DTU Library

The transition to aquaponics in support of a circular bioeconomy: policy recommendations to overcome geographical and scale barriers

Gregg, Jay Sterling; Jürgens, Jonas; Sandvold, Hilde Ness ; Sutherland Olsen, Dorothy

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

The transition to aquaponics in support of a circular bioeconomy: policy recommendations to overcome geographical and scale barriers

Jay Sterling Gregg, Jonas Jürgens, Hilde Ness Sandvold, Dorothy Sutherland Olsen

Technical University of Denmark, Department of Innovation (JSG, JJ)

University of Stavanger (HNS)

Nordic institute for studies in Innovation, Research and Education (DSO)

Keywords: Aquaponics, aquaculture, global value chain, scale, circular bioeconomy, sustainable food production

Abstract

We explore aquaponics in the Scandinavian countries (Norway, Sweden and Denmark) through policy analysis, a review of the historical context, and semi-structured case study interviews. The semi-structured case study interviews are conducted with relevant actors that have a stake in the future development of aquaponics. These actors include: (1) large scale commercial salmon producers, who are currently moving a larger proportion of the smolt production on land to counter problems with sea lice; (2) small-scale aquaculture farms; (3) small-scale hydroponic vegetable growers; (4) hobby-scale aquaponics enthusiasts, (5) demonstration-scale aquaponic producers; (6) aquaponics support organizations and (7) relevant policy makers. All of these actors have the potential to be key players in the transition to where aquaponics production systems contribute a substantial share of food to regional markets. We analyze the incentive structures and roles of the various actors and potentials for synergies. We also explore possible pathways for the expansion of aquaponics in the near future from a global value chain perspective (Gereffi, 2005).

We find that there remain geographic co-location barriers, as well as barriers related to an unequal production scale by the current regime actors. These issues, along with the dominant institutional legacies from fisheries and agriculture, result in a regulatory landscape in Scandinavian countries that hinder the development and transition to a more sustainably produced food source. We also find the regulatory landscape for aquaponics in respective countries has emerged in reaction to historical precedents in aquaculture and agriculture, and specific legislation on aquaponics has been slow to develop. Aquaponics operations typically must meet disparate sets of regulations. As such, it creates a complex barrier to commercial scaling up and the transition to a more sustainable circular economy. We conclude with specific policy suggestions for aquaponics, but also note larger lessons for the regulatory challenges that occur when the circular economy application attempt to bridge two or more different areas of policies.

Introduction

Circular Bioeconomy

Discussion of the circular bioeconomy has been growing as academics, policy makers and industry partners seek ways to transition to more sustainable production models (Bugge, et al., 2016). The circular economy focuses on cascading uses of materials and reducing material throughput in order to create both environmental and economic benefits to businesses. The circular bioeconomy brings together the circular economy, the green economy (which contains both biological and non-biological renewable resources (Lewandowski, et al., 2018), and the bioeconomy (D'Amato, et al., 2017). In so doing, the circular bioeconomy aligns the throughput of different bio-industrial production processes such that the material outputs of a production process serve as an input to other processes. This includes principles of sharing, reusing, remanufacturing, and recycling of material, cascading uses, utilization of organic residue streams, resource efficiency, and nutrient cycling (Carus and Dammer, 2018). In principle, the circular bioeconomy makes the greatest possible use of bio-resources, and therefore promotes greater economic and environmental efficiency. Moreover, as renewable resources by nature, biobased materials are necessary for a truly circular economy (Sheridan, 2016), and the circular bioeconomy can contribute to the United Nations Sustainable Development Goals (Lokesh, et al., 2018).

