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Published in:
From Waste to Value: Valorisation Pathways for Organic Waste Streams in Circular Bioeconomies

Link to article, DOI:
10.4324/9780429460289

Publication date:
2019

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

Citation (APA):
Sandvold, H., Gregg, J. S., & Sutherland Olsen, D. (2019). New pathways for organic waste in land-based farming of salmon: The case of Norway and Denmark. In *From Waste to Value: Valorisation Pathways for Organic Waste Streams in Circular Bioeconomies* Taylor & Francis. https://doi.org/10.4324/9780429460289

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8 New pathways for organic waste in land-based farming of salmon

The case of Norway and Denmark

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8.1 Introduction

In this chapter, we explore the possibilities for sustainable pathways for the increased valorisation of organic waste from the aquaculture salmon industry. The chapter has a special focus on valorisation of sludge of the land-based stage of salmon production, and is based on interviews with fish producers and technology providers in Norway and Denmark.

The chapter is organised as follows: after the Introduction follows a section on the background of aquaculture, summarising important trends in general for aquaculture and explaining the developments of salmon production, including waste streams and environmental regulations. In the Findings section we explain the current utilisation of the sludge and describe challenges in the current system. The analytical section addresses the main barriers for new path development, and describes the structural elements of a development of sustainable aquaculture from the perspective of the recent literature on socio-technical transitions.

8.2 Background

8.2.1 Aquaculture trends

Global demand for animal-based food products, particularly fish, is increasing: the production of seafood from aquaculture has grown 15-fold since 1980 and has doubled since 2000 (FAO, 2016). Aquaculture now produces over half of all fish for human consumption in the world and is the world's fastest-growing food production sector (FAO, 2016). The growth in demand for seafood is largely driven by increasing wealth and urbanisation in developing regions of the world (FAO, 2016). In the developed world, concerns over sustainability issues, animal welfare, food safety and health are increasingly driving consumer behaviour with respect to seafood consumption (FAO, 2016). Nevertheless, demand is expected to increase in all areas of the world over the next decade (FAO, 2016).

Economically, salmonids are the most important fish family, comprising nearly 17% of the global seafood market, and have the largest commodity value of any group of fish, with demand steadily growing (FAO, 2016). After years of overfishing Atlantic salmon (*Salmo salar*), and habitat damage from river damming and intensive aquaculture, capture fisheries are no longer commercially viable (Parrish, Behnke, Gephard, McCormick & Reeves, 1998). Today, nearly all the world's supply of Atlantic salmon is farmed, producing 1.5–2% of the global aquaculture industry (Ernst & Young, 2018; FAO, 2016), and is the most economically important farmed salmonid (Asche, 2008; Ernst & Young, 2018). Trends and forecasts predict a large potential for growth (5% compound annual growth rate) in the Atlantic salmon industry (Ernst & Young, 2018).

Scandinavia, Norway and Denmark in particular, has pioneered innovation and technological progress in the Atlantic salmon industry, resulting in increased productivity and reduced costs (Asche, 2008; Asche & Bjørndal, 2011; Asche, Guttormsen & Nielsen, 2013; Asche, Guttormsen & Tveterås, 1999; Asche, Roll, Sandvold, Sørvig & Zhang, 2013; Kumbhakar & Tveterås, 2003; Roll, 2013; Sandvold, 2016; Tveterås, 1999; Tveterås & Battese, 2006). This innovation and expertise is also seen as a valuable commodity that can be exported and developed for other regions and fish species (Ernst & Young, 2018; Paisley et al., 2010). Atlantic salmon production in Norway grew by a factor of 10 between 1990 and 2013 (FAO, 2016) and Norway currently produces over half of the world's Atlantic salmon: 1.3 million tons of farmed salmon annually. Of this, 95% is exported, with a value of 61.5 billion NOK (6.5 billion €) in 2016 (Ernst & Young, 2018). That year, the Norwegian industry itself (which also has holdings outside of Norway) reported record revenues of 212.7 billion NOK (22 billion €), a 300% increase compared to a decade earlier (Ernst & Young, 2018). In 2017, a total of 195 licences for juvenile production and 1,015 for grow-out farming were given in Norway. Elsewhere, Denmark has a long tradition of aquaculture and is now at the forefront of land-based technological solutions, especially in the development of Recirculating Aquaculture Systems (RAS) (Nielsen, 2011, 2012). RAS has proven successful with eel and trout, and has recently been developed to produce Atlantic salmon completely on land at demonstration-scale facilities (Badiola, Mendiola & Bostock, 2012; Bergheim, Drengstig, Ulgenes & Fivelstad, 2009; Del Campo, Ibarra, Gutièrrez & Takle, 2010; Kristensen, Åtland, Rosten, Urke & Rosseland, 2009).

