Marine Policy 152 (2023) 105624

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Innovation policy in the Norwegian aquaculture industry: Reshaping aquaculture production innovation networks

Samson Afewerki [a,*], Tonje Osmundsen [b], Marit Schei Olsen [b], Kristine Vedal Størkersen [a,1], Andreas Misund [a], Trine Thorvaldsen [a]

[a] SINTEF Ocean, Department of Aquaculture, Trondheim 7465, Norway
[b] NTNU Social Research, Trondheim 7491, Norway

ARTICLE INFO

Keywords:
Innovation policy
Innovation networks
Aquaculture
Development licenses
Fish-farming technology

ABSTRACT

While aquaculture production in a number of countries has been highly successful in terms of production growth, there is also a number of instances where the rapid growth has been curtailed due to sustainability challenges. In response, fostering sustainable aquaculture production has become a key policy and research agenda. The point of departure for this paper is the radical technological innovations based sustainable restructuring dynamics of the Norwegian salmon farming industry, which despite becoming one of the most profitable aquaculture industries in the world, has in recent years seen its growth curtailed due to sustainability challenges. To address these challenges and to enable the use of new areas currently inaccessible by the incumbent aquaculture technology, the Norwegian authorities launched in 2015 a new type of innovation policy instrument, known as *development licences*. Based on a mapping of the aquaculture production technology development projects as well as in-depth interviews, this paper elucidates how the targeted innovation policy instrument has instigated the sustainable restructuring process of the Norwegian aquaculture industry. Our findings indicate that in the short term, the innovation policy appears to have succeeded in the reconfiguration, and more precisely, the 'renewal' process of the aquaculture production technology innovation networks (ecosystems) thanks to the entry of the new capable actors into the segment. However, we emphasise that the overall success of the innovation policy instrument will ultimately hinge upon sufficiently addressing certain aspects of the institutional failures in the sector.

1. Introduction

With an average annual growth rate of 8% since the 1970 s, aquaculture has been the food sector with the fastest growth rate in recent decades globally [13,48]. Currently, the sector accounts for approximately half of global seafood consumption and by reducing the supply-demand gap for aquatic food, the sector plays a crucial role in global food security and nutrition [26]. However, the rapid growth of aquaculture production is also associated with environmental challenges such as emissions and pollution, animal welfare challenges and loss of biodiversity [30,56,63,62]. In response, fostering sustainable aquaculture production has become an important policy under the 'blue transformation' mission umbrella as well as research agenda [26]. Consequently, in recent years issues such as 'social licences to operate' (see e.g., [4]; [15]; [40]; [45]; [51]; [57]) and 'sustainability certification' (see e.g., [5]; [6]; [11]; [64]) have received significant attention. By contrast, the government induced radical technological innovations based sectoral reconfiguration and/or restructuring dynamics to address the environmental (sustainability) challenges in the sector and its wider implications have received less attention. In this paper we address this gap drawing on innovation policy literature (see e.g., [23]; [22]; [41]; [79]).

Empirically, this paper investigates the recent innovation policy induced reconfiguration processes of the Norwegian salmon aquaculture industry, which is comprised of two species, namely Atlantic salmon (*Salmo salar*) and rainbow trout (*Onchorynchus mykiss*). Norway is the largest farmed salmon producing country in the world, and the industry is a global leader in a number of technology and knowledge dimensions

* Corresponding author.
E-mail addresses: samson.afewerki@sintef.no (S. Afewerki), tonje.osmundsen@samforsk.no (T. Osmundsen), marit.olsen@samforsk.no (M.S. Olsen), kristine.storkersen@sintef.no (K.V. Størkersen), andreas.misund@sintef.no (A. Misund), trine.thorvaldsen@sintef.no (T. Thorvaldsen).
[1] 0000-0003-4752-1957

https://doi.org/10.1016/j.marpol.2023.105624
Received 2 February 2022; Received in revised form 3 April 2023; Accepted 5 April 2023
Available online 13 April 2023

not only for salmon but also for aquaculture more generally [10,72]. The success of the industry is attributed to the number of innovations across the aquaculture value chain that has increased the competitiveness of the sector [8,14,44]. The innovations have moved the industry from a technological regime with poor degree of control and labour-intensive production processes in the 1970 s to one that can be characterised by a higher degree of control that is more capital-intensive with larger scale units and which are approaching 'biological manufacturing' [8].