Aquaponics

Aquaponics approaches an ideal in food production from the standpoint of a circular bioeconomy (Carus and Damer, 2018). Within aquaponics systems, the only major biological input is fish feed, and the system produces both fish and vegetables, where fish produce nutrients for the vegetable production, and the hydroponic vegetables filter the water for the fish (Graber and Junge, 2009). In theory, production waste can be minimized in an aquaponics system (Graber and Junge, 2009). While the concept of modern aquaponics systems has been around for decades (Villarroel et al., 2016), it is only in recent years that the recirculating aquaculture system (RAS) technology has begun reaching a level of sophistication to potentially make the systems economically feasible (König et al., 2018; Love, et al. 2015). However, there has yet to be a commercial breakthrough in aquaponics, though it has potential be to an economically efficient and sustainable way to produce food (Blidariu and Grozea, 2011).

In a review of 100 papers on innovation in aquaculture, Joffre et al. (2017) concluded that the majority of current research has focused on the farm level and taken a technological approach. There was a lack of papers taking a systemic, interdisciplinary, multi-dimensional, and multi-level interplay perspective to developments in aquaculture (Joffre, et al. 2017). The latter was needed to understand better the complex interactions within aquaculture systems (Joffre, et al. 2017). While Joffre et al. (2017) did not address aquaponics specifically; the literature has similarly focused on the engineering and fish production aspects of aquaponics installations (e.g. aquaculture, hydroponics, water quality, engineering, microbiology) and less on the larger questions of integration (political, economic, etc.).

König, et al. (2018), use a Technological Innovation Systems (TIS) approach to analyze current developments of aquaponics. This is done in an interdisciplinary fashion, combining natural sciences, agronomy, governance, and technological and sectoral knowledge (König, et al., 2018). König, et al. (2018) adopt a multi-level approach to understand the integrated and complex nature of aquaponics, subdividing it into the following three system levels:

1) The system core- "hardware" - the engineering aspects, system hardware and technological processes;
2) System characteristics- "software" - factors that directly influence the processes and planning (actors, networks, knowledge base); and
3) Institutional system- where factors interact with institutional settings (legal frameworks, regulation, intellectual property, existent technological regimes).

In this study, we also take a multi-level, multi-dimensional perspective, focusing on the aquaponics as a system for food production that includes not only the technological aspects, but an associated philosophy and political entity. We explore the potential of aquaponics systems to form value chains to deliver goods to market, and the regulatory landscape in which they exist in Scandinavia.

Analytical framework

Joffre et al. (2017), note that value chain analysis is useful in understanding trade flows development of standards. Aquaponics is a technology that has had many small-scale proofs of concept (e.g., systems have been developed in the US since the 1980s (Villarroel et al., 2016)), but, in general, has not reached commercial success yet. Value chains for aquaponics products are different from those for aquaculture (which has captured open water fishery value chains to some extent) and different from those for agriculture.

We therefore employ a global value chain analysis (Gereffi, et al., 2005) to understand better the barriers to value chain formation for commercial scale production, and how these can potentially be overcome. Gereffi, et al., (2005) classified five different types of viable value chains, based on determinants of knowledge complexity, transfer efficiency, and supplier capabilities. From here, Gereffi, et al. (2005) describes five possible value chains:

1. Markets (low complexity, high efficiency, and high supplier capability) creates linkages with low cost for switching to new parties;
2. Modular (high complexity, high efficiency, and high supplier capability), where suppliers deliver products according to customer specifications, so called “turn-key” relationships;
3. Relational (high complexity, low efficiency, and high supplier capability), with complex interaction and mutual dependence between buyers and sellers, and therefore, cost of switching parties is high;
4. Captive (high complexity, high efficiency, and low supplier capability), with small suppliers that are dependent on large buyers; and
5. Hierarchical (high complexity, low efficiency, and low supplier capability), with a large degree of vertical integration and managerial control, typically where a lead firm will supply needs in-house.

We adapt this frame to aquaponics by viewing knowledge complexity as the technical complexity of various aquaponics systems, transfer efficiency as market dynamics for the products and by-products, and supplier capability as the in-house / within-firm abilities to manage an aquaponics system.