8.2.2 Salmon production

Currently, in production-scale firms, farmed Atlantic salmon are raised in land-based freshwater farms as smolt then transferred to sea-based cages where they stay until they are ready to be slaughtered (Asche & Bjørndal, 2011; Sandvold & Tveterås, 2014). Figure 8.1 illustrates the production process for salmon, which is divided into three main steps: the freshwater phase in hatcheries, the grow-out phase in salt water and the final processing at slaughterhouses. The hatcheries acquire fertilised eggs, which are hatched after a period in tempered freshwater. The fingerlings are kept in closed tanks until they smoltify and are ready for further growth in saltwater.[1] This usually takes place when the fish (named smolt) are 80–100 g. After vaccination, well-boats transfer the smolt to grow-out farms – floating cages at sea – and the salmon remain there until they reach a weight of 4–5 kg. Thereafter, the mature salmon are transferred to processing facilities where they are slaughtered. The whole production cycle takes three to four years.

The environmental impact of this type of production is threefold. First, organic waste can have a negative impact on the environment. While the severity of impact on the eco-system will depend on the specific local conditions of the farm, the nitrogen and the phosphorus in the waste create algae blooms and anoxic conditions in the coastal water, which can kill other aquatic life (Wu, 1995). Second, the crowded nets attract sea lice, a parasite that costs the industry up to 1.5 billion € per year (Costello, 2009). The Norwegian industry suffered a 5% loss in harvest quality (versus 2015) and a mortality rate of 19%, up from 16% in 2015, corresponding to 53 million individual fish (Ernst & Young, 2018). This has resulted in higher operational expenses in the industry and the introduction of new regulations by the Norwegian government (Ernst & Young, 2018). Chemical mitigation of sea lice is expensive and inefficient, causing additional adverse environmental impacts to coastal zones and becoming ineffectual with overuse (Burridge, Weis, Cabello, Pizarro & Bostick, 2010; Grant, 2002). Third, escaped fish can have large ecological impacts. Inter-breeding between wild and more genetically homogenous farmed salmon has been shown to reduce the life and fitness of indigenous fish populations over two generations (Thorstad et al., 2008).

Therefore, several alternatives to the traditional schedule (one year in land-based freshwater hatcheries; two years in sea-based cages in saltwater) are being considered, with the aim of shortening the period in the sea. One alternative is fully land-based production; another is moving the farm to offshore locations. These two options represent large operational, biological and technological changes, and substantial investments, with high risk. Other alternatives the industry is considering are closed underwater tanks, or floating basins in the grow-out phase. Currently, the majority of the salmon producers in Norway are using a production line with an extended land phase. This means that the smolts are not released to the sea at the standard size at 80–100 g, but rather held in the closed surroundings in the hatcheries until they reach a weight of more than 250 g.[2] In the short term, an extended land-based phase is the most realistic alternative to the traditional production schedule. Innovations and technological improvements for this alternative have become prevalent in recent years. For example, the two Danish firms are completely land-based, and Denmark is leading the innovation in this area.

This reorganisation of the production strategy and connected operational activities will lead to two major changes. First, it will require large investments for the industry in new hatcheries. These new hatcheries will all be using new water treatment technologies (RAS) (Badiola et al., 2012; Bergheim et al., 2009). Second, it means the volume of collected organic waste will increase substantially (Del Campo et al., 2010). In 2017, 330 million smolts with an average weight of 150 g were produced in Norway, generating 85,000 tons of sludge. These calculations assume a waste factor of 1.5 for the sludge (Del Campo et al., 2010). Increasing the smolt weight to 1 kg, which is now permitted, will increase the volume of stored sludge to 570,000 tons. Denmark's capacity for waste generation is much smaller, at an estimated 150 tons, but, as the innovation leader, this represents a scale where new technologies for waste handling can be developed. Farmed salmon production capacity in Denmark is currently 3,000 tons per annum. This calculation assumes 4.5 kg per finished fish.

