Universiteit Utrecht

Master's Thesis - master Innovation Science

Aquaponics Development in the Netherlands

The Role of the Emerging Aquaponics Technology and the Transition towards Sustainable Agriculture

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Summary

A sustainability transition in the agri-food regime is urgently required to interrupt the strong reciprocal effect between current food production standards and climate change (Willett et al., 2019). One sustainable innovation in the agri-food sector is aquaponics. Aquaponics is the combination of hydroponics and recirculating aquaculture in one controlled environment (Somerville, Cohen, Pantanella, Stankus & Lovatelli, 2014). At first sight, the water and nutrient-saving character of aquaponics, amongst other features (Somerville et al., 2014), sound promising for a transition towards sustainable agriculture. Therefore, the following research question emerged:

How can the emerging aquaponics technology contribute to the sustainability transition in the Dutch agri-food sector based on Dutch aquaponics developments in the period 2008-2018?

To answer this overarching research question, three sub-questions were developed. An integrated framework combining the *multilevel perspective* (MLP) and the *technological innovation system* (TIS) was used to understand the dynamics between overall structural trends, the current Dutch agri-food sector and the emerging aquaponics innovation. The innovation was also set into a broader European context. The research was of exploratory nature and used a qualitative content analysis to process 23 interviews, scientific articles, practitioner websites, publication, patent and Google Trend statistics, etc.

By utilizing the integrated framework, an in-depth understanding of the emerging aquaponics innovation system and a context-view of the unique Dutch agri-food environment and the broader European perspective it aims to operate in, have been gained. This research showed that the aquaponics innovation system currently lacks the ability to contribute to the sustainability transitions in the Dutch agri-food sector. The main barriers identified in this research can be attributed to shortcomings of the aquaponics innovation system itself. Multiple drawbacks in all aspects of the emerging innovation system lead to the fact that aquaponics is currently not economically viable. As a result, the technology cannot compete with conventional agri-food practices which is amplified in the Dutch context of high efficiency and low food prices.

While the research provides theoretical contribution to the field of agri-food sustainability transitions, aquaponics in particular, and the application of the integrated MPL-TIS framework, practical recommendations are also made to foster the development of aquaponics in the Netherlands and Europe. *Entrepreneurial activities*, *knowledge development* and *knowledge diffusion through networks* were identified as critical functions to the development of the technology. They will need to be fostered on a European and national level for aquaponics to gain market access and momentum.

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Table of Abbreviations

ACAC	Association of Commercial Aquaponics Companies
ASC	Aquaculture Stewardship Council
D	dimension
Etc.	et cetera
EEA	European Environment Agency
e.g.	for example
EMFF	European Maritime and Fisheries Fund
EUAA	EU Aquaponics Association
EU	European Union
EUMOFA	EU Market Observatory for Fisheries and Aquaculture
F	function
FAO	Food and Agriculture Organization
i.e.	that is
Imares	Institute for Marine Resources and Ecosystem Studies
LTO	Land- en Tuinbouw Organisatie
MLP	Multilevel perspective
MSC	Marine Stewardship Council
n.d.	no date
NGO	Non-governmental Organization
NWO	Dutch Research Council
OECD	Organisation for Economic Co-operation and Development
SDG	Sustainable Development Goals
TIS	Technological innovation system
UN	United Nations
USD	US Dollar
WIPO	World Intellectual Property Organization
WOS	Web of Science

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1 Introduction

It is estimated that by 2050 we will have an additional 2.2 billion human beings that need to live on and be fed by the means of our planet (UN News, 2017). It has been stated by multiple sources (Willett et al., 2019; Dutch National Research Agenda, 2016; EEA, 2016; Sadik, 1991) that the unique balance of our biophysical environment is being disturbed in negative ways. The reasons for this are multifold but include, amongst others, climate change, pollution as well as sea and land degradation. All of them are caused by human activity. Therefore, to ensure food security for all humans without degrading our planet even more, sustainable solutions are crucial for the well-being of current and future generations (Willett et al., 2019).

There is a strong reciprocal effect between current food production standards and climate change. Thus, changes in climate impinge upon crop yields in terms of quality, quantity and timing by influencing parameters such as soil, water, temperature, sunlight, pests, etc. Not only is land being affected but also the marine biology. Climate change is causing negative changes on marine species, influenced by water temperature among other conditions (EEA, 2016; European Commission, 2015).

Adding to the developments, the agri-food industry is contributing to climate change by an accumulated share of 30% of global greenhouse gas emissions according to the Lancet Commission Report 2019 (Willett et al., 2019). Profound negative effects caused by plant-based farming are biodiversity loss, freshwater availability, groundwater and oceanic contamination, degradation of soil as well as water resources. These effects result from unsustainable practices such as the wide and unconsidered use of chemicals, synthetic fertilizer and pesticides (Willett et al., 2019; Krall, 2015; Ponisio et al., 2014; Rasul & Thapa, 2004; D'souza, Cyphers & Phipps, 1993). Furthermore, current fishing practices are disrupting the marine ecosystem causing the decline of fish species (Willett et al., 2019; EU News, 2018; Jackson et at., 2001). Predictions indicate that the overall impact of these negative effects will grow drastically without intervention (Ponisio, et al., 2014, p. 1).

The United Nations took action in September 2015 by articulating 17 specific Sustainable Development Goals (SDG) towards the great goal of a better, fairer and more sustainable future for the Agenda 2030 (United Nations, 2018a). The following five SDGs can be tied directly to the agri-food sector and, if achieved, result in making current practices more sustainable: SDG 2 (no hunger), SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production), SDG 14 (life below water) and SDG 15 (life on land) (United Nations, 2018a).

Promotion, focus on, and actions taken towards sustainable agriculture are vital as conventional practices in the agri-food sector are connected to detrimental environmental and health-related damages. Following Krall (2015), sustainable agriculture is defined as "*minimizing climate, soil, water, biodiversity and human health damages while increasing productivity*" (p. 5). Sustainable agriculture focuses on utilizing renewable energy instead of fossil fuels and other finite carbon-intense resources. By being climate-resistant and economically stable these practices can assure appropriate working and living conditions throughout the supply chain. Sustainable agriculture supports environmental and social sustainability, by being respectful towards the local population considering their needs, knowledge, skills, norms and institutions. It ensures that basic needs of food and agricultural resources are quantitatively and qualitatively satisfying for current and future generations (Krall, 2015).

Aquaponics is one solution which focuses on sustainable agriculture in a holistic way. It inherently incorporates the theme of circularity in food production and thus, appears to be promising for achieving the five SDGs relevant for the agri-food sector. Aquaponics is the combination of *hydroponics* (soilless plant production) and *recirculating aquaculture* (captive fish farming), in one controlled environment (Junge et al., 2017; Somerville, Cohen, Pantanella, Stankus & Lovatelli, 2014). There are two main concepts in aquaponics: One constitutes a one-loop or coupled system and is mimicking an integrated ecosystem. It assures constant ecological recycling of the water by the plants filtering the water for the fish. In turn, the filtered water is utilized by fish, as visualized in figure 1 (Lennard & Goddek, 2019; Love, Uhl & Genello, 2015; Lennard & Leonard, 2006). In contrast, in the multi-loop or decoupled aquaponics system (figure 2) the water is not looped back from the plant to the fish. However, this approach allows for individual optimized conditions in each loop, as portrayed in figure 2. Importantly, both concepts entail the flow of nutrients from the fish excretions to the plants (Lennard & Goddek, 2019).

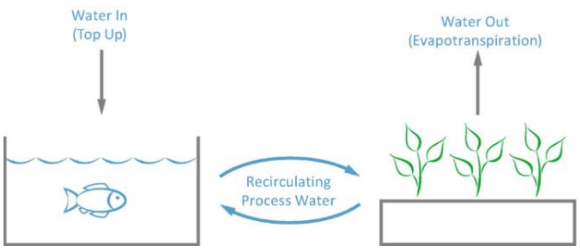

Figure 1 Coupled aquaponics system by Lennard & Goddek, 2019, p. 118

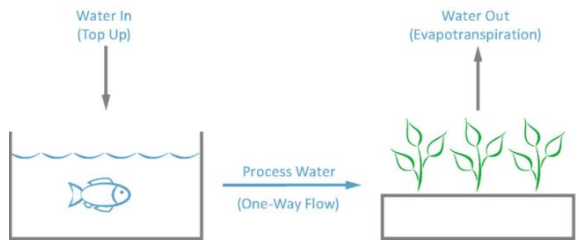

Figure 2 Decoupled aquaponics system by Lennard & Goddek, 2019, p. 119

In comparison to conventional agriculture, aquaponics is more environmentally sustainable because it is water-efficient, provides a higher level of biosecurity and does not use pesticides due to being operated in a controlled environment. The technology produces little waste and exploits organic fertilizer instead of using synthetic fertilizer (Somerville et al., 2014). In addition to environmental sustainability, aquaponics is also considered socially sustainable as it consists of an educational component which is considered a vital part of the technology. Proponents of aquaponics aim to teach this way of food production while stressing the reduction of intense labor compared to conventional farming (König, Junge, Bittsanszky, Villarroel & Komives, 2016; Somerville et al., 2014). Due to the rising awareness of climate change and need for sustainable food production methods, the topic of aquaponics gained increasing awareness and recognition in practice and research (König et al., 2016; Somerville et al., 2014).

The aquaponic system can be set up in atypical locations such as urban areas or deserts, contributing to commercial urban farming and secure food production on non-arable soil (König et al., 2016; Somerville et al., 2014). Moreover, the technology can be scaled accordingly to varying purposes: *small-scale personal usage*, *medium-scale local community contexts* and *large-scale industrial settings.* Furthermore, *teaching* in the form of education, awareness and knowledge transfer plays a vital role for the aquaponics technology in commercial and research-driven settings (Love et al., 2014).

The United States of America and Australia took advantage of their early aquaponics research and entrepreneurial leadership, leading to the commercialization of aquaponics[1]. Commercialization efforts

[1] Aquaponics was influenced by early research on hydroponics starting in 1929 by Dr. William Gericke at the University of California. Further research on recirculating aquaculture systems picked up in the early 1970s and led to research on biofilters due to arising problems with toxic fish excretions. Research on biofilters included the utilization of soilless plants, which first

in Europe are rather premature (Villarroel et al., 2016). The overall limited extent of scientific research (Junge et al., 2017) and small number of commercial enterprises (Villarroel et al., 2016) leave the emerging technology of aquaponics rather poorly researched and untried in Europe (König et al., 2018). This has resulted in poor development of the technology and missed economic as well as environmental opportunities up until now. Hence, further research on the development of aquaponics in Europe can provide more insight into its current development phase, discover barriers as well as opportunities to foster the technology and provide an outlook on its ability to contribute to the sustainability transition in the agri-food sector. This is of high significance as a shift towards sustainable agriculture is globally required under Agenda 2030 (Junge et al., 2017; Villarroel et al., 2016).

The complex issue of transforming the incumbent agri-food sector into a sustainable one demands novel and innovative solutions. König et al. (2018) used the technological innovation system framework for the analysis of aquaponics in Germany and found that their research does not provide any institutional context related to the existing dominant agri-food sector. It has been found that the context of the agri-food sector and how it relates to aquaponics is generally not yet researched and understood. However, providing a holistic view to fully understand the development and potential of the aquaponics innovation is seen as critical. Managing the transition complexity in the agri-food sector requires a holistic view provided by both, analyzing the institutionalized incumbent agri-food sector as well as the potential of sustainable agri-food innovations, such as aquaponics. Therefore, this research is building on the integrated framework of Markard and Truffer (2008), which combines two important theoretical strains in the field of transition studies: the *multilevel perspective* (MLP) and the *technological innovation system* (TIS).

This framework provides the opportunity to analyze the development of aquaponics specifically in relation to the agri-food sector in the Netherlands. The Netherlands is particularly interesting for aquaponics as the Dutch agri-food economy is one of the most productive and profitable ones in the world all while focusing on technical innovation and sustainability (Viviano, 2017; Government of the Netherlands, 2018a; Government of the Netherlands, 2018b; Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2019). Aquaponics only recently developed in the Netherlands and Europe (König et al., 2018) which is why the concrete timeframe of 2008-2018 has been chosen for this research. More in-depth elaboration on the scope of location and timeframe follows in the *Methodology Chapter*. The urgency for a transition towards sustainable agriculture, the seemingly beneficial and sustainable technology of aquaponics paired with the lack of existing research of aquaponics development in Europe and especially in the Netherlands (Junge et al., 2017) leads to the following research question:

How can the emerging aquaponics technology contribute to the sustainability transition in the Dutch agri-food sector based on Dutch aquaponics developments in the period 2008-2018?

This research has been conducted with the aim of making progress on the five SDGs mentioned earlier and their achievements in order to enhance the sustainability transition in agri-food. The *theoretical*

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introduced aquaponics as known today. Supported by the sustainable agriculture movement, aquaponics was further developed and experimented on by various scholars and institutes in the late 1970 until early 1990, emphasizing the valuable work of Ron Zweig and colleagues, James Rakocy and Mark McMurtry. Sparked in the United States of America and Australia, knowledge diffused to other countries and resulted in additional research, designs and practices, leading to further development in aquaponics (König et al., 2018; Love et al., 2014).

contribution lies in applying and in-depth studying sustainability transition theory in the agri-food sector specifically with regard to the emerging technology of aquaponics. Applying the integrated framework of Markard and Truffer (2008) allows for the introduction of aquaponics to the context of the agri-food sector in the Netherlands and within a broader European perspective. Therefore, in-depth insights are gained on the aquaponics development, its dynamics and interdependencies to other system factors. *Practical contributions* include recommendations for policymakers, researchers and entrepreneurs concerned with aquaponics. Policymakers are provided with ideas on how to induce the development of the specific sustainable agri-food innovation. For researchers, further research gaps are identified by pointing out barriers to their progress on aquaponics. Additionally, this research provides commercially active entrepreneurs with knowledge about the technology's market position, state of development and bottlenecks that require most attention.

The structure of this research paper is as follows: *Chapter 2* addresses the theoretical framework and conceptual model for the study. *Chapter 3* explains the methodological approach. *Chapter 4* shows the results, while *Chapter 5* analyzes them. The paper finished with the conclusion in *Chapter 6* and the discussion of the approach and potential implications in *Chapter 7*.

2 Theory

The agri-food sector, challenged by *"global climatic changes, global loss in biodiversity, global food security issues, global food health and global water crisis"* (Bhat, 2017, p. 4), is in urgent need for a sustainability transition and more sustainable practices. Sustainability transitions aim at transforming current patterns of production and consumption into sustainable ones, while enhancing the ecologic as well as economic situation (Coenen & Truffer, 2012). The two most common frameworks used to analyze sustainability transitions are the multilevel perspective (MLP) and the technological innovation system (TIS) approach (Coenen & Truffer, 2012; Markard & Truffer, 2008; Markard, Raven & Truffer 2012; Hekkert et al., 2007; Geels, 2002).

Both frameworks, first the MLP (2.1) and second the TIS (2.2) are elaborated on, and then combined in an integrated framework (2.3) at the end of this chapter. The integration of both frameworks is vital to understand the potential of aquaponics from an emerging innovation's perspective as well as from an incumbent agri-food regime perspective. Insights gained through the integrated framework are the foundation to answer the main research question mentioned in the *Introduction Chapter* as well as the sub-questions which will be introduced in this chapter.

2.1 Multilevel Perspective

The MLP is a theoretical framework, which explains a dynamic transition process emerging from the combination of three levels in a societal system: *landscape*, *regime* and *niche* (Geels, 2002). Development and interplay within each level and between the levels take place and enhance the *"co-evolution of technology and society*" (Geels, 2002, p. 682; Rip & Kemp, 1998).

The *landscape* level represents natural trajectories, which are deep structural trends (Geels, 2002; Rip & Kemp, 1998). It is the wider environment able to put sociotechnical pressures on the regime (Geels, 2002). These pressures force the regime to change and adopt sustainable characteristics. A "window of opportunity" opens for niche innovations due to the pressure from the landscape put on the regime. This is the opportunity for the niche innovation to break into the regime (Penna & Geels, 2015; Smith, Voß & Grin, 2010; Geels, 2002). Landscape pressures, which affect the aquaponics development can be divided into environmental and socio-political pressures: *climate change, biodiversity loss, land and water degradation, food and water scarcity, urbanization, Paris Agreement*. These pressures operate on macro-level and enable dynamic transitions (Whitmarsh, 2012).

A *regime*, in this case the agri-food regime, is driven by rules and cognitive routines (Geels, 2002; Rip & Kemp, 1998). The regime encompasses (technological) standards, user practices as well as incremental innovation in a (dynamically) stable manner (Geels, 2011, 2002). Regime processes perform on meso-level (Markard & Truffer, 2008) and encompass the six dimensions: *culture* (D1), *markets/user preferences* (D2), *industry* (D3), *science* (D4), *technology* (D5) and *policy* (D6) (Geels & Schot, 2007). To illustrate: A vegetable product, which is bought by the consumer at the food retailer shows markets/user preferences, which are influenced by cultural aspects. To provide the vegetable in quality and quantity at the location, regulations have to be met and technological standards need to be complied to by producers as well as distributors. Many stakeholders are involved in the agri-food industry. A list of stakeholders includes the agricultural input industries (i.e. chemical sector, seed providers, tool and machine builders), farmers, food processors and traders as well as food retailers (von Braun & Diaz-Bonilla, 2008). Due to this complexity, regimes can suffer from inertia. Individual stakeholders, one regime or even the whole agri-food sector can be lockedin, when they fear profit reduction due to innovation from the niche level (Penna & Geels, 2014; Unruh, 2000; Kemp, 1994). Due to landscape pressures, regimes can be forced to open up and let niche innovations enter. If the innovation succeeds, the regime must rearrange (Geels, 2002).

The original MLP framework only takes into account one specific regime as being part of the transition in the MLP framework (Smith et al., 2010; Geels, 2002). However, as described earlier, aquaponics is combining two disciplines (hydroponics and aquaculture) which are part of two very different regimes. Markard & Truffer (2008) include the option for multiple regimes in their integrated framework introduced later this section. Consequently, the overarching agri-food regime is accompanied by two sub-regimes. The sub-regimes of this study are two sectors which intersect with aquaponics': the *conventional plant-based farming regime* (sub-regime1) and the *conventional fish production regime* (sub-regime2). It is yet to be analyzed how the Dutch agri-food regime comprising the two sub-regimes reacts and acts towards a sustainable niche innovation like aquaponics. To receive a deeper understanding the following first sub-question (SQ1) is posed:

SQ1: Considering the conventional standards in plant-based farming and fish production, does the Dutch agri-food regime leave room for the embedding of the aquaponics niche innovation?

The sustainability transition of the agri-food sector starts with an innovation at the n*iche* level. Geels (2002) defines the niche as "*the locus of radical innovation*" (p. 684). To improve the innovation's competitiveness with the incumbent technology at regime level, niches provide a protected space similar to incubation rooms for radical, expensive, yet possibly path-breaking innovations to develop (Geels, 2011, 2002; Kemp, 1994). In the beginning niche-innovations are neither well defined, sufficiently regulated nor do they have an adequate economic position. However, if (1) they achieved a stable dominant design, (2) increase the volume and quality of the network, (3) gain competitiveness by current and future price and performance improvements and (4) surpass a cumulative market share of 5% (of all niches building on the respective innovation), internal momentum is reached and the niche is prepared to challenge the regime (Geels & Schot, 2007).

The aquaponics innovation is analyzed on niche level. However, in the light of the integrated framework of Markard and Truffer (2008) the original niche level as proposed by Geels (2002) is modified. Since the MLP shows a simplified picture of a very complex reality (Smith et al., 2010), using this framework solely does not provide sufficient insights into the aquaponics technology. An additional and more analytical perspective is required to understand the development of aquaponics: the technological innovation system (TIS). Therefore, the TIS framework is integrated at niche level in the MLP and used to gain in-depth insights into the aquaponics development.

2.2 Technological Innovation System

An innovation system is a theoretical approach used to understand innovations and their diffusion in a network. There are several interpretations of the innovation system focusing on specific characteristics of the systemic framework (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007). The technological innovation system (TIS) is a social network constructed around one specific technology (Suurs & Hekkert, 2009). The TIS comprises seven functions, which are interdependent and thus, influence each other in a network of institutions and actors (Hekkert & Negro, 2009; Nelson & Nelson, 2002; Nelson, 1994).

The first function, *entrepreneurial activities* (F1) relates to entrepreneurs who strive for aquaponics business opportunities by using and generating new knowledge, networks as well as markets and translating them into value for the technology (Bergek, Jacobsson, Carlsson, Lindmark & Rickne, 2008; Hekkert et al., 2007). New knowledge is gained from experimentation, leading to new technologies, applications and overall decreased uncertainty. These activities can be performed by incumbent firms as well as new enterprises (Bergek et al., 2008; Hekkert et al., 2007). In Europe only a few commercial aquaponics farms have been developed so far (Villarroel et al., 2016).

Learning processes through *learning-by-searching* and *learning-by-doing* are consolidated by the second function: *knowledge development* (F2) (Hekkert et al., 2007). Aquaponics knowledge can be of technological, scientific, marketing or producing nature. It can be gained by universities, R&D laboratories, entrepreneurs and practicing individuals. Villarroel et al. (2016) found that knowledge development plays the most important role for aquaponics in Europe. Out of 68 European aquaponics practitioners 75% identified their primary interest as research.

The third function, *knowledge diffusion through networks* (F3), considers networks to be platforms of information and knowledge exchange (Bergek et al., 2008; Hekkert et al., 2007). Networks such as the European Aquaponics Hub and the European Aquaponics Association, facilitate interaction, learning, spillovers as well as understanding. Such networks are considered essential for the aquaponics development and diffusion. According to Hekkert et al. (2007), networks can consist of innovators, the government, competitors and other market actors.

The fourth function, g*uidance of search* (F4), refers to system forces, which manipulate the direction of search and thus, lead to a selection process between competing technologies and business models, among others. König et al. (2018) found that visions, expectations and perceptions on the future development of aquaponics differ between European stakeholders, leaving no distinct force to direct the search. For the Netherlands, forces influencing the search process are: industry, government regulations and policy, market, producers, users, resources, crisis, bottlenecks, visions and expectations, perceptions and opportunities (Bergek et al., 2008; Hekkert et al., 2007).

Market formation (F5), function five, is concerned with a protected space for the aquaponic technology. This is necessary as the technology still lags behind conventional and more established practices in terms of efficiency, demand and capabilities. A niche market is required to help the technology develop and flourish. Niche markets can benefit from supportive tax advantages or minimal consumption quotes (Bergek et al., 2008; Hekkert et al., 2007). Bergek et al. (2008) explain that market formation grows by three stages. First, the *nursing market* which provides aquaponics with a learning space to further develop. Second, in the *birding market* the technology expands in terms of actor involvement and volume. Three, the *mass market* is finally reached when volume increases and the TIS develops to be profitable.

R*esource mobilization* (F6) poses the sixth function and includes financial and human capital as well as the allocation thereof (Bergek et al., 2008; Hekkert et al., 2007). Furthermore, complementary assets, such as complementary products or network infrastructure, are included (Bergek et al., 2008; Hekkert et al., 2007). König et al. (2018) argue that resource mobilization efforts for aquaponics are unsuccessful due to a high degree of uncertainty and complexity. For example, the EU *"has not yet legislated on aquaponics and, as such, it is not clear how policy-makers might legislate for funding to be directed towards this technology"* (van Woensel, Archer, Panades-Estruch & Vrscaj, 2015, p. 22).

Creation of legitimacy/counteract resistance to change (F7) is the seventh function. It entails conformity within as well as the institutional and social agreement of the aquaponics TIS with larger society and legislation (Bergek et al., 2008; Hekkert et al., 2007). If aquaponics is seen as advantageous and well-suited by relevant actors, it can gain strength and legitimacy. However, lasting ambiguity in legislation weakens aquaponics' legitimacy (European Aquaponics Hub, 2018a; van Woensel et al., 2015).

Hekkert et al. (2007) explain *that "function fulfillment could lead to virtuous cycles of processes of change (or positive feedback loops) that strengthen each other and lead to the building up of momentum"* (p. 426). The drivers of function development are called inducement mechanisms (Bergek et al., 2008). However, there are also so-called blocking mechanisms which stifle the development of a function to its full potential. Ultimately, these blocking mechanisms affect the whole TIS due to the interdependence of the functions and can lead to a vicious cycle (Bergek et al., 2008; Johnson & Jacobsson, 2001; Unruh 2000). Unfulfilled functions, or functions which are blocked, can be improved by e.g. policy stimuli (Hekkert et al., 2007). Given this background, the following research sub-question arises to address the dynamics in the aquaponics innovation system:

SQ2: What is blocking or inducing the emerging aquaponics innovation system to become embedded in the Dutch agri-food regime?

2.3 The Integrated Framework

Both the MLP and the TIS are rooted in the same field of evolutionary economics originated by Nelson and Winter (1982) analyzing a similar phenomenon: technological transformation due to innovation within complex systems, influenced by society, technology, market structures, actors and institutions (Coenen & Truffer, 2012; Markard & Truffer, 2008). Both theories take interest in the diffusion of an innovation and its important drivers and barriers. Due to the common grounds, scholars have taken interest in examining further similarities and differences between the theories. These efforts have resulted in integrated frameworks[2], combining both theories while focusing on different complementary effects. Markard and Truffer (2008) propose a general integrated framework combining the analytical advantages of TIS and the main strength of the MLP of setting technological transitions into an environmental and institutional context. Such a combined framework provides the opportunity to analyze the potential of the aquaponics technology from both sides. Nevertheless, to answer the research question "*How can the emerging aquaponics technology contribute to the sustainability transition in the Dutch agri-food sector based on Dutch aquaponics developments in the period 2008-2018?"* the following issues need to be grasped: first of all, the development of aquaponics itself needs to be fundamentally understood to gather insights about the current phase of development. Secondly, it is also critical to analyze the technology's potential to diffuse and be embedded in the current regime. These insights can only be gained by using the integrated framework allowing for an analytical and contextual assessment at the same time on multiple levels.

Both, the regime as well as the niche level of the MLP can integrate the TIS framework, according to Markard and Truffer (2008). Depending on the maturity of the TIS, it can be positioned in one of two

[2] Markard and Truffer (2008), Weber and Rohracher (2012) as well as Meelen and Farla (2013) argue complementary effects between MLP and TIS and each propose an integrated framework. While Weber and Rohrbacher (2012) focus on aligning and adding system failures, Meelen and Farla (2013) concentrate on policy outcomes. Markard and Truffer (2008) propose a general integrated framework.

phases of development: *formative phase* or *growth phase*. In the *formative phase* the TIS' basic structure is in the process of establishing. This means constituent elements align, new actors (e.g. firms) join, networks are formed, and finally, an overall institution assimilates. Uncertain structures result in insecurities in fields such as market, application, price, performance, feedback loops and supporting externalities. Furthermore, there is no certain knowledge of demand, diffusion and economic capability; however, potential is estimated. When the basic structures are set up and the TIS is self-sustaining it advances to the *growth phase*. Here the target is to expand the system and widely distribute the technology to ultimately reach mass markets (Bergek et al., 2008). König et al. (2018) conclude that aquaponics is in the *formative phase* since basic structures are not yet secured. Consequently, the emerging technology of aquaponics is analyzed by the TIS framework which is integrated on niche level in the MLP.

While being on niche level in the integrated framework of Markard and Truffer (2008), the emerging aquaponics innovation system comprises multiple niches or niche applications. Scholars identified different fields of application for aquaponics which constitute the niches in this study: *small aquaponics systems in private settings* (*niche1*), *middle-size aquaponics systems in local production settings* (*niche2*), *big aquaponics systems in large scale production settings* (*niche3*) *and teaching purposes* (*niche4*). Besides the fact that Markard and Truffer's (2008) framework includes multiple niches, also multiple regimes can be integrated, in contrast to the original MLP framework. The two different sub-regimes within the general agri-food regime were introduced in the section *2.1 Regime Level*. Above that, Markard & Truffer (2008) argue that one TIS is not autarkic but interacts with complementary or competing TISs, which possibly impact and are impacted by similar niches. In the case of aquaponics, the complementary TISs are *hydroponics* (*complementary TIS 1*) and *aquaculture* (*complementary TIS 2*). Hydroponics and aquaculture influence the aquaponics development strongly as they are also the two system components of the aquaponics technology (Love et al., 2015; Somerville et al., 2014). Figure 3 ties together all elements of the integrated framework and illustrated their connections.

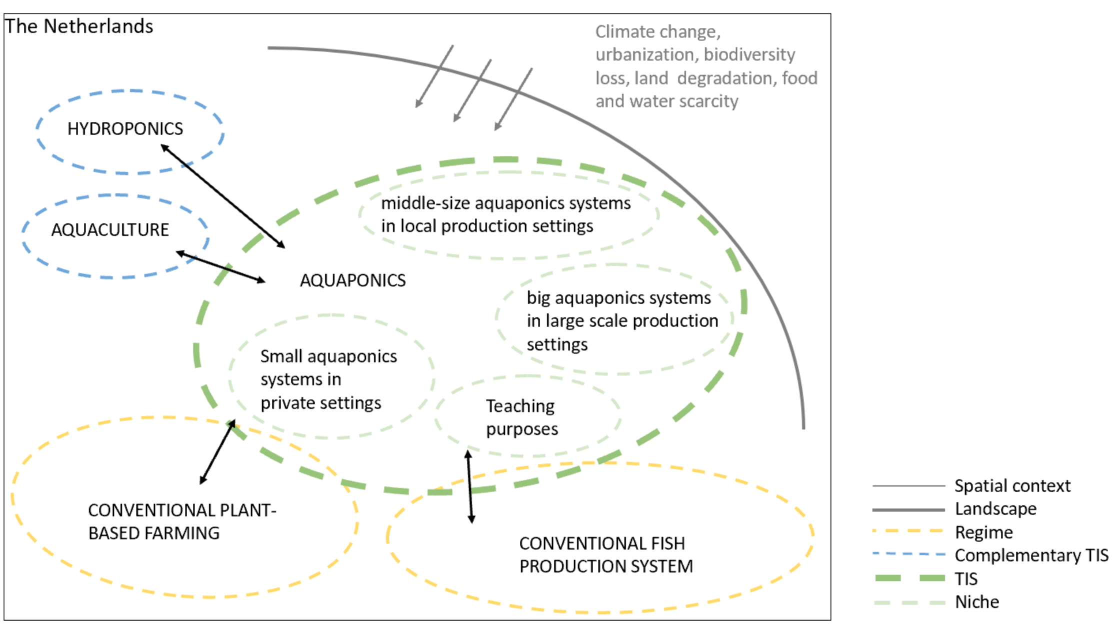

Figure 3 Aquaponic-specific integrated conceptual framework for the case of the Netherlands (based on Markard & Truffer, 2008, p. 612)

The MLP and TIS framework were critiqued by Coenen, Benneworth and Truffer (2012) for offering "*little reflection about the specific spatial contexts and conditions*" (p.976) when it comes to sustainability transitions. Regarding the spatial context, a country perspective has been chosen to cover the nation specific characteristics and institutions of the Netherlands. The country specification can influence the development of aquaponics (Coenen et al., 2012) and also enables a short reflection about the Dutch aquaponics development in the wider European context.

SQ3: Is it possible to generalize the findings of the Dutch aquaponics development to the wider European context or is the Dutch agri-food regime a unique case for the aquaponics development?

3 Methodology

The research design (3.1), the sampling strategy (3.2), the data collection (3.3), the operationalization (3.4) as well as the data analysis (3.5) are described in this chapter.

3.1 Research Design

This research is of exploratory nature, aiming at inductively examining the aquaponics innovation system, including factors that hinder (blocking mechanisms) or enable (inducement mechanisms) its breakthrough in the existing agri-food regime in the Netherlands. The theoretical framework explained in *Chapter 2* has provided a guideline for the operationalization of this research. The operationalization table as well as the coding guideline can be found in Appendix 1 and 2.

Based on publication numbers analyzed by Junge et al. (2017), interest in aquaponics significantly started to rise after 2010. König et al. (2018) state that aquaponics research in Europe was initiated around 2009 with the first study by Graber and Junge (2009). A ten-year timeframe from 2008 to 2018 has been chosen for this research to include both, the initial kick-off and recent developments in aquaponics.

To grasp the aquaponics development as a whole, its two main components hydroponics and aquaculture were included in the research as far as feasible. Their research progress influences the aquaponics development and therefore, is crucial to incorporate.

The analysis was performed on country-level as the information gathered through multiple sources and units (interviews, articles, statistics, etc.) was aggregated to the Netherlands. The diversely collected data was analyzed qualitatively. Furthermore, this research provides analysis and evaluation of the unique aquaponics development in the Netherlands as the spatial context is included. In the second step the findings are set into context by relating them to the European aquaponics developments in general.

It is especially interesting to analyze Dutch agri-food innovations because the Netherlands are the second largest exporter of agricultural goods worldwide, including produce as well as technology (Government of the Netherlands, 2018a). Climate change poses a threat to the Dutch agriculture sector and economy. Natural disasters resulting from the climate crisis can harm the coastal country e.g. through flooding. Therefore, the Netherlands is eager to cooperate on climate-resilient agriculture, working together across disciplines and nations in order to sustain food security (Croqué, 2012). Another factor which makes the Netherlands unique is its high degree of population living in urbanized areas. In 2017, 91.52% of the total population was reported to live in cities. This is in stark contrast to the European average of 74% (2018) (Statista, 2018a, 2018b). This leads to a shortage in surfaces available for agriculture and buffer zones as a rising amount of land is made available for housing, roads and dumping sites (Eurostat, 2018d). Ongoing research and development in technologies and practices gaining higher yields with less resources are trying to counteract limited space issues in the Netherlands (Viviano, 2017). While Dutch farmers work very resource efficiently, the agri-food sector is not focused on organic farming. Organic farming can be considered poor in the Dutch agri-food sector with a total market share of 2.91% (EU average: 6.67%, Eurostat, 2018a). It can be concluded, that the Netherlands are in high need of sustainable and climate-resistant agriculture technologies to remain at their high level of production. Facing the above-mentioned issues coupled with the Dutch expertise in research and development, it can be said that the Netherlands possess the know-how to develop sustainable technologies, including aquaponics.

3.2 Sampling Strategy

The research is based on multiple data sources which align in the following strategic requirements: timeframe (2008 – 2018), country (Netherlands) and the topic of aquaponics development.