Method

A series of interviews were conducted with Danish and Norwegian fisheries, a Danish technology provider. For the large firms, the interviews were semi-structured and focused on the issue of organic waste in Atlantic Salmon smolt production (see Sandvold et al., 2019). The information revealed in these interviews warranted further investigation into aquaponics systems, and are thus included here and listed as scoping interviews. A further scoping interview was conducted with a pilot-scale Norwegian hydroponic vegetable grower. From here, we developed a new interview protocol focused on aquaponics, and conducted semi-structured interviews with hobbyists, consultants, large firms, supporting firms, NGOs, and government officials. The interviews are listed in Table 1. In addition, current policies relevant to aquaponics within the relevant ministries were consulted for Denmark, Norway, and Sweden.

Table 1. Interviewees, firm, scale (or production, market, influence, etc.), and type of interview conducted.

Affiliation and Location of Interviewee	Description of Affiliation	Relevant Scale of Affiliation	Interview Type and Date
Langsand Laks A/S Denmark	Land-based Atlantic Salmon production,	Demonstration	Scoping In Person, 30 minutes 26 February, 2016
Billund Aquaculture A/S Denmark	Technology supplier of RAS	Commercial	Scoping In Person, 90 minutes 26 February, 2016
Aquaponics AS Norway	Hydroponic cucumber and tomato production, defunct aquaponics system	Pilot	Scoping In Person, 180 minutes 6 May, 2016
Marine Harvest ASA Norway	Land- & sea-based Atlantic Salmon production	Commercial	Scoping Phone, 45 minutes 13 December 2016
Grieg Seafood ASA Norway	Land- & sea-based Atlantic Salmon production	Commercial	Scoping Phone, 25 minutes 14 December 2016
Alsaker Fjordbruk AS Norway	Land- & sea-based Atlantic Salmon production	Commercial	Scoping Phone, 30 minutes 27 January, 2017
Sævareid Fiskeanlegg AS Norway	Land- & sea-based Atlantic Salmon production	Commercial	Scoping Phone, 45 minutes 1 March, 2017
Bremnas Seashore AS Norway	Land- & sea-based Atlantic Salmon production	Commercial	Scoping Phone, 30 minutes 1 March, 2017
Refarm Linné, Sweden	NGO supporting aquaponics	National	Semi-Structured In Person, 45 minutes

			12 December, 2018
Institute of Global Food and Farming, Denmark	Private Aquaponics Applied Research Consultancy	International	Semi-Structured In Person, 70 minutes 14 February, 2019
Akvaponi, Denmark	Aquaponics	Hobbyist	Semi-Structured In Person, 70 minutes 21 February, 2019
Peckas Naturodlingar AB, Sweden	Tomato production with aquaponics	Commercial	Semi-Structured Web meeting, 45 minutes 19 March, 2019
Bioark AS, Denmark	Food-producing architecture; urban food production systems	Commercial	Semi-Structured Phone, 50 minutes 10 April, 2019
Ministry of Environment and Food, Denmark	Government	National	Semi-Structured In Person, 50 minutes 13 May, 2019

Policies

European Union

Aquaponics is viewed as a technology with high potential, both by the EU Parliament and by the EU Commission (Hoevenaars et al., 2018). Yet, it is still being debated whether a special set of policies are needed to address aquaponics at the European level, or if current policies for agriculture, fisheries, food safety, and environment are sufficient to regulate aquaponics operations (Hoevenaars et al., 2018). Currently, regulation of aquaponics falls under the Common Agricultural Policy (CAP), Common Fisheries Policy (CFP) (which has established the Aquaculture Advisory Council (AAC), EU Food Safety and nutrition policy and the EU Environmental policy. Within the European Commission, The Directorate General for the Maritime Affairs and Fisheries (DG MARE) has left regulation of aquaponics up to individual member states. The EU has supported aquaponics projects through innovation partnerships and research funding. For example, the Seventh Framework Programme funded some projects relevant to aquaponics, with the most relevant being INAPRO (Innovative model and demonstration based water management for resource efficiency in integrated multitrophic agriculture and aquaculture systems). Horizon 2020 has also funded aquaponic initiatives, such as EASY, CoolFarm and ECOFISH. These projects mostly technical in nature.