8.2.3 Organic waste in salmon production

The waste streams from salmon production will differ in shape and volume in relation to the different phases in the production process. In Figure 8.1, the different waste streams coming from the three different phases of salmon farming are illustrated.

By-products from land-based hatcheries (first phase in Figure 8.1) consist of feed residues and fish faeces. The sludge is over 97% water but it is generally free of salt in juvenile smolt production (Badiola et al., 2012; Bergheim et al., 2009; Del Campo et al., 2010; Fivelstad, Bergheim, Hølland & Fjermedal, 2004). In contrast, waste from adult salmon in grow-out farms (second phase in Figure 8.1) will have salt content. The sludge is concentrated with a polymer and dewatered on a belt filter, which reduces the water content to roughly 80% feed (Badiola et al., 2012). Centrifuge technology can reduce the water concentration to under 70% feed (Kristensen et al.,

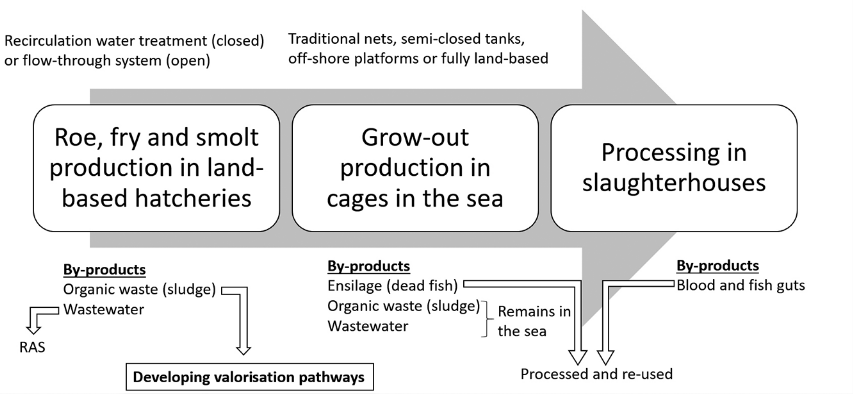

Figure 8.1 The organic waste streams along the production chain for salmon farming (by-products).

2009). Systems for drying sludge are theoretically able to reduce the water content to 20%. The sludge is rich in nitrogen, phosphorus and minerals (Del Campo et al., 2010). Because of this, there is interest in finding pathways to valorise it for re-use.

By-products from traditional grow-out farming remain in the sea (Figure 8.1). Aside from ensilage (dead fish), nothing is collected, and, with the salmon living in open nets, the organic waste is released into the local coastal ecosystem. We do not consider processing waste from the grow-out phase, because it is not collected in traditional cage systems. By-products from processing plants (blood, innards, heads, etc.) differ considerably from the waste streams from salmon production (Figure 8.1). We also do not consider waste from the slaughter of the fish because this has similar valorisation pathways to slaughterhouse waste, discussed in Chapter 7.

However, the literature on salmon production has thus far predominately focused on the grow-out phase (Asche, Guttormsen et al., 2013; Asche et al., 1999; Asche & Roll, 2013). Except for Sandvold and Tveterås (2014) and Sandvold (2016), little research has been conducted in relation to the juvenile phase. Even less attention has been given to new and sustainable applications for the increased volumes of collected organic waste in this industry. Therefore, this chapter analyses current valorisation pathways for the sludge from land-based production of juvenile salmonids. As the industry reorganises their production process in a more sustainable direction, some new challenges and opportunities appear concerning the handling of organic waste from land-based systems.

8.2.4 Environmental regulation and historical innovation in salmon production

Norwegian legislation and regulations for freshwater fish production have changed since the late 1970s, but not dramatically. As with the grow-out farms, the production of juveniles is highly regulated, and one needs a licence to legally operate in this sector. A number of requirements must be satisfied to obtain a juvenile licence, including access to a sufficient supply of fresh water, prevention of escapees, safe discharge of wastewater, as well as health, environment and safety requirements for the employees. Juvenile production has traditionally been restricted by the maximum number of units that can be produced each year, and maximum production varies by farm depending on different environmental concerns. Currently, given licences place no restriction on the number of units produced, but do place a maximum on the withdrawal of freshwater as well as a maximum on the discharge of wastewater.