A study by Dos Santos (2018) analyzed aquaponics development by Google Trends data and argued to include hydroponics as well as aquaculture in aquaponics research to understand the origin and evolution of aquaponics more in depth. Accordingly, the statistical information of patents, publications and Google Trends development is retrieved for aquaponics, hydroponics and aquaculture.

The literature review predominantly focused on aquaponics due to time constraints. The review followed the strategy of data saturation. When using this strategy, data collection is finished when concepts and information repeat themselves and no new insights can be gained (Bryman, 2012).

Interviews were conducted to receive the rich data that each interviewee shared about the individual experience with, tacit knowledge about, and perceived development of aquaponics in the Netherlands. In total, 24 interviews were conducted of which 23[3] were included in the writing process. The interviewee pool comprised of researchers, entrepreneurs, policymakers, agri-food associations and other experts. For an overview of interviewees connected to the respective stakeholder group[4], see Appendix 3. The interviewees were selected by snowball sampling. A small group was interviewed initially who were considered to be relevant to the research topic and research question (Bryman, 2012). During the interview, the researcher asked the interviewees to connect them with other network contacts who were familiar with or directly contributing to the research topic.

3.3 Data Collection

This section is alphabetically ordered by data source. All data was collected for the Netherlands and limited to the timeframe 2008-2018 to disclose the respective aquaponics trend over ten years.

(1) <u>Expert interviews</u>
The interviews were semi-structured and followed a pre-constructed interview guide (provided in Appendix 4). In other words, these interviews were guided along substantial questions and yet allowed enough flexibility for a generic conversation flow. Interviews were conducted through telephone, Skype and personal meetings, depending on availability and feasibility. Face-to-face interviews were conducted with 12 of the interviewees which also allowed for a simultaneous site-visit of the aquaponics system if in place. The rest of the interviews were done via Skype or telephone. Recording the interview was allowed by almost all of the interviewees to make transcribing easier. The transcripts were used for coding as described in section *Data Analysis (3.5)*. For presenting the insights gained in the *Result Chapter*, the interviewees were anonymized

[3] One of the interviews did not deliver any insights into the aquaponics technology as such, it's development in the Netherlands or the Dutch agri-food regime. Consequently, it was not included.

[4] The following stakeholder groups were retrieved from Bergek et al., 2008; Hekkert et al., 2007 and Geels, 2002:

(1) Market and industry: Incumbents using conventional or innovative forms of farming, entrepreneurs such as aquaponics farm owners, suppliers for technological components and organic components (e.g. seeds), capital suppliers, other enterprises connected to aquaponics, users
(2) Technology and science: Technology developers, researchers, universities, technical institute, R&D laboratory
(3) Government: Local, national and international authorities, government-based network groups
(4) Society: Interest or network groups, non-governmental organizations

(e.g. Expert 1, Entrepreneur 2, Researcher 3, etc.). For more information about the interviewees see *Appendix 3*.

(2) Google Trends

Google Trends provided data on Google search requests for aquaponics, hydroponics and aquaculture. The following search terms were grouped for a comparison of terms within the Netherlands from 01.01.2008 - 31.12.2018:

Table 1 Overview of the group terms and associated Google Trend search terms

Group	Associated search terms
Aquaponics	aquaponics + aquaponic
Hydroponics	hydroponics + hydroponic + hydrocultuur
Aquaculture	aquaculture + aquacultuur
Agri-Food Context	agriculture + fisheries + plant science + landbouw + visserij + plantenwetenschap

The Google Trend analysis was run for Google Search, YouTube, Google News and Google Image. The numbers of Google Trend analytics are only to be seen figuratively, not literally, as they are all relative to the highest score of 100 and the lowest score of 0. Google Trends provides numbers on a monthly basis which were manually aggregated to the respective year.

(3) Literature, statistics and additional information

The literature review allows for the integration of expert findings on aquaponics published in scientific journals. Academic papers were retrieved from Google Scholar and Web of Science. Furthermore, expert and practitioner websites, statistics as well as white papers such as government documents were included. Websites and white papers were found through Google Web.

(4) Patents

Global patent numbers were retrieved from the World Intellectual Property Organization (WIPO) platform Patentscope for aquaponics, hydroponics and aquaculture. In order to be included in the statistic, the respective technology had to be included on the front page of the patent application document which covers the title as well as the abstract. The request was manually prepared for the analysis of 2008-2018 and the patent origin (country, patent organization) on a global basis.

Table 2 Overview of the group terms and associated search terms

Group	Search Term
Aquaponics	Aquaponic*
Hydroponics	Hydroponic*
Aquaculture	Aquaculture

The same request was made for on Espacenet, a platform by the European Patent Office. To retrieve specific data on the Netherlands, the application number which starts with a country code was adjusted accordingly.

(5) <u>Publications</u>

Mainly Web of Science (WOS) but also Scopus was used as the database for publication numbers on aquaponics, hydroponics and aquaculture. In WOS, only English keywords resonate with the platforms which is why only the following terms and combinations were searched for (see table 3). The relevant field tag for the search was *Topic*, which includes title, abstract, author keywords and keywords plus. The timeframe was set 2008-2018 and applied worldwide as well as for the Netherlands. Furthermore, the field tag *Research Area* was used to get a general picture of the total number of published articles concerned with topics related to aquaponics. These are agriculture, fisheries and plant science. This was done to extract the share of publications of the three technologies and conclude the importance that aquaponics, hydroponics and aquaculture play in the field of agri-food.

Table 3 Overview of the group terms and associated WOS and Scopus keywords

Group	Associated keywords
Aquaponics	aquaponic OR aquaponics
Hydroponics	hydroponic OR hydroponics
Aquaculture	aquaculture
Agri-Food Context	agriculture OR fisheries OR plant science

The same parameters presented for WOS were applied to Scopus to receive comparable results. These parameters include the timeframe, the keywords and the country limitation. In Scopus keywords were searched for in the field codes title, abstract and keywords.

To explore and understand aquaponics better, the researcher visited an aquaponics rooftop farm in The Hague in summer 2018 before the start of this thesis. The one-hour tour, targeting eco-tourists, provided a useful first impression of the technology and its commercial implementation. Pictures of the tour can be seen in figure 4 below. Additionally, during the research proposal phase Murry Hallam's aquaponics online course[5] was completed and an aquaponics expert from Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin was consulted.

Figure 4 Pictures form the Urban Farmers tour on June 30, 2018 (from left to right: picture 1 leafy greens, picture 2 eggplant and tomatoes, pictures 3 fish tanks)

[5] The free Murry Hallam online course consists of weekly videos for an eight-week period which explore different aspects of aquaponics. Video topics include fish health, a system set-up, heating, filtration strategies, etc.

3.4 Operationalization

Based on theoretical insights primarily gained from Geels and Schot (2007), Bergek et al. (2008), Hekkert et al. (2007) and Markard & Truffer (2008) an operationalization table was created which can be found in Appendix 1. The categories and sub-categories for the MLP were retrieved from Geels and Schot (2007): landscape and regime (culture, science, technology, industry, policy and markets/user preferences). The niche level in the MLP described by Geels and Schot (2007) was operationalized by using the TIS with the seven functions which formed the sub-categories in the operationalization table: entrepreneurial activities, knowledge development, knowledge diffusion through networks, guidance of search, market formation, resource mobilization and creation of legitimacy/counteract resistance to change. The concepts per sub-category and respective data sources were adjusted to the agri-food and aquaponics specifications before beginning the research phase and data gathering. The sub-categories and concepts are partly built on theoretical insights and partly on agri-food and aquaponics specifications. When conducting the research, it was found that not all concepts were useful or possible to feed with the data gathered. The operationalization table was adjusted and refined based on the new insights. The operationalization table provided the base for the preliminary coding guideline used for coding the interviews conducted. Likewise, the coding guideline, which can be found in Appendix 2, was adjusted and refined in the process.

3.5 Data Analysis

The data was processed by a qualitative content analysis, meaning "*a searching out of underlying themes in the materials being analyzed*" (Bryman, 2012, p. 557). Expected underlying themes were displayed in the operationalization table prior to coding. Specifically, the categories and sub-categories of the operationalization table provided the foundation for the coding logic, for the coding guideline and NVIVO, a tool for qualitative data analysis. NVIVO was used to assure a well-documented coding process and a well-organized analysis. Each of the 24 interviews was coded thoroughly in an axial as well as selective way of coding, meaning that data which belonged into the categories of the coding guideline were coded accordingly. The following nodes/categories were added: "other" on each level (landscape, regime, niche) to leave room for undedicated pieces of information, "complementary TISs" for insights on the complementary TIS and "European context" for later comparison to the European level. Furthermore, the regime nodes/categories were duplicated to have a clear separation between both regimes analyzed. After the first coding step, when putting the information found in writing, the coding, along with the coding guideline, was slightly revised and adjusted. This was done to help with coherence and understanding of the coding and its guidelines. The preconstructed operationalization table and coding guideline were not fundamentally changed throughout the process. However, in most cases the predefined concepts were not met for aquaponics and the agri-food sector.

Based on the insights gained from the different data sources described, the results were presented by describing the landscape pressures, the regime dimensions, complementary TIS insights and then focal aquaponics innovation system's functions. Next, the qualitative information was analyzed in the same order: first landscape pressures, second regime dimensions, third complementary TIS insights, last the focal TIS. Above that, further insights were gained from analyzing functional and structural development patterns, the current development phase of the aquaponics innovation system, and blocking/inducement mechanisms influencing the aquaponics development from all levels examined. Moreover, interactions and interdependencies between the landscape, regime and TIS level and within each of the levels were analyzed.

External reliability relates to the replicability of the study (Bryman, 2012). By giving detailed documentation of the theoretical framework, the methodological approach including the interview guide, interviewee description as well as the operationalization table and coding guideline, external reliability was aimed at. *Internal reliability*, relating to inter-observer consistency, can be achieved when more than one observer perceives information equally (Bryman, 2012). Since this a single-person research, inter-observer consistency could not be achieved. *Internal validity* refers to the match between the observations by the researcher and the theory developed (Bryman, 2012). As the theoretical framework forms the grounds on which the research is conducted, the alignment between theory and practice is apparent. *External validity* refers to the generalizability of the research outcome (Bryman, 2012). The findings of this study can be generalized to the Netherlands as country statistics and a diverse mix of interviewees reflect this. Furthermore, the research aimed at further generalizability on a European level, which could not be claimed.

4 Results

The *Result Chapter* has been organized according to the developed conceptual framework introduced in the *Theory Chapter*. First, the landscape level (4.1), divided into environmental and socio-political pressures, is described. Second, general agri-food regime characteristics in the Netherlands are presented (4.2.1) before the sub-regimes of the plant-based farming (4.2.2) as well as the fish production (4.2.3) are elaborated upon. The complementary TISs hydroponics and aquaculture are included in the results presented on regime level (4.2) as well as on niche level (4.3). Third, the aquaponics development is explained on niche level using the TIS functions (4.3).

4.1 Landscape Level

The landscape level represents deep structural trends which pressure the agri-food sector to adapt more sustainable characteristics. The environmental (4.1.1) and socio-political pressures (4.1.2) impact the agri-food sector and support sustainable solutions such as aquaponics.

4.1.1 Environmental Pressures

Environmental pressures directly resulting from the current agri-food practices are impacting the Dutch agri-food regime and arising innovations.

Freshwater availability and quality are increasing issues in water scarce areas worldwide and push for new water-saving and clean solutions (Researcher 1, 2 & 5). Whether this is already a typical Dutch pressure, or whether the Netherlands will be affected by this in the future, remains unclear. While there is currently sufficient freshwater in the Netherlands, or Europe in general (Researcher 1 & 5), future bottlenecks may arise due to soil salination. This concerns especially salt-sensitive vegetable production (Ministry 1 & 2; Entrepreneur 4; Römkens & Oenema, 2004). The Dutch province of Zeeland faces another type of *water stress*: Salty soils reduce conventional agricultural activities on salinized land. Adaptation strategies for these areas include a diversified range of production procedures, such as experimenting with saline-tolerant plant species or changing the land use from food to energy production (Ministry 1 & 2; Entrepreneur 4). Strategies for optimal land use are crucial, especially in the Netherlands, due to a limited land size (Retailer; Ministry 1 & 2).

Furthermore, *land and water degradation* are critical topics worldwide, but especially in the Netherlands. The strong and highly productive Dutch agri-food sector incorporates unsustainable farming practices such as a high use of fertilizer on a mass scale. This leads to nutrient excess and leaching especially of nitrogen and phosphorus. This approach does not only directly contaminate the soil but also impacts soil biodiversity and pollutes surface as well as ground waters in the Netherlands. The effect exceeds national borders through rivers and coastal streams (Expert 1 & 4; Researcher 1 & 2; Entrepreneur 3; Rozemeijer, Klein, Broers, van Tol-Leenders & Van Der Grift, 2014; Römkens & Oenema, 2004). Moreover, international waters have become scrutinized due to the prominent *plastic pollution* further affecting the maritime ecosystem and biodiversity. In the light of these issues, sustainable and organic food production as well as packaging form strong pressures driving Dutch producers and food retailers towards more sustainable practices (Retailer; Expert 1).

"We fish on five economic feasible, very nice fish species. But when the sea water is rising in temperature, they will move. And the question is, will our fishermen move as well?" (Ministry 2)

Climate change is a present topic for the Dutch agri-food sector as current climate developments influence the sector directly (Willet et al., 2019). Furthermore, the severity as well as frequency of disastrous climate events is predicted to increase in the future. Dry periods on land pose the main problem for the Dutch plant-based farming regime. Simultaneously, the sub-regime contributes to climate change with current production methods. In plant-based farming most significantly the use of nitrogen fertilizer contributes to climate change (Ministry 2; EEA, 2016; European Commission, 2015). This in turn leads to rising sea temperatures which is likely to impact the fishery sector in negative ways. While this threat to the environment and the economy is known to citizens, policymakers and fisheries alike, there are little to no solutions to counteract current developments (Ministry 1 & 2; Expert 5).

4.1.2 Socio-Political Pressures

Trends driven by society and pressures originating from the political spectrum impact the Dutch agri-food regime and arising innovations as well.

Global trends in *population growth* and *urbanization* have an impact on the Dutch agri-food regime. This is due to the fact that yield and space efficiency are driven by land scarcity and the increasing global need for food. Furthermore, these two major trends influence consumption behavior (Eurostat, 2018b; Viviano, 2017; Dutch National Research Agenda, 2016). The Food and Agriculture Organization, FAO (2017) expects an increased demand in processed food, meat, vegetables and fruit as well as a labor shift from the producing sector (e.g. farmer) to the service sector (e.g. transport or retailer). This means an increasing number of consumers are supplied by a decreasing number of producers. This development puts farmers under pressure and leaves them calling for more support in feeding the rising population while simultaneously increasing land efficiency (Researcher 2).

The *sustainability movement* connected to the agri-food sector is growing in significance. It concerns the production, distribution and consumption standards of produce and is demanded by society as well as non-governmental organizations (NGOs). In food *production*, organic methods are valued while in terms of *distribution* short supply chains are advocated for. In *consumption* plastic use is critically perceived (Retailer; Expert 1 & 8; Ministry 1 & 2). Connected to the topic of sustainability, the *degrowth movement* is taking place in different European regions. This movement calls for a higher prioritization and focus on human and ecological well-being and a lower priority for GDP growth (Researcher 2; The Guardian, 2018).

Although the *awareness of sustainability issues* is rising (Entrepreneur 1; Retailer), the holistic understanding of the complex and global topic of climate change is at times hard to grasp for citizens and consumers. Imminent threats are not tangible and provide a platform for insecurity and disconnect (Expert 1; Researcher 2). NGOs can support the understanding on every societal level and pressure further awareness (Expert 1). Regarding fish extinction or plastic pollution one can, for example, observe that society has been gradually educated about these threats by NGOs and certification schemes. This understanding leads to socio-political pressures on the current practices in place (Expert 1 & 5; Retailer).

On an international level, the *Paris Agreement* brought into force by the United Nations in 2015 represents a political pressure for multiple sectors, including the European and Dutch agri-food regime (Expert 7; Government of the Netherlands, 2018d). Multiple SDGs are concerned with the sustainability transition in the agri-food regime: SDG2 (Zero Hunger), SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production), SDG 14 (life below water) and SDG 15 (life on land). Taking the example of SDG2 (Zero Hunger), the goal and focus of the agri-food sector can be twofold which adds complexity:

While aiming at increased productivity (e.g. yields) for food safety, greenhouse gas emissions and other negative environmental consequences should be reduced (OECD, 2018; United Nations, 2018a).

On a national level, the Dutch Ministry of Agriculture, Nature and Food Quality communicates its vision of *Circular Agriculture* since 2018: *Kringlooplandbouw*. To reach circularity in farming, horticulture and fisheries, it is the goal of this ministry to counteract unsustainable procedures, socially as well as ecologically speaking. The focus lies on the optimized use of soil, freshwater, nutrients, energy and raw materials and the enhancement of biodiversity. In 2019 the vision was concretized by the *Realization Plan*, which was introduced by the Minister of Agriculture, Nature and Food Quality Carola Schouten. As the second largest agri-food exporter, the role of the Netherlands is an important and leading one. According to the ministry, the country wishes to set a good example, which inspires other nations to transition towards sustainable and circular agriculture as well (Ministry 1 & 2; Expert 6; Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2019; Kraa, 2019; Thijssen, 2018; Government of the Netherlands, 2018b).

In short, the Dutch agri-food sector faces multiple landscape pressures originating from the environmental and socio-political spectrum. Environmentally, land and water degradation as well as biodiversity loss due to climate change are current developments, which pressure the sector towards more sustainable procedures. On a socio-political level, the issue of population growth, the increasing awareness of food related sustainability problems as well as the international and national political agendas for more sustainability in food production influence the agri-food sector in the Netherlands.

4.2 Regime Level

The Dutch agri-food regime described in this section includes the general Dutch agri-food characteristics, the plant-based farming regime as well as the fish production regime. They encompass six dimensions, which are represented in this section: culture, markets/user preferences, industry, science, technology and policy (Geels & Schot, 2007). In the first part of this chapter, the general agri-food regime characteristics in the Netherlands (4.2.1) are described, which hold for both sub-regimes at hand. Secondly, the conventional plant-based farming regime (4.2.2) and thirdly, the conventional fish production regime (4.2.3) are elaborated upon. Both specific sub-regimes, plant-based farming and fish production, need to be studied in order to understand the development, diffusion and barriers that aquaponics faces from the niche level.

4.2.1 General Agri-Food Regime Characteristics in the Netherlands

The general Dutch agri-food regime characteristics are briefly outlined from a consumer perspective, encompassing markets/user preferences and Dutch consumer culture, and a supplier perspective, including industry, science, technology, policy and the culture within these dimensions. Both perspectives presented in this part were found to be true for both sub-regimes and thus, summarized generally.

4.2.1.1 The Agri-Food Regime from a Consumer Perspective

"*Dutch people don't care so much, as long as it's cheap*." (Expert 3)

Sustainability is valued from a consumer perspective. However, it has been found that price has a higher priority to Dutch consumers and is the main driver of decision-making (Ministry 1 & 2; Expert 1 & 5; Researcher 5; Entrepreneur 4). According to interviewees, the price-sensitive consumers in the Netherlands are spoiled with good quality food for low costs (Entrepreneur 2 & 3; Retailer; Researcher 5; Expert 7). Similarly, Dutch producers and retailers have to compete to meet these demands of low price and high quality (Retailer, Expert 2 & 8). Researcher 5 and Expert 3 only see a way to drive consumers away from the price-focus with convincing marketing.

"*And I think there's a lot of market in between to selling something special. A special variety, special taste, special brands. There's more and more room for that part, to do smart marketing*." (Expert 3)

Some interviewees perceive the Dutch consumer to be a customer with interest in food (Entrepreneur 1), health and the environment, which evolved over time (Expert 2; Researcher 4). There is an increasing awareness of sustainability issues and demand for organic products (Researcher 2; Entrepreneur 1 & 4). Organic and healthy products build a niche market; however, the intention to buy them is not necessarily connected to environmental sustainability (Expert 1; Researcher 2 & 4). Some interviewees claim that Dutch consumers are not engaged or concerned with food production at all (Researcher 2; Entrepreneur 2) and that there is no sentiment to food other than the price incentive (Expert 1; Entrepreneur 2).

"*The citizen is really thinking about the people, the planet and the profit but the consumers [are] just buying the cheapest.*" (Expert 1)

The citizen-consumer-dilemma reflects on the issue of the citizen being concerned with sustainability while the (Dutch) consumer is opting for personal profit (Expert 1, 4 & 6; Ministry 1 & 2; Researcher 4; Retailer; Berglund & Matti, 2006). This poses an issue for retailers due to the discrepancy between citizens' demands and actual purchase decisions by consumers. Especially price is an important topic which all retailers stand in competition for. Sentiment or loyalty towards one specific retailer is not a behavior which is common in the Netherlands nowadays (Expert 1, 2, 5 & 6; Ministry 1 & 2).

"*I think the retailers are really trying to find a way on how to deal with this because society and everybody knows we need to do something. And of course, we have a lot of thoughts about it, but our actions are not the same as the words we say*." (Expert 1)

Expert 1 states, that the issue of sustainable consumption has to be made easier for consumers, which often put the responsibility of sustainability on the retailer. Retailers see themselves in the position to initiate change and to re-narrate the story of sustainable products and organic production (Retailer). Retailers as well as producers are pressured to be highly efficient and produce good quality, whilst becoming more sustainable (Retailer; Researcher 2; Expert 4).

"*They have the same expectation towards organic and sustainable and reducing plastic. So, the Dutch consumer, is really a consumer of complaints. But it's the high expectations, putting pressure on the companies, and make sure that you live up to the expectations. So, I think in a sense, that's good.*" (Retailer)

There are specific differences between the production and consumption of vegetables and fish. They differ in their standards, knowledge and cultures (Expert 4) which is why in the following sections 4.2.2 and 4.2.3 sector-specific information is elaborated on.

4.2.1.2 The Agri-Food Regime from a Supplier Perspective

The Dutch agri-food regime poses such a unique and interesting case, as it is the second largest exporter in agri-food products while being a country of comparably small size and dense population (Ministry 1; Government of the Netherlands, 2018a; Viviano, 2017). Entrepreneur 1 calls the Netherlands a global giant in food trade. The export value in 2017 accumulated to €92 billion in agri-food products, including produce as well as technology (Government of the Netherlands, 2018a).

The Dutch are very well aware and proud of their *global forerunner position* in the agri-food sector (Ministry 1 & 2; Expert 3, 4, 5 & 9). One might call it the Dutch ego or arrogance (Entrepreneur 1). Nevertheless, the Netherlands have the goal to sustain and expand their leading position in agri-food through innovation and sustainability (Government of the Netherlands, 2018a).

Innovation and sustainability goals were formulated not only to retain this frontrunner position but to counteract climate change scenarios including natural disasters such as floods and droughts (Ministry 1 & 2; Croqué, 2012). The Netherlands cooperate on climate-resilient agriculture, working together across disciplines and nations in order to sustain food security (Croqué, 2012). Dominant global supply chains make international cooperation necessary (Expert 5).

The Dutch agri-food industry is predominantly described as open and cooperative (Expert 1, 3 & 5; Ministry 1 & 2). The cooperative nature is a part of the Dutch culture in general and fostered by the government (Expert 1; Ministry 1 & 2). To enhance cooperation and innovation, government investment and research support is mainly connected to cooperation between the industry, academia and the government itself (Ministry 2; Croqué, 2012; OECD, 2015). In the Ministry of Agriculture, Nature and Food Quality this cooperation between the three entities is called the *Golden Triangle*. It was first introduced and facilitated around 2010 (Ministry 2).

Concerning the *goal of innovation*, Wageningen University, with its focus on Life Sciences, is of high importance to the Dutch agri-food sector. Moreover, the Wageningen University is world-renowned and plays a significant role for agri-food worldwide (Researcher 1 & 4; Expert 9; Ministry 1 & 2; Viviano, 2017; OECD, 2015). Croqué explains (2012) *"the Dutch agricultural sector depends on a relatively highly skilled labour force"* (p. 1), due to its knowledge-intensive nature. However, there is a lack of human capital perceived (Researcher 2). Research efforts in the Dutch agri-food sector are mainly productivity and efficiency driven (Ministry 2; Expert 1 & 3; OECD, 2015) and current liaisons to the commercial sector are watched critically (Researcher 2).

The *overarching goal of sustainability* has been approached from different angles in the Netherlands. First, *environmental sustainability (planet)* developed, approximately 20 years ago. This movement contributed more awareness to the impact of pesticide and fertilizer application, water and land use. As a result, this led to a significant reduction of resources used and certification schemes were developed (Expert 1; Viviano, 2017). In 2018, the Dutch agri-food sector was again stimulated for environmental sustainability by the vision of *Circular Agriculture* of the Dutch Ministry of Agriculture, Nature and Food Quality (Expert 6; Government of the Netherlands, 2018b). This vision promotes the internalization of external costs of the agri-food sector to counteract current negative impacts. Consequently, a rise of costs for food products is expected (Expert 6). Nonetheless, the Netherlands want to hold on to this vision to portray a good example and show best practices to Europe and the rest of the world in the field of Circular Agriculture (Expert 6; Government of the Netherlands, 2018b). Equally important, *social sustainability (people)* followed and was developed approximately ten to five years ago. This movement is concerned with the conditions of labor. Certification schemes for good labor conditions as well as rehabilitation programs for Dutch citizens were created (Expert 1; Entrepreneur 1; Researcher 2). As of recently, *corporate sustainability (profit)* has been developing which is concerned with the aim that every stakeholder in the supply chain can operate sustainably while sustaining oneself, without exploitation

(Expert 1). In the Netherlands, a *fair price for the producer* is focused on and driven by the Ministry of Agriculture, Nature and Food Quality since 2018 (Ministry 1).

"There just a few big supermarket chains, that buy all your vegetables, and they can set the price." (Expert 3)

Farmers and fishermen do not earn the main share of the end product, but only a small portion of the final profit (Expert 1; Ministry 1; Ministry of Agriculture, Nature and Food Quality of the Netherlands, 2018). A highly anticipated topic in this regard is the S*hort Supply Chain*, which is supported by grassroot initiatives, researchers as well as the Ministry of Agriculture, Nature and Food Quality. Short supply chains enable the producer to obtain a fairer price and offer more local consumption choices to the customer (Ministry 1; Expert 1, 5 & 6; Ministry of Agriculture, Nature and Food Quality of the Netherlands, 2018). The dominant position in long food supply chains is occupied by the retailers, who provide the value added and receive the higher margins (Expert 3 & 4; Ministry 1 & 2; Silvis & Leenstra, 2009). The price is set by the retailer due to the push situation of the producer who is in need to sell the daily fresh produce (Expert 3). The power imbalance has been developed over the last 10 to 15 years (Expert 3). Retailers profit from the current market situation and their storytelling (Entrepreneur 1; Expert 4) which, in turn, also enables them to play a pivotal role for change (Expert 1).

"And then the large global companies, they also like to change but in a certain way. Because in fact, they are conservatives aligned to preserve their capital." (Expert 6)

From the perspective of the producer, the principle of sustainability is sometimes working with but also in part working against the Dutch approach of efficiency, productivity and technical innovation (Expert 6; Research 2). Concerning sustainability, the Dutch agri-food sector does not appreciate disruption of any kind. Thus, current greening efforts focus on making food production processes more efficient and reducing harmful impacts on the environment (Expert 1, 3 & 6; Researcher 2, 3 & 5; Entrepreneur 4). Researcher 2 describes it as applying *patches of sustainability* on current practices. An explanation for this incremental change approach is given by Expert 6, who explains that people are less risk-averse and more conservative when it comes to change, because they profit from current standards.

"And of course, you have the big food industry. And then there's the money and with the money you can steer the system." (Expert 6)

Lobbying is a vital topic in the agri-food sector and the agricultural input industries (i.e. chemical sector, seed providers, tool and machine builders), the food producers, food processors and traders as well as food retailers are very active in regard to lobbying activities on both, the Dutch as well as the European level (Ministry 1 & 2; Expert 6 & 7; Researcher 1; Entrepreneur 5). Simultaneously, NGOs lobby for more sustainability and animal welfare in the agri-food sector (Ministry 1 & 2). There are European initiatives trying to align different stakeholders for sustainable development in the agri-food sector. Initiatives, such as the Transition Coalition Food, Food Nexus, Sustainable Food Initiative, among others work towards the zero-emission goal in 2050, aimed at by the United Nations (Expert 6). Different stakeholders cooperate for a more sustainable agri-food system: academics, farmers, representatives of the (process-)food industry as well as the government and other organizations. These programs aim at lobbying, exchanging best practice and fostering progress through large research initiatives (Expert 6).

While Dutch experts participate in sustainable agriculture initiatives on European level, different stakeholders also come together to work on solutions in the agri-food sector on a national level. Generally, the Dutch government integrates all relevant stakeholders in a legal discussion to come to the best solution possible which is then implemented. Moreover, it is stated that NGOS and one political party concerned with animal welfare have a strong influence on the Dutch parliament (Ministry 1). Ministry 1 and 2 claim that NGOs hold a uniquely strong position in the Netherlands because they are an integral part of the cooperation efforts. The approach of cooperation is unique to the Netherlands compared to other European countries (Expert 1). However, to reach major change on national level, European laws have to be adjusted which increases complexity as well as time required (Ministry 1). Expert 1 states that stimulation by the government is necessary for progress; however, momentous change in behavior of the industry and the consumers is a very time-intensive process.

The Dutch agri-food sector is accompanied by Rabo Bank and ABN Amro as well as ASN Bank and Triodos which are so-called sustainable banks (Ministry 2; Expert 5). Expert 1 explains that the Rabo Bank and other sustainable banks provide lower rates for sustainable endeavors with specific environmental certificates than conventional ones in the Netherlands. Likewise, private and public investment has been following a similar strategy in the support of sustainable developments for some years now (Expert 1). Especially Rabo Bank is known as the bank for all agri-food related businesses (Ministry 2) and supports sustainable food production with its initiative "banking for food" (Expert 6). The financing strategies of different banks changed throughout the last 10 years particularly in regard to sustainability and agricultural projects. Recently, the banks upgraded their loan and investment criteria and set stricter rules for funding (also adding sustainability criteria) to limit risk (Ministry 2). However, Entrepreneur 5 claims that funding is approved more easily if a project is built upon already existing concepts rather than researching fundamentally new concepts. Furthermore, the postcode lottery also invests in nature related projects (Ministry 2). Lastly, there are multiple funding schemes on Dutch as well as on European level initiated by the governments which are specifically mentioned for each sector below.

4.2.2 Conventional Plant-Based Farming Regime

The results presented in this section cover the findings on the conventional plant-based farming regime including hydroponics, the complementary TIS. All six regime dimensions are elaborated on in this section; however, they were meaningfully regrouped to align closer with the findings of the Dutch agri-food system and the flow of presenting them: markets/user preferences and consumer culture (4.2.2.1), industry and industry culture (4.2.2.2), science and technology (4.2.2.3) and policy (4.2.2.4).

4.2.2.1 Markets/User Preferences and Consumer Culture

The number of Dutch consumers purchasing fresh, healthy and locally grown food is increasing (Entrepreneur 1; Expert 6 & 10). The demand for fresh food is met by growers (Expert 2); and retailers perceive that fresh food is a distinctive part of the offer which enables them to stand out from the competition. In turn, retailers also notice their ability to influence the production conditions worldwide through their requirements (Retailer; Expert 5). The marketing of retailers is intense due to the strong competition. Price and promotion play a major role in the sales of the fresh product categories (Retailer).

Prices for vegetables and fruits in the Netherlands are very cheap due to high efficiency standards, productivity and the fact that the Netherlands act as a major European trade hub. However, low prices also stem from externalized costs and unfair prices for farmers (Researcher 2 & 4; Expert 6 & 9; Ministry 2).

"Even if the skin of the apples is loaded with pesticides, but the quality is good." (Researcher 2)

The organic market is growing in the Netherlands, a development which is codependent on the trend of sustainability (Retailer; Entrepreneur 1 & 4). The consumer is relating organic production to sustainability. Thus, organic food production and its labelling became a crucial factor in the sector in every step of the supply chain. Organic products are commonly more expensive than non-organic products. This is due to higher production costs, although differing between crops, but also due to the consumer expectation of higher prices (Retailer).

Dutch as well as international growers must meet the criteria set by retailers which require less chemical use, a requirement set forth due to a change in the market demand. This development needs to be met on national, European and global level (Expert 2). Growers are in a push position where they need to follow the requirements of retailers in order to sell their daily fresh product. This lies in contrast to the past as only in the last 10 years the Dutch agri-food market developed from a consumer pull to a producer push market of produce. The variety and surplus leave growers in a highly competitive position in which meeting consumer demand is key (Expert 2).

However, the Dutch consumer demand is very ambiguous. While there is the trend for convenience products, there is also an anti-plastic movement (Retailer). As a result, in addition to the consumer-citizen dilemma which was described on the example of the conflict between price and sustainability, there are further conflicts within and between consumers, which the market has to solve.

4.2.2.2 Industry and Industry Culture

There has been a substantial change in the way farms are led which impacts business decisions and operations. Previously, farms were owned by growers who put emphasis on the art of growing and were described as *people with the green fingers* (Expert 1). Nowadays, farms have evolved into businesses, led from an economic and profit-driven point of view by entrepreneurs. Interviewees explain, that as soon as Dutch entrepreneurs in the plant-based farming sector see an effective way of doing business, they are open to good ideas (Expert 1 & 2; Researcher 1; Retailer). Economic viability and profitability are especially key in the horticulture sector (Researcher 2; Retailer; Entrepreneur 1).

"So, the owner [was] the one who grows and knows about the plants, knows about fertilization, knows about pesticides. And what you see now: the owner is the businessman and they have growers to do crops." (Expert 1)

This economic approach caused small and individual family-owned farms with small production volumes and different crop species to become large and investment-intense companies focused on optimization. This push towards optimization and efficiency, including heating, lighting and crop species, led to monoculture. Economies of scale allow for large investments in maintenance, technology and research (Expert 1, 2, 3 & 4; Retailer; Eurostat, 2018c; CBS, 2001) as well as low prices (Entrepreneur 4; CBS, 2013).

In fruit and vegetable farming there are three approaches: (1) agriculture outside for e.g. onions and potatoes, (2) agriculture indoors in the greenhouse for e.g. tomatoes and salads and (3) the small mushroom sector, which also grows indoors but on different substrate (Expert 1). Taking a closer look at the greenhouse production for horticulture in the Netherlands, the Westland area is *the* well-known area most of the businesses operate in (Entrepreneur 1; Expert 4; Researcher 1). The area used as space for greenhouses is expanding (Researcher 4).