Norway

Aquaculture is Norway's second largest export, and Norway is the world leader in Atlantic Salmon production. Aquaculture policy in Norway is crafted with large-scale commercial production firms in mind. Aquaponics operations, particularly small scale, could in principle meet the regulations and be granted a permit.

Regulation of aquaponics would fall under Norway's *Lov om akvalultur* (aquaculture law), managed by the Ministry of Trade, Industry and Fisheries (Nærings- og fiskeridepartementet), which covers all aquatic organisms (both plants and fish) and is applicable both to land-based and sea-based aquaculture. This ministry is also responsible for granting permits, which are required to be allowed to do any form of aquaculture. The permit gives the producer right to produce certain species in a certain location. Applications for a permit must demonstrate that a proposed project:

a) is environmentally defensible;

b) does not conflict with existing zoning regulation, biodiversity regulations or cultural heritage regulations (unless special exemptions are given);

c) in accordance with the applicants' need for land, any alternative uses of the land other than aquaculture, other land use in the area, and any other special protection measures not included in b);

d) has relevant permits on food production and food safety, pollution prevention and waste management, harbors and waters, and waterways and groundwater.

Further regulations apply for salmon and trout production. The ministry can also require the producer to perform an environmental assessment at the proposed location prior to receiving a permit, and may require the production to establish and complete systematic controls. The ministry is in charge of deciding on the controlling authority. Permits can be revoked if:

a) necessary because of environmental concerns;
b) major conditions for granting the permit have changed;
c) the producer significantly or repeatedly breaks relevant laws;
d) the permit is not used, or is only in limited use;
e) other of the required permits have been revoked.

Denmark

Aquaculture regulation began in 1989 when the government introduced regulation to reduce nutrient-rich effluent flows into waterways, which lead to a 50% reduction in effluent flows. In 2002, a modernization scheme "*modeldambrugsbekendtgørelsen*" made it possible to convert traditional "*dambrug*" to modern facilities, which generally have lower effluent emissions. In 2012, it became possible to change to emission control instead of feed control, meaning producers were no longer regulated on the amount of feed input, but only on effluent output.

Aquaculture is also a focus area for the Ministry's export strategy as production in Denmark and the EU has stagnated in the last 25 years. Farmed fish production in Denmark is currently 40,000 tonnes per year. The industry sees a potential to increase this to 100,000 tonnes per year by 2020. A further goal is to increase the development of aquaculture technology such as RAS, also with export in mind.

Aquaculture is regulated under the Ministry for Environment and Food. Additionally, the Environment Protection Agency, has specific legislation for land-based aquaculture. There are currently around 175 fresh water fish farms in Denmark, only 35 of which are modern facilities. They primarily produce rainbow trout, and to a lesser extent, eel and shellfish. By law, environmental approval for a facility is given by the local municipality, which is also responsible for annual inspections. Approval is based on environmental impact, including parameters of water usage and measurements of nutrients in the effluent discharge. Light, transportation, sound are also factors in the environmental approval. The permits are reviewed every 10 years, allowing for the advancement of knowledge. Water use is also regulated by the Water Supply Act. For operations under 100 tonnes fish production per year, a calculated impact based on fish food inputs is sufficient.

For systems that use RAS, and have fully recirculating systems (more than 98% recirculated), then there is no regulation in terms of water usage. For any operation that sells fish, feed sourcing is regulated by the energy demand and requires government veterinary approval. There are also food safety and traceability regulations.

Sweden

The number of fish farms in Sweden peaked in the late 1980s, but problems of environmental degradation and eutrophication, led to a negative public view of the industry and stricter environmental regulations. Eventually, most of the farms went bankrupt, even though total output of farmed fish has increased since then.

The Swedish aquaculture office, under the Ministry of Agriculture provides and over and vision for the expansion of sustainable and environmentally friendly aquaculture (Jordbruksverket, 2012). The impetus for this is regional development and employment (Jordbruksverket, 2012).

There are no policies specifically for aquaponics, though there are five areas of policy relevant policy for aquaculture: fisheries, environment, infectious disease, animal welfare, food legisilation.