Beginning in 2017, however, the Norwegian Ministry of Trade, Industry and Fisheries instituted a "traffic light" system that gives a green, yellow or red assessment to geographical areas based on losses caused by sea lice. Only in green areas may firms increase production at sea; in yellow areas, production increases are prohibited and, in red areas, firms must decrease production at sea (Ernst & Young, 2018). As such, the political landscape is evolving to address environmental concerns.

The Danish Environmental Protection Act regulates freshwater fish farms in Denmark. Regulations were introduced in 1987, and included water use and discharge, as well as waste handling. Theoretically, the regulations focused on nitrogen, phosphorus and organic matter in the effluent, although these proved problematic to reliably measure. The regulations instead focused on feed ratios, which were strict and curtailed aquaculture development, except for fisheries using new water technology, which have dramatically improved the feed ratios (Paisley et al., 2010). The 2004 Fisheries Act gives the Ministry of Food, Agriculture and Fisheries authority to regulate fisheries. The Ministry also has a goal of expanding production, but as most suitable freshwater locations have already been used, it means that RAS will be an increasingly important technology in Denmark (Paisley et al., 2010).

The increase in production volume in salmon farming in recent years has exacerbated the environmental challenges. As a response to these issues, the industry is now considering and testing different strategies for changing the production, waste handling and related technologies. RAS technology is increasingly replacing the traditional flow-through systems in juvenile production of salmon (Badiola et al., 2012; Bergheim et al., 2009). The system was developed in the 1970s in Denmark, out of small-scale laboratory equipment used to study living fish. The system was first applied to salmon smolt production as a lower-cost alternative to flow-through systems, which required more energy to heat the water. Additionally, RAS was seen as an attractive alternative to circumvent siting and regulation barriers on flow-through systems, because environmental risk factors such as escapees and polluted water spills are minimised using this technology. RAS uses 90–99% less water than flow-through systems, which also reduces energy consumption for heat. In order to recycle the water, solid waste (principally fish faeces and some feed residues) must be mechanically removed as soon as possible in order to prevent the build-up of bacteria that cause anoxic conditions. A biological filter is also used to clean the water for re-use.

Related to the organic waste, the individual Norwegian hatcheries have different restrictions in relation to their effluent. The fish farms are responsible for treating their waste in a responsible manner, yet there is no nationally required practice regarding the treatment of the outlet water. The differences in the disposal of sludge are primarily related to three different factors: (1) where they are located (north or south), (2) their age (when the hatcheries had their licences granted and (3) which technology they use; flow-through system or RAS. Restrictions tend to be lower in the northern regions of Norway than in the southern because the concentration of the farms is lower in the North and the following environmental impact will be lower. The older farms (from the 1980s) have fewer restrictions placed on the effluent, and very often still use a flow-through system. However, many of these are now closing down or being upgraded. All new farms have strict restrictions requiring waste management and emissions, and they use the RAS.

8.3 Methodology

To understand the valorisation of waste and to analyse possibilities for new and sustainable pathways for organic waste from juvenile salmon production, we have used two different sources of data. This analysis consists of both secondary and primary data.

We used secondary data in the initial phases of the study: industrial reports, government documents and the academic literature. This shaped the seven semi-structured interviews (primary data) with different fish producers and technology providers. The purpose of the interviews was to investigate waste streams in land-based farming, in order to understand the potential challenges connected to the current system from the perspective of the salmon producers. The interviews included questions about:

- How the organic waste is currently managed: processes, policy and potential challenges;
- Current and potential new value chains for organic waste: innovation, competition and barriers;
- Options for upgrading the firm, as well as incentives, trade-offs and demand factors;
- Social, economic and environmental sustainability factors that influence waste handling.