The main production technology in the industry, open net pens, remains largely unchanged since the inception of the industry beyond a dramatic increase in size [3]. Better production practices have reduced a number of environmental externalities such as antibiotics use [76], feed use and particularly the use of marine ingredients in the feed [82], and escapes [67]. However, a number of environmental challenges remains related to parasitic salmon lice, escapees, disease, feed residues and other discharges [28,30,61,73,75]. These concerns (including increasing level of conflicts with other and not least the emerging users of the oceans/fjords), are perceived to increase with increased production and is therefore limiting the industry's production growth [38,62], and future growth is now primarily tied to one environmental indicator, salmon lice levels [36,54]. As the industry is highly profitable [10,70,83], further production growth is desirable to foster economic growth primarily in coastal communities. To help address the environmental challenges and foster the sustainable growth of the sector in 2015, the Norwegian government launched new innovation policy instruments known as *development licences* with the aim of steering the innovations in the sector towards achieving a sustainable restructuring process of the industry [39,62]. Additionally, the scheme aimed to solve the areal challenges in the sector as further expansion has been limited due to the scarcity of both production sites and permits (licenses)[2] (see e.g. [39]) mainly due to stricter regulation as a result of increasing environmental and fish welfare concerns [59,55].

The industry has accommodated numerous innovations over the years, including in response to the government's regulatory initiatives, such as the sea lice regulations in 2009 and the green licenses introduced in 2013 [78]. Nonetheless, these initiatives fell short of sufficiently meeting the government's clearly defined goal of addressing the sustainability challenges in the sector by 'greening' salmon aquaculture production [38,37]. Apparently, other measures including environmental taxes were deemed inappropriate due to the complex nature of the challenges (e.g., non-point source pollution) (see e.g., [36]). To foster a predictable and environmentally sustainable value creation and increased growth in Norwegian aquaculture sector (see [52], therefore, the design and implementation of a new growth system, and the implementation of the development licenses was crucial. As a clear indication of the crucial role of public policy in steering (pushing) innovations, the main objective of the licencing scheme was to actively induce the industry (i.e., incentivise aquaculture companies) to engage in the development of new (ground-breaking) knowledge and/or utilization existing knowledge (from research or practical experience) in the development of new sustainable aquaculture production technologies [21].

This paper sheds light on the impact of the development licencing scheme, as an important innovation policy instrument on fish-farming-related technological innovations with a specific focus on implications for actors and network reconfiguration processes in the Norwegian aquaculture industry. Based on a mapping of the technological development projects as well as in-depth interviews with approximately 30 firm and non-firm actors involved in selected technology development projects, the paper shows that in the short term, the development licensing scheme appears to have succeeded in the reconfiguration, and more precisely, the 'renewal', of the Norwegian aquaculture innovation networks (ecosystems) thanks to the entry of the new capable actors into the industry. However, the overall success of the innovation policy instrument may ultimately hinge upon sufficiently addressing specific aspects of the institutional failures in the sector. Notably, there is a need for the current regulatory regime in the sector to be more attuned to or catch up with the rapid technological developments in the sector. Furthermore, the overall sustainability of the sector is contingent on the sustainable activities across all segments in the aquaculture value chain. Thus, for a successful sustainable industrial restructuring of the entire industry, there is still significant scope for public policy across the entire aquaculture value chains.

The paper is structured as follows. The next section delineates the methodological underpinnings of the paper. This is followed a by brief introduction of the Norwegian aquaculture industry, with a primary focus on its structure, including its value chains, the key actors and the main activities executed across these value chains. This section further provides a brief review of the emerging sea-farming related technological paths in the Norwegian aquaculture industry. The subsequent section indicates the theoretical framing of the paper. This is followed by sections on the paper's findings and a discussion on the impact of the development licensing scheme on the structure of the Norwegian aquaculture industry. The closing section elucidates the conclusions of the paper.

2. Materials and methods

To gain an in-depth understanding of how the development licenses scheme has impacted and re-shaped the innovation networks in the Norwegian aquaculture industry, this paper employs a qualitative case study approach [80]. This approach is helpful both in shedding light on policy-centric research, such as the impact and implications thereof, as well as in informing decision-making processes and/or making policy recommendations [65]. The data gathering process involved the following steps. The first step involved mapping the concepts that have been awarded development permits licenses as per December 2020 to gain insight into the types of actors involved in the technology development projects. Based on this, three distinctive categories of actors emerged, namely, the technology development project owners, traditional suppliers as well as new entrants to the aquaculture innovation networks (all of which are suppliers). The mapping further enabled an observation of how the scheme has impacted actor-constellations and specifically the structure of the Norwegian aquaculture innovation ecosystem. The second step involved in-depth semi-structured interviews with 30 informants across six development projects to assess the qualitative impact of the scheme on the Norwegian aquaculture industry in general and on these actors in particular. The six development projects were selected based on the type of technology involved, notably, offshore farming and farming in closed facilities, and the technology development phase. While five of the selected projects were either realised or close to realisation, one of the concepts was not awarded a development license permit. In each of the selected concepts, three to six informants directly involved in the development projects were interviewed. These actors include those who developed the concept, project owners and/or investors who are the fish farmers (henceforth aquaculture companies) (D) and suppliers (S), including technology suppliers, service providers and fish health personnel. The interviews include other actors, such as representatives of verification