All producers must have a license before they can begin production, provided by the region ("länsstyrelsen"). Additionally, a license is needed to release fish to a water area, and to move them from one water area to another, for disease control. The Agency for Marine and Water management has the overall responsibility for this area.

Facilities that use greater than 40 tonnes of feed every year must be approved by the region. The municipality must approve facilities that use between 1.5 and 40 tonnes of feed every year. Facilities that use less than 1.5 tonnes of feed every year do not need a license. When applying for a license, the applicant needs to provide an environmental impact assessment – this is also sometimes needed when applying to the municipality. Usually no license or permit is needed to use water from a lake, river or groundwater.

Even though diseases that spread from livestock to humans (zoonoses) are very rare in aquaculture, relevant legislation still applies. Essentially aquaculture facilities have an obligation to report suspicions of disease to a veterinarian. If diseases are found, they must be reported to Jordbruksverket. All licensed producers are controlled by Jordbruksverket or outsourced to an approved organization or veterinarian, according to a risk assessment. The frequency and number of tests is dependent on how high risk the facility is. Jordbruksverket is also responsible for legislation on how to handle the by-products of slaughter. The region is responsible for control of animal diseases on aquaculture facilities.

All producers of fish and shellfish must be registered as primary producers at the National Food Agency (*Livsmedelsverket*). Slaugtherhouses and processing facilities are regulated by environmental legislation. The National Food Agency is responsible for the central oversight, legislation on the food area, and control of mussel water (in facilities that produce this, since you can test the water for harmful algae, bacteria, and viruses). The Environment and Health Board in the municipality is responsible for performing the control.

Results and Discussion

Potential Value Chains for Aquaponics

Aquaponics systems are complex, and produce fish and vegetable that compete with analogous, conventional products within well-developed, efficient distribution networks. From the point of view of a firm or individual using an aquaponics system to produce food, these determinants are rather inherent, and thus are essentially exogenous factors. Therefore, according GVC theory (Gereffi, et al., 2005) the possible value chains, depending on the supplier's capabilities, are modular (where suppliers have a high degree of capability and are able to deliver according to customer specifications) or captive (where suppliers have lower capabilities and are dependent on large buyers, particularly when it comes to processing fish). Captive value chains, in contrast to modular value chains, have greater power asymmetries and require higher levels of coordination.

From the point of view of technology provider, the market is much less efficient, thus the value chain is characterized by relational or hierarchical, according to GVC (Gereffi, et al., 2005), based on the level of capabilities of the tech producing firm (e.g. to provide continued technical support to aquaponics firms).

Hobby farmers have lower capabilities than large firms do, thus they would hypothetically form captive value chains with a distributor, and relational value chains with a tech supplier that could provide support (and where the cost of switching tech suppliers is high). While hobbyists can be more flexible and work at a smaller scale, the high investment costs and complex relationship needed with a tech supplier would act as a barrier to expansion. The other barrier is the demands of the distributors (in the form of production quotas) required to access the market.

Large food producing firms, on the other hand, would tend to form modular value chains with the market, aiming to create niche markets (e.g., high-end restaurants; local, organic, conscientious consumers), and hierarchical value chains with tech suppliers (requiring in-house expertise in operating and maintaining the complex aquaponics system). Among large producing firms, aquaponics could be approached aquaculture firms, which have incentives for waste valorization from RAS (Sandoval, et al., 2019) and meeting regulations for effluent discharge. Large-scale vegetable producing firms have incentives to reduce inputs (e.g. soil, fertilizer, water) and to grow produce with an ecological source of nitrogen. Nevertheless, aside from a few standout firms, value chains have not yet developed to incorporate aquaponics systems, and this has not yet emerged as an economically viable means for producing food.