We interviewed six salmon production companies: five in Norway and one in Denmark. These firms represent the majority of the Norwegian and Danish production of smolt. Geographically, the firms are located across the whole coastline in Norway, and on the west coast of Denmark. Each of the interviewed fish production firms produce salmon all the way from hatchery to slaughter-ready fish, although our interviews focused on their land-based smolt production operations. We also interviewed a technology supplier in Denmark to understand the future trends and market outlook for this industry.

8.4 Findings

8.4.1 Current utilisation

From the data collection, we find that the sludge from land-based salmon production primarily has three different areas for use; as soil improvement and fertiliser in agricultural farming, as combustible material for heating in processing of new industrial products or as a replacement of fossil fuel after recycling, for example in transportation.

Soil improvement

Currently, the main utilisation of organic waste from land-based salmon production is soil improvement and fertiliser in agricultural production, either directly or indirectly.

The most common practice is through collaboration with local farmers, where the farmers come to the hatchery to pick up the sludge, normally by tractor and trailer. Since the sludge typically has a water content of 80–90%, the farmers need to use large tanks during transport. The organic liquid is applied directly on the soil without any kind of processing. The farmers are paid between 0.09€/kg and 0.21€/kg for the job. This collaboration is by far the most common practice to re-use the waste from smolt production.

However, some hatcheries choose to transport their wastewater to local recycling facilities. Here the sludge is dried, mixed and further processed with other kinds of organic waste (human sewage, for example). After processing, the new by-product is further sold as fertiliser as a dried biomass and also here used as soil improvement.

Replacement of fossil fuel (biogas)

When organic material goes through anaerobic decomposition, bacteria transform the waste into 60% methane and 40% carbon dioxide and other trace gases. The methane portion of the gas, often called biogas, can be used to produce new energy such as heat and electric power.

Sludge from smolt production is high in iron, because of the use of iron-chloride as a precipitate within the RA technology. This is a positive aspect of this feedstock for biogas production because it reduces the hydrogen-sulphide production as well as carbon dioxide, and is more efficiently converted to methane. The whole organic waste is generally high in fat and is therefore high in energy content; the large amount of fatty acids is nevertheless a challenge when it comes to biogas producers because they tend to inhibit methanogenic bacteria (Nges, Mbatia & Björnsson, 2012). So far, the biogas-producers have solved this by mixing in waste from agricultural farming.

Currently, biogas has two main areas for use: as a motor fuel for transport and as a heating fuel for greenhouses. In Norway, around 40 biogas plants currently exist and the sector is not yet as developed as it is in Denmark. Nevertheless, interest is increasing in Norway because it represents a sustainable energy source and the Norwegian firms see it as an interesting future possibility if the biogas facilities could be located near the fish farms, and if the requirements of mixing the waste with other agricultural residues could be met.

Biogas production has so far been driven by the agricultural sector. Yet low electricity costs have, to date, slowed down the development of biogas. At the time of the interview, the biogas production firms in Denmark were struggling financially, and although the sludge was of economic value to the biogas producers, the firm had an agreement to give it away and pay for the transport. The firm took the longer view in that they wanted to support the biogas producers as an outlet for this waste stream. The firm's representative said that they would later consider negotiating a price for the sludge, but only if the biogas producer was in a position to pay for it. The representative said it was not a high priority in terms of the fish farm's economy.

Combustible material for heating

Dried sludge can serve as a fuel in industrial production of different products, e.g. cement. In cement production, clinker is heated to 1,400–1,500°C. There is currently a collaboration between one of the salmon firms in our sample and a cement-producing firm, where the dried sludge is used to fuel the clinker ovens.

8.4.2 Challenges with current system

Waste volumes are expected to increase

One of the biggest challenges with today's waste stream management is the expected increase in volume in the years to come. The valorisation pathways are still in a nascent stage and are unlikely to be able to handle the expected increase in volume of organic waste. Because the volume is currently small, the firms have entered into simple agreements with farmers, and, in some cases, biogas producers are given the waste free or even paid to remove it. While many fish production firms have local agreements with other actors to handle the organic waste, as the scale increases, the interviewees noted that these actors may not be able to handle the increased volume of sludge, and new strategies would have to be explored.