“In general, they are really very much concerned about optimizing production within their greenhouse and not so much about adding value outside of it.” (Expert 4)

Greenhouses are very efficiency driven, specialized and optimized for the respective crop produced (Expert 4 & 7; Researcher 4; Entrepreneur 1). Monoculture, which means producing one specific crop instead of multiple ones, is driven by these optimization approaches (Ministry 1 & 2; Expert 5; Researcher 2; OECD, 2015). However, this approach makes production with chemical additives such as pesticides and fertilizer necessary to prevent pests and other diseases which can affect the entire yield. While fertilizer prices are very low (Expert 4; Researcher 5; Entrepreneur 3), seeding optimization is another vital topic, especially in monoculture (Researcher 2). Given all these optimization strategies, efficiency is the keyword which has been in the focus of Dutch horticulture producers over the last years (Expert 3).

“We can get a lot of product from one hectare of soil. But we pay a high price because our soils are very degraded.” (Ministry 2)

The industrial standard of growing vegetables in the Dutch greenhouses is hydroponics on rockwool and sometimes coconut fiber (Expert 2, 3 & 4; Researcher 1; Entrepreneur 5). Purely hydroponics produce, without any substrate, is mostly found with leafy greens (Expert 1). To push the growing rate, however, synthetic fertilizer is used in the greenhouses (Expert 4, 7 & 8; Researcher 2). This is mainly due to the fact that synthetic fertilizer provides a base for a highly controlled environment (Expert 7; Ministry 2). In contrast, the problem with organic fertilizer, e.g. manure, is its insoluble nature (Expert 4). Nevertheless, the Dutch horticulture standards on hydroponic base create more sustainable production patterns than extensive land use standards in other countries (Expert 4; Researcher 2). Environmental problems originating from extensive conventional plant-based farming in the Netherlands include the degradation of soil, water pollution and other environmental issues. To counteract soil degradation a soil program as well as regulations on wastewater have been introduced by the Ministry of Agriculture, Nature and Food Quality (Ministry 2; Researcher 2 &5; Expert 3; Entrepreneur 4).

“So, because when you are talking about organic farming or ecological farming, everybody thinks you're very weak and soft and old age and [], but if you use the new techniques together, then there is really a way to sustainability.” (Ministry 2)

The culture in the horticulture sector can be described as open, straightforward, dynamic and highly innovative yet stubborn (Expert 1 & 2; Researcher 1), the latter being implied especially for the older generation (Expert 9). The Dutch horticulture sector is very much concerned with innovative high-tech solutions which are indirectly fostering sustainability. The focus lies on decreasing the use of resources while increasing the level of productivity (Expert 1, 3 & 4; Viviano, 2017; OECD, 2015).

“They want to change but they want to change because otherwise they lose a part of the market. So that’s another kind of motivation.” (Expert 6)

Nonetheless, the call and need for sustainability is taken seriously by the agri-food sector (Ministry 1 & 2; Expert 1 & 5; Entrepreneur 5). Efforts towards *Circular Agriculture* in production are currently being made by the Land- en Tuinbouw Organisatie (LTO) and growers (Expert 2 & 3; Researcher 4). The LTO is the Dutch Federation of Agriculture and Horticulture (LTO, n.d.) and has developed its own vision of Circular Agriculture and approaches towards zero emission (Expert 2). Sustainability efforts such as climate-neutral production, less chemical use and circular methods are increasingly adopted, especially by indoor growers. Indoor growers in the horticulture industry are considered more innovative and dynamic than outdoor farmers (Expert 1). The reasoning behind the circular approach is the sustainability trend, which farmers need to follow in order to sustain their businesses. Furthermore, it helps them to be prepared for the future expectations and regulations by consumers, government and retailers (Expert 2 & 6). Equally, having a good reputation is important for both, growers and the whole agri-food sector in order to sell their products (Expert 2).

Expert 1 claims that growers are very aware of their energy and heating costs, however, not so much of their environmental impact resulting from it. Nevertheless, the largest environmental impact in the plant-based farming sector lies with the producers in horticulture due to the warming of the greenhouses (Expert 1). Entrepreneur 1 explains on the other hand that the awareness of the production footprint is rising for CO^2, water and other parameters in the farming sector. Expert 2 experienced, that retailers leave the responsibility of reducing the production impact to the growers who are pressured to change their procedures. In contrast, Retailer explains that to meet sustainability expectations, producers need to change their practices. Sustainability expectations of consumers need to be included which is why retailers pressure growers towards high and sustainable standards.

The process from grower to retailer incorporates a small number of approximately five to ten bureaus/traders which coordinate the trading processes to national as well as international markets (Expert 1, 3 & 4; Retailer; Researcher 5; Ministry 2). Producers sell their produce to one specific bureau/trader[6], to which they are contracted to. One bureau/trader is connected to one or two retailers (Expert 1 & 3; Ministry 2; Retailer). This trade process provides security for all parties involved and is described as very transparent and well-organized due to food safety regulations (Expert 1 & 5; Ministry 2; Researcher 5; Silvis & Leenstra, 2009). Some interviewees indicate that in this supply chain concept, producers do not get a fair share of the price. In the industry this is called *milking of the suppliers* (Expert 1 & 4; Ministry 2; Researcher 4).

"Some retailers are really minded like: we are a supply chain, we need to work together, we need to invest in our suppliers in a way that if we give the contract for two years, then the grower knows that he will earn such an amount of money, so he has a guarantee and he can go to a bank and get a loan and invest. That kind of working-togetherness, this is now." (Expert 1)

Stakeholders in the supply chain are very well connected and develop solutions for high labor costs, energy saving and lower prices collaboratively (Retailer; Expert 3; Researcher 2). Besides collaborations within the supply chain, outsiders can be valuable collaboration partners too (Retailer; Expert 1 & 2). To provide an example: A retailer worked together with growers and the Ministry of Health to maintain biodiversity in farming. To further stimulate innovation and sustainability, one retailer introduced pitching days for farmers and other entrepreneurs with new ideas connected to the goal of collaboration (Retailer).

But not only the retailers and growers are drivers for change in this industry. The LTO provides a network for the sector and further supports growers in collective research and knowledge exchange (Expert 2). Moreover, they lobby for the growers and advocate for improvements in labor, regulations, innovation, etc. on the growers' behalf (Expert 1 & 3; Researcher 5). Lobby efforts on national and especially on

[6] At times, growers have two growing areas with two company names. For this case one grower is allowed to supply two different bureaus/traders (Expert 1).

European scale are generally well-organized for the growers (Expert 1; Researcher 5). However, lobby actions can be twofold, also in the agri-food industry. The example of pesticides shows, that although circular agriculture is the declared goal of the LTO and growers, efficiency and profitability maintain to be *the* core goals of the sector. Although sustainability goals were set, conservatives (LTO, chemical companies) lobby against the limitation of pesticides (Expert 1). Lastly, mediation and cooperation with the government to shape the future of farming are other responsibilities which are held by the sector (Expert 1 & 2).

According to the LTO (2012) *"expertise, infrastructure, the food processing industry, commerce and logistics are all on an extremely high level in the Netherlands"* (p. 2). Nonetheless, a lack of human capital in the form of experts such as crop protection specialists, well-trained growers, location managers and researchers is perceived (Expert 2 & 3, Jan; Silvis & Leenstra, 2009). Adding to this, there is a global shortage of experts while the demand for well-educated Dutch horticulture experts is high (Expert 3). Consequently, a shrinking number of farmers needs to supply food for an increasing number of customers (Researcher 2). In the same way some interviewees claim that there is a lack of financial capital for the development and purchase of new technologies as well as action for sustainability (Expert 2 & 6; Researcher 2). This is despite high investment requirements which are necessary to start and run a greenhouse business (Expert 3).

In 2008, the credit crisis also affected the Dutch agri-food sector, especially the horticulture industry. Greenhouse owners had invested heavily into their businesses previously but were unable to pay off their loans. Likewise, banks also lent heavily to these businesses and thus, decided to further invest to not lose all money involved. As a result, food prices decreased. The greenhouse sector regained strength approximately two years ago and the Dutch market flourished. As a result of the crisis, Dutch businesses learned to not only rely on one market but to expand to international markets and focus on the export of food and technology. Furthermore, Dutch banks changed their approach after 2008 and established new requirements to obtain a loan (Expert 3; OECD, 2015).

The Dutch agriculture sector is focused on upscaling, technology and export (Ministry 2). Researcher 2 describes the Dutch approach as a purely technological school of thought.

4.2.2.3 Science & Technology

"*A lot of the new ideas stem from the Netherlands because it's a very well-connected sector, everybody knows another person - whether it's a supplier or a greenhouse builder or even a plant supplier, seed companies.*" (Expert 3)

Most current production issues and research topics for indoor greenhouse farming, more specifically horticulture, are stimulated by the government, academia and the industry throughout the supply chain. Horticulture is one of the leading sectors in the Dutch economy in the *Topsectors* Agri & Food and Horticulture & Propagation Materials (Topsectoren, n.d.). The sector is further supported by research funds to maintain the current forerunner position of the Netherlands worldwide (Expert 4; Topsectoren, n.d.). Research areas include CO^2 reduction, focusing on heating but also lighting potential, plant health, pesticides and fertilizer as well as yield efficiency (Expert 1 & 4; Researcher 2, 3 & 4; Retailer; Ministry 2). These topics are also intended to enhance the industry's sustainability performance (Ministry 2).

(1) Heating topics are concerned with multiple heating sources. Instead of fossil energy, geothermal energy, solar energy, warmed coupled central heating and hot water storage in

the ground were developed and are perceived to be successful substitutes (Expert 1, 2, 3 & 4; Entrepreneur 2).

(2) Lighting efforts, which started in the past 10 years and gained momentum, are enabling production all year around (Expert 2) and increased plant growth (Entrepreneur 2).

(3) Yield efficiency in the form of right seeding is an important topic as well (Retailer; Researcher 2). For this type of specific technical development, companies innovate individually. This gradually changed from a former collective thinking to a more competitive thinking nowadays (Expert 2).

(4) Plant health, a topic mainly concerned with pest resilience, is a shared effort in research between farmers who cooperate to develop good solutions (Expert 2). Protecting the plant is a high priority and vital, especially in a globalized environment where invasive and non-native insects, fungi and other pests can threaten entire ecosystems (Expert 2 & 4). Nonetheless, from a legal perspective the amount of allowed chemicals is shrinking to protect environmental and human health. In addition, farmers claim they want to reduce chemicals used if this does not impact their profitability negatively (Expert 2 & 4).

"Well, growers just don't like the spray. It's not the best work to do. So, if you can do it biologically, they will. They're not 100% organic, but you know, they use a lot of predatory insects to kill the insects that are harming the plants. So that's a change you see." (Expert 2)

(5) "For example, here they develop machines for detecting when the plants need to be harvested or when the plants are sick and where you should apply pesticides directly. So instead of the pesticide going to all of the plants, even if they don't need them, they localize it." (Researcher 2)

Automation and high-tech in the form of sensor technology are two major fields researchers are involved in in the horticulture industry. These solutions, while in development, are not necessarily focused on sustainability; however, they improve the production's footprint by enhancing efficiency. For example, more targeted fertilizer application prevents fertilizer excess and waste (Expert 2; Researcher 2; Silvis & Leenstra, 2009). However, Expert 3 experienced that automation technology was not mainly bought by Dutch farmers but rather abroad. According to Expert 3, the investment does not pay off due to the high efficiency of Dutch growers. The sector is people-driven in the form of (or lack of) experts and manual labor.

"*We found out that universities worldwide are not up to what Wageningen does, for example. What the greenhouse builders and the whole technology system in the Netherlands does. Usually we found out that abroad they are still lagging behind*." (Expert 3)

In terms of production efficiency and technology know-how, the Netherlands can be considered a forerunner (Expert 3 & 8; Ministry 1). A decreasing amount of energy is used, and farming became more precise and efficient over the years (Expert 2). The focus of industry and science now lies on increasing yields and using space most effectively as space in the Netherlands is limited (Retail; Expert 2; Researcher 2; Ministry 2; Eurostat, 2018b). Scarce land leads to higher land prices and increasing competition amongst farmers. However, it has also been noted that other business opportunities such as energy production are affecting the land use as well (Ministry 2; Silvis & Leenstra, 2009; OECD, 2015). Nevertheless, Entrepreneur 1 stated that the leading know-how in farm technology is met with confidence.

In the light of the policy vision of Circular Agriculture, researchers have given more attention to circularity in agriculture in general and considered possible efficiency gains of circular efforts in particular (Researcher 4). One push of the circularity movement is the reduction of wastewater produced. In the case of wastewater, regulations pressured the sector towards developing new solutions (Researcher 5). Generally, wastewater from greenhouses is minimal due to the very efficient and water saving production methods; however, chemicals which are used for production accumulate in it (Researcher 5; Expert 4). Project groups are funded to tackle this problem of excess chemicals in wastewater and to develop circular concepts to counteract these and other linear production approaches (Researcher 5).

Likewise, rekindling old farming methods with new technologies is a current trend in research to foster sustainability developments. A pilot project by Wageningen University is concerned with this combination of old and new; it is called ecological farm and technique (Ministry 2). This approach is turning its back on monoculture and towards a more natural approach of multiple crop species. These experiments, combining old and new farming methods are operating on a local level in terms of production and sales (Expert 6). Located in the Rhine-Meuse-Scheldt river delta, the Netherlands have a lot of arable land. However, technical and chemical developments have moved the country away from natural procedures towards complete productivity. The aim is now to learn from those who are not yet that advanced in terms of technical development. It is the intent to grow more naturally again, e.g. with less pesticides and more manure (Ministry 1 & 2). As mentioned before, organic production is not considered a strength of the Dutch agri-food sector and is often viewed as weak, unproductive or idealistic (Ministry 1 & 2; Researcher 2).

Wageningen University has a Plant Science group (Viviano, 2017) which deals with topics concerning the Dutch horticulture sector. Wageningen University has their own greenhouse in Blijswijk for research and experimentation (Researcher 2). In addition to Wageningen University, also the Delft University of Technology and other schools of applied science are partners in research for agri-food stakeholders (Expert 2; Researcher 5). Many of the researchers in farm technology are somehow personally connected to the farming sector (Researcher 2). Overall, it has been stated that the horticulture sector is very well aware of new developments somehow affecting its sector. Innovations and other schools of thought, such as aquaponics or urban farming[7] are known and watched (Expert 2; Researcher 2; Entrepreneur 1).

[7] Urban farming efforts are not considered a necessity in the Dutch agriculture sector, but more of a prestige project or research environment (Expert 2 & 3). There are specific areas designated to agricultural activity, which is called *zoning*. Especially in urban areas, agricultural activities become unprofitable due to the high return on residential areas (Expert 4). One interviewee explains, that urban farming is not a topic of interest in the Netherlands because it is figuratively what is being done currently, due to the country's high population density and urbanization. Expert 3 says that the country is rather one empty city than one densely populated country. Furthermore, poor communication about vertical and urban farming substituting conventional farming has pushed growers away. It is not *the next big thing* but can be an addition to current practices (Expert 3). Nonetheless, urban farming solutions can be exported or used to educate citizens about growing food (Expert 3 & Researcher 2). Dutch companies export their high-end technology to countries abroad (Expert 3).

4.2.2.4 Policy

The Netherlands were and are highly engaged in the Common Agricultural Policy on European level and comply to it (Ministry 2; Silvis & Leenstra, 2009). Sustainability efforts towards zero-emission were discussed between the government, environmental groups, water management officials and led to wastewater guidelines which prohibit the discharge of wastewater into the soil, rivers or similar. This is due to the fact that wastewater is very hazardous for the environment. Fertilizer-enriched water, although often reused once, still contains excess nutrients and salts. To be allowed to drain the water, purification technologies need to be further developed and implemented. Alternatively, to release wastewater growers need to take into account costs per liter. These targets stimulate the development for more sustainable solutions (Researcher 1, 2 & 5; Entrepreneur 1; Hortidaily, 2014; Kamermans, n.d.). Stricter regulations for the use of chemicals for example for pest control on European level were implemented under the Integrated Pest Control regulation (Expert 3)[8].

Regulations can portray barriers for innovation (Expert 2) but can also be vital in the process of fostering innovation, pressuring the current standards towards more sustainability and raising awareness (Expert 1; Researcher 3). Expert 1 claims that the awareness of plastic pollution stems from the European regulation on plastic which slowly influenced national strategies and behavior. These national strategies are developed differently depending on the country: While some countries such as Germany approach regulation more as a directive which businesses need to comply to, Dutch regulation is the outcome of a discussion and an agreement of multiple parties involved (Expert 1). The starting point of regulation is generally at European level which is also where strong lobby representatives are located (Expert 1; Researcher 1) and laws are grounded (Ministry 1).

Research projects and collaboration in innovation is funded and facilitated by the government (Ministry 1 & 2; Expert 3; Entrepreneur 1; Silvis & Leenstra, 2009). This type of support for collaboration and innovation is especially called for by the horticulture sector as circularity efforts require shared efforts (Expert 2). The government supports research and respective research groups by contributing 50% of the required financial capital (Expert 2). Many agricultural endeavors along the supply chain are subsidized on national as well as European level (Expert 1). Innovations enhancing sustainability are especially relevant, and eligible for subsidies (Retailer).

4.2.3 Conventional Fish Production Regime

The results presented in this section cover the findings on the conventional fish production regime including aquaculture, the complementary TIS. All six regime dimensions are elaborated on in this section; however, they were meaningfully regrouped to align closer with the findings of the Dutch agri-food system and the flow of presenting them: markets/user preferences and consumer culture (4.2.2.1), industry and industry culture (4.2.2.2), science and technology (4.2.2.3) and policy (4.2.2.4).

4.2.3.1 Markets/User Preferences and Consumer Culture

Fish can be considered a part of a healthy lifestyle, which is why the Dutch government is promoting its consumption. Nonetheless, the Netherlands is not a country of high fish consumption (Ministry 1 & 2; CBS, 2015). Interviewees have been in disagreement which type, and origin of fish is predominantly chosen by Dutch consumers. While some argue that they prefer marine water fish over freshwater fish

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[8] Due to the large volumes produced in the Netherlands, growing efforts under 0.5 hectare do not need to comply with regulations such as fertilizer stock or spray application controls (Entrepreneur 1).

and describe the taste of freshwater aquaculture fish as *muddy* (Expert 3, 4, 5 & 9), others experience the opposite. The proponents of freshwater fish explain that mostly white anonymous fish is being consumed, and the *stinky* sea fish is not the preference (Ministry 1 & 2). According to information by the Dutch government, Dutch consumers buy sea fish approximately as much as aquaculture fish (Government of the Netherlands, n.d. a). However, they do not consume fish from their national aquaculture production (FAO, n.d. b). Main species consumed in the Netherlands are salmon, shrimp, mussels, herring, mackerel, cod, pangasius, trout and plaice, among others. These species are partly imported and partly from national production (Expert 5; EUMOFA, 2018).

Dealing with fish, animal welfare becomes an issue which reaches the emotions of the consumer and is gaining more attention lately (Expert 1 & 5). Consequently, the topic can be identified as consumer driven. NGOs pressure producers and retailers for more sustainable approaches in the conservative yet innovative fishery sector (Expert 1 & 5). For marine capture, the main criticisms are the issues of overfishing as well as pollution and therefore, the depletion of marine species (Expert 1 & 5; Researcher 2 & 5). For aquaculture production, the volume of fish in one tank and the use of antibiotics is criticized (Entrepreneur 1; Researcher 2 & 5).

Voluntary certification and labelling programs, such as the Marine Stewardship Council (MSC) or the Aquaculture Stewardship Council (ASC), can support the shift towards more sustainable procedures when dealing with seafood and increase transparency for the market as well as the consumer (Expert 5; Government of the Netherlands, n.d. a). Nowadays, retailers demand a label as a standard certification from seafood suppliers. This type of market pull is able to improve fish capture and farming on a national as well as international level (Expert 5).

4.2.3.2 Industry and Industry Culture

The Dutch seafood industry highly contributes to the global trade of seafood as the most traded commodity worldwide (Expert 5; EUMOFA, 2018). Exemplifying the Dutch trade of fish in 2014, 4.0 billion USD worth of seafood was imported while 4.6 billion USD worth of seafood was exported (FAO, 2016). Dutch seafood originates from marine fishery as well as aquaculture. As visualized in figure 5, marine fishery holds a higher share of the seafood production by capturing 500 986 tons in 2017 compared to aquaculture production with 61 600 tons.

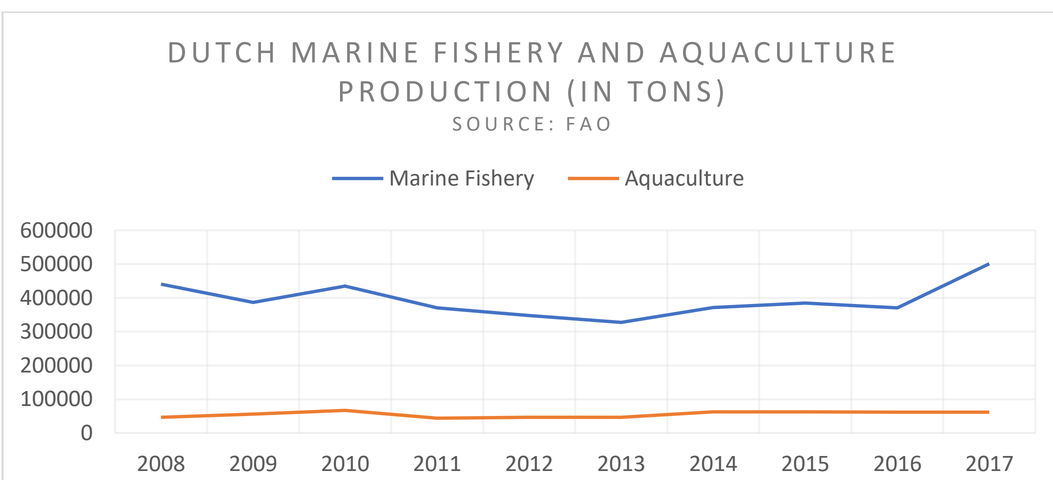

Figure 5 Dutch marine fishery and aquaculture production in tons; source: FAO, 2016

The Netherlands have a considerable *fishery sector* (Expert 5, 6 & 9; Researcher 4 & 5; DutchFish, n.d.) and Dutch fisheries are considered a forerunner in innovation, sustainability and selective fishing in Europe (Ministry 1; EUMOFA, 2018). This enables the Dutch fish fleet, which is well equipped in size and quality (Expert 5; Researcher 4; DutchFish, n.d.), to operate profitably and efficiently (Ministry 1; Expert 5).

"We have always been a fishing nation. We have quite a significant fishery fleet." (Expert 5)

The amount and quality of fish that the fishermen catch is vital to their business (Expert 5). Especially the fish species caught by Dutch fishermen determine the profitability of their daily business. Profitability is the number one priority in the sector and therefore decides the target species (Expert 5, Ministry 1 & 2). So far, the Dutch fishing sector has been profitable as captured fishes include plaice, sole, mackerel, sardine, shrimp and herring (Expert 5; Ministry 2; EMFF, n.d.; FAO, 2016). However, the sector is aware of possible changes in species due to climate change. Profitable fish species such as sardine, which are currently available in the Dutch waters, might not be the breadwinner of the future (Ministry 1 & 2).

The fishery sector is strengthened by its two main organizations who lobby on behalf of, connect and support Dutch fishermen: Nederlandse Vissersbond and VisNed (Expert 5; Nederlandse Visserbond, 2019; VisNed, n.d.). The fishery lobby is well established and demanding (Expert 5). Furthermore, the Dutch fishery sector is concerned with sustainable innovation and in cooperation to do so (Expert 5; Government of the Netherlands; n.d. b).

The *Dutch aquaculture* industry is divided between shellfish production and fish farming in terms of approaches, success and support. Additionally, the sector has shown interest in experimentation regarding new species and production methods (Ministry 1; FAO, n.d. a). Generally speaking, mostly mussels, eel and oyster are produced (EUMOFA, 2018; FAO, 2016). The Dutch Director-General of the Ministry of Economic Affairs, Dr. Hans Hoogeveen (2016) explained, that the Dutch aquaculture sector is small in terms of quantity of produce. However, he claims this is compensated for by cooperating and sharing knowledge as well as by innovation originating from the Netherlands. Further, he also stresses that on European level the aquaculture sector needs more attention and focus on sustainability as well as economic development.

(1) There is a well-established extensive *marine aquaculture production* of mussels and oysters, in the Wadden Sea and Dutch Rhine-Meuse-Scheldt Delta (Ministry 1; Entrepreneur 5; FAO, n.d. a). It is the largest and most profitable form of aquaculture in the Netherlands (FAO, n.d. b).

(2) Freshwater fish production in *recirculation systems by inland aquaculture* is less established and very small (Expert 5; Researcher 4; FAO, n.d. a). Some would say it has never proven to be successful and presents more of a niche (Expert 5; Researcher 5). The Dutch fish farming industry is very much isolated (Expert 3 & 5). The few aquaculture farms operating are producing fish such as eel, catfish, pike perch, tilapia and trout (Expert 5; Ministry 1; FAO, n.d. a). For the inland aquaculture sector, technical problems such as diseases and production control, low margins, high investments, high energy costs and high labor costs pose an issue to the knowledge-intensive sector (Expert 5; Researcher 2 & 5; FAO, n.d. b). Therefore, freshwater fish is mostly imported from Asia as it is cheaper to buy and ship it from there (Expert 3, 7 & 9; Researcher 4).

"You have to invest in expensive facilities on land, you have to invest in complex regulations to be allowed to farm a specific species, you are confronted with high costs in terms of permits, and costs are high because of the people that work on your farm." (Expert 5)

Inland fish farming with freshwater poses a problem in the Netherlands due to suboptimal climatic conditions, which result in high energy costs (for warm water fish) and slower growth of fish or different fish species (for cold water fish) (Entrepreneur 5; Ministry 1). Furthermore, the cost of high-skilled labor is very high (Ministry 1). Therefore, the focus in production lies on high-value aquaculture in the Netherlands at the moment which has also been recommended by the Ministry of Agriculture, Nature and Food Quality (Ministry 1).

Aquaculture businesses are not thriving and are rather ill-organized. Interviewees describe Dutch aquaculture fish farming as *loose initiatives* with an uncooperative nature (Expert 5; Researcher 5). The aquaculture community is described as closed off and hard to get in contact with (Expert 3; Researcher 5). Individual farms were not able to construct valid supply chains and were not successful in selling their fish produce due to lack of volumes, quality and predictability; however, this is required by retailers (Expert 5). Expert 5 explains, that a niche setting is the place for aquaculture due to its production uncertainty (Expert 5) and another interviewee concludes that the Netherlands have simply lost the race in aquaculture (Entrepreneur 5).

Moreover, the lack of veterinarians specialized in fish can pose a problem for future developments in the Dutch fish farming sector (Researcher 5). Some interviewees argue for the sustainability of land-based fish farming especially in recirculation systems due to the recycling of water and anti-ocean interruption (e.g. pollution, depletion of marine species). Others criticize the lack of animal welfare due to the volume of fish in a certain sized tank and the use of chemicals such as antibiotics (Researcher 1, 2 & 5; Ministry 1; Entrepreneur 1). Furthermore, there are pressures to reduce water usage and sludge volume which fish farmers have to deal with (Researcher 2 & 3). Moreover, a credibility crisis emerged for tilapia when an early production failure led to the fish species not exhibiting the health benefits which it usually entails. Trust has to be regained (Researcher 2).

NGOs strongly advocated against the production and consumption of eel. Eel, only born in their natural environment, are taken as fingerlings and put into tanks. Combined with the decreasing distribution of eel worldwide, this process received a lot of criticism and NGOs forced retailers to stop the sales of this fish (Expert 5; Researcher 5; Palstra, 2017).

(3) There is experimentation in the aquaculture sector with seaweed (Ministry 1). Moreover, there are companies developing the production of yellowtail fish and salmon for land-based aquaculture (Researcher 5).

Some interviewees were not aware of any associations for general aquaculture on a national level; however, for fish breeding specifically (Expert 5; Researcher 5). Other interviewees perceive lobby actions on aquaculture in the Netherlands (Expert 4 & 7). Expert 5 explains, that lobbying for aquaculture is mainly done by researchers from Wageningen University, which see great potential in the technology. On

European level, the European Aquaculture Society represents a networking organization for the support of aquaculture development (EAS, n.d.).

4.2.3.3 Science & Technology

Innovation in the fishery sector is driven by profitability (Expert 5; Researcher 4). It is an innovative sector with high investments in research and progress, which is driven by the industry, the government as well as research institutes (Expert 5 & 6; Researcher 4; Ministry 1). The fish production sector is included in the *Topsectors* under the category Water & Maritime and Agri & Food (Topsectoren, n.d.). This means that the sector is supported; however, Expert 5 claims that the support of the fish production sector does not have a high priority for the Ministry of Agriculture, Nature and Food Quality compared to other *Topsectors*.

A lot of innovation has allowed for more selective fishing, assistance for fishermen and a progressive fleet (Expert 4 & 5; Ministry 1; DutchFish, n.d.). However, Dutch innovation does not necessarily succeed due to disagreement on European level. The European Parliament decided to prohibit the innovation of *pulse fishing*[9] in 2019 on grounds of *political and socio-economic considerations*, after 2 years of usage by the Dutch fishery sector (Expert 5 & 6; Ministry 1; Researcher 4; Rijnsdorp, n.d.).

Current promotion of the stagnating aquaculture sector by the Dutch government and European Union benefits the sector's progress (Expert 7; Hoogeveen, 2016). Research in aquaculture is mainly driven by academia. Wageningen University with its focus on Life Sciences and high importance to the Dutch and global agri-food sector, has an Aquaculture & Fisheries Department. The department is known to employ one of the best aquaculture research groups and educates students in aquaculture on Bachelor, Master[10] as well as PhD level (Expert 5; FAO, n.d. b). More applied research for the sector is conducted by Imares, the Institute for Marine Resources and Ecosystem Studies (Expert 5; FAO, n.d. b) as well as other research institutes (Expert 5; Researcher 5).

Aquaculture is a knowledge-intensive field, which is driven by academia in the Netherlands. Research in aquaculture is mainly concerned with nutrient recycling (Researcher 5), feed, optimal growing conditions (Researcher 2) and disease control, the latter being a vital topic in the aquaculture world (Researcher 5; Expert 7).

4.2.3.4 Policy

Generally speaking, Dutch fishery activities in the North Sea are bound to the European law of Common Fisheries Policy. This law legally regulates the issue of overfishing on European level in order to sustain healthy fish stocks. Dutch fishery activities in coastal areas and inland waters fall under Dutch law which is also concerned with sustainability measures (Government of the Netherlands, n.d. a). Interviewees perceive numerous regulations for marine fishery as well as for the aquaculture sector on national and European level (Expert 5; Researcher 4).

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[9] "The traditional beam-trawl fishery for flatfish uses so-called tickler chains to startle fish like common sole and plaice and make them leap into the net. The chains are dragged over the seabed, disturbing the sediment and causing mortality of organisms in the trawl track. In the fishery using the pulse technique, the tickler chains have been replaced by electric pulses to make the flatfish leap into the net." (Rijnsdorp, n.d.)

[10] Expert 5 estimates 50 to 70 graduates in the field of aquaculture.

The Dutch government can enhance new developments in the sector through the National Fishery Fund and the European Maritime and Fishery Fund which financially support the sustainability, innovation, cooperation and knowledge development (Ministry 1; Expert 5 & 7). For example, the European Maritime and Fishery Fund financially supported the fishery industry in the adjustment to the so-called *landing obligation* or *discard-ban*. The landing obligation was initiated by the European Commission in 2011 and first adopted by the Netherlands in 2015[11]. Until the introduction of the landing obligation, Dutch fishermen threw caught but unwanted fish back into the ocean. Often, these fish do not survive; however, the status of the discarded fish is unknown and therefore, stock assessments cannot be certain (Expert 5; Government of the Netherlands, n.d. c; Steins, van Helmond & Kraan, n.d.).

New developments on the European regulatory level such as the introduction of new laws (e.g. the yearly quotas) or the prohibition of certain innovative technology (e.g. pulse fishing) affect the Dutch fishery sector and its productivity (Expert 5 & 6; Government of the Netherlands, n.d. d). Furthermore, political changes can also have a profound effect on the Dutch fishery sector. For example, the Dutch fishery sector faces uncertainty with the upcoming Brexit as about 50% of Dutch fishing activities are performed in UK waters (Ministry 1 & 2).

The European Commission as well as the Dutch government are aiming to enhance the aquaculture sector. Expert 5 claims that these efforts stem from food dependency issues involving the import of 80% of all fish consumed. Hoogeveen (2016) explains that the aquaculture developments are based on sustainability efforts and innovation for climate-efficient yet nutritious food production. The Dutch National Strategic Plan for Aquaculture is focusing on innovation and collaboration (Ministry 1; Hoogreveen, 2016). The Dutch Operational Programme aims at enhancing fish production by a set of sub goals, of which one argues to foster *"environmentally sustainable, resource-efficient, innovative, competitive and knowledge-based aquaculture"* (EMFF, n.d., p. 2). Expert 5 criticizes the research-driven nature of many projects and questions their economic orientation. Current governmental support is focused on aquaculture developments on pilot scale to validate research, and is not predominantly concerned with the economic scaleup of projects (Ministry 1).

However, conservative government actions such as regulations can also pose a barrier to the aquaculture development. For example, the inland production and selling of shellfish is legally not allowed (Ministry 1). However, sustainability issues in the Wadden Sea where shellfish is mainly farmed pressure the industry and government to change (Ministry 1; Hoogreveen, 2016). These regulations and developments present a predicament for the Dutch fishing production regime. NGOs lobby against fishery activities in the Wadden Sea, which is a natura 2000[12] area in Dutch territory (Ministry 1). Respecting the natura 2000 requirements, the Dutch government, together with the industry and academia, work on the efficient and sustainable use of limited space. Efforts for efficient space use in fish production are tied to energy production and nature development as part of the National Strategic Plan for Aquaculture (Ministry 1).

[11] The Dutch retailer Plus reacted to the landing obligation and offered former discarded fish species. One expert however described that consumers were ignorant to unknown species and claimed that the market for special fish species has not formed (Expert 5). Most of the fish landed due to the obligation is used in fishmeal production (Government of the Netherlands, n.d. c).

[12] *„Stretching over 18 % of the EU's land area and almost 9,5% % of its marine territory, it is the largest coordinated network of protected areas in the world. It offers a haven to Europe's most valuable and threatened species and habitats."* (European Commission, 2019).