Perception of Aquaponics

König, et al., (2018) note also the need for legitimizing aquaponics products. Indeed, many of the interviewees expressed the importance of "the story" of aquaponics. From the interviews, the story included a mishmash of concepts: aspects of a circular bioeconomy, the future, clever way to produce food, a sustainable healthy, local alternative to conventional agriculture and aquaculture, etc. The story also creates links to cultural identity and traditional diets. For example, according to interviewees in Sweden, fish has a traditionally been a large part of the historic diet, and now the majority of what is consumed it is frozen and imported. Climate impacts were also mentioned (e.g., the vegetable grower uses the claims of lower water and fertilizer consumption, creating more climate friendly and non-toxic products).

The story is important in three ways. First, it is important for driving consumer demand, and even acceptance of exotic fish species. In order to create a price premium for the product (e.g. in high end restaurants), the story is important to create market differentiation for the product. Second, the story is important for hobbyists who see aquaponics as a sustainable and innovative alternative to conventional food production. Interviewees were attracted to the idea for a chance to do something, however small, to be part of what they believe to be an emerging sustainable food revolution. Third, the story is important for NGOs to educate not only the population to change the image of aquaponics as a contrast to conventional aquaculture (which has garnered environmental concerns in the press (Olsen and Osmundsen, 2017), but to lobby government agencies to reduce regulations and promote aquaculture as a sustainable food production system. Interviewees mentioned a knowledge gap among policy makers regarding aquaponics.

How true the story is not as important to how it is perceived. Nevertheless, a certification scheme specific for aquaponics would be beneficial to establishing the story. Currently, there is the Marine Stewardship Council (MSC) for wild caught fish and the Aquaculture Stewardship Council (ASC) for aquaculture, but no similar council for aquaponics.

Regulatory landscapes

Given this situation, the regulatory landscape becomes a critical component. Favorable policies are necessary to nurture the development of aquaponics as a viable production system. Likewise, complicated or conflicting regulatory landscapes represent nearly insurmountable barriers for aquaponics.

As there is no overarching EU policy for aquaponics, there is a patchwork of regulations across EU member states, even when Scandinavia. This is further complicated by aquaculture being between two sectors in terms of regulation. This adds difficulty in setting up multi-state a commercial aquaponics firm. At smaller scales, there are no direct policies at the EU level to incentivize, promote, or otherwise support urban agriculture, thus aquaponics is not supported in this specific capacity. Nevertheless, The CAP is currently being reformed with one focus being higher resource efficiency. To achieve this, the budget for agricultural research is being doubled, which could be beneficial for aquaponics. The EU Commission has a history of funding innovation and research projects in aquaponics. A major hurdle for aquaponics is that it falls between two chairs - aquaculture and hydroponics – meaning that it can be difficult to secure research funding for study ways to optimize and entire aquaponics system.

At the national scale in Scandinavian countries, none of the national governments have specific policies governing aquaponics. Some of this is due to a lack of definition on which systems constitute aquaponics (e.g., a system that recirculates only a fraction of the water). Another reason is that there has not yet been a need to introduce specific policies for something that does not yet have much of a role yet- the current aquaculture policies regarding environmental impact, water usage and effluent discharge, food safety, and animal welfare are broad enough to cover aquaponics. Nevertheless, this could result in a chicken-egg problem, that the aquaculture policies are too cumbersome and partially not applicable, the permitting slow (up to 2 years for larger scale operations in Denmark, and up to 6 years in Sweden), thus stifling innovation in this direction. The multitude of regulations can also be a barrier for small-scale producers as well. For example, the limitations on imported fish species, along with the food safety regulations proved significant barriers to one interviewee in our study, who ultimately decide to remove the fish and convert the aquaponics system back into a hydroponics vegetable system.

Among the countries, all are interested in developing aquaculture, both for domestic consumption and rural development (particularly in Sweden) and for fish and technology exports (particularly in Denmark). Sweden's aquaculture policies stem from a time with there was great public concern about the environmental impact to fresh water systems. Denmark's policies are broad to cover many different types of aquaculture production, and more discretion is given to the municipalities in assessing the environmental impact. Denmark has a history of driving innovation in aquaculture technology development.

