumers behave differently now in the past when they choose food on the store shelf?
14. How do customers perceive food that is not produced in a traditional way? For example, fish produced in the countryside or cucumbers grown in water? Could there be a cultural resistance to such foods?
15. Are there any recent changes in legislation that impose a framework on greenhouse production and drive it in a certain direction?
16. What impact can the geopolitical situation (the war in Ukraine) have on the industry?

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