Transport

A substantial challenge related to organic waste from salmon production is transport. If the sludge, which has a high water content, needs to be moved over large distances (which is to be expected), it is both a practical and economic issue. There is considerable distance between the smolt production facilities and the places where it can be used: typically, fish farms are located on the coast and agricultural areas are further inland. Sludge can only be economically transported short distances. The interviewees noted that the logistics are not yet in place for increased volumes of stored sludge, so transport and distribution is one of the bottlenecks in the full valorisation of fish farm waste.

Immature technology

Drying the sludge gives it a higher stability for storage, makes transport easier and cheaper and increases the fuel value. In biogas production, for example, at least 20% dry raw material is needed. However, the technology for drying is a bottleneck in re-use of the organic waste.

The experience with this technology is limited. Few of the hatcheries have invested in in-house knowledge of how to run drying facilities. Furthermore, the ones that have this are not satisfied with the technology and the labour resources required for running these systems. Current systems are difficult and costly to run. All the fish farms interviewed report that the largest motivation for this kind of investment is to reduce the costs in the end of the entire fish production process, and the drying technology has not developed to a stage where this is the case.

Another potential solution mentioned by the Danish firm was to explore algae that could break down the sludge and produce omega-3 fatty acids. Nonetheless, the volume of waste from this firm was not sufficiently large to warrant an exploration into this emerging technology. Theoretically, the waste could also be incorporated into a full aquaponics cycle, producing both fish and (hydroponic) vegetables, though this has not yet been demonstrated at scale.

Likewise, many firms recognised that there were other emerging technologies available for better procurement and transport of waste, but that this required investment in infrastructure and labour that, economically, would be more profitably directed towards other activities, such as procurement of nearby wind turbines to provide electricity to the facility. Essentially, handling of waste was not a high priority for the fish production firms in terms of their current economies and business models.

8.5 Analysis

8.5.1 Barriers for new pathways

Lack of available technology

Lack of knowledge related both to biological and technological aspects could be a barrier to realising the potential of the suggested new valorisation pathways. Many technologies are still in proof of concept or demonstration stages and it is still costly to invest in them.

Economic priorities

Fish waste does not have much value with respect to the total operating budget. The cost of producing salmon is much higher on land, and the economic incentives and willingness to invest in large-scale processing of the sludge are not yet in place. Our interviewees did not view the waste as a valuable product and it was of little interest in relation to the greater costs of running a profitable fish farm. These short-term economic priorities may also be a reason for the low levels of investment and experimentation into new ways of waste utilisation.

Resistance to go into new business areas

The firms are reluctant to diversify into new business areas. The major fish-producing firms' priorities are geared more towards producing salmon, whereas disposing waste is seen as a responsibility. Lacking expertise and seeing the waste as a small component to their bottom line, the fish firms were counting on existing recycling companies to introduce new alternatives. When asked, the firms were not interested in diversifying into other markets and did not see a financial advantage in this.

Patchwork regulation

Another barrier comes from the lack of legislation and fragmentation of policies, particularly in Norway, where the salmon farming industry is rapidly expanding. The different counties along the coastline have different guidelines for how they process and grant applications, and there are no cohesive national guidelines on how to handle the waste. Consequently, hatcheries experience different regulatory requirements regarding the treatment of effluent. On the one hand, this lack of common regulation means that salmon farms are free to use and test different solutions within the requirements. Our interviews suggest that this situation is fostering local innovation and entrepreneurial initiatives, but there is no large-scale, industry-wide solution to handle the waste in a cost-efficient manner. Therefore, on the other hand, the current regulatory environment is not conducive to developing a market for waste.

Lack of collaboration

On the local level, fish producers seem to collaborate well with external partners in order to deal with their waste. However, on the national level, there seems to be a lack of collaboration between the agricultural sector, aquaculture, producers of technology and the recycling sector. The fact that all firms and sectors specialise in their own niches results in a lack of cross-sectoral expertise. Some of the fish-producing firms we interviewed had little understanding of how other industries might benefit from their waste, and the potential it has for valorisation. Better collaboration between different industries could increase the potential of alternative uses of waste.

Co-location issues

Logistics and transport are current barriers to valorisation of waste. The fish-producing firms are typically located in the coastal districts and the processors of the waste are often located inland. Without technology for drying the waste, this results in high transport costs of biomass with high water content.