Norway already has a substantial aquaculture industry and thus the government has an interest in protecting fish exports. Interviewees from the large Norwegian firms had either never heard of aquaponics, and the one who had did not see it as an interesting area for development. Large firms in Norway expressed a desire for more basic national regulations for handling of organic waste from the raising of smolt salmon. As it is, regulations of waste are largely left to the counties and they have different guidelines for processing waste and requirements for permitting.

Challenges facing Aquaponics

The main challenges facing aquaponics are not technical. Diffusion of aquaponics suffers from a problem of scale and economics. Aquaponics systems, with RAS in particular, is capital intensive (Dalsgaard et al., 2013). This leaves it out of range for most hobbyists without support from funders such as research institutions, such as the pilot scale firm in our current study. Research funding in this situation was temporary, and after the proof of concept was established, funding for the operation ceased along with the fish production. Therefore, continued support would be needed at the hobbyist and pilot scale.

At larger production scales, aquaponics is deemed too economically risky. Because it is an integrated dependent system, any problems will cascade, e.g., a failure with the fish will cause a failure in the vegetables. Moreover, it is knowledge intensive- operators must understand both vegetable production and fish production. Still more, they then need to be integrated into two different value chains and markets, with a rather rigid production ratio of 6:1 vegetables to fish. This means they could not simultaneously adjust the production to fit two different market demands, thus it becomes and optimization problem. Finally, firms would need to satisfy the regulations of multiple different agencies. For the expansion of aquaculture to this scale, firms would need to be incentivized by insurance programs and a streamlined, aquaculture-specific regulatory landscape.

Aquaponics is currently only economically feasible if there is market differentiation from conventionally produced food products, which can be produced much cheaper and more reliably. This has largely been accomplished by the organic food market, and while organic products are more expensive than conventional products, they are still cheaper to produce than products produced from aquaponics systems. Due to the ratio of about 6:1 vegetable mass to fish mass output, aquaponics should perhaps be viewed more as a greenhouse vegetable production system that includes fish, rather than a fish production system that can also produce vegetables. In this respect, it is unclear how much consumer preference and willingness to pay there is for hydroponic vegetables fertilized by live fish waste. According to our interviewees, the production cost is too prohibitive and current and past aquaponics projects in the EU only exist with external financial support. Perhaps marketing could emphasize hyper-local produce (e.g. systems located within a restaurant, urban food production, or rural communities).

One way forward, particularly in Scandinavia, would be quasi-aquaponics solutions, where the waste from the fish production is then used as a soil conditioner by different actors. These value chains, linking actors in fish production firms and vegetable farmers, are already forming to meet environmental regulations for effluent and to valorize an increasing resource of nutrient rich fish sludge. This development also allows these actors to maintain a greater degree of specialization; these actors have difficulty merging into a joint production ventures due to co-location issues and institutional legacies (Sandvold, et al. 2019).

Conclusions

There are substantial challenges in creating viable business models in the circular economy, largely because of the need to create new and reorient existing value chains for the products. Aquaponics is case example. In general, large incumbents control the value chains, and have a left a legacy of environmental impacts that have resulted in strict environmental policies and problems with public perception. Moreover, the integrated circular aspect of aquaponics makes it more difficult to regulate. The regulations and permitting process are barriers to entry for smaller firms and hobbyists. The policy landscape therefore benefits large incumbents who are driven only to meet the regulations, but are uninterested in innovating circular production systems.

Establishment of an Aquaponics Stewardship Council, or something equivalent would help legitimize and better define what an aquaponics system is and how it is different from a conventional fish farm. Lowering the barrier for entry level and pilot scale firms, and providing research and financial support would help in creating innovative new ways to produce food sustainably. Governing bodies should also be directed to developing the captive value chains for small producers to modular value chains. This could be done by offering extension and expertise to small scale producers and incentivizing more innovation food distributors for processing and marketing from a host of smaller producers, and allowing more flexibility by law. This could be a potential for smart digital solutions in food distribution networks. Moreover, educating consumers would help create a market for locally produced food and promote more economic development in rural areas as well as urban food production.