Interviewees (Entrepreneur 1; Researcher 5) describe *grey areas* for inland aquaculture regulation in the field of wastewater and sludge. Both are currently said to be accepted due to the small-size and insignificance of the Dutch aquaculture sector.

Both sub-regimes, the conventional plant-based farming regime and fish production regime, are very well established and eminent sectors in the Netherlands. Although, both regimes are highly efficient and innovative, they lack sustainability focus and drive. Profitability for all stakeholders involved is key and achieved in the Dutch agri-food sector which is why both sub-regimes seem indisputable. However, in order to meet the SDGs, the agri-food sector needs to transition towards more sustainable practices. Hereby, a niche innovation like aquaponics can come into play.

4.3 Niche Level

Aquaponic systems are sustainable niche innovations in the agri-food regime, which aim at circularity in food production. This technology is positioned at niche level because it is still emerging, not yet competitive on regime level and not yet sufficiently defined in terms of design, network, price-performance and strength. The two components, which aquaponics encompasses are hydroponics and aquaculture. Both of these technologies were elaborated on in the previous section. Hydroponics as well as aquaculture form complementary technologies to aquaponics (Somerville et al., 2014). Likewise, research in either one of these disciplines can advance aquaponics in terms of research as well as practical application (Researcher 1, 2 & 5; Expert 7). Although, the strong connection with and dependence of aquaponics on both hydroponics and aquaculture is evident, the systematic integration of aquaponics as a niche innovation in either the plant-based farming regime or fish production regime has not yet happened (Entrepreneur 1).

4.3.1 Technological Innovation System

In order to understand the emerging *aquaponics innovation* system, how it is performing, and what blocks or induces its success, this section provides insights on the aquaponics development. The seven functions help to portray the aquaponics developments and network dynamics in the following order: entrepreneurial activities (4.3.1.1), knowledge development (4.3.1.2), knowledge diffusion through networks (4.3.1.3), guidance of search (4.3.1.4), market formation (4.3.1.5), resource mobilization (4.3.1.6) and creation of legitimacy/counteract resistance to change (4.3.1.7).

4.3.1.1 Entrepreneurial Activities

The aquaponics development has led to a diversification of entrepreneurial activities in the Dutch agri-food niche market in the period 2008-2018. The ten-year portfolio of Dutch aquaponics efforts includes (1) commercial farms, (2) integrated business models and (3) system providers. Each aquaponics business venture is elaborated on in the following paragraphs and grouped accordingly to the three concepts mentioned above.

(1) There are two examples of Dutch commercial aquaponics farms. At the moment, *Duurzame Kost* is the only still existing commercial aquaponics farm in Eindhoven in the Netherlands and operating since 2014 (see figure 6). It is a social business which has two main goals: circular food production and the rehabilitation of people with disabilities. Next to delivering their produce to 35 restaurants in Eindhoven, ecotourism is a vital part of their business model (Entrepreneur 2; Duurzame kost, n.d.). Another example, *Urban Farmers* was a completely commercial urban rooftop farm in The Hague, which started to grow and sell vegetables and fish in May 2016. The reason for the Swizz company to implement the system in the Netherlands was the horticulture industry which at the same time portrayed a market barrier. They declared bankruptcy in July 2018 due to unprofitability. Their sales strategy changed between direct sales to consumers, restaurants and retailers. The business plan included tours, amongst other selling points. (Entrepreneur 1; The Hague Online, 2018).

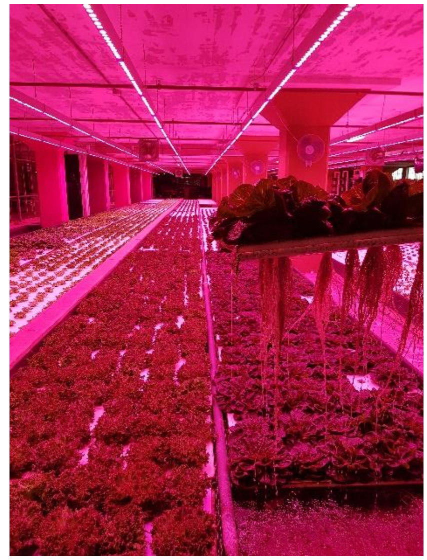

Figure 6 Leafy green production from the aquaponics system at Duurzame kost May 30, 2019

"That's a good way of earning money. It's not selling lettuce, but it is selling sustainability." (Entrepreneur 2)

Adding education in the form of tours and workshops to the commercial system secures a complementary revenue stream and provides financial security, as described in the examples above. The sales of the produce alone cannot break even to the costs of the system and thus, it cannot sustain itself autonomously (Researcher 2; Entrepreneur 3).

(2) Multiple entrepreneurial efforts by aquaponics enthusiasts went into an integrated business model of aquaponics as an in-house production system accompanying a restaurant. *Mediamatic* is an art institute, which got in contact with aquaponics around 2012 through a befriended permaculture expert, who recommended the technology for arid land. Today the aquaponics system, left picture in figure 7, is mainly used for educational reasons in the form of internships and workshops. Nonetheless, it supplies their restaurant with predominantly herbs and flowers (Expert 8; Mediamatic, n.d.). *Uit je eigen stad* was a restaurant in the industrial district of Rotterdam (Researcher 2) which aimed at producing its own fish and vegetables. They started building the facilities in 2012 (van der Heijden, 2015) and filed bankruptcy in 2016, mainly due to the failure of the in-house aquaponics system (de Graaf, 2016; Researcher 2). Next to the restaurant also tours were a source of income. *De Ceuvel* is a green-tech ground, which is cooperating with Metabolic, a sustainability consulting venture and think tank, in the establishment and maintenance of a small aquaponics system since September 2017. The system, which can be partly seen in the right picture in figure 7, provides the De Ceuvel restaurant with herbs and edible flowers since (Expert 10; De Ceuvel, n.d.; Metabolic, n.d.).

Aquaponics experts have different views on integrated business models. While some argue it's a more profitable and creative business case (Entrepreneur 3), others claim that in this case aquaponics is only used as a marketing instrument (Expert 7).

Figure 7 Pictures taken of the aquaponics greenhouse at Mediamatic (left) and the De Ceuvel herb production (right)

(3) Different entrepreneurs are not developing aquaponic systems to produce vegetables or fish to sell but to provide a system and its implementation. *TGS* is a consultancy for vegetable farming solutions, established in 2014 in Wageningen. Their portfolio includes the aquaponics technology among others. Their approach is to assess, consult and implement the best-fit technology per individual case, mostly in developing countries (Expert 9; TGS, n.d.). *Vierhout Engineering*, who founded 2016 in Hengelo, integrated aquaponics as one of the company's business branches at the end of 2016, which is currently situated in the planning phase. Their approach is to develop systems and implement them with a Dutch partner (Entrepreneur 4; Vierhout Engineering, 2019). *Kikaboni AgriVentures* is a demonstration aquaponics farm, which was founded in 2018 by a researcher from Wageningen University in Kenya to enhance local food safety in the country (Researcher 1 & 4; Kikaboni, 2018). Another *not yet officially established startup* from Leiden is developing aquaponics applications for offices and apartment buildings (Entrepreneur 3).

Exceeding the ten-year timeframe chosen as a research objective to give an insight into their effects on current developments, new entrants are described as hesitant or cautious in starting aquaponics-based businesses (Entrepreneur 2 & 4; Researcher 2).

"I think there is that now new realization [for entrepreneurs] that okay, if we are going to try, we have to be more careful. So sadly, that's going to mean like people are going to be afraid of trying because they have seen those who try fail. So, it will take a while I think for another little bloom of entrepreneurs, who give it a try." (Researcher 2)

Two new aquaponics projects have occurred in the Netherlands in 2019. First, the same Dutch researcher from Wageningen University, who founded *Kikaboni AgriVentures* in Kenya, established *desertfoods*, which operates an aquaponics farm in Namibia (Researcher 1 & 4; desertfoods, 2018). Second, the QO hotel in Amsterdam implemented their own aquaponics system in May 2019 and aim at using their own produce for the in-house restaurant (Expert 4 & 10).

4.3.1.2 Knowledge Development

Knowledge can be generated by either learning-by-searching which refers to research for example by university, or by learning-by-doing which is typically done by entrepreneurs.

Aquaponic learning-by-searching is mainly performed by researchers from Wageningen University (Researcher 1; Entrepreneur 1; Expert 9). In the Netherlands, in Europe but also worldwide Wageningen University worked its way up to the number one university of publications on aquaponics. A search on Web of Science reveals that cumulatively over the 10-year timeframe chosen, Wageningen ranks first in publications on aquaponics worldwide on university-level. Taking a closer look at the development of aquaponics research, this section also considers hydroponics as well as aquaculture publications for a better understanding and relation of shared value.

The following publication statistics are based on data from Web of Science (WOS). To assure accuracy when displaying the development visually, a comparison between WOS and Scopus was made. Comparing publication data retrieved from both sources for the Netherlands it becomes clear that there are systematically more publications for aquaponics, hydroponics and aquaculture in Scopus[13] (see Appendix 5 for a table view of the data). Nonetheless, the development trend in the Netherlands is similar as can be seen in figure 8 and 9. There is a gradual increase in aquaculture publications (yellow line) with a peak in 2016, drop in 2017 and peak again in 2018. Hydroponics publications (blue line) show a more stable development with a slight increase in publications over the years. Aquaponics publication efforts (green line) in the Netherlands only started after 2015. These developments and trends for Dutch publications on aquaculture, hydroponics and aquaponics retrieved from the Dutch publication statistics of both, WOS and Scopus, show that the chosen source becomes insignificant for this research.

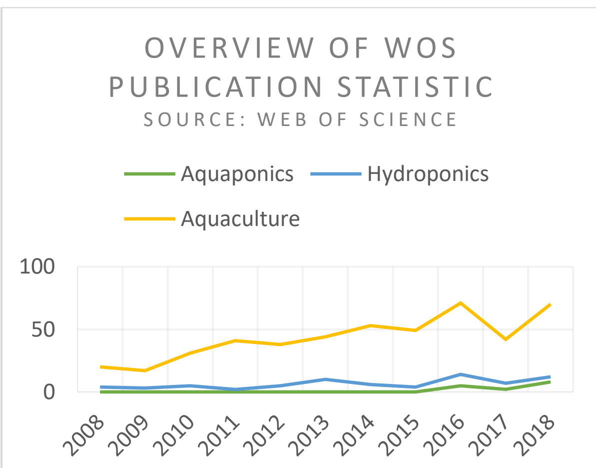

Figure 8 Publication data on the Netherlands regarding the keyword aquaponics, hydroponics and aquaculture; source: Web of Science

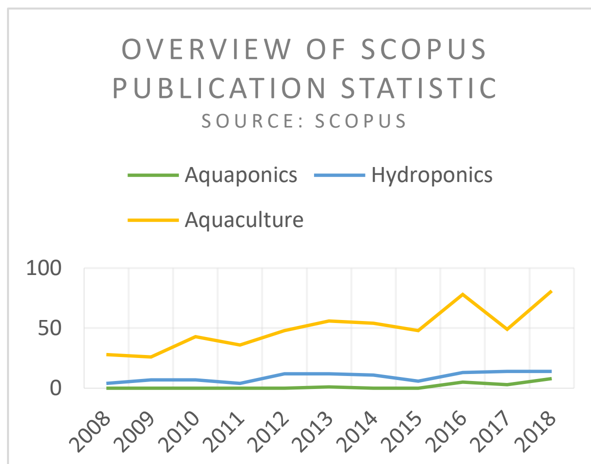

Figure 9 Publication data on the Netherlands regarding the keyword aquaponics, hydroponics and aquaculture; source: Scopus

[13] Both Web of Science and Scopus, are valuable publication a citation databases. There is a high publication overlap between the two sources, according to Vieira and Gomes (2009), who researched the coverage of articles published for two Portuguese universities, claimed to be typical universities, on both platforms. The overlap is 2/3 of the total amount. The results retrievable from the databases Web of Science, Scopus and Google Scholar, differs depending on the topic, discipline, institution and location. Since this study was conducted for the Netherlands, so Europe, which is covered by all databases, and for aquaponics which is of a multidisciplinary nature, the database chosen is not of high relevance for this research. Google Scholar was not included in the comparison, due to the fact that already a lot of other data was retrieved from Google and data triangulation efforts wanted to be assured.

In relation to the general sum of Dutch publications on agriculture, fisheries and plant science, it becomes clear that publications on aquaponics and hydroponics are constantly less pursued than aquaculture-related research over a period of 10 years in the Netherlands. Aquaculture reaches 8.5% with 70 publications in 2018, while hydroponics reaches 1.5% with 12 publications and aquaponics tops at 1.0% with 8 publications, as visualized in figure 10. For further details, see Appendix 6. Interestingly, figure 10 shows a similar development for aquaculture, hydroponics and aquaponics from 2016 onwards: An increase from 2015 to 2016, a decrease from 2016 to 2017 and again an increase from 2017 to 2018 in Dutch publications.

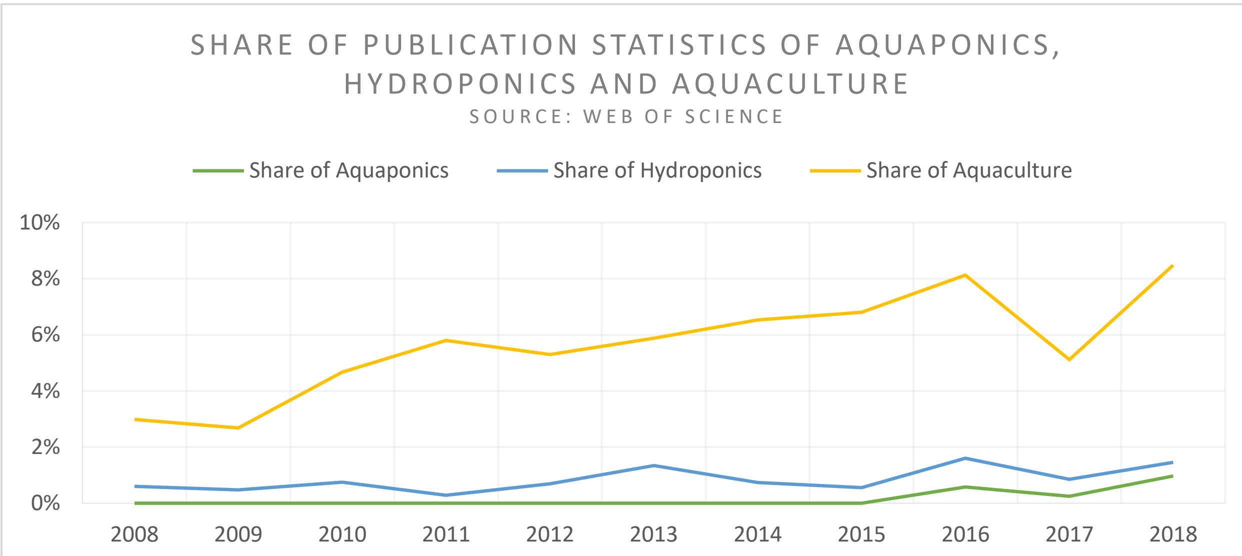

Figure 10 Share of the Dutch publication statistics of aquaponics, hydroponics and aquaculture in relation to general categories (agriculture, fisheries and plant science); source: Web of Science

Zooming in on the aquaponics research in the Netherlands and relating it to the worldwide developments of aquaponics publications, figure 11 visualizes the trend of aquaponics publications over the 10-year timeframe for the Netherlands as well as globally. For a table view on this data, see Appendix 6. While worldwide academic interest in aquaponics can be described as low but steady at first, it rose drastically from 2015 onwards. In the Netherlands, aquaponics was not a topic of interest before 2015; however, in 2016 researchers from Wageningen University published five scientific papers on aquaponics research and by that kicked of the topic in the Dutch academic field. Wageningen University got into contact with aquaponics around 2013 due to a Chinese-Dutch-German research collaboration, which after researching aquaculture shifted to aquaponics (Researcher 4). The research force increased drastically at Wageningen when two PhD positions for aquaponics were filled in 2015 (Researcher 1, 2 & 4). This could be an explanation for the sudden rise of aquaponics publications from 2016 onwards. These circumstances led to the fact that in 2018 the Netherlands was ranked second worldwide in terms of Web of Science publications on aquaponics with eight publications, after the United States of America with 15 publications.

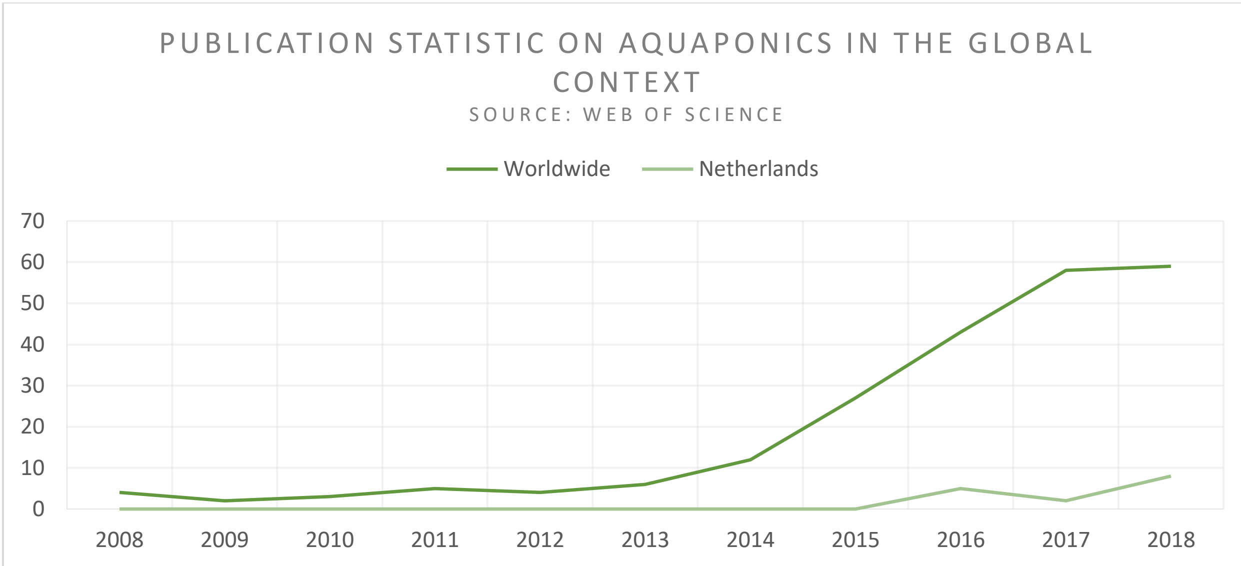

Figure 11 Aquaponics publication data on the Netherlands in the global context regarding the keyword aquaponics; source: Web of Science

The scientific knowledge on aquaponics produced in Wageningen focusses on multi-loop systems (Goddek et al. 2016), production optimization (Delaide, Goddek, Gott, Soyeurt & Jijakli, 2016), system dynamics of e.g. nutrients (Goddek et al., 2018), and profitability calculations (Karimanzira et al., 2017). The complexity and sensibility of the system requires a lot of research as the system performance is always dependent on numerous variables: plant species, fish species, age of the fish, nutrient levels in the water, timing of the nutrient water transfer, water temperature, etc. (Researcher 1, 2 & 5).

Despite the role of Wageningen University as the leading university in aquaponics research and Life Sciences in general, the university does not own an aquaponics demonstration system for research and testing in the Netherlands. Researchers and students are able to visit demonstration farms of shared research projects abroad or commercial aquaponics farms in the Netherlands built and maintained by entrepreneurs (Researcher 1, 2 & 4).

Entrepreneurs are typically perform learning-by-doing, which manifests in their approach on aquaponics. This can be described as *applied science* and *trial-and-error* (Entrepreneur 2; Expert 8). Most aquaponics entrepreneurs in the Netherlands did not have prior education in vegetable or fish farming. Therefore, they heavily relied on openly available knowledge sources such as books, blogs, online trainings, and most importantly YouTube content. Especially YouTube was used as a starting point for acquiring knowledge to attempt the setup of an aquaponics system. With a gradually increasing amount of practical knowledge and understanding, the systems could be stabilized. Dutch entrepreneurs have individually gathered practical experience and knowledge about the system's dynamics, its maintenance and sensitivities. Above that, the entrepreneurs were able to learn about the market environment, marketing, customer acquisition, aquaponic business case developments, etc. first-hand (Entrepreneur 2; Expert 8, 9 & 10; Researcher 5).

While nowadays, aquaponics entrepreneurs operate independently from aquaponics researchers and vice versa, a vital task for the future will be to connect the two expert groups to enhance the aquaponics development (Researcher 2 & 4). Current standards in aquaponics production such as leafy greens, tomatoes and tilapia are researched, optimized and applied predominantly from researchers as well as entrepreneurs (Researcher 1, 2 & 5). However, testing new combinations of vegetables and fish, from a theoretical and practical perspective, can improve the viability of the aquaponics technology. Further efforts to increase its economic feasibility are crucial and a main focus for entrepreneurs as well as researchers (Researcher 1, Entrepreneur 3, Expert 7, Ministry 1 & 2).

From an academic perspective and a market perspective the multidisciplinary and cross-sectoral nature of the aquaponics technology is a crucial factor. Fish and plant science differ greatly in terms of knowledge, practices and individual cultures which increases the complexity of the aquaponics system. Educating individuals on both disciplines, fish as well as plant science and their interrelationship poses an obstacle to the development of the aquaponics technology itself (Researcher 1 & 4).

There are several private persons, researchers and entrepreneurs engaging in experiments with aquaponics for further development. The optimization of current practices as well as the experimentation with new approaches fall under these efforts. However, these experiments have not yet been patented by an aquaponics entrepreneur in the Netherlands. An analysis made based on patent data from the World Intellectual Property Organization showed that the Dutch neither hold patents for aquaponics, hydroponics nor aquaculture. Global patent numbers accumulate to a total of 190 aquaponics patents, 2418 hydroponics patents and 8623 aquaculture patents over the 10-year timeframe. For an overview of the worldwide patent distribution for these three technologies see Appendix 8. In addition to that also Espacenet, the patent platform of the European Patent Office, does not display any Dutch aquaponic patents in the timeframe chosen. However, it reveals one patent for aquaculture and two for hydroponics.

To sum up, owning patents on either one of the three technologies at hand is not of high interest in the Netherlands. One interviewee argues that the technologies are too simple to patent and the danger of a big agri-food producer taking over and scaling up fast is too high for engaging in patent efforts (Entrepreneur 3).

4.3.1.3 Knowledge Diffusion through Networks

Networks are platforms of exchange which enable knowledge diffusion between multiple stakeholders (Hekkert et al., 2007). For aquaponics in the Netherlands, there are no networks in place to enhance the diffusion of aquaponics-specific knowledge. Aquaponics experts and proponents have not yet been able to organize such an organization or platform in the Netherlands. On European level, four network initiatives have been identified: (1) Inapro, (2) the European Aquaponics Hub, (3) the EU Aquaponics Association (EUAA) and (4) CityFood. *Inapro* was a large European association connecting companies, researchers and individuals. It started in September 2014 and ended in December 2017 (Inapro, n.d.). Next to offering a network, the association also invested in research projects, trainings and made publications publicly available (Researcher 2; Cordis, 2014). The *European Aquaponics Hub* operated from 2014 to 2018 to facilitate aquaponics by means of a network and platform for communication comprised of researchers and entrepreneurs. Similar to Inapro, their main output was research publications (European Aquaponics Hub, 2019). In April 2018 the *EUAA* and its sub-initiative *Association of Commercial Aquaponic Companies* (ACAC) was founded with similar goals of facilitating aquaponics research as well as entrepreneurship (European Aquaponics Hub, 2018b; Inapro, 2018). Although still ongoing, the EUAA is not as highly anticipated as prior associations in terms of promotion, outreach and engagement from its members (Researcher 1). Resulting from this, a smaller research-based initiative called *CityFood* started in 2018 with the aim of facilitating the aquaponics development in specific areas (CityFood, 2018;

Researcher 1). While researchers have been generally engaged in these networks, Dutch entrepreneurs have not experienced the type of support they expected. Entrepreneurs concerned with aquaponics still perceive a lack of practical research, helpful network partners and financial support (Entrepreneur 1 & 2; Researcher 1 & 2).

"What I see now is that everybody is starting in aquaponics, starting like there would be no yesterday, there is no past knowledge. We always start from zero, everybody's making two steps. And nobody walks 20 steps." (Entrepreneur 1)

An explanation for the fact that there is no knowledge buildup and exploitation as described by Entrepreneur 1 could be (1) an organizational failure, (2) the lack of willingness to share or (3) the absence of a one-fits-all-solution for aquaponics (Entrepreneur 1; Researcher 1; Expert 10).

(1) Although, on European level aquaponics is fostered by various network initiatives such as the European Aquaponics Association oftentimes knowledge diffuses within a predefined network, so-called research groups. These networks consist of selected participants which form through cooperation (Researcher 1 & 2). Such patterns foster the competitiveness and political arm-wrestle in academia between researchers, research groups and institutes. This behavior is especially harmful for a niche innovation such as aquaponics (Researcher 2).

    In the Netherlands, aquaponics experts and advocates barely know about each other and thus, sparsely cooperate. Only a very few research projects between researchers and aquaponics entrepreneurs happened, provided spillovers and the opportunity for researchers to learn-by-doing (Entrepreneur 1; Researcher 5; Ministry 2).

    Moreover, the opportunity to connect with complementary associations should be taken into account. Dutch aquaponics proponents joining forces with for example the aquaculture sector could improve the development of both streams (Entrepreneur 1).

(2) Especially the collaboration on aquaponics between entrepreneurs remains an exception in the Netherlands. Every entrepreneur has an economic interest which is individually pursued. Responsibility towards investors can drive secrecy, but also the risk of investment and experimentation needs to be compensated for (Entrepreneur 1, 2 & 3; Researcher 5). Entrepreneur 1 describes knowledge and success in aquaponics as the *holy grail* which is discovered and from that moment on safe-guarded for personal benefit. However, collaborating and sharing knowledge through networks is especially crucial for aquaponics due to its multidisciplinary nature (Entrepreneur 3, Researcher 2).

(3) The sensitivity and complexity of the aquaponics system does not allow for a one-fits-all-solution. Research and testing done for the combination of tomatoes and tilapia in a Dutch system cannot be directly translated to the conditions in Spain or Sweden. Neither do the system specifications for tomatoes and ginger or tilapia and trout align. System specification per species of plant and fish are different (Researcher 2 & 5).

A global source of knowledge diffusion and networking is represented by social media and other online platforms. Entrepreneurs perceive a large aquaponics online community, which globally connects enthusiasts, educates early adapters and advances aquaponics (Entrepreneur 2 & 5; Expert 10, Researcher 5). Most dominantly YouTube, but also blogs and the Murry Hallam online course provide basic knowledge. This basic knowledge is applied in the development and implementation of aquaponics systems in the Netherlands (Expert 8, 9 & 10; Entrepreneur 2). YouTube is used as a tool to provide and consume aquaponics knowledge in an accessible and visual way. Therefore, it is a go-to knowledge source in the aquaponics community (Expert 8, 9 & 10). The result of that is described as a *YouTube movement* for aquaponics, a *hype* starting around 2011 in the Netherlands which was experienced by rising public interest in aquaponics. Shortly after the hype started the first Dutch aquaponics businesses was founded (Expert 8 & 9). This description of interviewees corresponds to the insights gained on Dutch YouTube developments visualized in figure 12. The data retrieved from Google Trends shows a strong increase in the search frequency of aquaponics from 2010 to 2011 (139%) and from 2011 to 2012 (135%) on YouTube. In the years after, between 2012 and 2017, the hype flattens to a 17% increase. Interviewees also perceived the decrease of general interest in the aquaponics technology in recent years (Researcher 1 & 2; Entrepreneur 2; Expert 8). While some argue the cause of disinterest to be the failed commercial aquaponics projects in the Netherlands, others criticize the aquaponics videos on YouTube to be romanticized and misleading (Researcher 2; Expert 8).

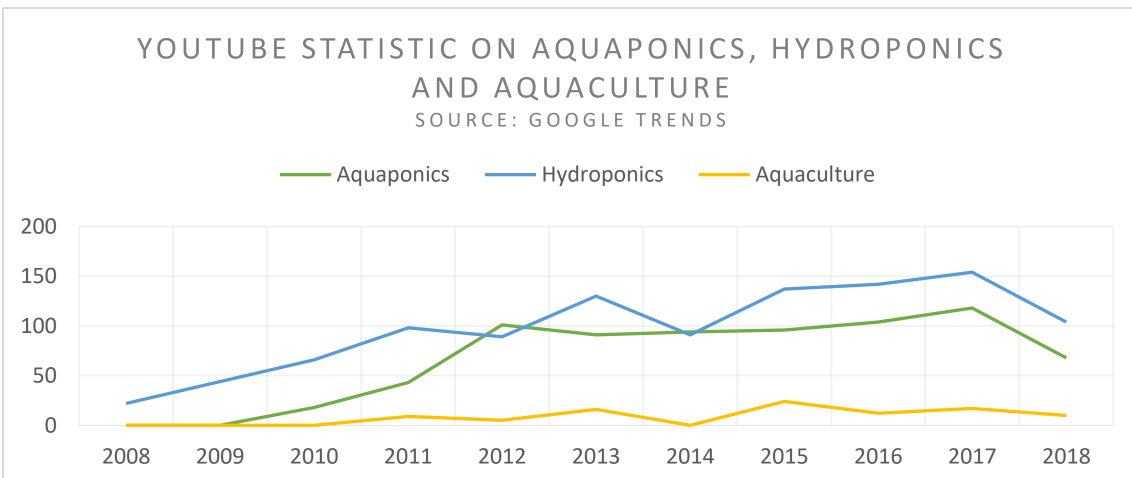

Figure 12 YouTube data on aquaponics, hydroponics and aquaculture; source: Google Trends

The aquaponics, hydroponics and aquaculture statistics of Google Search (figure 13) and Google Images (figure 14) provide a similar picture. Figure 13 and 14 show that aquaponics is the technology with the highest increase in search frequency between 2008 and 2018. However, the described hype development of aquaponics seen in figure 12 resulting from the *YouTube movement* cannot be claimed for the steadily increasing search frequency of aquaponics in Google Search and Google Image, as shown in figure 13 and 14. While hydroponics has increased less drastically, it is receiving the highest shares among the three technologies in all Google Trend statistics in terms of search frequency. In the period 2008-2018 aquaculture has a consistent and rather low search frequency in all Google Trend statistics.

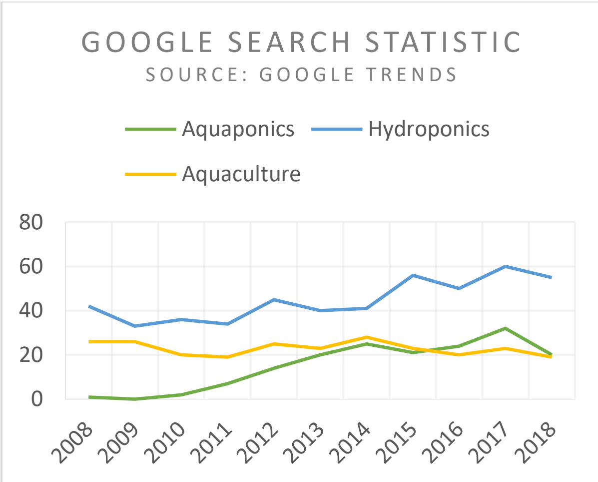

Figure 13 Google Search data of aquaponics, hydroponics and aquaculture; source: Google Trends

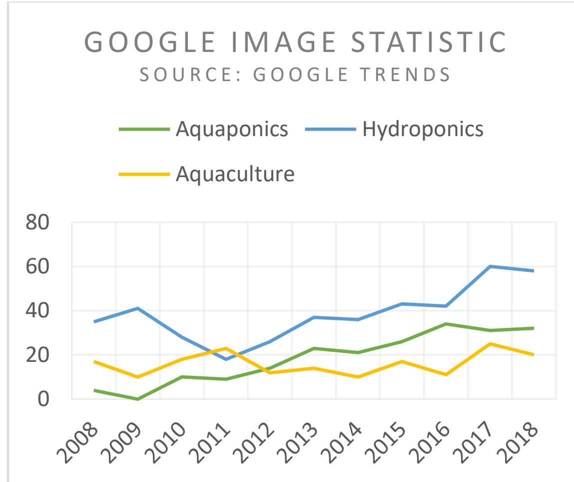

Figure 14 Google Image data of aquaponics, hydroponics and aquaculture; source: Google Trends

To receive a better understanding of the overall significance of aquaponics, hydroponics and aquaculture the three technologies are set in relation to the agri-food context in the Netherlands in figure 15. The agri-food context of this research comprises the following keywords for Google Search: agriculture, fisheries and plant science. Visualized by figure 15, it becomes clear that all three technologies have a relatively small share compared to the large Dutch agri-food context.

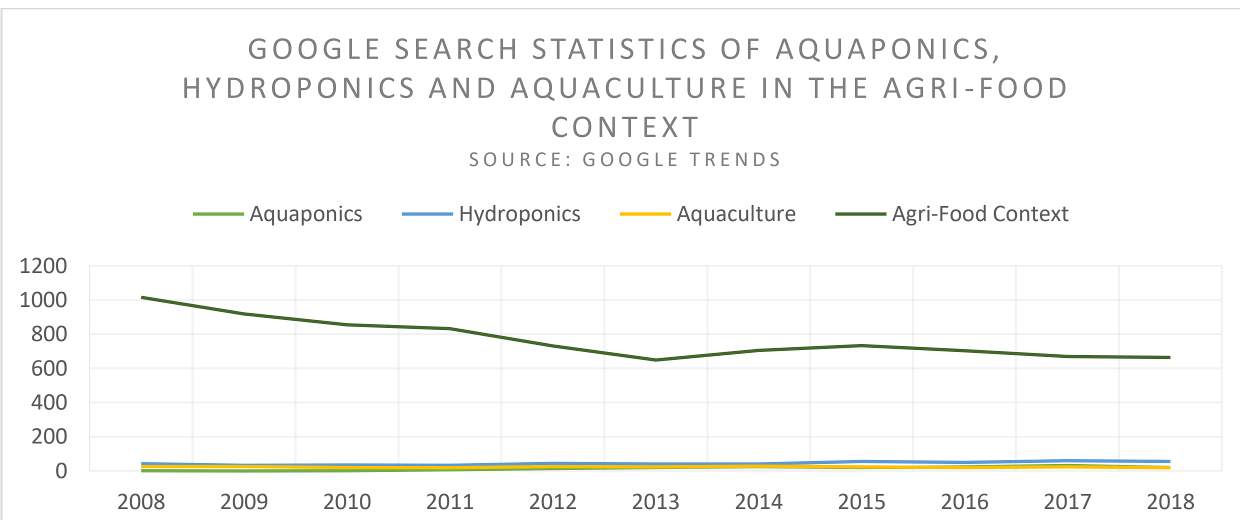

Figure 15 Google Search data of aquaponics, hydroponics and aquaculture compared to agri-food context; source: Google Trends

4.3.1.4 Guidance of Search

The direction of the aquaponics development in the Netherlands is dependent on institutional guidance, perceptions and significant events that influence the aquaponics development.