8.5.2 Socio-technical transition

As wild catch can no longer meet current demand, aquaculture will continue to expand if fish, and salmon in particular, are to continue to be supplied to the market at the current prices. Salmon-producing firms are currently in transition, in response to both a growing global demand for salmon and the calls to reduce their impact on local coastal ecologies, as well as the economic necessity of responding to the damage sea lice cause to the fish stocks. The following looks at aspects of the socio-technical transition, applying elements inspired by actor network theory (Simandan, 2018), technological innovation systems theory (Smits, 2002) and multilevel perspective theory (Geels & Schot, 2007).

Actors

Several of our interviewees claimed that consumers are becoming more interested in sustainability. The firm's image and the story of their products are therefore becoming more important. This was especially the case for the fully land-based firm in our study – market differentiation and the sustainability angle was their competitive edge in the marketplace.

Governments are also driving the transition, principally in supporting the industry, which provides jobs to rural communities and a valuable export. In Norway, we found several examples of how the industry has benefitted indirectly from regional policy. They are also responding to a growing awareness of environmental impacts through regulation, although, as yet, there is little coordination and guidance on how to handle waste.

Technology firms specialising in RAS are the main enablers of this transition, as it is now becoming more cost-efficient and easier to meet regulations regarding wastewater. Moreover, RAS allows the sludge to be more easily collected and concentrated. Further technological development is needed in centrifuge- and heat-based drying systems to make waste storage and transport more economical. Moreover, additional research is needed into new ways to process waste. Biotechnology providers could be key actors in this regard.

End-use actors (for organic waste) are not yet fully coordinated with the fish production firms. This stems from co-related factors: a lack of consistent and coordinated policy for waste handling, a lack of economic incentives, a lack of research and entrepreneurship and a lack of overlapping expertise.

Capabilities

With respect to the waste pyramid (see Chapter 3), current waste management strategies in land-based production include recycling (through transfer to wastewater recycling centres) and re-use (through transfer to agriculture, biogas production and cement industries). However, from the point of view of the fish firms, it harkens more towards disposal, since the firms are paying other actors to come and collect the waste and currently they have little interest in its fate. To move up on this pyramid will require more active coordination between actors, particularly between agriculture and aquaculture firms. Prevention is theoretically possible through integrated aquaponics systems, although there are limited capabilities and expertise in the respective industries. On-site algae production is also a possibility for waste prevention, though similar limitations in expertise exist here.

Networks

In their current state, the agricultural producers and land-based fisheries are too disparate to merge in joint production (i.e. aquaponics), yet the biogas represents a key intermediary that brings different actors together into a network. The biogas production also produces residues and there is a need to create a market for this as well (the bio-residue can be used as a soil conditioner; see Chapter 5). Thus, alternative use of the by-products, like biogas production, needs collaboration with other suppliers and users of biomass. Good collaboration requires co-location of the fish farm, the agricultural biomass producers and the biogas facility.

Industries such as cement firms utilising the waste in clinker production and energy suppliers are also emerging networks for salmon farms. However, these end-uses do not benefit from the high nutrient content of the waste; they are lower on the cascading use (see Chapter 3). Therefore, the valorisation potentials from these pathways are likely to be more limited.

A linkage that could emerge in the future could come between the RAS technology providers and key end-use actors. This would promote technology development in waste recovery: sludge dewatering, processing and handling targeted to specific ends in order to incorporate potential waste re-use and valorisation into the technology design.

Infrastructures

Because of co-location issues, infrastructure development is challenging. For example, expanding the use of organic waste from aquaculture in biogas production is a developing opportunity that potentially utilises both the nutrients and energy content of the waste. While this is performed in Denmark, it is performed in Norway to a lower degree, largely because the infrastructure is currently lacking.

Co-location of vegetable production and fish farms is not likely, as the most suitable place for aquaculture is near the coast (particularly with cage-based grow-out) and the most suitable place for agriculture is more inland. Hydroponic systems for aquaculture are costlier and would require a large capital expense for producing a low-value food source far away from existing distribution networks. The spatial embeddedness of the firms contributes to the lack of shared context.

Institutions

New business models for the re-use of organic fish waste are slow to develop. The salmon-producing companies themselves are not driving innovation in this part of the value chain. Furthermore, little research has been conducted to determine the most effective use for the sludge, either from a lifecycle assessment, or simply from an economic cost-benefit perspective. Thus, there is little to drive the industry to invent new usages for the waste.