Aquaponics could be a case example in how national governments can sort out and streamline larger issues of fragmented policy when it comes to integrated systems. It may be the aquaponics proves not to be economically feasible, but policy could nevertheless be redirected to create more opportunities to explore the possibilities.

References

Blidariu, F., & Grozea, A. (2011). Increasing the economical efficiency and sustainability of indoor fish farming by means of aquaponics-review. Scientific Papers Animal Science and Biotechnologies, 44(2), 1-8.

Bugge, M., Hansen, T. and Klitkou, A. (2016). "What Is the Bioeconomy? A Review of the Literature." *Sustainability* 8(7): 691.

Carus, M., & Dammer, L. (2018). The Circular Bioeconomy—Concepts, Opportunities, and Limitations. *Industrial Biotechnology*, 14(2), 83-91.

Dalsgaard, J., Lund, I., Thorarinsdottir, R., Drengstig, A., Arvonen, K., & Pedersen, P. B. (2013). Farming different species in RAS in Nordic countries: Current status and future perspectives. *Aquacultural engineering*, *53*, 2-13.

D'Amato, D., Droste, N., Allen, B., Kettunen, M., Lähtinen, K., Korhonen, J., … Toppinen, A. (2017). Green, circular, bio economy: A comparative analysis of sustainability avenues. *Journal of Cleaner Production*, 168, 716–734.

Gereffi, G., Humphrey, J., & Sturgeon, T. (2005). The governance of global value chains. *Review of international political economy*, *12*(1), 78-104.

Graber, A., & Junge, R. (2009). Aquaponic Systems: Nutrient recycling from fish wastewater by vegetable production. Desalination, 246(1-3), 147-156.

Hoevenaars, K., Junge, R., Bardocz, T., & Leskovec, M. (2018). EU policies: New opportunities for aquaponics. *Ecocycles*, *4*(1), 10-15.

Joffre, O. M., Klerkx, L., Dickson, M., & Verdegem, M. (2017). How is innovation in aquaculture conceptualized and managed? A systematic literature review and reflection framework to inform analysis and action. Aquaculture, 470, 129-148.

Jordbrugsverket (2012) Swedish aquaculture – a green industry in blue fields Strategy 2012–2020. http://www.svensktvattenbruk.se/download/18.65ea4bd915019557221948d4/1443605006808/Swedishaquacultureagreenindustry_w.pdf

König, B., Janker, J., Reinhardt, T., Villarroel, M., & Junge, R. (2018). Analysis of aquaponics as an emerging technological innovation system. Journal of Cleaner Production, 180, 232-243.

Lewandowski, I. (2018). Bioeconomy: Shaping the Transition to a Sustainable, Biobased Economy. Springer.

Lokesh, K., Ladu, L., and Summerton, L. (2018). Bridging the gaps for a 'circular' bioeconomy: Selection criteria, bio-based value chain and stakeholder mapping. *Sustainability*, 10(6), 1695.

Love, D. C., Fry, J. P., Li, X., Hill, E. S., Genello, L., Semmens, K., & Thompson, R. E. (2015). Commercial aquaponics production and profitability: Findings from an international survey. Aquaculture, 435, 67-74.

Olsen, M. S., & Osmundsen, T. C. (2017). Media framing of aquaculture. *Marine Policy*, 76, 19-27.

Sandvold, H. N., Gregg, J. S., & Sutherland, D. (2019). Chapter 8: New pathways for organic waste in land-based farming of salmon- the case of Norway and Denmark. *From Waste to Value: Valorisation Pathways for Organic Waste Streams in Circular Bioeconomies* pp 145-161.

Sheridan, K. (2016). Making the Bioeconomy Circular: The Biobased Industries' Next Goal? *Industrial Biotechnology*, 12(6), 339–340.

Villarroel, M., Junge, R., Komives, T., König, B., Plaza, I., Bittsánszky, A., & Joly, A. (2016). Survey of aquaponics in Europe. Water, 8(10), 468.