Institutional guidance influencing the aquaponics development has been taking place on a global, European as well as national level. *On global level*, the SDGs formulated by the United Nations emphasized the urgency of taking sustainable action. Particularly SDG 2 (no hunger), SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production), SDG 14 (life below water) and SDG 15 (life on land) take into account the current agri-food regime and can be valuable advocates for the aquaponics technology in the Netherlands (Government of the Netherlands, 2018b; Government of the Netherlands, 2018c; United Nations, 2017). *On European level*, aquaponics was named one of the ten most influential technologies for the future on behalf of the European Parliament Research Service (Van Woensel et al., 2015). However, there are no concrete regulations, targets or incentives following the announcement. As a consequence, there is no guiding for researchers, entrepreneurs and other proponents of aquaponics from European level (Researcher 1; Entrepreneur 3 & 5; Expert 9; Ministry 1 & 2). *On national level*, the Dutch Ministry of Agriculture, Nature and Food Quality introduced the policy vision of Circular Agriculture, followed up by a realization plan. The vision of Circular Agriculture can be summarized as follows:

"This means closing cycles of minerals and other resources as far as possible, strengthening our focus on biodiversity and respecting the Earth's natural limits, preventing waste and ensuring farmers are paid a fair price for their hard work." (Government of the Netherlands, 2018b)

This vision speaks to the resource saving and recycling nature of aquaponics. However, aquaponics has not yet directly benefited from this vision in terms of specific targets or incentives (Research 1; Expert 9; Entrepreneur 3 & 5; Ministry 1 &2).

Aquaponics experts have different, often contrasting perceptions about the core goal of the technology. As shown below, this leads to different business models, research streams and opinions about the future development of aquaponics as well as its current state. Entrepreneur 1 perceives a need for an institution, globally coordinating research projects, overseeing all topics on aquaponics and guiding the process of research towards advancing *the state of the art* of aquaponics. The following contrasting perceptions on aquaponics have been found:

(1) Driven by the water-saving approach and the issue of freshwater scarcity (Researcher 1; Expert 8) versus driven by the circular nature in nutrient recycling (especially for phosphate and nitrogen), soil degradation and biodiversity loss (Entrepreneur 1, 2 & 3) versus driven by fresh and healthy local produce and short supply chains (Expert 10; Ministry 1 & 2).

(2) Coupled or one-loop systems which require overall sustainable and stable conditions (Entrepreneur 2; Palm et al., 2018; Somerville et al., 2014) versus decoupled or multi-loop systems which focus on commercial viability and success (Researcher 1; Entrepreneur 1; Palm et al., 2018).

    "You've got two streams, two movements in aquaponics: we've got the circular die-hards, and you also have the people trying to get aquaponics as competitive as fast as possible." (Entrepreneur 2)

    Including the argumentation of economic viability versus technical complexity versus maximum sustainability (Researcher 2, 4 & 5; Entrepreneur 2; Ministry 2).

(3) Facilitating food education, awareness and experience (Entrepreneur 1 & 2; Researcher 2; Expert 9) versus facilitating domestic production (Researcher 1; Entrepreneur 5) versus facilitating urban farming solution scaled small- to mid-size (Researcher 2 & 4; Entrepreneur 3; Ministry 2) versus facilitating the competitive way of growing large-scale and profiting from economies of scale (Entrepreneur 2; Researcher 1).

(4) Competition against the current agri-food regime (Entrepreneur 2; Researcher 1) versus integration into the current agri-food standard (Entrepreneur 3; Researcher 2) versus distance to the current agri-food regime (Researcher 4; Expert 10; Ministry 2).

(5) Fish versus plant in terms of affiliation, knowledge, practices, individual culture, profitability and necessity[14] (Entrepreneur 2 & 3; Researcher 1 & 4)

(6) Food safety with easy-to-grow species (Researcher 1 & 4; Entrepreneur 2) versus high value products (Expert 8 & 10; Researcher 5).

These very diverse core goals result in diverse and contrasting visions and expectations of aquaponics for the future. Some aquaponics proponents, particularly entrepreneurs, strongly believe that aquaponics is *the* technology to watch. They foresee an increase in need for water and nutrient saving solutions as well as an optimization of the technology's performance. Consequently, they envision aquaponics to be a sustainable regime technology in the future (Entrepreneur 1, 2 & 4; Expert 10). It should be emphasized that the shared opinion among interviewees is that aquaponics will not be *the* single best solution transforming the incumbent agri-food regime as it is considered a shared effort of multiple sustainable technologies[15]. Some interviewees expect these other technologies to outperform aquaponics (Researcher 1; Entrepreneur 1; Expert 10). Some aquaponics experts doubt aquaponics' success in general and in the Netherlands due to persistent uncertainty about the aquaponics technology itself and its development (Ministry 1 & 2; Researcher 1 & 4; Expert 7). To decrease this uncertainty, continuing research and experimentation are considered a vital task for the upcoming years (Researcher 1; Entrepreneur 1, 2 & 4). Interviewees perceive a higher chance for aquaponics' commercial success predominantly for countries which are water scarce, have a desert-like climate or a shortage of affordable fresh food due to a large distance to food sources. Countries which were named include developing countries and deserted areas, islands, specific locations in Scandinavia, Australia, and the United States (Researcher 1; Entrepreneur 3 & 4; Expert 7).

"I think there is that now new realization that okay, if we are going to try, we have to be more careful. So sadly, that's going to mean people are going to be afraid of trying because they have seen those who try fail. So, it will take a while, I think." (Researcher 2)

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[14] The systematic integration of aquaponics as a niche innovation of either the horticulture or fishery sector is yet another uncertainty to be agreed upon (Entrepreneur 1). Some interviewees identify aquaponics to be a subsection of the aquaculture sector (Ministry 1; Researcher 5) and explain, that the fish are the product, which is of higher value (Entrepreneur 3). Others see the main value in the plants and argue that they are the system's core (Entrepreneur 2). Generally speaking, the disciplines of fish and plant science differ greatly in terms of knowledge, practices and individual culture, which increases the complexity of the aquaponics system (Researcher 1 & 4).

[15] Technologies mentioned include: Not in one ecosystem, but separately collecting and processing animal or human manure as fertilizer (Researcher 1 & 5; Entrepreneur 1; Expert 4 & 8). Research on salty agriculture, to grow vegetables with saltwater (Ministry 1 & 2) is taking place and might enhance saltwater aquaponics (Entrepreneur 4). Hydroponics (Entrepreneur 4; Expert 9) or permaculture (Researcher 1) are expected to prevail in vegetable farming. Lab grown fish is one of the future expectations in fish production (Expert 4).

Specific events which have influenced the perceptions and expectations of many individuals concerning aquaponics are the failures of multiple aquaponic projects in the Netherlands. Entrepreneurs, researchers and government officials are more critical and cautious towards the technology nowadays. These anti-success stories in the Netherlands have left experts and proponents with a certain disbelief and caution towards aquaponics. This circumstance and the resulting reactions can be categorized as a crisis for the Dutch aquaponics development (Researcher 2; Expert 9; Entrepreneur 2; Ministry 1 & 2; Sijmonsma, 2018).

4.3.1.5 Market Formation

"*Aquaponics is a process innovation, not a product innovation - the products are competing on the market with conventionally or organically grown produce from horticulture as well as with conventional saltwater and freshwater products, responsible or organic aquaculture and wild catch."* (König et al., 2018)

Many interviewees have recognized that the unique market environment in the Netherlands which derives from the dominant agri-food sector influences the development of innovations such as aquaponics (Entrepreneur 1 & 2; Ministry 1 & 2; Researcher 1; Expert 4). Entrepreneur 1 explains that especially the highly efficient, profitable and knowledge intensive horticulture sector was the reason behind setting up a commercial aquaponics system in the Netherlands. Other interviewees advice strictly against it, exactly because of the strong horticulture sector in the plant-based farming regime and weak aquaculture market (Researcher 1 & 4; Expert 9).

"At one point, the innovation has to leave the tech universe and go into real markets. And if the market says: "We don't care, we even profit more from an existing solution", then you lost." (Entrepreneur 1)

The current aquaponics market in the Netherlands is very small with only very few aquaponics initiatives operating (Researcher 1, Entrepreneur 5). While Expert 9 argues for a standstill in the market development of aquaponics, Researcher 1 questions that there ever was a market to begin with. Interviewees are in disagreement whether aquaponics will ever form a confident niche market or stay in a local niche setting in the Netherlands and Europe (Researcher 1, 2 & 4; Entrepreneur 2). Likewise, there are no institutional stimuli in place for aquaponics in the form of tax regimes, certification schemes, such as an organic label, or similar, to support its development and competitiveness.

Currently aquaponics is in a learning space with the focus on research and experimentation from both researchers and entrepreneurs. Aquaponics can be considered being in an early phase of a *nursing market*. Despite the fact that there has been an increasing amount of research and experimentation, there is still a long way to go for the aquaponics technology to mature and develop (Researcher 1 & 4; Expert 9; Ministry 1; Entrepreneur 4).

"There is no common standard for technology, there was even a huge debate. 2014 to 2018 there was the Cost EU Aquaponics Hub initiative. And even they didn't finish with a proper definition because there is no common denominator what it actually is. And so, if there is not even a definition, there is also not really a state of the art which is recognized." (Entrepreneur 1)

There is a widely adapted one-loop aquaponics model by practitioners which is the so called UVI model that developed at the University of Virgin Islands more than 30 ago (Entrepreneur 1; Expert 9; Monsees, Kloas & Wuertz, 2017; Watten & Busch, 1984). Recent efforts in developing new aquaponics models have been made by Urban Farmers and Wageningen University (Entrepreneur 1; Expert 9). Especially, the latter drives the shift from the standard one-loop system to the multi-loop approach. Proponents of the multi-loop system argue that the optimization of each loop is an advantage to the one-loop system which offers suboptimal conditions to both loops. Likewise, proponents of the one-loop system argue that it is more transparent, and that maintenance and production practices are more sustainable compared to the multi-loop system (Researcher 1; Entrepreneur 2; Goddek et al., 2016; Monsees et al., 2017).

According to interviewees, the aquaponics development is following a hype curve in the Dutch niche market (Researcher 1 & 2; Expert 8). In the Netherlands, the first entrepreneurial activities started in 2011. The idea received increasingly more attention and especially with the commercial endeavors of *Uit je eigen stad, Duurzame kost* and *Urban Farmers* gained popularity – one interviewee (Researcher 2) described it as a *boom*. However, with two of the three aquaponics businesses going bankrupt in 2016 the hype was over. This circumstance initiated a decline in engagement which was noticeable in the form of fewer new entrants, disinterest in the technology and disbelief of policymakers and other regime actors from industry, science and technology (Researcher 2; Entrepreneur 5). Nevertheless, between 2008 and 2018 a few niche applications have formed and diversified the aquaponics portfolio in the Netherlands. The following aquaponics niche applications have been found:

(1) Backyard aquaponics describes small-scale applications with a maximum of 50^2, operated by hobbyists and private persons for domestic use (Researcher 1; Entrepreneur 3 & 5; Palm et al., 2018).

(2) Education and teaching can be done in commercial as well as specific demonstration systems (Entrepreneur 1 & 2; Researcher 2; Palm et al., 2018). In commercial settings visitors or consumers are educated in the form of tours, workshops and other events (Entrepreneur 1 & 2). Demonstration systems which are purely in place for research and education are rarely found in the Netherlands (Researcher 1 & 5). Generally speaking, education is of high priority for aquaponics (Villarroel et al., 2016).

    "The strongest value of aquaponics is the diversity of the package. [] So, when you're teaching, your teaching about plants, fish, and biology, nitrogen cycle, plumbing. So, there's a lot of different skills that come together. And I think that's useful package to teach to people, children." (Expert 8)

(3) Advisory and consultancy agencies including aquaponics in their portfolio of food production methods (Expert 8 & 9; Researcher 2).

(4) Entrepreneurs offering aquaponics equipment or whole self-designed systems and their integration in a certain environment (Entrepreneur 2, 3 & 5; Expert 9; Aquaponics Shop, 2019). The demand of such products is a very small in the Netherlands (Entrepreneur 2).

(5) Small- to medium-scale applications are used for urban commercial production and local community gardening (Entrepreneur 2 & 3; Expert 8 & 10; Researcher 4; Palm et al., 2018). The system's size is between $50m^2$ and $100m^2$ (Palm et al., 2018) and does not threaten to disrupt the current system. This is a local niche solution (Entrepreneur 3; Researcher 4).

(6) Intermediate-scale applications are categorized between $100m^2$ and $500m^2$ and large-scale systems exceed $500m^2$ (Palm et al., 2018). There is disagreement amongst the interviewees if this

should be the actual goal of the technology. For further elaboration, see section *Guidance of Search (4.3.1.4)*. Commercial large-scale systems are opting for industrialized production methods and raise the question of combining hydroponic greenhouses in the Netherlands with the needed nutrients from aquaculture (Palm et al., 2018).

The general consumer group targeted for aquaponics products is the increasing group of organic buyers who seek sustainable, locally grown and fresh food (Entrepreneur 1; Expert 10; Miličić, Thorarinsdottir, Santos & Hančič, 2017). However, aquaponics entrepreneurs do not experience this group to be large and determined enough to sustain a professional aquaponics business in the Netherlands. One reason is the lack of retailer relationships; the lack of scale and thus, the small amount of produce is not well-fitting for the large amounts which retailers purchase and distribute (Entrepreneur 1; Expert 5 & 7). Moreover, the fact that aquaponics cannot cater to the standard organic market in all European countries is argued to be a barrier as well (Entrepreneur 1; Expert 9). For the retailer this circumstance raises the issue of labelling, promoting and storytelling. Entrepreneur 1 claims, that retailers would have to *change the story* they currently profit from in order to offer aquaponics products. According to Entrepreneur 1, aquaponics' sustainability exceeds market standards which forms a dilemma for the current promotion strategies of retailers.

"They could not place and advertise our fish into their fish desk and say: hundred percent free of antibiotics. What would that say to the rest of their fish, which they had? They could not say this is the freshest thing that you'll have. They could not say this is better than organic, because […] for 20 years, they were preaching organic is highest end." (Entrepreneur 1)

Between 2008-2018 aquaponics entrepreneurs were performing different sales strategies: direct sale to consumers through (B2C), indirect sale through in-house restaurants (B2C) and external sale to third-party restaurants (B2B) (Entrepreneur 1 & 2; Expert 10). According to Expert 3, in order to succeed with an aquaponics business, the target customer group has to be well known and approached strategically. In order to form an aquaponics market, the price performance issue of aquaponics products requires further attention. Currently, the high prices of aquaponics products cannot compete with the low standard market prices for the same vegetables and fish (Entrepreneur 3 & 4; Researcher 4 & 5; Expert 7), it's a *battle you can't win* (Entrepreneur 2). The high prices stem from the high maintenance costs, investment costs especially in the aquaculture loop, and the long return on investment time (Researcher 1 & 2; Expert 7). To offer aquaponics products cheaper, economies of scale are necessary; however, it has not been achieved yet (Researcher 1).

Yet again, some interviewees experienced that aquaponics can be a buzzword and used as a sales tool, which draws the attention of prospective customers, future farmers and the interest and investment of government officials (Expert 9 & 10).

4.3.1.6 Resource Mobilization

Resources can be of financial or human nature. The amount of financial investments required for an aquaponics system and the necessary skillset of system operators depend on the size and goal of the respective aquaponics system. A large commercial farm requires a higher investment than a small-scale neighborhood project (Entrepreneur 1 & 3; Somerville et al., 2014; Palm et al., 2018; Turnsek et al., 2019).

The investment costs for an aquaponics system are high nonetheless[16] (Entrepreneur 1 & 3; Expert 8). The high investment is not mainly required for the hydroponic system part, it is assigned to the aquaculture. In order to compensate and payback high investment costs one would need to achieve economies of scale which in return lead to higher upfront investment costs (Researcher 1; Palm et al., 2018; Somerville et al., 2014). The highest share of costs in maintaining an aquaponics system are energy and labor which accumulate to 75% of the total costs. The high costs in energy and labor result from the national climate and labor conditions (Researcher 1; Turnsek et al., 2019). Entrepreneur 3 and Researcher 2 experienced that oftentimes the high energy costs are underestimated by aquaponics entrepreneurs.

Currently available *financial investment* sources for commercial aquaponics efforts differ between projects and business cases, between public and private money. While smaller student projects have the chance to receive funding from university, municipality as well as European grants (Entrepreneur 3), other endeavors which are able to present a good business case, are also eligible for private investments next to government funding and European grants, e.g. from the EUAA (Entrepreneur 2 & 3; Researcher 1; Expert 8; European Aquaponics Hub, 2018b). Earlier aquaponics projects in the Netherlands, such as the Urban Farmers, were able to receive a large amount of public as well as private money. Current aquaponics proponents perceive a decrease in investment directed towards aquaponics, especially due to hesitation from the private sector (Expert 5; 7; 9 & 10; Entrepreneur 5). This circumstance is the result of missing proof of successful Dutch aquaponics projects which increases the perceived risk of investment (Researcher 2; Expert 7; Ministry 1).

"We just need kind of that realization: It's a long-term solution. And we have to work with it as if it's a risky investment and realize that that's what it is. And we have done it in the past but it's a test to our capacity for long-term thinking." (Researcher 2)

A financial resource not to be underestimated for commercial aquaponics projects is the selling of the produce. Without selling the produce and earning money the investment cannot be returned, and the system cannot be sustained (Entrepreneur 1; Expert 8). Furthermore, the type of crop and fish that is grown in the system influences the profitability of the produce and thus, the revenue and financial resources. As an example: Herbs, edible flowers and ginger are high-value products which can increase the revenue compared to other low-value products (Researcher 5; Expert 10). Additional income strategy for an established aquaponics project is ecotourism (Entrepreneur 2). Depending on the business model, also state support in the form of social financing is a possibility for aquaponics projects (Entrepreneur 2; Expert 9; Government of the Netherlands, n.d. e; OECD, 2007).

"If you have the initial investment, it can definitely perform. The question mainly is: Can it perform without outside investment just by itself?" (Entrepreneur 3)

Projects which are not strictly commercial, but integrate a cooperative research theme, are financially supported by the government, mostly by the municipality. This support is usually not bound to one specific technology (Ministry 1 & 2; Expert 9; Researcher 2 & 5; Entrepreneur 4). The deciding factor is cooperation between industry, academia and government. Consequently, in order to receive a subsidy from the Dutch

[16] An example: Urban Farmers a former commercial farm on the rooftop in The Haag grew 1500m² of vegetables and 370m² of fish (Andreas; DutchNews, 2016; Miličić et al., 2017). According to Palm et al. (2018), this farm qualifies as an intermediate/large-scale commercial system. The financial investment received is estimated between 3 and 5 million Euros. The largest invest came from SVn, which is a Dutch non-profit foundation financing sustainable and social projects (Entrepreneur 1; DutchNews, 2016; NRC, 2018; SVn, 2018).

fishery fund or agriculture fund, the project has to include one private partner, one research partner, which is most commonly is Wageningen University for agri-food projects, and the government in some capacity, which can be the municipality as well as the ministry (Ministry 1 & 2). Therefore, an aquaponics project is generally applicable for government support if the entrepreneur or researcher is willing to cooperate (Ministry 1 & 2; Researcher 5; Expert 10). Some interviewees criticize that aquaponics projects are predominantly state financed and perceive this fact as an indicator for the economic weakness of the technology's business cases. Other interviewees argue that Dutch government funding as well as European grants are beneficial for the entrepreneur as well as the investing party as both are eager to drive sustainable innovation in the light of striving for a *greener Europe* (Entrepreneur 3; Expert 9; Hoevenaars, Junge, Bardocz & Leskovec, 2018).

Research is generally funded by the Dutch Research Council (NWO). However, in recent years the NWO has not accepted the applications for aquaponics by researchers from Wageningen University and thus, has not funded them. The reasoning behind the rejection was that aquaponics is a small niche issue which is of low significance (Researcher 1 & 4). In contrast to the Dutch approach, researchers perceive a higher funding potential for aquaponics from the European Union. The European Union, by means of the European Research Council established a fund for research and innovation: Horizon 2020 (Researcher 1, 2, 4 & 5; Cordis, 2014; Hoevenaars et al., 2018; Aquaponics Hub, 2017). European aquaponics initiatives, such as the Inapro project, were also financially supported by the Horizon 2020 program (Researcher 2 & 5; Aquaponics Hub, 2017). Notwithstanding, it is challenging for researchers to receive European funding and aquaponics is not prioritized over other research fields (Researcher 1).

Taking a closer look at the resource mobilization of *human capital*: Wageningen University has integrated two full-time PhD positions preoccupied with research on aquaponics since 2015 and further researchers joining aquaponics research projects. Wageningen University, considering its expertise in Life Sciences, is also considered the expert to talk to in terms of aquaponics. Consequently, Wageningen University is *the* contact point for the Ministry of Agriculture, Nature and Food Quality, municipalities, aquaponics entrepreneurs and proponents, researchers and other stakeholders (Researcher 1 & 2; Ministry 2; Entrepreneur 2). However, the number of experts on aquaponics is small. This is a result of the complexity and multi-disciplinarily of the aquaponics technology. Plant-based farming is distinctly different from fish production in terms of education, skills and mentality. Introducing an expert of one discipline to the other one is considered difficult. Consequently, this forms a barrier for aquaponics as only very few people have the skillset of both disciplines (Researcher 2 & 5).

Additional knowledge exceeding hydroponics and aquaculture is above all required for aquaponics. Nevertheless, development and innovation in either hydroponics or aquaculture can influence the aquaponics development in terms of costs as well as performance. As an example: The trend towards automatization and less manual labor in the horticulture sector (Researcher 2; Entrepreneur 2) can offer opportunities to minimize aquaponics' high labor costs (Researcher 1 & 2). Regarding the fish production sector, there are only very few veterinarians who are specialized in fish and fish diseases. This fact can develop to be a problem for aquaponics in terms of lack of specialists and lack of knowledge (Researcher 5).

In terms of *resource infrastructure*, networks are considered in section *Knowledge Diffusion through Networks (4.3.1.3)*. Regarding physical infrastructure for aquaponics, interviewees have stated that using the established infrastructure in the Netherlands and organizing equipment has not posed a barrier for the setup of an aquaponics system (Researcher 2; Expert 8; Entrepreneur 3). As an example: Piping appliances which are needed for the setup of an aquaponics system are very expensive and require special properties for food production. Nonetheless, the appliances can be bought readily on the market and at times even cheaply through recycling channels (Researcher 2).

It needs to be highlighted that special requirements apply for an aquaponics setup in urban areas. Urban areas provide readily available infrastructure for aquaponics such as old warehouses with connection to the energy grid. However, if a rooftop farm is the goal of the setup, then the entrepreneur has to take a closer look at the building (Entrepreneur 3):

"You need a really strong structure to hold it because it has a lot of weight. So, in The Hague for example there were only six buildings that were fit to do it. So, it depends on how many aquaponics systems you want to build. So, if you want an entire city to be supplied with your urban farming then at the current moment that is definitely not possible." (Entrepreneur 3)

Regarding the infrastructure, but also regarding knowledge and expertise, it is most cost-efficient to start an aquaponics system with one already existing and established loop and add the other loop onto it. As an example: Integrating an aquaculture tank into an existing hydroponic horticulture greenhouse to build an aquaponics system is considered more cost-efficient. Building a completely new aquaponics system requires significantly more effort (Researcher 2). However, it should be emphasized that generally speaking, saving resources such as water and fertilizer through the circular logic of aquaponic systems has not proven to be beneficial. Fertilizers are cheap commodities with which the aquaponics setup cannot compete in terms of costs (Researcher 5). However, if current practices were to internalize their external costs, such as fertilizer production and pollution, resource saving initiatives such as aquaponics can become more profitable (Expert 6).

4.3.1.7 Creation of Legitimacy/Counteract Resistance to Change

An innovation such as aquaponics is legitimized by aligning with the institutional and social values of the Dutch agri-food regime. The legitimacy of an aquaponics innovation system is strongly dependent on its location: The need for a water-saving technology is especially present in regions which are water scarce. Labor intensive and high energy applications become reasonable in areas where labor is cheap, and less energy is needed (Entrepreneur 1; Researcher 1).

Interviewees comment, that in the Netherlands and in Western countries in general, aquaponics is not economically feasible, lacks relevance and thus cannot succeed in this environment (Researcher 1, 2 & 4; Expert 7; Entrepreneur 4). Especially prior unsuccessful aquaponics projects endorse this argument and exacerbate the aquaponics development and its support. Also, policy makers are aware of this situation (Ministry 1 & 2).

A binding legal framework specifically for aquaponics is not defined, neither on Dutch national nor on European level (Entrepreneur 1 & 2; Researcher 2; Expert 4; Joly, n.d.; Reinhardt, Hoevenaars & Joyce, 2019). Aquaponics is required to conform with the national-binding European regulations on plant production (Pest Management, site regulations), fish farming (Common Fisheries Policy), water and waste management (Water Framework Directive), food safety (Hygiene Package), etc. (Expert 4 & 7; Joly, n.d.; Reinhardt et al., 2019). The requirement to comply with multiple legal frameworks leads to an increase in complexity, risk and irritation which increases costs in the process and maintenance to comply to all regulations (Expert 7). This can be a disadvantage compared to technologies which only cover one expertise area (Expert 8; Entrepreneur 4). However, Entrepreneur 1 and 2 experienced that farming legislations in the Netherlands are bound to the size of the endeavor. A farmer only qualifies as a farmer if a certain size of area is owned and a certain number of products are produced and sold. Heretofore, no Dutch aquaponics business passed this threshold, so legally speaking their owners have never been farmers (Entrepreneur 1 & 2). This circumstance delegitimizes aquaponics farmers and their businesses.

The current vision of Circular Agriculture by the Dutch Ministry of Agriculture, Nature and Food Quality aims at improving the use of soil, freshwater, nutrients, energy and raw materials while fostering biodiversity (Ministry 1 & 2; Expert 6; Government of the Netherlands, 2018b). This vision aligns with the circular nature of aquaponics. However, interviewees take different point of views when asked if aquaponics can be identified as *more sustainable* than conventional agri-food practices (Ministry 2; Expert 4 & 9; Entrepreneur 3; Researcher 1 & 2). Also, literature does not have a definite answer to this question. The reason for this uncertainty is the complexity of the system. The complexity originates from potential changes in processual or technical system characteristics, the source and amount of energy used, the type of fish feed, the system size and the environment of the system. All of these and more factors influence the systems social, environmental and economic sustainability performance (Forchino, Lourguioui, Brigolin & Pastres, 2017; König et al., 2016). This insecurity can be an issue for the creation of legitimacy for the aquaponics technology in the Netherlands.

Another problem identified is the fact that neither aquaponic nor hydroponic products qualify as organic. The standard definition of *organic* states the necessity of soil as substrate for vegetables and fruits (Entrepreneur 1; Researcher 1; European Commission, n.d.; Reinhardt et al. 2019). There are two approaches in the aquaponics field on how to handle this issue. On the one hand, one could argue that the original definition is concerned with *culturing the land sustainably* and additionally, there should be an organic label developed for *culturing the water sustainably*, as water is the substrate used in aquaponic and hydroponic production. On the other hand, the aquaponic and hydoponics plant receives all nutrients and necessary benefits which an organic and healthy plant requires. Therefore, aquaponics should be able to receive the original organic label (Entrepreneur 1 & 3; Researcher 1; König et al., 2018).

Scientists and entrepreneurs lobbied for aquaponics to qualify as organic at European level. However, the lobby initiative which started at the European Aquaponics Hub failed (Researcher 1; Entrepreneur 1; Miličić et al., 2017). Interviewees argue that as a niche innovation aquaponics was unable to compete with the powerful agri-food lobby in Brussels (Researcher 1; Entrepreneur 1). In the Netherlands there are no lobbying efforts in the form of lobby groups advocating for aquaponics (Expert 7; Entrepreneur 4).

Without the organic label aquaponics produce cannot serve the organic market. Consequently, it cannot be promoted as part of the growing organic market. This results in a dilemma in price communication (Entrepreneur 1 & 4; Expert 9; Turnsek et al., 2019; Miličić et al., 2017): If aquaponics products are not tagged with the organic label do consumers expect cheap non-organic prices? As aquaponics cannot cater to the organic market and is not a broadly known technology, interviewees perceive a barrier in selling the produce (Entrepreneur 2; Expert 9 & 10; Researcher 5). This is why strong marketing is a vital tool to promote aquaponics products and *tell their story* (Entrepreneur 1; Expert 9; Researcher 4; Turnsek et al., 2019; König et al., 2018). Strong marketing tools can help to educate the market, the consumers, policymakers and other stakeholders to increase their knowledge, general understanding and thus, acceptance of aquaponics (Entrepreneur 2; Expert 9; Miličić et al., 2017).

Despite marketing, the price of aquaponics products is a crucial factor (König et al., 2018; Miličić et al., 2017). In the case of sustainable and higher priced products in general the *consumer-citizen dilemma* emerges. Likewise, this dilemma holds for aquaponics. The *citizens* are aware of their CO2 footprint, want to support sustainability, especially the local and free of pesticide/herbicide/antibiotic production methods and legitimize aquaponics. However, the *consumers* are opting for the cheapest product, their own personal profit and do not act upon the call for sustainability (Expert 6; Ministry 1 & 2; Entrepreneur 1).

"The willingness to pay for fresh food, local grown food, it's emerging. But it's not a customer base where you can say they are paying half a million a year." (Entrepreneur 1)

While some consumers value the sustainability, transparency and local nature of aquaponics, others disagree with inland fish farming practices. The conditions of aquaponic fish production can shock and scare off potential customers. Especially when having special diets such as veganism, potential customers can face moral conflict about eating vegetables fertilized by a suffering fish (Entrepreneur 1; Miličić et al., 2017). Likewise, meat-eaters are forced to awareness when choosing to be educated about aquaponics, especially on site by workshops or tours (Entrepreneur 1; Researcher 2). The proximity to a living animal and the task to kill it for later preparation also posed an ethical barrier for individuals working with aquaponics in private as well as entrepreneurial settings (Expert 8; Entrepreneur 3).

"So, this immediate exposure of saying: If I am eating a fish, I'm guilty for this fish living in here and I'm guilty that it is being killed for me." (Entrepreneur 1)

This described form of awareness by Entrepreneur 1 is not common amongst Dutch and European consumers yet, however increasing. Aquaponics can be a valuable tool for education on agri-food production for the general public in Western society (Entrepreneur 1 & 2; Researcher 2). System owners who educate ecotourists and enthusiasts about aquaponics receive a positive reaction and engagement from their audience (Entrepreneur 2; Expert 8). In Dutch regions, such as Eindhoven where an aquaponics system is implemented people are more aware and open towards aquaponics - accept it even (Entrepreneur 2). However, in the Netherlands in general it is neither a well-known nor a highly accepted technology (Entrepreneur 2; Ministry 1 & 2).

Interesting enough, also aquaculture has not yet been able to successfully establish in the Netherlands (Researcher 2 & 4; Expert 5). A reason for the fact that both aquaponics and aquaculture have not been able to create legitimacy was given by some of the interviewees. Expert 4 and 5 state that freshwater fish are not popular in the Netherlands. Furthermore, the production of inland freshwater fish production is sensible and investment intense. On the other hand, aquaponics' plant produce does is differ from conventionally produced plant produce and thus, legitimacy should not be an issue (Researcher 1).

To sum up, the integrated framework provided a valuable tool to structure the insights gained for the development of the aquaponics innovation system in the Netherlands between 2008 – 2018 as well as the information received concerning the Dutch agri-food regime and landscape pressures. In the following chapter the results just presented are analyzed.

5 Analysis

This chapter analyzes the findings presented in the *Result Chapter* and organizes insights found regarding landscape pressures, regime structures and TIS dynamics in the Netherlands (5.1) using the integrated conceptual framework. Blocking as well as inducement mechanism and interdependencies on landscape, regime and niche level are at the core of the analysis for the emerging aquaponics innovation in the Netherlands. Above that, the Dutch aquaponics development is set into a wider European context (5.2).

5.1 The Emerging Aquaponics Innovation in the Netherlands

The integrated framework by Markard and Truffer (2008), as shown in the *Theory* chapter, provided the opportunity to gain insights on both, the perspective of the emerging aquaponics innovation and the perspective of the regime dynamics and landscape pressures. The refined integrated framework derived from the insights of this research can be found in figure 16 below and is described in the following paragraphs.