Much of this can be explained by territorial embeddedness (Pallares-Barbera, Tulla & Vera, 2004) of the various institutions and their respective established networks. Therefore, there is little shared context for waste valorisation, and, as such, little incentive for research or entrepreneurship to link these disparate institutions.

8.6 Conclusion

8.6.1 Overcoming the barriers: key actors

There are still open questions concerning which actors and what type of institutional development will eventually emerge to handle this. Our findings show a general "wait-and-see" strategy for the business case for waste valorisation within the aquaculture industry. Disparate industries with diverse competencies, industrial expertise and institutional territorial embeddedness define the current landscape, and thus no viable market has yet emerged for sludge from juvenile salmon production. As such, there are currently no plans for large investments or any push for innovation in the near future.

Innovations at this nascent stage are accompanied with large risks and high costs, and the salmon-production firms choose to wait for innovative, new solutions before investing. Since there are no economic incentives for the firms to invest in new waste-handling technologies, it is not strategically prioritised by the fish producers. The fish-producing firms fulfil the government's restrictions, but have little incentive, currently, to explore options beyond that. National governments therefore have the potential to be key actors, especially as awareness grows of the environmental impact of this growing industry.

Other external actors also have the potential to play a key role. While the role of fish farm waste as fertiliser in agricultural systems can still be developed, further processing of the sludge through microbial conversion into value-added products could achieve future valorisation pathways. The interviews indicated some new valorisation pathways for organic waste in land-based salmon farming, such as aquaponics, niche chemicals or as an energy feedstock.

8.6.2 Impetus for future waste valorisation pathways

The development of new valorisation is therefore likely to come from three key drivers: (1) the expected scale-up of the sludge in the near future, (2) external actors discovering and seizing new business opportunities and (3) the benefits of the improved environmental reputation of the industry.

1 Globally, wild fisheries are no longer able to meet the increased demand for seafood. Consequently, the aquaculture industry in general, and the salmon sector in particular, continues to expand to meet this growing demand. In Norway, biological challenges related to the sea phase for salmon farming have forced the salmon industry to move more of its production onto land. The volumes of collected sludge will increase dramatically. Despite this, few solutions for the re-use of the waste have been successfully established. New applications will therefore be a necessity when the scale increases.

2 Organic waste from salmon farming has a high nutritional content. It is, for example, rich in nitrogen and phosphorus, which is a scarce resource globally. Processed carefully, high-value by-products can be developed from these residues. It is expected that entrepreneurs will seize this business opportunity. The high value of the raw material will therefore be a fundamental key driver for product innovation and development of new by-products in this industry.

3 Finally, by contributing to develop innovative waste-handling strategies, the salmon industry will benefit from creating a more sustainable and responsible image. Currently, pressure is being placed on the industry by environmental groups and local activists. Better utilisation of the rest products will contribute to improving the sustainability aspects. As such, fish-producing firms are becoming increasingly interested in their image and, as a result, market differentiation of their product has begun to emerge. This is particularly the case in Denmark, because it is now feasible to produce salmon completely on land. The Danish firm's model of market differentiation will become more important as the industry expands and public awareness increases about the environmental impact of this industry. The image and "selling the story" of ecologically produced fish are important components to the business model. We assume an increasing need to utilise the organic waste streams in an environmentally friendly and mutually beneficial manner for the salmon-producing companies, even though they do not want to be the leaders in the development process.

Notes

1 The smolt stage is here defined as the period where a salmon has gone through the smoltification process, where it has physically gone from being a freshwater fish to a salmon that tolerates saltwater. It attains a silver skin. There is no specific size clearly defined in the literature of the salmon at this stage. However, here we use smolt to describe a salmon with a weight between 0.1 and 250 grams, and post-smolt between 250 grams and 1 kg.

2 The size of the fish in the hatcheries has traditionally been restricted to a maximum of 250 g. However, as a pilot project from May 1, 2012, the Norwegian Ministry has given the farmers the right to grant an exemption to extend the juvenile phase in closed land-based systems until the fish reaches a size of up to 1 kg.

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