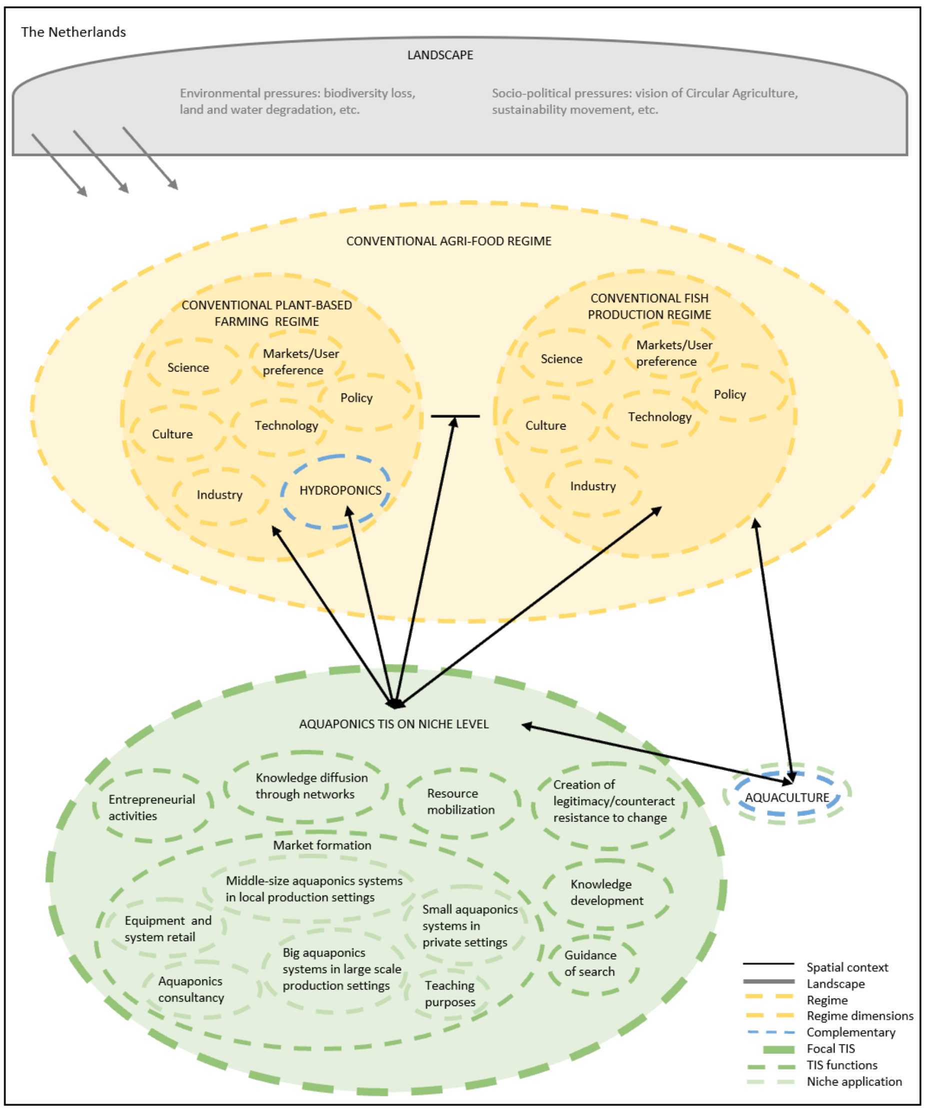

Figure 16 Adjusted integrated framework portraying system dynamics between the landscape level, the Dutch agri-food regime and the aquaponics TIS on niche level

The theoretically proposed and assumed interactions between and within levels by Markard and Truffer (2008) have been examined more in-depth in this research. The interdependencies between and within the landscape, regime and niche level are visualized in figure 17 and picked up on throughout the chapter. Moreover, this chapter will reveal the effects specific regime dimensions and specific TIS functions have on each other. Identified interdependencies, blocking mechanisms and inducement mechanisms influencing aquaponics are highlighted; and based on that an overall assessment of the aquaponics development is presented.

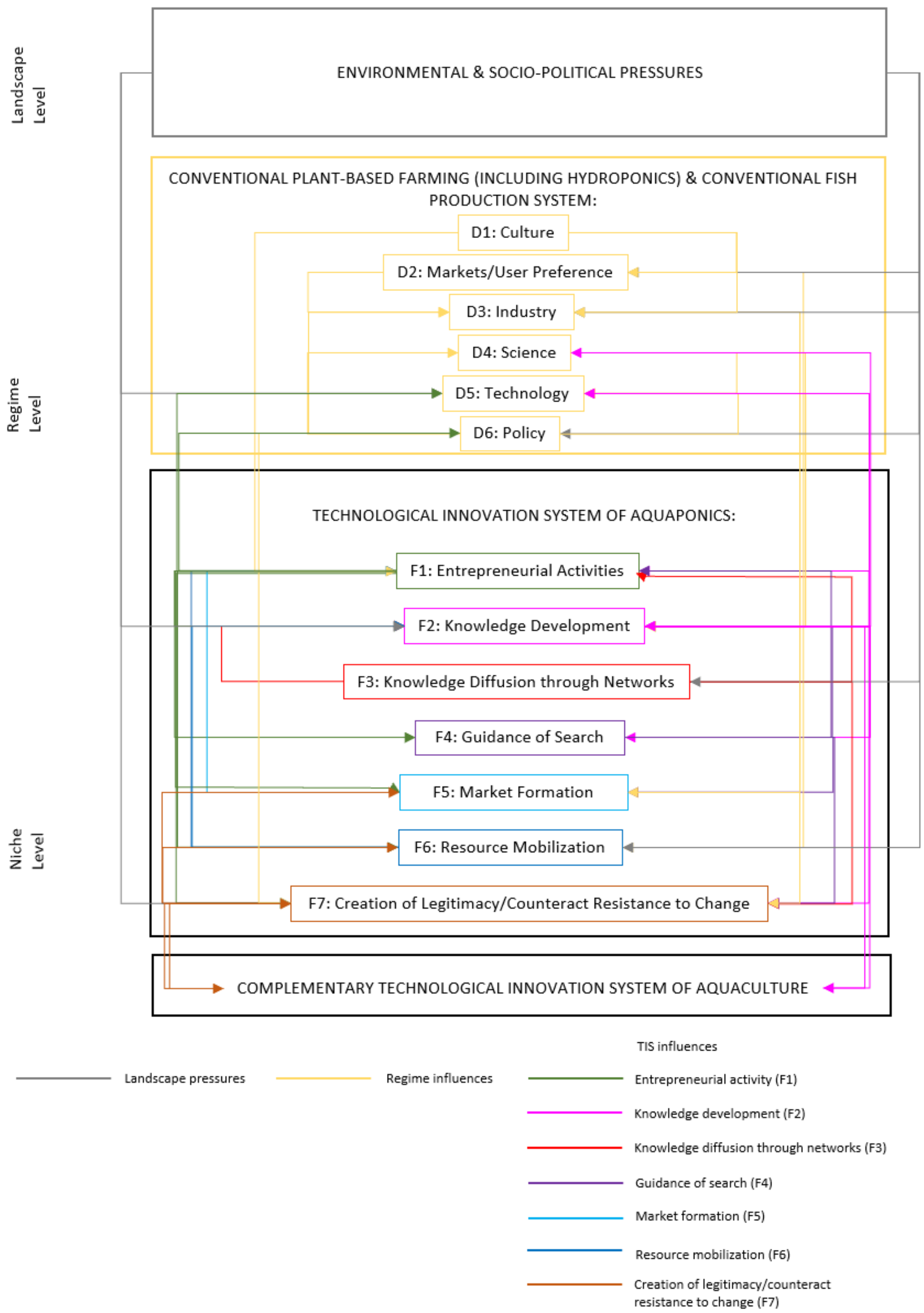

Figure 17 Inter-dependencies within the integrated framework for the case of aquaponics innovations

5.1.1 Landscape Pressures

The environmental and socio-political pressures found on *landscape level* put pressure on the Dutch agri-food sector on regime level as well as aquaponics developments on niche level. Some pressures call for immediate action: (1) *population growth* and *urbanization* have an impact on the Dutch agri-food regime as yield and space efficiency are needed to be improved due to land scarcity for the plant-based farming regime and the increasing global need for food; (2) the *sustainability movement* connected to the Dutch agri-food sector is gaining significance and support among the public, its resulting impact on the Dutch consumer behavior needs to be met by suppliers; (3) the vision of Circular Agriculture introduced by the Dutch Ministry of Agriculture, Nature and Food Quality in 2018 (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2019) was followed up with a realization plan in 2019; now greening efforts in the Dutch agri-food sector are pressured and expected. These pressures specifically influence the current plant-based farming regime in the Netherlands. Current actions taken by actors of the Dutch plant-based farming regime in response to these pressures are: (1) more research for increased crop yields and efficiency from actors of the dimensions science (D4) and technology (D5), which can be academic actors or actors from research institutes; (2) an overall greening strategy by actors in the agri-food industry (D3) to meet the relevant changes demanded by society and resulting consumer behavior reflected in market/user preferences (D2); (3) efforts to become more efficient, more circular and sustainable, which are required by policymakers (D6) are invested in by the industry (D3) in order to develop advanced technologies and processes for more efficient food production. Nonetheless, there are also landscape pressures which are perceived as less urgent by actors in the agri-food regime. An example hereof is the current fish production regime, more specifically the actors of the marine fishery industry (D3) who are aware of long-term changes in species stocks in oceanic waters. However, currently they do not counteract or collaborate on solution strategies and little urgency is conveyed by other regime actors. Due to less perceptible threats the fish production regime takes little to no greening action at the moment.

Environmental and socio-political landscape pressures have an effect on emerging niche technologies. In the case of aquaponics, there are multiple pressures offering the opportunity for the future development of aquaponics and thus, portraying inducement mechanisms: (1) *land and water degradation* are increasing pressures perceived in the Netherlands (inducement mechanism 1) which aquaponics can counteract and thus benefit from in the process of creating legitimacy (F7); (2) the *sustainability movement* concerned with unsustainable practices in the agri-food regime is demanding sustainable alternatives (inducement mechanism 2). This gives actors in the emerging aquaponics innovation system the opportunity to introduce aquaponics as one of the sustainable alternatives, diffuse its sustainability advantages across networks (F3) and create more legitimacy for aquaponics (F7); (3) the policy vision of *Circular Agriculture* communicated by the Dutch Ministry of Agriculture, Nature and Food Quality in 2018 opens a platform for aquaponics (F3), as a circular technology for water and nutrients, to be legitimized (F7), further developed (F2) and funded (F6).

Table 4 Overview of blocking/inducement mechanism influencing the aquaponics development from the landscape level

LANDSCAPE PRESSURES	→ F2, F3, F6, F7
Land and water degradation	Inducement mechanisms 1
Sustainability movement	Inducement mechanism 2

5.1.2 Agri-Food Regime Interactions

The structural trends described as landscape pressures in the prior paragraphs have led the Dutch *agri-food regime* in general to incrementally become more sustainable by improving the efficiency of resources used in the process. Both Dutch agri-food sub-regimes studied, the *conventional plant-based farming regime* (sub-regime1) and *conventional fish production regime* (sub-regime2) comprise of the six dimensions: *culture* (D1), *markets/user preferences* (D2), *industry* (D3), *science* (D4), *technology* (D5), *policy* (D6) (Geels & Schot, 2007). These dimensions within the respective sub-regimes as well as the overarching agri-food regime were found to be co-dependent because regime actors are well-connected by a strong network not only within but also between dimensions. Taking the example of the agri-food regime, the industry culture (D1) and industry's character (D3) of productivity and efficiency co-depends with the efforts made in technological progress (D5) and the focus of science when doing research (D4). Innovation is appreciated in the agri-food industry (D3) of both sub-regimes when enhancing profitability. Simultaneously, this approach of productivity and efficiency in food production influences the markets/user preference (D2) in their expectation of price and performance of produce and vice versa. The overall Dutch economic performance is heavily impacted by the agri-food regime (D3) as both researched sub-regimes are among the so-called Dutch *Topsectors* (i.e. Agri & Food, Horticulture & Propagation Materials, Water & Maritime). Thus, special attention is given to them by policymakers (D6). Regulations enforced by the Dutch and European government (D6) supporting or prohibiting certain procedures in both of the sub-regimes influence actors in the markets (D2), industry (D3), science (D4) and technology (D5). At the same time, by lobbying and cooperating for research grants provided by the Dutch government, the industries (D3) of the two agri-food sub-regimes ultimately also have an effect on policy. The interconnectivity between dimensions in the agri-food regime is fostered by the Golden Triangle approach introduced by the Dutch government to enhance collaboration between industry (D3), science (D4) and government (D6). The interdependency between the agri-food regime dimensions just described makes the agri-food regime and its two sub-regimes strong while allowing it to be dynamically stable. This means the regime leaves room for actors to kick off improvements and changes in one dimension which then have the ability to influence the rest of the regime. However, the general agri-food regime is stable enough to dynamically react and adapt, without being interrupted or disrupted. This allows for absorption of new (sustainable) innovations to the market while providing stability in price and quality to consumers.

Besides interacting between regime dimensions, actors in the agri-food regime dimensions also influence aquaponics' innovation system developments. In the Dutch agri-food industry (D3) efficiency and profitability (<u>blocking mechanism 1</u>) are some of the guiding principles to satisfy the demand of Dutch consumers (D2) for low-cost and high-quality products (<u>blocking mechanism 2</u>). This influences the success of entrepreneurial activities in the aquaponics innovation system (F1), the aquaponics market formation (F5) and the legitimacy of aquaponics (F7). This is especially due to the fact that the emerging aquaponics technology cannot compete with the characteristics of efficiency and profitability praised by the two agri-food sub-regimes. While a majority of Dutch consumers is price-driven and the number of consumers who prefer organic products is only slowly rising, the higher priced nature of aquaponics products seems to be a deterrent for most consumers. These higher prices appear to be a barrier to adoption, especially when deployed in the mass-market. Additionally, incumbent political regulations (D6) for each of the individual sub-regimes are not suitable for aquaponics (blocking mechanism 3) and thus affect its legitimacy.

Fears of inertia or resistance from the agri-food regime by either one of the two industries (D3) as described by Penna & Geels (2014) towards aquaponics, or in general towards (profitable) sustainable progress, could not be found. It is argued by multiple interviewees that aquaponics is perceived as too small, uncompetitive and unprofitable and thus, does not pose a threat to the existing agri-food regime. Nonetheless, aquaponics is an agri-food innovation which the regime, in particular industry, science and policy are aware of and observe. Entrepreneurial activities (F1) in aquaponics are curiously watched and received partial support in the establishment of commercial aquaponics systems. Offers for knowledge support by the industry (D3) and science (D4) as well as municipality grants (D6) were targeted at specific commercial aquaponics endeavors.

5.1.3 Complementary TISs Interactions

As explained above, the term *complementary TIS* was introduced by Markard and Truffer (2008) and describes one or more TISs which share complementary effects with the aquaponics development. When studying the two sub-regimes more in-depth, it became apparent that the *complementary TISs* should not be seen as individual parameters in the framework. In contrast, in the context of this research the one complementary TIS, hydroponics, is represented by the horticulture sector and consequently, embedded in the conventional plant-based farming regime in the Netherlands. The other complementary TIS, aquaculture, is a niche within the conventional fish production regime. These findings were adjusted in the integrated framework of Markard & Truffer (2008) as visualized in figure 16.

Hydroponics as well as aquaculture within the respective sub-regimes, the plant-based farming regime and fish production regime, have a strong connection to the aquaponics knowledge development (F2) through the dimensions science (D4) and technology (D5). They are driven by Wageningen University, other inhouse as well as independent research institutes concerned with agri-food development and innovation. Research and progress that is made in hydroponics, e.g. plant lighting for better growth, or aquaculture, e.g. fish feed for faster growth, represents a base for aquaponics research and developments (inducement mechanism 3). Both sub-regimes, plant-based farming and fish production, are economically strong and have the resources to drive innovation in their field. Consequently, they influence the focus of the scientific (D4) technological (D5) progress being made by different institutes in the Netherlands (blocking mechanism 4). Whether all of this knowledge produced is beneficial for aquaponics and can be picked up by aquaponics researchers or entrepreneurs is questionable. Simultaneously, knowledge developed (F2) and progress reached during research on aquaponics can benefit state-of-the-art technology and science on hydroponics and aquaculture. However, as aquaculture is a niche technology is lacking economic viability in the Netherlands (blocking mechanism 5), which also influences the legitimacy of aquaponics (F7).

Table 5 Overview of blocking/inducement mechanism influencing the aquaponics development from the regime level and complementary TISs on regime and niche level

REGIME LEVEL	→ F1, F2, F5, F7
High standards in food production in terms of efficiency and profitability (D3)	Blocking mechanism 1
Cheap products and purchasing patterns of Dutch consumers (D2)	Blocking mechanism 2
Policy regulations per sub-regime (D6)	Blocking mechanism 3
Investment from the industry (D3) in science (D4) and technology (D5)	Blocking mechanism 4

Aquaculture is lacking viability in the Netherlands	Blocking mechanism 5
Research and progress in the complementary TISs of hydroponics and aquaculture can enhance the aquaponics development	Inducement mechanism 3

5.1.4 Aquaponic Innovation System Interaction

In addition to the influences from the landscape and regime level on the emerging TIS of aquaponics, the seven functions also influence each other on niche level and act co-dependently. This has been visualized in figure 17 and is described in the following paragraphs. The analysis of the aquaponics innovation system confirms the expectation that the Dutch aquaponics system is being in the formative phase (König et al., 2018). It resembles an innovation at niche level, which is at the very beginning of its development, according to Geels and Schot (2007).

Function 1, *entrepreneurial activities* (F1), was presented as a diversified but rather unfulfilled function based on the course and fluctuation of entrepreneurial activities in the Netherlands. Dutch aquaponics entrepreneurs followed the so-called YouTube Hype around 2012 and attempted a successful market implementation with multiple business models: purely commercial aquaponics farms, integrated aquaponics production into a restaurant business model, aquaponic system providers and consultancy. However, most of them failed due to economic unfeasibility and complexity of the aquaponics system. This led to rather immature entrepreneurial activities, leaving F1 unfulfilled. Only a few Dutch aquaponics entrepreneurs are left in 2019 and currently, only one entrepreneur is putting aquaponics in the center of his business case. The anti-success-stories of aquaponics (blocking mechanism 6) do not only cause hesitation among new entrants to join aquaponics activities but also provide a base for disbelief towards the technology and its economic viability (blocking mechanism 7). The *legitimacy* (F7) of aquaponics as a technology in food production in the Netherlands on small-, medium- or large scale is questioned and due to the lack of concept proof or a success case, financial and human *resources* (F6) are not readily available. Consequently, the aquaponics *market* (F5) is not equipped to be formed. Furthermore, the anti-success stories of aquaponics influence the *guidance of search* (F4) as a crisis. This affects the development of aquaponics in terms of expectations as a distinct strategy is not articulated and applied *knowledge* (F2) cannot be developed. As a consequence, since the function of entrepreneurial activity (F1) is not sufficiently fulfilled, other functions lack fulfillment as they are codependent: F2, F4, F5, F6 and F7 are affected by a vicious cycle (Hekkert et al., 2007).

Table 6 Overview of blocking/inducement mechanism in function 1 of the aquaponics innovation system influencing the aquaponics development

ENTREPRENEURIAL ACTIVITIES (F1)	→ F2, F4, F5, F6, F7
Anti-success-stories	Blocking mechanism 6
Economically unviable	Blocking mechanism 7

Regarding function 2, *knowledge development* (F2) for aquaponics is mainly driven by the Dutch Wageningen University through learning-by-searching. Wageningen University in its forerunner position is contributing to major progress, in cooperation with their respective research groups, for the aquaponics development in the Netherlands, Europe and worldwide (inducement mechanism 4). Learning-by-doing regarding aquaponics is not as often performed due to the lack of a demonstration system at Wageningen University and a lack of commercial systems (blocking mechanism 8). The knowledge-intense and multidisciplinary nature of aquaponics (blocking mechanism 9) requires further research and experimentation. Aquaponics knowledge development is currently not sufficient and requires more attention. Despite this, function 2 is the most fulfilled and mature function in the aquaponics innovation system. Knowledge developed on aquaponics is influencing the *guidance of search* (F4), contributing to a clearer set of expectations and visions of researchers, policymakers and entrepreneurs about aquaponics in the Netherlands. Furthermore, the *legitimacy* (F7) of aquaponics is impacted by knowledge development as research results provide more certainty and clarification about its applicability. This has an effect on the technology's validity and its acceptance by different actors such as policymakers, industry incumbents and researchers. More knowledge enables aquaponics experts to engage in cooperation with the Dutch government, industry and researchers which opens the door for the consultation of the Dutch government for any matters on aquaponics and circularity in the plant-based farming regime and fish production regime. F2 also supports *entrepreneurial activities* (F1) as a lot of knowledge is needed when setting up aquaponics systems for commercial reasons. The function knowledge development (F2) is crucial in the development of aquaponics in the Netherlands as the knowledge gap concerning system dynamics and economic viability is yet to be closed in order to start a virtuous cycle (Hekkert et al., 2007) and to improve further functions: F1, F4 and F7, as mentioned above.

Table 7 Overview of blocking/inducement mechanism in function 2 of the aquaponics innovation system influencing the aquaponics development

KNOWLEDGE DEVELOPMENT (F2)	→ F1, F4, F7
Lack of aquaponics demonstration systems for research	Blocking mechanism 8
Knowledge-intense and multidisciplinary nature of aquaponics	Blocking mechanism 9
Aquaponics research driven by Wageningen University	Inducement mechanism 4

Knowledge diffusion through networks (F3), function 3, is not fulfilled on Dutch level, but internationally on European level. Missing communication between Dutch researchers concerned with aquaponics and aquaponics entrepreneurs (blocking mechanism 10) leads to low knowledge diffusion within the Netherlands. Moreover, especially Dutch entrepreneurs are not sharing their experience and knowledge amongst each other fearing they could lose their individual competitive advantage (blocking mechanism 11). On European level, there have been multiple efforts to create aquaponics networks, progress and a lobby advocating for the technology as shown by the example of the European Aquaponics Hub, Inapro, etc. However, aquaponics networks on European level are neither considered powerful, active nor highly participated in by aquaponics researchers and entrepreneurs due to their lack of results (blocking mechanism 12). Knowledge, even if diffusing, is not necessarily beneficial to all other parties or regions, as there is an absence of a one-fits-all-solution for aquaponics (blocking mechanism 13). Consequently, function 3 is in development, however, not sufficiently fulfilled. The knowledge diffusion through networks influences Dutch *entrepreneurial activities* (F1) and *knowledge development* (F2) as shared knowledge on aquaponics can enhance these two functions. Furthermore, networks strengthen the *legitimacy* (F7) of aquaponics by advocating for the technology, e.g. for the approval of the organic label Europe-wide for aquaponics produce. Moreover, sharing the scientific as well as practical knowledge created, communicating best practices and working on progress together is especially important for aquaponics due to its multidisciplinary and complex nature. The fulfillment of this function could enhance aquaponics development in the Netherlands and above that the aquaponics development in Europe. Stronger aquaponics networks could lead to a virtuous cycle of improvements for the functions F1, F2 and F7 and thus, it can be argued to be vital for the aquaponics development in the Netherlands and Europe.

Table 8 Overview of blocking/inducement mechanism in function 3 of the aquaponics innovation system influencing the aquaponics development

KNOWLEDGE DIFFUSION THROUGH NETWORKS (F3)	→ F1, F2, F7
Lack of communication between researchers and entrepreneurs	Blocking mechanism 10
Entrepreneurs not sharing aquaponics knowledge (secrecy)	Blocking mechanism 11
Networks in place are not powerful nor advantageous for actors	Blocking mechanism 12
No one-fits-all-solution	Blocking mechanism 13

Insights on function 4, *guidance of search* (F4), revealed that the topic of aquaponics is met with diverse visions, expectations, ambiguity in research and different opinions on how aquaponics should be implemented in the Netherlands (blocking mechanism 14). This function is not yet fulfilled. The unalignment and disagreement between aquaponics experts leads to a lack of *legitimacy* (F7) and uncoordinated *knowledge development* (F2) efforts. Furthermore, the crisis in the aquaponics sector caused by multiple commercial aquaponics business failures influences current and future *entrepreneurial activities* (F1) and consequently, the *market formation* (F5) of aquaponics in the Netherlands.

Table 9 Overview of blocking/inducement mechanism in function 4 of the aquaponics innovation system influencing the aquaponics development

GUIDANCE OF SEARCH (F4)	→ F1, F2, F5, F7
Ambiguity in vision, expectation, research and opinions on application and implementation	Blocking mechanism 14

Function 5, the *market formation* (F5) of aquaponics is very low. A very small niche market in the Netherlands has developed first in 2012, when the technology was hyped. However, currently, the niche market has not progressed but rather regressed (blocking mechanism 15). A system standard for aquaponics is not applied by Dutch entrepreneurs but rather designed and constructed individually by each aquaponics entrepreneur. Moreover, a distinctly prevailing niche application has not been able to manifest (blocking mechanism 16). A few private aquaponic systems are operating in Dutch backyards, however, domestic production is not highly distributed. Local medium-scale as well as industrial-sized aquaponics systems for urban food production have gone to market in the Netherlands. Despite this development the niche has not proven to be successful, at least not for direct sales to consumers. Teaching efforts in the form of ecotourism supports aquaponics businesses; however, demonstration systems have not been operating. The weak market environment of aquaponics in the Netherlands influences the *entrepreneurial activity* (F1).

Table 10 Overview of blocking/inducement mechanism in function 5 of the aquaponics innovation system influencing the aquaponics development

MARKET FORMATION (F5)	→ F1
Regressing aquaponics market	Blocking mechanism 15
No prevailing niche application	Blocking mechanism 16

Insights into function 6, *resource mobilization* (F6), showed that in terms of human resources, there are not enough experts to theoretically as well as practically tackle the issues and potential of aquaponics. Due to the multidisciplinarity of the aquaponics system and specialized knowledge needed for each individual loop as well as the dynamics in the entire aquaponics system, experts are rare (blocking mechanism 17). The availability of financial capital depends on the respective business case of each entrepreneur. In general, the function is not sufficiently fulfilled, however, developing. Current and former aquaponics businesses were able to be financed. Nevertheless, future financing potential is expected to be smaller for aquaponics-related ideas in the Netherlands due to Dutch anti-success stories with aquaponics (blocking mechanism 18). The mobilization or absence of resources influence *knowledge development* (F2) and *entrepreneurial activities* (F1), where experts are engaging in aquaponics and creating solutions.

Table 11 Overview of blocking/inducement mechanism in function 6 of the aquaponics innovation system influencing the aquaponics development

RESOURCE MOBILIZATION (F6)	→ F1, F2
Lack of experts due to multidisciplinary	Blocking mechanism 17
Perceived smaller financing potential in the future	Blocking mechanism 18

Regarding function 7, *creation of legitimacy/counteract resistance to change* (F7), aquaponics is neither perceived as an economically feasible, reliable technology (blocking mechanism 19), nor were lobby actions successful so far (blocking mechanism 20). Likewise, aquaponics is not aligned with the division between plant-based farming and fish production made by current legislation (blocking mechanism 21). Lastly, aquaponics does not seem to be taken very seriously by many stakeholders (blocking mechanism 22). Consequently, creation of legitimacy (F7) is weak. However, depending on the strength of the policy vision of Circular Agriculture of 2018 by the Ministry of Agriculture, Nature and Food Quality, the legitimacy of aquaponics can potentially rise in the near future. Legitimacy of aquaponics can have an influence on the aquaponics-related *mobilization of resources* (F6) and on the *market formation* (F5).

Table 12 Overview of blocking/inducement mechanism in function 7 of the aquaponics innovation system influencing the aquaponics development

Creation of legitimacy/counteract resistance to change (F7)	→ F5, F6
Perceived as an unfeasible and unreliable technology	Blocking mechanism 19
Unsuccessful lobbying	Blocking mechanism 20
Not aligning with current legislation	Blocking mechanism 21
Not being taken seriously by many stakeholders	Blocking mechanism 22

The overall performance of the aquaponics innovation system in the Netherlands is rather low due to multiple, systemic reasons. These reasons include the interdependencies between and within the aquaponics innovation system functions, agri-food regime dimensions as well as environmental and socio-political landscape pressures (see figure 17). Other reasons for the low performance of the aquaponics innovation system in the Netherlands are the large number of blocking mechanisms identified and the low fulfillment of the functions. To understand the development phase of the aquaponics innovation system, the overall function fulfillment of aquaponics is visualized by the spiderweb diagram in figure 18. Notably, the second function, knowledge development (F2) is the most fulfilled which is mainly due to research driven by Wageningen University. Nevertheless, it still lacks a lot of insight into the dynamics of an aquaponics system, its economic feasibility and other issues. Entrepreneurial activities (F1), knowledge diffusion through networks (F3) and resource mobilization (F6) have been realized; however, not with a large outreach. Guidance of search (F4) lacks behind, and market formation (F5) as well as the creation of legitimacy/counteract resistance to change (F7) are completely unfulfilled due to largely unsuccessful attempts or no action taken at all.

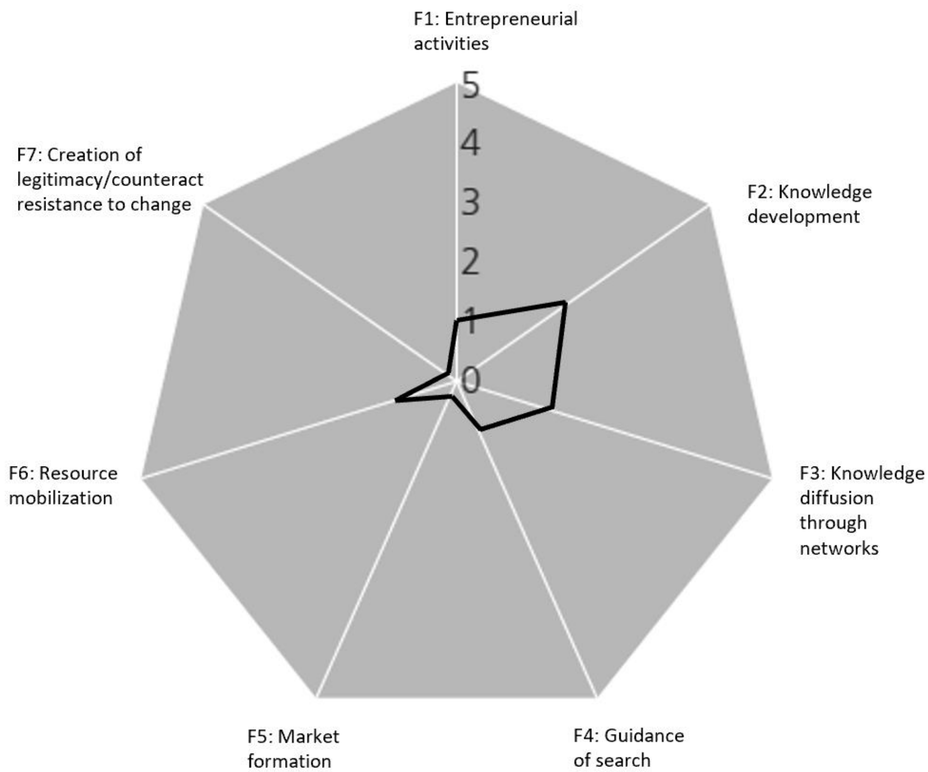

Figure 18 Assessment of the fulfilment of aquaponics innovation system functions

In conclusion, currently in the Netherlands the aquaponics technology itself is not well defined, well known, lobbied for or economically well positioned. The aquaponics innovation system can be considered to be in a very early development stage where research, experimentation and communication need to be fostered in order to empower functions which currently lack minimum fulfillment. The emerging technology is a very small niche innovation which is still too immature to become a technological standard in the Dutch agri-food regime in the upcoming years. Moreover, the environmental as well as socio-political pressures from the landscape level are not yet high enough to emphasize urgency on aquaponics' development.

5.2 Emerging Aquaponics Innovation in the European Context

In order to put the findings of the Dutch aquaponics development into perspective, the Dutch aquaponics developments are briefly compared to European aquaponics developments to understand the emerging technology's potential in a broader international context. Putting the findings into a broader perspective, it amplifies the contributions aquaponics can make towards the Sustainable Development Goals (SDGs) such as SDG 2 (no hunger) but also SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production), SDG 14 (life below water) and SDG 15 (life on land). They all refer to the aim of understanding and implementing more sustainable production methods in the agri-food sector (United Nations, 2018a, 2018b). Furthermore, the dependency of the Dutch aquaponics development on international developments can be sketched.

At the European level, aquaponic *entrepreneurial activities* (F1) are influenced by the lack of economic viability of European aquaponics businesses (König et al., 2018); this is similar to the Netherlands. According to the findings of Villarroel et al. (2016) the majority of aquaponics systems in Europe were built after 2010, which aligns with the results of this research regarding Dutch aquaponics developments. Most of the aquaponics systems operating are set up for research and education purposes[17] (Villarroel et al., 2016). It needs to be highlighted, that aquaponics is a rather research driven topic in both contexts, the Netherlands and Europe (Expert 5; Villarroel et al., 2016).

Although, the Netherlands can be considered a forerunner in *knowledge development* (F2) on aquaponics research in Europe according to publication statistics discussed in the *Result Chapter*, they cannot be considered a forerunner in actual aquaponics application and implementation[18]. European research groups enhance European aquaponics development through cooperation in learning-by-searching (Researcher 1, 2 & 4). Acquiring practical knowledge through learning-by-doing is done by researchers, entrepreneurs and private persons; however, it is done rather independently from others (Villarroel et al., 2016). A similar uncooperative or secretive nature of aquaponics practitioners, especially of entrepreneurs, was also found in the Netherlands. It has been noted that a secrecy approach seems to be preferred over patent applications in both the Netherlands and other European countries (König et al., 2018; Appendix 8).

Since there are no Dutch aquaponics organizations, Dutch aquaponics researchers and entrepreneurs rely on European networks for *knowledge diffusion* (F3), e.g. the European Aquaponics Hub (European Aquaponics Hub, 2018a). Relying on European aquaponics networks appears to be a practice commonly shared amongst European countries. Most aquaponics networks, cooperation and lobby efforts are established on European level, enhanced by European aquaponics associations and programs (König et al., 2018).

Moreover, *guidance of search* (F4) in terms of European targets, visions and shared expectations of aquaponics is also lacking on European level (König et al., 2018). This is despite the fact that aquaponics was mentioned as being one of the ten most influential technologies for the future on behalf of the European Parliament Research Service (Van Woensel et al., 2015). The same ambiguity found between Dutch researchers, entrepreneurs and experts, also hold for discussions about aquaponics expectations in Europe.

In European context, one cannot speak of a formed aquaponics *market* (F5) in general. There are sporadic entrepreneurial efforts in Europe, however, these are very few individual and isolated success cases. Furthermore, there has not been any consensus on the most beneficial niche application. Similar to the Netherlands, there has been disagreement between small aquaponics systems in private settings, middle-size aquaponics systems in local production settings, big aquaponics systems in large scale production settings and teaching purposes on European level (König et al., 2018; Love et al., 2014).

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[17] Villarroel et al. (2016) discovered that approximately 2/3 of European aquaponics systems operate for research and education purposes, while 1/3 are used for commercial production and urban farming.

[18] The number of aquaponics businesses and demonstration systems, which were found in a study by Villarroel et al., 2016, suggests that the amount of aquaponics systems in operation in the Netherlands (3 respondents) is much lower than other European countries: France (12 respondents), Hungary (12 respondents), Belgium (9 respondents), Germany (7 respondents), Switzerland (7 respondents), etc.

Resources (F6) in the form of financial capital are mobilized by intra-European financing schemes developed for (sustainable) innovation and research (König et al., 2018; Villarroel et al., 2016). Aquaponics researchers, entrepreneurs and whole networks have benefitted from these European financing schemes. Likewise, Dutch research and entrepreneurial activities have been and continue to be financed by European funds (Researcher 4; Entrepreneur 3).

The topic of lacking *legitimacy* (F7) is also an issue from the European perspective. Lobbying efforts for aquaponics in Brussels failed so far and thus, there is no European aquaponics regulation in place or currently in discussion (König et al., 2018; Joly, n.d.). Consequently, also on European level aquaponics is not aligning with current institutions and legislation which influences the legitimacy of aquaponics in all European countries.

Gaining brief insights into the European context of aquaponics, it appears that the Dutch aquaponics development is not significantly different from, but in fact very similar to the European one. It becomes clear that the following functions elaborated on for aquaponics in the Netherlands strongly depend on European developments: knowledge development (F2), knowledge diffusion through networks (F3), guidance of search (F4), resource mobilization (F6) and creation of legitimacy (F7). These functions are shaped in the European context of cooperation between research groups, organizations, networks and the European legislation. This results in the finding that in order to stimulate the virtuous cycles identified for the Dutch aquaponics development, action has to be taken on European level. Therefore, it can be claimed that the Dutch aquaponics development is strongly connected to European developments. This shows the dependency between European stakeholders in aquaponics development and the broad European context the emerging technology needs to be analyzed in.

6 Conclusion

It is estimated that by 2050 we will have an additional 2.2 billion humans that need to live on and be fed by the means of our planet (UN News, 2017). Current standards in food production are strongly affected by climate conditions and vice versa. Changes in the climate influence the crop yields in terms of quality, quantity and timing. Moreover, marine species, influenced by water temperature and other conditions, are reacting to changes in the oceans (Willett et al., 2019; EEA, 2016; European Commission, 2015). At the same time, the agri-food industry is disturbing our environment by contributing to biodiversity loss, groundwater and oceanic contamination, degradation of soil as well as water resources (Krall, 2015; Ponisio et al., 2014; Rasul & Thapa, 2004). A transition towards more sustainable practices in the agri-food regime are therefore required. Agenda 2030 formulated by the United Nations in 2015 addresses a sustainability transformation in the global agri-food sector with SDG 2 (no hunger), SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production), SDG 14 (life below water) and SDG 15 (life on land) (United Nations, 2018a).

Sustainable solutions are being sought urgently in order to assure food security for all humans without aggravating current developments. One sustainable solution in the agri-food sector is aquaponics. Especially, the water and nutrient-saving character of aquaponics, amongst other features, sounds promising for a transition towards sustainable agriculture (Somerville et al., 2014). Despite this, aquaponics is neither a well-known nor a highly distributed technology in Europe (König et al., 2018; Junge et al., 2017) and only recently developing as the first paper in Europe was published in 2009 (Graber & Junge, 2009). The Dutch agri-food sector poses an interesting case for the aquaponics development over the last 10 years while also considering a wider European context. The Netherlands seemed especially interesting as the country has a highly productive agri-food sector while also striving for sustainability and innovation. Additionally, the Dutch government passed a policy vision on Circular Agriculture in 2018 (Viviano, 2017; Government of the Netherlands, 2018a; Government of the Netherlands, 2018b; Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2019). Given these circumstances, it was considered interesting to answer the following research question:

How can the emerging aquaponics technology contribute to the sustainability transition in the Dutch agri-food sector based on Dutch aquaponics developments in the period 2008-2018?

To answer this overarching research question, three sub-questions were developed. The integrated framework based on Markard and Truffer (2008), combining the multilevel perspective and the technological innovation system, was used to understand the dynamics between overall environmental and socio-political pressures, the current Dutch agri-food sector and the emerging aquaponics innovation system. This approach allowed for answering the following sub-questions as well as the main research question.

SQ1: Considering the conventional standards in plant-based farming and fish production, does the Dutch agri-food regime leave room for the embedding of the aquaponics niche innovation?

The Dutch agri-food sector is holding efficiency and profitability as very high standards and thus, is able to offer cheap agri-food products to the Dutch consumers. The characteristics of profitability and efficiency on both ends, the production and the consumption side, present blocking mechanisms for the aquaponics development as aquaponics cannot reached these high standards as of now. Consequently, it cannot be stated that action needs to be taken by the Dutch agri-food sector. Instead it has been found that necessary action needs to be taken by aquaponics proponents to counteract the lack of compliance of aquaponics with the current standard in place.

Both sub-regimes, the plant-based farming regime and fish production regime, were described as innovative and open towards technological progress enhancing profitability and efficiency. Furthermore, actors in both sub-regimes were found to be respectively well-connected throughout the markets/user preferences, industry, science, technology and policy dimensions. The high level of connectivity within the respective sub-regime is benefitting the regime which could be described as a virtuous cycle on regime level. The overarching agri-food regime is built on a strong foundation, profitability-driven, synchronized and highly optimized. This in turn has been found to result in five of 22 blocking mechanisms for aquaponics' development affiliated with the Dutch agri-food regime.

SQ2: What is blocking or inducing the emerging aquaponics innovation system to become embedded in the Dutch agri-food regime?

At this moment, the emerging aquaponics innovation system is not mature enough to become a standard in food production and be embedded in the Dutch agri-food regime. 17 of the 22 blocking mechanisms found in this research concerned with the aquaponics development in the Netherlands were localized in the TIS functions, in other words within the establishment of the emerging aquaponics innovation system itself. All functions comprise of blocking mechanisms concerning aquaponics' current development. Those require the attention of multiple stakeholders, mainly researchers, entrepreneurs, policymakers, and financial resources attributed to them in order to foster future aquaponics development. Three functions were identified as fundamental groundwork which needs to be fulfilled in order to start a virtuous cycle of positive development. This virtuous cycle is only possible due to the interdependency of the functions identified for the aquaponics innovation system. According to the results of this research, following three functions and their respective blocking mechanisms needs to be of the highest priority, especially for entrepreneurs, researchers and policymakers concerned with aquaponics, to start positive developments: entrepreneurial activities (F1), knowledge development (F2) and knowledge diffusion through networks (F3). Consequently, the key for the enhancement of the emerging aquaponics technology is research, experimentation and communication.

SQ3: Is it possible to generalize the findings of the Dutch aquaponics development to the wider European context or is the Dutch agri-food regime a unique case for the aquaponics development?

The Dutch agri-food regime is a uniquely efficient and profitable one; however, the aquaponics development in the Netherlands does not inherently differ from other European countries, when analyzed in the European context. This became inherently clear, when discovering that knowledge development (F2), knowledge diffusion through networks (F3), guidance of search (F4), resource mobilization (F6) and creation of legitimacy (F7) are shaped in the European context of cooperation between research groups, organizations, networks and the European legislation. This leads to the conclusion that the Dutch aquaponics development is strongly connected to European developments. This displays the co-dependency between European stakeholders in aquaponics development and the broad European context the emerging aquaponics technology needs to be analyzed in.

Finally, the main research question can be answered:

How can the emerging aquaponics technology contribute to the sustainability transition in the Dutch agri-food sector based on Dutch aquaponics developments in the period 2008-2018?

Analyzing the aquaponics development in the period 2008-2018, with an *in-depth* understanding on how the emerging technological system is functioning and a *context-view* of the unique Dutch agri-food environment and the broader European perspective it aims to operate in, it becomes clear that currently aquaponics developments cannot directly contribute to the sustainability transition in the Dutch agri-food sector. In the upcoming years aquaponics can be developed further in the Netherlands; however, without any major environmental or socio-political pressures, aquaponics is not expected to be embedded in the dominant Dutch agri-food regime in the near future. The emerging aquaponics technology struggles with unfulfilled yet interdependent functions and a large number of fundamental blocking mechanisms currently hindering a virtuous cycle to enhance its development. Actors need to enforce the potential of virtuous cycles identified for the functions entrepreneurial activities (F1), knowledge development (F2) and knowledge diffusion through networks (F3) to foster the aquaponics development. Next to blocking factors inherited by the aquaponics innovation system directly, also attributes of the Dutch agri-food regime influence the aquaponics success in the Netherlands.

The profitability-driven Dutch agri-food regime does not leave much room for idealistic, unprofitable and inefficient innovations. Nevertheless, a sustainability transition in the agri-food regime is necessary to reach the SDGs by 2030, and to reduce the current negative impacts made by the agri-food sector. If voices, regulations and action manifest which pressure the greening of the sector and help to internalize all costs of production (economic, environmental, social), maybe then aquaponics, if further matured, can aid the transition. Lastly, it needs to be understood that aquaponics is not a one-fits-all solution, not for every produce, not for every region, not for every agri-food regime and maybe not in general. Notwithstanding, the aquaponics technology provides a starting point to talk about the sustainability transition in the Dutch agri-food sector in less incremental and more drastic ways, as drastic changes are needed.

7 Discussion

The *Discussion Chapter* starts with the theoretical contribution (7.1) of this research being discussed in terms of implications for the integrated framework (7.1.1) as well as for aquaponics research (7.1.2). Next, the limitations of this research are brought forward (7.2). The chapter ends with the practical implications for practitioners who include politicians, entrepreneurs and researchers concerned with aquaponics (7.3).

7.1 Theoretical Contributions and Future Research

This research contributes to sustainability transition theory in general. First, it provides theoretical contributions to the integrated framework, which was used conducting this research. Second, it specifically contributes to aquaponics research and development. Suggestions for future research are made gradually throughout this section.

7.1.1 Theoretical Implications for the Integrated Framework

By applying the theories and framework chosen for this research, contributions could be achieved in the field of agri-food sustainability transitions and in the field of applying theoretical integrated frameworks for understanding transition processes.

According to Bilali (2018), for research in the field of agri-food sustainability transitions the most utilized framework is the multilevel perspective (MLP) of Geels (2002) (e.g. Meynard et al., 2017; Darnhofer, 2015; Levidow, Pimbert & Vanloqueren, 2014). Nevertheless, other transition frameworks are progressively integrated into the MLP framework to get a better and more holistic understanding of transition processes in the agri-food sector (Bilali, 2018). The technological innovation system (TIS) framework of Bergek et al. (2008) and Hekkert et al. (2007) has only been sparsely used for research on agri-food sustainability transitions (Bilali, 2018); however, it is considered one of the "*core research strands in the field of sustainability transition studies*" (Markard et al., 2012). The TIS framework lacks empirical cases in the agri-food field, especially in combination with the MLP in an integrated framework as proposed by Markard and Truffer (2008). Combining well-known concepts of the agri-food sustainability transition theory with an in-depth functional analysis using the TIS in this field was perceived beneficial for analyzing an emerging innovation in the agri-food sector. Therefore, the integrated framework of Markard and Truffer (2008) was chosen.

The integrated framework of Markard and Truffer (2008) has proven to be useful to examine the aquaponics development in the Netherlands. Especially, due to the strong agri-food regime in the Netherlands, taking regime factors into account allows to inherently understand the innovation's development and potential. The integrated framework by Markard and Truffer (2008) was applied in this study because it offers insights into the socio-technical agri-food regime, its underlying rules, routines, standard procedures and behavior, while on the other hand it provided more in-depth and rich insights into the emerging technological innovation system of aquaponics. Therefore, using both, the MPL as well as the TIS theory, in one integrated framework gave the opportunity to exploit the benefits of both frameworks:

- Describing and analyzing the transition processes on landscape, regime and niche level including their interaction, networks and institution by using the multilevel perspective.
- Describing and analyzing emerging innovation dynamics and developments, actor strategies and interconnectivity of functions by using the analytical approach of the technological innovation system.

- In addition to each individual framework, the integrated framework includes the systematic identification of interdependencies between all actors and institutions. Developments originating from and influencing the landscape, regime dimensions and TIS functions on niche level are observed and thus, all connections in the innovation process (Markard & Truffer, 2008)

Nonetheless, some difficulties have been identified when applying the integrated framework to the agri-food sector and aquaponics innovation. The framework proposed by Markard and Truffer (2008) appeared to be deficiently operationalized in terms of the interdependencies between the three levels including the TIS on niche level. In addition, the framework lacked explanations how the different dimensions (MLP) and functions (TIS) of the respective frameworks influence each other. The integrated framework is more of a descriptive tool for the analysis and requires further concrete concepts. These were gained from the framework's application in this research and explained in the following paragraph.

Above the expected interdependencies of TIS functions emphasized by Bergek et al. (2008) and Hekkert et al. (2007) and the underlying yet not explicitly discussed interdependencies between dimensions mentioned by Geels (2010), the following additional interdependencies have been found:

Distinct interdependencies between specific MLP dimensions for the case of the Dutch agri-food regime:

→ Markets/user preference (D2) affects industry (D3)
→ Industry (D3) affects markets/consumer preference (D2), science (D4), technology (D5)
→ Industry (D3) affects policy (D6), which has also been found by Geels (2010)
→ Policy (D6) affects markets/user preference (D2), industry (D3), science (D4) and technology (D5)
→ Collaboration between industry (D3), science (D4) and policy (D6) is fostered

Distinct interdependencies between specific MLP dimensions and specific TIS functions for the case of the aquaponics development in the Dutch agri-food regime:

→ Regime policy (D6) affects aquaponics' creation of legitimacy/counteract resistance to change (F7)
→ Regime markets/consumer preference (D2) and industry (D3) affects aquaponics' entrepreneurial activities (F1), market formation (F5) and creation of legitimacy/counteract resistance to change (F7)
→ Regime science (D4) and technology (D5) affects aquaponics' knowledge development (F2) and vice versa (for the case of the complementary TISs hydroponics)

Distinct interdependencies between specific TIS functions for the case of aquaponics in the Netherlands and complementary TISs:

→ Knowledge development (F2) affects the TISs amongst each other
→ Market formation (F5) and legitimacy (F7) struggles in aquaculture affect aquaponics

Distinct interdependencies between specific TIS functions for the case of the aquaponics development in the Netherlands:

→ Entrepreneurial activities (F1) affect knowledge development (F2), guidance of search (F4), market formation (F5), resource mobilization (F6) and creation of legitimacy/counteract resistance to change (F7)
→ Knowledge development (F2) affects entrepreneurial activities (F1), guidance of search (F4) and creation of legitimacy/counteract resistance to change (F7)
→ Knowledge diffusion through networks affects entrepreneurial activities (F1), knowledge development (F2) and creation of legitimacy/counteract resistance to change (F7)
→ Guidance of search (F4) affects entrepreneurial activities (F1), knowledge development (F2), market formation (F5) and creation of legitimacy/counteract resistance to change (F7)
→ Market formation (F5) affects entrepreneurial activities (F1)
→ Resource mobilization (F6) affects entrepreneurial activity (F1) and knowledge development (F2)
→ Creation of legitimacy/counteract resistance to change (F7) affects market formation (F5) and mobilization of resources (F6)

Further research examining the co-dependencies between the landscape, regime and niche levels in-depth is necessary to further increase our understanding of the innovation dynamics in the agri-food sector in the Netherlands, in other countries, for aquaponics and other emerging agri-food innovations.

It became apparent during the research process, that the complementary TISs introduced in the conceptual integrated framework by Markard and Truffer (2008) are vital to be recognized for aquaponics. This is due to the fact that the complementary TISs of this study, hydroponics and aquaculture, influence aquaponics' development (inducement mechanism 4 & blocking mechanism 5). According to Markard and Truffer (2008) a complementary TIS is an individual entity, which is only connected to the focal TIS and seemingly on a similar development level as the focal TIS. In this research, the complementary TIS of aquaculture is simultaneously a niche of the conventional fish production regime. Moreover, the complementary TIS of hydroponics represents the standard of conventional plant-based farming regime in the Netherlands. The refined conceptual model can be found in the *Analysis Chapter* in figure 16 and shows that there are strong interdependencies between the regime and the complementary TISs. The connection between the complementary TIS and the regime should be recognized, and further examined in future empirical research in the agri-food field.

Moreover, this research provided further insights to the integrated framework. The integration of niches in the focal TIS on niche level are not further explained by Markard and Truffer (2008). The application of this research showed that integrating the niches in the form of niche applications in function 5 of the aquaponics innovation system was an important adjustment to the conceptual integrated framework. To confirm the positioning of the niches in function 5 and further develop the integrated model of Markard and Truffer (2008) additional empirical research should be done.

The operationalization of the TIS functions as proposed by Bergek et al. (2008) and Hekkert et al. (2007) were adapted accordingly to the case of an emerging aquaponics innovation system. The operationalization of sub-categories and concepts for the MLP were added according to the specifications of this research for the landscape level as well as the agri-food regime. This is beneficial as they offer more refined concepts and an analytical approach to enrich the MLP framework. However, it should be emphasized, that these concepts are highly specialized to the agri-food sector and thus, not generalizable for the MLP as such. Since the MLP presents an adequate framework to analyze sustainability transitions for agri-food (Bilali, 2018), the operationalized concepts of the landscape and regime dimensions of this research can be of use for future studies.

7.1.2 Theoretical Implications for Aquaponics

This research contributed to the understanding of the aquaponics development specifically in the Netherlands. Examining the aquaponics development in the Netherlands was particularly interesting because of the country's economically strong, highly productive and vital agri-food regime. As the second largest exporter of agricultural goods, the Dutch agri-food regime does not only export food produce but also technology (Government of the Netherlands, 2018a). The knowledge-intensive Dutch agri-food sector is a good starting point for the emerging technology of aquaponics because of know-how and expertise, especially in the horticulture sector, which is concerned with hydroponics. While this knowledge is a benefit for aquaponics, the efficiency and profitability of the sector represents a great barrier. Therefore, the Netherlands were considered a default case in the beginning, which suggests that if aquaponics can succeed there, it could succeed in other European countries too. However, this claim, and generalization could not be made. Neither do the findings of this research support the claim of the default case nor do they lead to the conclusion of aquaponics' success in the Netherlands or Europe. Additionally, this research shows that the Dutch aquaponics development is strongly connected to European developments, showing the dependency between European stakeholders in aquaponics development and the broad context in which this emerging technology is developing. Therefore, future research should especially focus on the European context for aquaponics development.

Scientific research on aquaponics has mainly been focused on technical characteristics such as a systems design (Goddek et al. 2016), production optimization (Delaide et al., 2016), system dynamics of e.g. nutrients (Goddek et al., 2018), and profitability calculations (Karimanzira et al., 2017). König et al. (2018) were the first to use the technological innovation system framework for the analysis of aquaponics for the case of Germany to understand the current development of aquaponics from a market perspective. Their research solely focused on the aquaponics TIS and did not include the analysis of e.g. the regime or landscape level. Thus, it did not provide any recommendation on how to stimulate the aquaponics development in the context of the agri-food regime. Managing the transition complexity in the agri-food sector requires a more refined framework analyzing not only the aquaponics innovation system but also the regime it is trying to be embedded in, the institutional environment it is obliged to comply to and the environmental as well as socio-political pressures that affect both. Only when these aspects are included, can the potential of sustainable agri-food innovations such as aquaponics be evaluated. How these incumbent structures relate to aquaponics is better understood by the means of this research. The standards in production (e.g. high productivity) and consumption (e.g. low price for high quality) accepted by all actors in the Dutch agri-food regime is considered the common understanding. Likewise, aquaponics has to meet these expectations in order to thrive and be accepted in the Dutch agri-food regime.

As expected, placing the aquaponics TIS on niche level was adequate, as the emerging innovation is in the formative phase and at the very beginning of its development (König et al., 2018; Markard & Truffer, 2008). Patents, publications and other data analyzed as well as experts interviewed confirmed the immature development phase of aquaponics. Analyzing publication, patent and Google Trend statistics as well as literature helped to understand the Dutch aquaponics development and was very helpful to fact-check the information given by interviewees. Nevertheless, the rich information received by the diverse set of interviewees was crucial to the outcome of this research and could have not been gathered in such variety and depth in any other way. The qualitative analysis provided the opportunity to process the rich information received and to transfer the in-depth knowledge in a structured way by the means of this study. The analytic approach built the foundation on which the dynamic interactions and blocking/inducement mechanisms described in the *Analysis Chapter* were identified.

Future research in aquaponics needs to focus on the technical progress of the system concerning production optimization, feasibility and profitability studies. This will help to develop a viable case for the implementation of aquaponic systems in the Netherlands and Europe and thus, counteract the system's current economic unfeasibility (blocking mechanism 7). Furthermore, aquaponic system dynamics require a large amount of research to analyze and share the numerous different individual system components (species of fish, plant, nutrients, water, temperature, etc.) which impact the aquaponic system. The insights gained by this research can provide a basis for further research identifying literature gaps e.g. the development of one dominant design and the urgently needed systems' validity. Advances in these topics can contribute to solving ambiguity in visions, expectations, research and implementation (blocking mechanism 14). Building up on this research, further research should include the development of an (integrated) framework which is completely dedicated to sustainability transition in agri-food. This would enable a more systematic analysis of different agri-food innovations in a similar and more comparable way. It would be interesting to examine how aquaponics performs compared to other emerging agri-food innovations.

Lastly, more applied research which enables entrepreneurs to operate an aquaponics system in a stable, profitable and secure way should also be focused on future research to generate positive and helpful impact. Conducting research as recommended enables the knowledge development of aquaponics. Moreover, it would be able to counteract the lack of aquaponics demonstration systems (blocking mechanism 8) and tackle the complexity of aquaponics' multidisciplinarity (blocking mechanism 9). Consequently, this could lead to an enhancement of scientific as well as applied knowledge development (inducement mechanism 4).

7.2 Limitations of the Research

This research was of exploratory nature and analyzed data qualitatively by means of a content analysis to better understand the aquaponics developments in the Netherlands and Europe. However, especially with qualitative and rich data, reliability and validity needs to be accounted for and taken care of.

Since this research was conducted by one person only, inter-observer consistency could not be reached and thus, internal reliability cannot be argued for. However, by giving detailed documentation of the theoretical framework, the methodological approach including the interview guide, interviewee description as well as the operationalization table and coding guideline, replicability and consequently, external reliability is aimed for. However, it is obvious that especially with interview data the risk of personal bias of the interviewee as well of the interviewer can stir the conversation. For this research some questions were not as elaborately answered by interviewees as others. Moreover, the sampling strategy chosen (snowball sampling) could potentially be biased to a certain network. Speaking against a bias in sampling is the fact that there is only a very limited number of experts on aquaponics in the Netherlands of which most were interviewed. Most interviewees were able to mention at least one other individual concerned with aquaponics; however, one cannot speak of a network of people that know each other. To counteract potential inconsistencies, biases and other limitations of interviews, a total of 24 interviews was conducted and data from multiple other sources was examined to achieve data triangulation, including publication, patent, Google Trend statistics, literature, practitioner and government websites, etc.

As the theoretical framework forms the foundation on which the research was conducted, the alignment between theory and practice is apparent and documented throughout this research. Ultimately, the integrated framework of Markard and Truffer (2008) has been slightly adapted for the aquaponics development in the Netherlands. Likewise, it needs to be mentioned that while the TIS is generally well operationalized with its functions and further indicators listed by Bergek et al. (2008) and Hekkert et al. (2007), the MLP and its dimensions are less well operationalized by Geels (2002) as well as Markard & Truffer (2008) in their integrated framework. The MLP dimensions were defined based on the pieces of information gathered and placed in the respective dimension.

Aquaponics is a very small niche innovation and at a very early stage of the innovation process. It is not a fully developed technology which limits generalizability and predictability of ongoing developments. However, the findings of this study are claimed to be generalizable to the Netherlands, as country statistics and a diverse mix of interviewees encourage to reflect that. To expand the generalizability of the study, the European context was also taken into account. Setting the findings of the Dutch aquaponics TIS into the European context appeared to be promising; however, valid representation and generalizability to the European level cannot be claimed. This is due to the fact that European aquaponics developments have not been studied in depth. Likewise, aquaponics innovation systems of other European countries have not been taken into account.

7.3 Practical Contributions

The aim of this research was to analyze the aquaponics innovation system in the Netherlands in its ability to support the sustainability transitions in agri-food. Aquaponics is at such an early development phase that, evaluating from this moment in time, it will not be the driver of a sustainable transition in the Dutch agri-food sector in the upcoming years. However, aquaponics has multiple sustainable advantages from which the Dutch agri-food system could benefit and therefore, recommendations on how to foster the aquaponics development are highlighted in this section. Practical implications for policy makers, entrepreneurs, researchers and the incumbent industry are made to support the development of aquaponics and to stimulate the agri-food sector for transition.

Aquaponics can be fostered by policy makers in two areas: on niche level by stimulating knowledge diffusion through networks and resource mobilization, and on regime level through policy. Hekkert et al. (2007) and Bergek et al. (2008) stress the role of the government especially for immature functions, which can be enhanced by policy stimuli. The Dutch government can foster knowledge diffusion through cooperation on aquaponics projects on national level. To foster cooperation and innovation the Ministry of Agriculture, Nature and Food Quality promotes the Golden Triangle approach which can be applied to enhance the aquaponics network formation between industry, academia and the government. Thus, it can counteract the lack of communication and cooperation between aquaponics proponents (blocking mechanism 10 & 11). Furthermore, engagement in European aquaponics initiatives can be supported by direct government participation as well as financial contribution. These actions can support the strengthening of an existing or the building of a new highly anticipated network for aquaponics researchers, entrepreneurs and other proponents to foster communication and cooperation (blocking mechanism 10 & 12). Mobilizing resources to financially support aquaponics does not only counteract the perceived smaller financing potential of aquaponics (blocking mechanism 18) but also enables knowledge diffusion. Moreover, it can increase knowledge development by financing aquaponics research projects and entrepreneurial activities as well as experimentation allowing more aquaponics systems and businesses to be built. As a result, this counteracts the lack of demonstration systems (blocking mechanism 8), the complexity of the multidisciplinary nature of aquaponics (blocking mechanism 9), the lack of experts (blocking mechanism 17), and further enhances the aquaponics research driven by Wageningen University (inducement mechanism 4). Furthermore, policy adjustments to simplify the regulatory framework around aquaponics can help entrepreneurs in the system's handling (blocking mechanism 21). Moreover, considering aquaponics in the transition towards the policy vision of Circular Agriculture, it can support the goals set by the Ministry of Agriculture, Nature and Food Quality. Both measures can contribute to the creation of legitimacy and counteract the lack of successful lobbying (blocking mechanism 20), the lack of legislation for aquaponics (blocking mechanism 21) and counteract the fact that aquaponics has not been taken seriously by stakeholders (blocking mechanism 22).

Blocking mechanisms which can be approached by practitioners mainly concern the functions entrepreneurial activity, knowledge development, knowledge diffusion through networks and creation of legitimacy. Entrepreneurs need to develop successful business concepts for aquaponics which do not only have an effect on the entrepreneurial success but also create legitimacy through economic feasibility. By applying this measure, the technology can overcome anti-success stories to counteract blocking mechanism 6, the lack of economic viability to solve blocking mechanism 7, and the fact that aquaponics is not taken seriously by stakeholders (blocking mechanism 22). Moreover, setting up commercial aquaponic systems can stimulate technical as well as economic learning and enhance the development of applied knowledge to counteract blocking mechanism 8. Practically, entrepreneurs would be required to solve the issue of economic infeasibility and to share their knowledge created in order to enhance the aquaponics development as a whole. Therefore, sharing knowledge through networks and counteracting the secrecy behavior for competitive advantage (blocking mechanism 11) benefits the emerging aquaponics innovation system and consequently, the respective business. Knowledge diffusion from the system owner to the consumer can also counteract the legitimacy issue originating from blocking mechanisms 22. Aquaponics systems are often used as a tool for teaching about food production. Aquaponic system owners can bring the topic of food production closer to the consumer and in this way educate them about sustainable alternatives. Another vital point discovered in the analysis is marketing. Promoting the business and product right is required to make the endeavor successful and worthwhile. Poor strategic planning and marketing has led prior aquaponics business to bankruptcy (blocking mechanism 6). Especially, for a comparably expensive aquaponics product in a highly competitive market, strong marketing can play a crucial factor. Furthermore, it has been found that aquaponics comprises more niche applications than first expected. Above small-scale personal usage, medium-scale local community contexts and large-scale industrial settings this research exposed two more niche applications: (1) equipment and system retail and (2) aquaponics consultancy. It is not clear if these additional aquaponics applications found in the Dutch aquaponics innovation system hold for other countries in the formation of their aquaponics markets. Further research can be used to find, examine and evaluate the potential of individual aquaponics niches for guidance in future market formation efforts of aquaponics entrepreneurs.

Researchers and entrepreneurs must join forces for aquaponics to become successful and counteract the lack of communication (blocking mechanism 10). Niche innovations gain strength by shared expectations and visions, interaction, learning processes and the alignment of constituent elements; all of them can be supported by counteracting blocking mechanisms identified. After building common ground by means of a vision which entices different stakeholders to cooperate, learn and share, aquaponics can develop a dominant design and grow in terms of supporters, competitiveness and market share (Geels & Schot, 2007). Furthermore, research findings can help commercially active entrepreneurs to understand the technology's market position, state of development and bottlenecks that require most attention.

Despite the connection of aquaponics to both, the plant-based farming regime and the fish production regime, the systematic integration of aquaponics as a niche innovation in either of the two agri-food sub-regimes has not yet been attempted. While some experts identify aquaponics to be a subsection of the rather small and niche-like aquaculture sector in the Netherlands (blocking mechanism 5) and therefore, should be allocated to the fish production regime; others perceive it as a plant-based system and thus, a niche to the plant-based farming regime. Some argue that a clear integration of aquaponics and its emerging technologies into one of the two sub-regimes in place would accelerate and improve the development of the aquaponics innovation system. This claim is based on the assumption that, in this way, aquaponics would receive a clearer definition of purpose and therefore, reach more consensus between actors in the system can be reached.

At the first look, aquaponics seems to be one of the ideal answers to the sustainability transition in the Dutch agri-food sector. However, the emerging aquaponics innovation system must fight many battles from within to mature and develop. Based on this research, it cannot be considered a driver to green the agri-food sector. Nonetheless, it is a kick-off concept providing a different approach to food production, where externalized costs are internalized to the highest degree. This valuable logic can and should be more exploited, especially in the light and with the help of the Circular Agriculture vision of the Ministry of Agriculture, Nature and Food Quality in the Netherlands, and more pressure from the United Nation's SDGs. But until then there is a lot of work to do for researchers, entrepreneurs, policymakers and other actors towards a more sustainable future in agri-food potentially supported by the aquaponics technology. Fostering knowledge, experimentation and communication to enhance the emerging aquaponics innovation should be a priority for its development and to understand its potential.

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Appendix

Appendix 1 Operationalization Table

Table 13 Operationalization Table

Category	Sub-Category	Concept	Indicator	Source
Landscape level	Environmental pressures	Active and noticeable environmental pressures due to for example climate change, soil degradation, droughts, floods, etc.	nominal	Expert interview, literature review, Google Web
	Socio-political pressures	Active and noticeable socio-political pressures due to changing regulations, governmental goals, NGOs, societal movements and perception	nominal	Expert interview, literature review, Google Web
Regime level	Science	Expertise and goals in agri-food	nominal	Expert interview, literature review, Google Web
		Ratio of aquaponics, hydroponics and aquaculture publications to total number of agricultural publications	ratio (in percent)	Web of Science
		Science institutions concerned with sustainability, agriculture and/or innovation	nominal	Expert interview, literature review, Google Web
	Culture	Perception of the regime's openness to innovation and sustainability	nominal	Expert interview, literature review, Google Web
		Industry culture	nominal	Expert interview, literature review, Google Web
		Perception of the people's openness to innovation and sustainability	nominal	Expert interview, literature review, Google Web
		Perception of people's desire for sustainable agriculture	nominal	Expert interview, literature review, Google Web
		Perception of people's knowledge about the agri-food regime and its impacts	nominal	Expert interview, literature review, Google Web
		Consumer culture	nominal	Expert interview, literature review, Google Web

	Technology	Technology directions of conventional agriculture	nominal	Expert interview, literature review, Google Web
		Technology directions of organic, sustainable, urban agriculture	nominal	Expert interview, literature review, Google Web
		Participants of technological development	nominal	Expert interview, literature review, Google Web
	Policy	Regulations or financial incentives enabling sustainable agricultural innovation	nominal	Expert interview, literature review, Google Web
		Regulations or financial incentives hindering sustainable agricultural innovation	nominal	Expert interview, literature review, Google Web
		Engagement in respective SDGs or other missions towards greening the agri-food sector	nominal	Expert interview, literature review, Google Web
	Industry	Conventional agricultural procedures in plant-based farming	nominal	Expert interview, literature review
		Conventional agricultural procedures in fish production	nominal	Expert interview, literature review
		Supply chain processes	nominal	Expert interview, literature review
		Involvement in alternative agricultural technologies and innovation	nominal	Expert interview, literature review
		Investment and focus on sustainability	nominal	Expert interview, literature review
	Market/user preference	Demand of organic and conventional food products	nominal	Expert interview, literature review, government website
		Market infrastructure for plant-based farming and consumption (seed until final product)	nominal	Expert interview, literature review, Google Web
		Market infrastructure for fish production and consumption (fish egg until final product)	nominal	Expert interview, literature review, Google Web
		Capital infrastructure for agri-food innovation	nominal	Expert interview, literature review, Google Web
TIS on niche level	Entrepreneurial activities	Number and characteristics of commercial aquaponics farms	nominal	Google Web, expert interview
		Incumbents concerned with aquaponics	nominal	Google Web, expert interview

		Different types of applications/systems in aquaponics and their perception of success	ordinal (ranking)	Literature review, expert Interview
		New entrepreneurial activities	nominal	Google Web, expert interview
	Knowledge development	Learning-by-searching is expressed by mentioning research efforts and topics	nominal	Expert interview, literature review, Google Web
		Learning-by-doing is expressed by entrepreneurs explaining system operations	nominal	Expert interview, literature review, Google Web
		Share of aquaponics, hydroponics and aquaculture publications in total number of agricultural publications	ratio (in percent)	Web of Science, Scopus
		Experimentation efforts published as patents for aquaponics, hydroponics and aquaculture	nominal	Patent scope, Espacenet
	Knowledge diffusion through networks	Information about the knowledge flow and sharing efforts for aquaponics	nominal	Expert interview, literature review, Google Web
		Organization, workshops and other initiatives organized for aquaponics communication	nominal	Expert interview, literature review, Google Web
		Combinatorial opportunities of aquaponics with other interest fields (e.g. research, pooled labor markets, etc.)	nominal	Expert interview
	Guidance of search	Targets or incentives by government for engaging in aquaponics	nominal	Expert interview, literature review, government website, Google Web
		Targets or incentives by industry for engaging in aquaponics	nominal	Expert interview, literature review, Google Web
		Mentioned visions and main goals of aquaponics	nominal	Expert interview, literature review, Google Web
		Expectations and visions for future aquaponics development	nominal	Expert interview, literature review, Google Web
		Crisis in aquaponics, which influences its development	nominal	Expert interview, literature review, Google Web
		Interest by leading customers disclosed by demand	nominal	Expert interview, literature review, Google Web

	Market formation	Described maturity of aquaponics, the phase and characteristics of its market	nominal	Expert interview, literature review
		Aquaponics niche applications described	nominal	Expert interview, literature review
		Technological standard	nominal	Expert interview, literature review
		Tax regimes or other institutional stimuli for aquaponics technology	nominal	Expert interview, literature review, government website
		Environmental standards (that enhance sustainable technologies)	nominal	Expert interview, literature review, government website
		Technology user and purchasing process for aquaponics farmers	nominal	Expert interview, literature review
		Actor strategies for market formation of aquaponics	nominal	Expert interview, Google Web, literature review
	Resource mobilization	Available funds of aquaponics or agricultural R&D programs by the industry	nominal	Expert interview, literature review, Eurostat, Google Web
		Available funds of aquaponics or agricultural R&D programs by government	nominal	Expert interview, literature review, Eurostat, Google Web
		Increasing financial capital for aquaponics	nominal	Expert interview, literature review, Eurostat, Google Web
		Perception of resource-sufficiency for aquaponics development	nominal	Expert interview, literature review, Eurostat, Google Web
		Quality and amount of human resources/experts on aquaponics	nominal	Expert interview, literature review, Eurostat, Google Web
	Legitimacy	Rise and growth of interest groups	nominal	Expert interview, literature review, Google Web
		Lobby actions	nominal	Expert interview, Google Web
		Alignment of aquaponics with legislation	nominal	Expert interview, literature review, government website
		Alignment with values of industry and society	nominal	Expert interview, literature review, Google Web
		Stakeholders’ perception on aquaponics	nominal	Expert interview, literature review, Google Web

Complementary TIS	Type of complementary technologies that enhance aquaponics	Insights into how hydroponics influences the aquaponics development	nominal	Expert interview, literature review, Google Web
		Insights into how aquaculture influences the aquaponics development	nominal	Expert interview, literature review, Google Web
European context	Differences or similarities	Finding differences or similarities between the Dutch and the European aquaponics development	nominal	Expert interview, literature review, Google Web, government website

Appendix 2 Coding Guideline

Figure 19 Coding Guideline

Category	Sub-Category	Concept of Coding	Example phrase
Landscape level	Environmental pressures	Active and noticeable environmental pressures due to for example climate change, soil degradation, droughts, floods, etc.	*"We have in, for instance, the province of Zeeland, we have a lot of salty water coming out of the soil instead of fresh water. So, and also in parts of the northern parts of Harlem and near, which is very difficult to have normal agriculture."* (Ministry 2)
	Socio-political pressures	Active and noticeable socio-political pressures due to changing regulations, governmental goals, NGOs, societal movements and perception	*"And I think that is due to a lot of NGOs, we're talking about the fishes going and there's no more fish left in the sea. Yes, that sentiment has really been made. And it's an animal thing. So, animal welfare is quite an important thing."* (Expert 1)
Regime level	Science	Expertise in agri-food	*"If you look at aquaculture, that requires quite some specific knowledge. But we have one of the best aquaculture scientific groups here, in Wageningen in the Netherlands. You know, with 50 to 70 students a year. So, it's not that we lack aquaculture expertise."* (Expert 5)
		Science institutions concerned with sustainability, agriculture and/or innovation	*"We found out that universities worldwide are not up to what Wageningen does, for example."* (Expert 3)
	Culture	Perception of the regime's openness to innovation and sustainability	*"The companies, that are operating now in the sector are all not just mere growers anymore, but they're getting more entrepreneurship. So, if you go with the right things to change, I think they will always be open to it. […] And you see more and more entrepreneurs that just look at it as a business. And if you come with a good idea that helps their business, they are overenjoyed."* (Expert 2)
		Industry culture	*"So, because when you are talking about organic farming or ecological farming, everybody thinks you're very weak and soft and old age and [], but if you use the new techniques together, then there is really a way to sustainability."* (Ministry 2)

		Perception of people's openness to innovation	*"So, you see from the people, from the consumer side, it was a lot of curiosity. Because food is an everyday is topic in the Netherlands, I think it is a good universe to start such things."* (Entrepreneur 1)
		Perception of people's desire for sustainable agriculture	*"So, they perceive the organic products, as sustainable products. And sustainability is an important trend, so organic products thrive with it. And also, organic production of food becomes more important because of that."* (Retailer)
		Perception of people's knowledge about the agri-food regime and its impacts	*"I think Dutch people don't care so much, as long as it's cheap."* (Expert 1)
		Consumer culture	*"The price quality in the Netherlands is really high. Because Dutch people are really price driven, and also accept a certain quality."* (Retailer)
	Technology	Technology directions of conventional agriculture	*"For example, here they develop machines for detecting when the plants need to be harvested or when the plants are sick and where you should apply pesticides directly. So instead of the pesticide going to all of the plants, even if they don't need them, they localize it."* (Researcher 2)
		Technology directions of organic, sustainable, urban agriculture	*"So, because when you are talking about organic farming or ecological farming, everybody thinks you're very weak and soft and old age and [], but if you use the new techniques together, then there is really a way to sustainability."* (Ministry 2)
		Participants of technological development	*"A lot of the new ideas stem from the Netherlands because it's a very well-connected sector, everybody knows another person - whether it's a supplier or a greenhouse builder or even a plant supplier, seed companies."* (Expert 3)
	Policy	Regulations or financial incentives enabling sustainable agricultural innovation	*"The two keywords for the ministry are innovation and cooperation, facilitating cooperation and innovation."* (Ministry 1)

		Regulations or financial incentives hindering sustainable agricultural innovation	*"But that was the [pulse] system in the Netherlands. It was a lot of opposition from France because they do not have that technique. As it was not really proven, if this now was a better solution or more sustainable. [] So, then there is a lot of investment now there is new European regulation, so it is not allowed anymore. It's only for two years, that the Dutch fishery may use this kind of technique. So, there is investments but not always successful."* (Expert 6)
		Engagement in respective SDGs or other missions towards greening the agri-food sector	*"In the Netherlands, so we have now a new policy, because we have a new Minister of Agriculture. And she has now a new policy about circular production, circular agriculture. And now it's worked out these missions, more concrete."* (Expert 6)
	Industry	Conventional agricultural procedures in plant-based farming	*"So, the owner [was] the one who grows and knows about the plants, knows about fertilization, knows about pesticides. And what you see now: the owner is the businessman and they have growers to do crops."* (Expert 1)
		Conventional agricultural procedures in fish production	*"So, we have always been a fishing nation. We have quite a significant fishery fleet. It's quite a specialized fishery fleet. A lot of what we catch, like place and soul, hiring, mackerel, is actually exported."* (Expert 5)
		Supply chain processes	"*And that's really a very difficult message to the existing very long chain, which is also completely, exports is part of it, we have a lot of supermarkets, we have a lot of farmers, but we only have five in between five bureaus who actually put farmer and supermarket together and always for the lowest price."* (Ministry 2)
		Involvement in alternative agricultural technologies	*"They're very well aware [of new innovations like aquaponics]. I think they like to look a little bit longer how it's working. And if it's working well, I think they will adapt."* (Expert 2)
		Investment and focus on sustainability	*"So, there's all different kinds of funding going on in the Netherlands to support growers, but even to support the next steps in the supply chain to increase impacted and to make the change possible."* (Expert 1)

	Market/user preference	Demand of organic and conventional food products	*“Dutch people don't care so much, as long as it’s cheap.”* (Expert 3)
		Market infrastructure for plant-based farming and consumption (seed until final product)	*“There just a few big supermarket chains, that buy all your vegetables, and they can set the price.”* (Expert 3)
		Market infrastructure for fish production and consumption (fish egg until final product)	*"If you see the total development of good food or healthy food or healthy lifestyles, then fish is part of it. But in the Netherlands, we are very lousy fish eaters, we don't eat that much of fish. [] And if we are eating fish, we’re eating most of it [as] anonymous fish, tilapia or pangasius, but not the fishes, which are swimming in front of our ocean."* (Ministry 2)
		Capital infrastructure for agri-food innovation	*"I would say pitching days. So small companies but also farmers, that think we have now a new product, which really fits the consumer profile of []. Two times a year, they can come to our company and they can win a prize and a spot in the shelf and get a budget for marketing."* (Retailer)
TIS on niche level	Entrepreneurial activities	Number and characteristics of commercial aquaponics farms mentioned	*"And there was a big project in Rotterdam, was on the roof of an old office building. They had a glass house and they produced tomatoes, sweet peppers, a lot of herbs. But it went bankrupt, I think last year. And there is one big project in Eindhoven left, I think. But it's really difficult to be commercially successful in aquaponics."* (Researcher 5)
		Incumbents concerned with aquaponics mentioned	*"I think they’re [the incumbent agri-food companies] very well aware. I think they like to look a little bit longer how it's working."* (Expert 2)
		Different types of applications/systems in aquaponics and their perception of success	*“Uit je eigen stad in Rotterdam, Urban Farmers in The Hague, both gone. I think because they choose a too competitive way of growing and marketing to the normal horticulture. And that’s a battle you can’t win."* (Entrepreneur 2)
		New entrepreneurial activities	*"But you also have this hotel, QO hotel in south Amsterdam where they have an aquaponics system as well for the hotel. It’s not working right now but from middle of May on."* (Expert 10)

		Learning-by-searching is expressed by mentioning research efforts and topics	*"They're still doing some research here at Wageningen University, on a new version of aquaponics."* (Expert 9)
		Learning-by-doing is expressed by entrepreneurs explaining system operations	*"And for me in this stage is more, I need the applied science and I need to get my system more effective. For me, it's not important right now to exactly know how the processes work. For me it's more applied science. Trial and error."* (Entrepreneur 2)
		Experimentation efforts published as patents	*"But then translating this into a market case is quite difficult because you cannot really do patents on it [aquaponics], it is something that is not so difficult to engineer. So, I think this also creates a bit of a barrier. You maybe make this really nice product and then just a few months later this big company takes it over because they can do it a lot more easily and have the production sites."* (Entrepreneur 3)
	Knowledge diffusion through networks	Information about the knowledge flow and sharing efforts for aquaponics	*"So, everybody's too much in love with the topic and then thinks, if I find something, this will be a breakthrough. So, I am not willing to share. With [XY] we were also doing that because we were responsible to our investors, of course."* (Entrepreneur 1)
		Organization, workshops and other initiatives organized for aquaponics communication	*"There were these initiatives like Inapro on one side and the aquaponics hub for another. But there was no platform to share results or everything in detail."* (Researcher 2)
		Combinatorial opportunities of aquaponics with other interest fields (e.g. research, pooled labor markets, etc.)	*"There was and there still is a recirculating agricultural farmers association. And we were considered to join them."* (Entrepreneur 1)
	Guidance of search	Targets or incentives by government for engaging in aquaponics	*"I've read some reports about aquaponics, as a as a candidate for future development. I don't see any grants or any subsidies or whatever to encourage that."* (Entrepreneur 5)
		Targets or incentives by industry for engaging in aquaponics	*"I believe firmly that in 5 to 10 years, aquaponics will be a competitive way of growing."* (Entrepreneur 2)

		Mentioned visions and main goals of aquaponics	*"And the emphasis laid much more on the fish. And it's not the fish that makes the system run, it's the vegetables."* (Entrepreneur 2)
		Expectations and visions for future aquaponics development	*"The it might be commercially more interesting if different types of plants are produced. Now most of the time is plants of low value produce like lettuce, herbs. Because they are easy to grow. And most of the time, they're not really needing in terms of their fertilizing. But there might be a chance for products, plants, who have more value. And here we would try to do tests, really small-scale tests with wasabi, for example. Because that's a really high value product. Also, ginger, we have some tests."* (Researcher 5)
		Crisis in aquaponics, which influences its development	*"I think there is that now new realization that okay, if we are going to try, we have to be more careful. So sadly, that's going to mean people are going to be afraid of trying because they have seen those who try fail. So, it will take a while, I think."* (Researcher 2)
		Interest by leading customers disclosed by demand	*"But just the willingness to pay for fresh food, local grown food. It's emerging. But it's no it's not a customer base where you can say: they are paying half a million a year, so they can really run a professional farm."* (Entrepreneur 1)
	Market formation	Described maturity of aquaponics and the phase and characteristics of its market	*"So far, aquaponics is such a niche technology, it's a bit of a hype and still a niche."* (Researcher 1)
		Aquaponics niche applications described	*"I don't aim at the consumer market, I aim on business to business, restaurants, caterers."* (Entrepreneur 2)
		Technological standard	*"There is no common standard for technology, there was even a huge debate. 2014 to 2018, there was the Cost EU Aquaponics Hub initiative. And even they didn't finish with a proper definition because there is no common denominator what it actually is. And so, if there is not even a definition, there is also not really a state of the art, which is recognized."* (Entrepreneur 1)

		Tax regimes or other institutional stimuli for aquaponics technology	*"There is a positive reaction of public money from the political environment. [...] You have to know that aquaponics systems were classified by European Commission as one of the ten techniques of the future, so there is pressure to get to that.* " (Researcher 3)
		Environmental standards (that enhance sustainable technologies)	*"There is an organic market. But this market you cannot cater with aquaponics. Because it's not certified organic. And it's not possible to certify organic. So basically, in Netherlands, you can sell it as aquaponics and ask a high price, but you will have to do a lot of very good marketing to make it happen."* (Expert 9)
		Technology user and purchasing process for aquaponics farmers	*"They were aiming for this like organic movement in the residential area."* (Researcher 2)
		Actor strategies for market formation of aquaponics	*"I think, when aquaponics is adapted by the mainstream supermarket or mainstream food manufacturer. When there is a lot of exposure. Because then it has to go on to retailers. But now the system is way too fragile for that. [] It needs to go from toddler to adult."* (Entrepreneur 2)
	Resource mobilization	Available funds of aquaponics or agricultural R&D programs	*"Our investors invested three to five million over there. And the farm there would not have been happened without the support of the SVN-stichting."* (Entrepreneur 1)
		Available funds of aquaponics or agricultural R&D programs by government	*"If it would have been a research packed set farm and not just a pure commercial farm, we would have been able to add another 300,000 to the budget."* (Entrepreneur 1)
		Increasing financial capital for aquaponics	*"There's a lot of government funding, European Union funds for aquaponics to research, but I haven't heard of subsidies for aquaponics companies, I think because it's a risk investment. Particularly these years, that all of those have been going bankrupt."* (Researcher 2)

		Perception of resource-sufficiency for aquaponics development	*"In fact, we submitted a proposal some three years ago in the Netherlands for the Dutch agency for scientific research [concerning aquaponics]. And it was not funded because the main complaint was okay, you just focus on such a small issue market, so why should we invest money into this? And therefore, I think at the EU level we're more successful."* (Researcher 4)
		Quality and amount of human resources/experts on aquaponics	*"When people start to figure out that it's a bit more complex than it sounds, that you really need a lot of expertise that pretty much a handful of people in the world have. Really experiencing growing fish and growing plants and market analysis because if this is still a niche activity in aquaculture and greenhouse horticulture. So, the combination of like 34 different disciplines, few people in the world half, if any at all. So, the idea is that it has to be multi-disciplinary."* (Researcher 2)
	Legitimacy	Rise and growth of interest groups	*"A few years ago, I had to explain what aquaponics was, every time I saw a new person. Now people know. I don't have to explain that much."* (Entrepreneur 5)
		Lobby actions	*"I know that many scientists and also commercial [] in the European Union try to make an aquaponics organic, like that it can be considered organic. Because now only soil derived products can be considered organic. But this didn't work so far. They tried to lobby in the European Union."* (Researcher 1)
		Alignment of aquaponics with legislation	*"There's certainly not specific regulation regarding aquaponics, because there is legislation about the greens and the protected cultivation."* (Expert 4)
		Alignment with values of industry and society	*"And I mean, there is an organic market. But this market you cannot cater with aquaponics. Because it's not certified organic. And it's not possible to certify organic. So basically, in Netherlands, you can sell it as aquaponics and ask a high price, but you will have to do a lot of very good marketing to make it happen."* (Expert 9)
		Stakeholders' perception on aquaponics	*"It takes too long to explain to customers, that's a pity. For now, it has to sink in, but that needs time, years."* (Entrepreneur 2)

Compleme ntary TIS	Type of complementar y technologies that enhance aquaponics	Insights into how hydroponics influences the aquaponics development	*"But the biggest obstacle I see is really the education. You need very educated people for hydroponic system itself even. Then to have a person who also understands aquaculture, I think that's the biggest barrier."* (Researcher 1)
		Insights into how aquaculture influences the aquaponics development	*"I'm a policy advisor at the directorate of fisheries, fisheries and aquaculture. [] Before two years, I was very involved in innovations, about aquaculture, aquaponics, and so and the role of the government, of the ministry, is to facilitate to stimulate all kinds of initiatives in that area."* (Ministry 1)
European context	Differences or similarities	Finding differences or similarities between the Dutch and the European aquaponics development	*"We submitted a proposal [for aquaponics] some three years ago in the Netherlands for the Dutch agency for scientific research. And it was not funded because the main complaint was okay, you just focus on such a small issue market, so why should we invest money into this? And therefore, I think at the EU level we're more successful. Because this is now the third EU [aquaponics] project in a row, that we are running on this."* (Researcher 4)

Appendix 3 Interview Overview

Table 14 Stakeholder groups covered by interviews

Stakeholder Group	Alias	Function	Interview Date	Duration
Market and industry	Entrepreneur 1	Aquaponics entrepreneur	06. May 2019	59min
Market and industry	Entrepreneur 2	Aquaponics entrepreneur	10. May 2019	45min
Market and industry	Entrepreneur 3	Aquaponics entrepreneur	03. May 2019	38min
Market and industry	Entrepreneur 4	Aquaponics entrepreneur	02. May 2019	NA
Market and industry	Entrepreneur 5	Aquaponics entrepreneur	06. May 2019	38min
Market and industry	Expert 1	Horticulture expert from a horticultural trade organization	10. May 2019	1h 21min
Market and industry	Expert 2	Horticulture expert from a grower's organization	03. July 2019	37min
Market and industry	Expert 3	Horticulture expert from a company concerned with automation solutions for horticulture	01. July 2019	43min
Market and industry & Government	Expert 4	Horticulture expert in a shared position between the Ministry of Agriculture, Nature and Food Quality and the Dutch grower's organization	03. May 2019	1h 07min
Market and industry	Expert 5	Fishery and aquaculture expert employed at a fish certification organization	11. June 2019	1h
Society	Expert 6	Agri-food expert involved in European food network	06. May 2019	56min
Technology and science	Expert 7	Aquaculture expert, researcher and consultant	11. April 2019	1h 07min
Society	Expert 8	Aquaponics expert with work experience in aquaponics	20. May 2019	28min
Market and industry	Expert 9	Aquaponics and hydroponics expert and consultant	27. May 2019	20min
Society	Expert 10	Aquaponics expert with work experience in aquaponics	02. May 2019	28min
Government	Ministry 1	Fishery and aquaculture expert employed at the Ministry of Agriculture, Nature and Food Quality	13. May 2019	1h 08min
Government	Ministry 2	Agri-food expert employed at the Ministry of Agriculture, Nature and Food Quality	13. May 2019	1h 08min
Technology and science	Researcher 1	Aquaponics researcher	14. May 2019	54min
Technology and science	Researcher 2	Aquaponics researcher	01. May 2019	2h 03 min
Technology and science	Researcher 3	Aquaponics researcher	02. May 2019	45min
Technology and science	Researcher 4	Aquaponics researcher	15. May 2019	26min
Technology and science	Researcher 5	Aquaponics researcher	13. May 2019	44min
Market and industry	Retail	Market expert employed at a retailer in the vegetable department	14. June 2019	34min

Appendix 4 Interview Guides

Table 15 Interview guide for aquaponics experts

Number	Question	Keyword
1	How would you describe the aquaponics development in the Netherlands in the last 10 years?	past development
2	Was there a specific event that influenced the development of aquaponics in the Netherlands? In which way?	event
3	What is the current state of aquaponics? And why? Would you describe the maturity of the technology but also of the economic and legal system around it?	maturity
4	To what extent is the aquaponics technology ‘ready’ to become a sustainable standard in food production? What are your indicators for this?	readiness
5	Is or will the current regime of the agri-food sector be allowing aquaponics a share of the market? What are your indicators for this?	regime
6	What do you think will be the future development path of aquaponics? And why?	future development
7	Which aquaponic application is strongest and will grow: private, local, large-scale production and/or teaching? And why?	application
8	Do you know people related to the topic in terms of entrepreneurship or research?	people
9	Are you aware of any type of support, incentives or targets from the government benefiting aquaponics?	government
10	Are there lobby structures or other support groups that strengthen the position of aquaponics? Any network groups that enhance the situation?	networks
11	Are there resources in terms of capital or experts that support your work on aquaponics? Industry, private, governmental, national, international?	resources
12	Do you think aquaponics is compatible with the country’s culture and consumer behavior? And why?	current structures
13	Do you think aquaponics is compatible with the country’s market infrastructure and legal structures? And why?	current structures
14	Is there another technology that might outperform aquaponics in the transition towards sustainable agriculture? Which advantages does it have?	rival technology
15	Is there another technology that might benefit aquaponics? And why?	other technology
16	Do you want to share a last interesting fact that we haven’t touched upon yet?	random
17	Can you connect me with other people in your network, which are open to be asked some interview questions?	interviewees

Table 16 Interview guide for agri-food experts

Number	Question	Keyword
1	How would you describe the agri-food development in the Netherlands in the last 10 years? And why?	past development
2	Was there a specific event that influenced the development of vegetable, fruit or fish farming in the Netherlands? In which way?	event
3	What do you think will be the future development path of agriculture and fish production? And why?	future development
4	Are there technological innovations that you see in the market that effect your business (especially, in becoming more sustainable)? To which extent?	innovations
5	Have you heard of aquaponics and do you know people related to the topic?	aquaponics
6	To what extent does the agri-food sector with its conventional standards in plant-based farming and fish farming allow aquaponics to become a standard? What are indicators for this?	standard
7	Can you develop your current production towards aquaponics? Which measures would you have to take? What hinders you to do that?	application of aquaponics
8	Are you aware of any type of support, incentives or target from the government of concerning your field of business? Especially, towards becoming more sustainable?	government
9	Are there resources in terms of capital or experts that support your work (also towards sustainability)? Industry, private, governmental, national, international?	resources
10	Are their lobby structures or other support groups that strengthen the position of your business?	networks
11	Do you perceive any pressures that make you think about or actively change things in your business? For example, towards sustainability, efficiency, etc.?	pressures
12	Do you perceive a shift in the country's culture and consumer behavior concerning your production? And why?	current structures
13	Do you perceive a shift in the market infrastructure or legal structures concerning your production? And why?	current structures
14	Do you want to share a last interesting fact that we haven't touched upon yet?	random
15	Can you connect me with other people in your network, which are open to be asked some interview questions?	interviewees

Table 17 Interview guide for politics, unions and others

Number	Question	Keyword
1	How would you describe the agri-food development in the Netherlands in the last 10 years? And why?	past development
2	Was there a specific event that influenced the development of vegetable, fruit or fish farming in the Netherlands? In which way?	event
3	What do you think will be the future development path of agriculture and fish production? And why?	future development
12	Do you perceive any specific pressures to change agriculture towards sustainability? In which way does it change?	pressures
7	Are you aware of any type of support, incentives or target from the government benefiting conventional agriculture vs. new sustainable innovations (aquaponics)?	government
9	Are their lobby structures or other support groups that strengthen the position of conventional agriculture vs new sustainable innovations (aquaponics)?	networks
8	Are there resources in terms of capital or experts that support agriculture and fisheries in general (also towards sustainability)? Industry, private, governmental, national, international?	resources
10	How would you describe your countries culture and consumer behavior in this regard? Do you think aquaponics is compatible with the country's culture and consumer behavior? And why?	current structures
11	How would you describe the countries market infrastructure and legal structures? Do you think aquaponics is compatible with the country's market infrastructure and legal structures? And why?	current structures
4	Are you aware of sustainable agriculture alternatives (innovations) to conventional standards in vegetable, fruit and fish farming?	innovations
5	Have you heard of aquaponics and do you know people (researchers, entrepreneurs or other experts) related to the topic?	aquaponics
6	To what extent does the agri-food sector with its conventional standards in plant-based farming and fish farming allow aquaponics to become a standard? What are indicators for this?	standard
13	Do you want to share a last interesting fact that we haven't touched upon yet?	random
14	Can you connect me with other people in your network, which are open to be asked some interview questions?	interviewees

Appendix 5 Statistical Data on Publications

Table 18 Overview of WOS publication data on keywords aquaponics, hydroponics, aquaculture

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Aquaponics	0	0	0	0	0	1	0	0	5	3	8
Hydroponics	4	7	7	4	12	12	11	6	13	14	14
Aquaculture	28	26	43	36	48	56	54	48	78	49	81

Table 19 Overview of Scopus publication data on keywords aquaponics, hydroponics, aquaculture

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Aquaponics	0	0	0	0	0	0	0	0	5	2	8
Hydroponics	4	3	5	2	5	10	6	4	14	7	12
Aquaculture	20	17	31	41	38	44	53	49	71	42	70

Appendix 6 Statistical Data on Publications

The Netherlands only began research on aquaponics in 2016 and had an unstable development of publication numbers since. Worldwide publication numbers have steadily risen.

Table 20 Overview of WOS publication data on the Netherlands and worldwide regarding keyword aquaponics

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Worldwide	4	2	3	5	4	6	12	27	43	58	59
Netherlands	0	0	0	0	0	0	0	0	5	2	8

The table below shows the number of publications on the three technologies, of which aquaculture continuously has the highest numbers within the timeframe chosen. However, it becomes apparent in the graph below that all three technologies are just one part of the agri-food context. The fields of agriculture, fisheries and plant science are concerned with multiple other topics.

Table 21 Overview of WOS publication data on keywords aquaponics, hydroponics, aquaculture and the agri-food context (agriculture, fisheries and plant science)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Aquaponics	0	0	0	0	0	0	0	0	5	2	8
Hydroponics	4	3	5	2	5	10	6	4	14	7	12
Aquaculture	20	17	31	41	38	44	53	49	71	42	70
Agri-Food Context	670	634	664	707	717	748	811	720	874	821	825

Table 22 Overview of WOS publication shares on keywords aquaponics, hydroponics, aquaculture and agri-food context (agriculture, fisheries and plant science)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Share of Aquaponics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.2%	1.0%
Share of Hydroponics	0.6%	0.5%	0.8%	0.3%	0.7%	1.3%	0.7%	0.6%	1.6%	0.9%	1.5%

Share of Aquaculture	3.0%	2.7%	4.7%	5.8%	5.3%	5.9%	6.5%	6.8%	8.1%	5.1%	8.5%

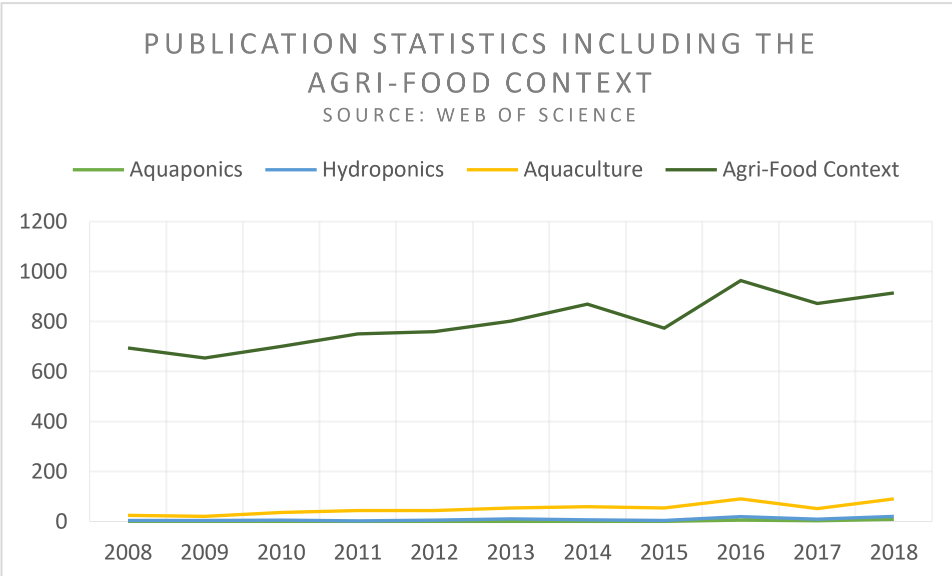

Figure 20 WOS data of keywords aquaponics, hydroponics, aquaculture and the agri-food context (agriculture, fisheries and plant science); source: Web of Science

Appendix 7 Statistical Data on Google Trends

Table 23 Overview of Google Trend data on YouTube terms aquaponics, hydroponics, aquaculture and the agri-food context (agriculture, fisheries and plant science)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	+/- (2008 to 2018)
Aquaponics	0	0	18	43	101	91	94	96	104	118	68	+67900%
Hydroponics	22	44	66	98	89	130	91	137	142	154	104	+373%
Aquaculture	0	0	0	9	5	16	0	24	12	17	10	+9900%
Agri-Food Context	455	328	300	313	342	426	469	541	375	318	154	

Table 24 Overview of Google Trend data on Google Search terms aquaponics, hydroponics, aquaculture and the agri-food context (agriculture, fisheries and plant science)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	+/- (2008 to 2018)
Aquaponics	1	0	2	7	14	20	25	21	24	32	20	+1900%
Hydroponics	42	33	36	34	45	40	41	56	50	60	55	+31%
Aquaculture	26	26	20	19	25	23	28	23	20	23	19	-27%
Agri-Food Context	1016	919	856	832	731	649	705	734	703	669	665	

Table 25 Overview of Google Trend data on Google Image terms aquaponics, hydroponics, aquaculture and the agri-food context (agriculture, fisheries and plant science)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	+/-

												(2008 to 2018)
Aquaponics	4	0	10	9	14	23	21	26	34	31	32	+700%
Hydroponics	35	41	28	18	26	37	36	43	42	60	58	+66%
Aquaculture	17	10	18	23	12	14	10	17	11	25	20	+18%
Agri-Food Context	826	786	692	623	609	504	501	528	544	522	569	

Appendix 8 Statistical Data on Patents

Table 26 Overview of WIPO patent data on aquaponics worldwide

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Grand Total
Australia		1	1	1		3	1			2	1	10
Canada			1			1	2	1		3		8
China		1	1				1	10	11	27	1	52
Denmark				1							1	2
EPO		1	1						1	3	2	8
India			2							1	2	5
Israel			1									1
Italy							1					1
Japan									1			1
Korea (South)							1	2	5	1	4	13
Malaysia										2	1	3
Mexico							1	1		1		3
Philippines											1	1
Portugal				1								1
Singapore											1	1
Tajikistan				1								1

United Kingdom										1		1
United States of America		1	1	2	2	6	7	11	7	13	5	55
WIPO	1		1				2	4	5	7	3	23
Grand Total	1	4	9	6	2	10	16	29	30	61	22	190

Table 27 Overview of WIPO patent data on hydroponics worldwide

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Grand Total
Australia	2	6	4	2	8	6	4	8	11	11	4	66
Brazil											1	1
Bulgaria				1						1		2
Canada	5	4	9	8	5	5	7	6	10	10	11	80
China	4	10	13	20	19	19	61	88	107	226	49	616
Denmark	1			1		1				1	5	9
Egypt				1								1
Estonia										1		1
Eurasian Patent Organization		1										1
EPO	1	8	7	8	10	3	5	9	13	17	15	96

France		2	1	2		1						6
Georgia				1	1							2
Germany		1		1								2
India		3	2		2	2	4	3	5	8	11	40
Indonesia									1	1	1	3
Israel		1	2	1				1	1	1		7
Italy							1					1
Japan	27	38	35	37	53	43	59	60	34			386
Korea (South)	9	12	13	27	43	53	35	37	51	38	37	355
Malaysia	1		1	1		1	1	1	2	1	1	10
Mexico	1			3	2	3	4	1	3	3	7	27
Philippines						1		1	1	3		6
Portugal	1					1	1					3
Romania							1		1			2
Russian Federation		1	2	2	5	6	3	7	3	8	6	43
Singapore					1		1	1	5	3	4	15
South Africa	1		1				1					3
Spain				1		1	1	1				4

Tajikistan				1								1
United Kingdom	1	1	1			3	2	1	1	4	10	24
United States of America	10	17	11	17	20	17	32	49	56	60	52	341
WIPO	9	14	19	16	19	10	17	34	36	42	48	264
Grand Total	73	119	121	151	188	176	240	308	341	439	262	2418

Table 28 Overview of WIPO patent data on aquaculture worldwide

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Grand Total
Australia	15	21	15	7	11	16	8	12	20	16	9	150
Brazil	1									2		3
Bulgaria		1	1									2
Canada	14	9	10	6	9	10	8	11	18	15	5	115
Chile			1		1							2
China	80	89	166	215	202	162	672	1118	1197	2515	467	6883
Denmark	3	2	3	4	1	3	1	2	1	1	2	23
Eurasian Patent Organization	1											1
EPO	7	6	16	11	10	11	10	14	19	18	19	141

France	4	2		2	2	2	3			1	4	20
Germany		1	1		2			1				5
India	3	2	8	3	5	9	3	11	14	22	11	91
Indonesia									1	5	3	9
Israel	1		1	3				1	4			10
Italy							1					1
Japan	8	5	6	4	7	3	6	13	10			62
Korea (South)	1	4	6	5	3	19	30	24	32	30	21	175
Malaysia	3	6	3	5	4	5	6	9	8	6	2	57
Mexico	5		4	13		1	4	4		10	2	43
Morocco				2								2
Philippines						1		1	1	7	1	11
Portugal		1		1	2				1			5
Romania					1	1	1	1			1	5
Russian Federation	1	3	3	3	2	2	1	2	2	1	10	30
Singapore		2			1	1	1	1	2	3	1	12
South Africa	1				2							3
Spain				1	2	3	3					9

Tajikistan				2			2	1				5
United Kingdom	5	1	1	1	4	3		1	1	5	1	23
United States of America	28	21	39	30	33	32	26	29	28	35	38	339
WIPO	25	20	31	28	31	24	37	47	56	43	44	386
Grand Total	206	196	315	346	335	308	823	1303	1415	2735	641	8623