[2] Around 1980–2000, access to permits were scarce due to regulations motivated by concerns of overproduction and trading conflicts with US/EU. Over the last 10–20 years, permits and sites have become scarce due to regulations motivated by environmental and fish health concerns. The major reason for scarcity of sites is due to the Food Authority's requirements for minimum distances between sites, which are now around 2.5 and 5 kilometers (see [39]). The major reason for the scarcity of permits is due to sea lice issues, which has manifested itself in both the authorities' restrictive attitude towards new licensing rounds and from 2017 onwards with the onset of the traffic light system. Also, it is worth noting that this is not only a Norwegian issue, but can also be found in other aquaculture industries (see e.g. [7]; [81]; [13]).

companies, regulators, technology developers and scholars, who had knowledge of several projects. The main themes of the interview revolved around the history of the technology development (i.e., innovation) process, the collaboration with partners and other actors, the application and evaluation process, motives and risks related to the sought project, the development license scheme in general, and knowledge dissemination and sharing processes. The interviews lasted between 60 and 90 min. All the interviews were conducted digitally (Teams video meetings) between February 2021 and June 2021. They were recorded and transcribed. Since the interviews were conducted in Norwegian, quotes were translated into English by the authors. Third, during the analysis of the interviews, they findings were further complemented and triangulated with a wide range of secondary data sources, including industry reports, project and public policy documents as well as the publicly accessible decision letters sent to applicants by the Norwegian Directorate of Fisheries.

3. The Norwegian aquaculture industry

Norway is the world's largest producer of farmed Atlantic salmon, and the industry is one of the leading export industries in Norway. The value creation from the salmon production is substantial; however, along with production growth, numerous environmental challenges have ensued.

Aquaculture entails the human cultivation of organisms in water. Accordingly, the aquaculture production process is determined by biological, technological, economic and environmental factors [8]. The aquaculture value chain is comprised of broodstock (egg and spawn), smolt, edible fish, fish processing (based on farmed fish), export and trade and suppliers of goods and services [25,77]. However, there are many other stages (value creation activities) and actors in the industry. This paper distinguishes between the following five interlinked aquaculture value chains and/or (value creation) segments: *technical solutions*, *biotechnology*, as well as *production*, *distribution* and *processing* segments (see Fig. 1). In the industry, the most important value creation activity occurs during the production and/or fish-farming stage. Thus, the entire value chain is structured around the aquaculture companies' backward linkages with actors in the technical solutions and biotechnology segments and the forward linkages with actors in the distribution and processing segments.

The Norwegian aquaculture value chain involves various actor (supplier) constellations, depending on stage-specific needs and the fish-farming companies' varying value chain and/or production network configuration strategies. In particular, three groups of suppliers can be identified: 1) technical solution and services providers, which are needed at every stage of the value chain, such as barges, feeding systems, cages, mooring systems, sea lice treatments and software, etc.; 2) biotechnology providers who deliver a wide range of biological or pharmaceutical products, including feed, vaccines, medicines and the little sea lice-eating helper, cleaner fish, etc.; and 3) distributors that include suppliers who provide sea transportation and other logistical services which are needed for both transporting smolt from fresh water and transporting harvestable fish to processing plants, service vessels, well boats and feed transportation vessels [25]. The fish-farming segment, which is by far the largest subsegment in the Norwegian aquaculture sector, is currently dominated by large MNCs such as Mowi, SalMar, Lerøy, Cermaq, Grieg Seafood, etc. Nevertheless, most Norwegian salmon producers are family-owned companies with few licenses and small production volumes [58].

As discussed above, the enormous growth of the Norwegian salmon farming industry over the last decades has largely resulted from innovations in numerous areas, such as genetics (breeding), fish feed, feeding equipment, vaccines, information technology and cages [3]. Innovations have contributed immensely to increased growth rates for salmon, lower mortality, higher product quality and lower production costs [12]. Nevertheless, in Norway, the dominant fish-farming technology since the inception of the industry has been the open net-pen production technology [29]. By instigating successful industrial path this technology has contributed to Norway becoming the world's largest producer of Atlantic salmon [27]. However, induced mainly by the development licencing scheme, the Norwegian aquaculture industry has recently witnessed rapid and radical fish-farming related technological developments (innovations) which are aimed at addressing the sustainability challenges related to the traditional technology [47,71]. Six of the technological concepts that have emerged through the development licencing scheme notably, Aquatraz, Akvafuture, Atlantis, Ocean Farm1 Havfarm 1 & 2, IFarm are currently fully operational in Norwegian waters. In the following section, a brief review of these emerging technological path(s) is presented, as this can help us contextualise the overall changes in the sector and the structure of the Norwegian aquaculture industry in particular.

3.1. Emerging technological paths in the Norwegian aquaculture sector

As mentioned above, the Norwegian aquaculture industry is highly profitable but is also hindered by formidable barriers to further growth.

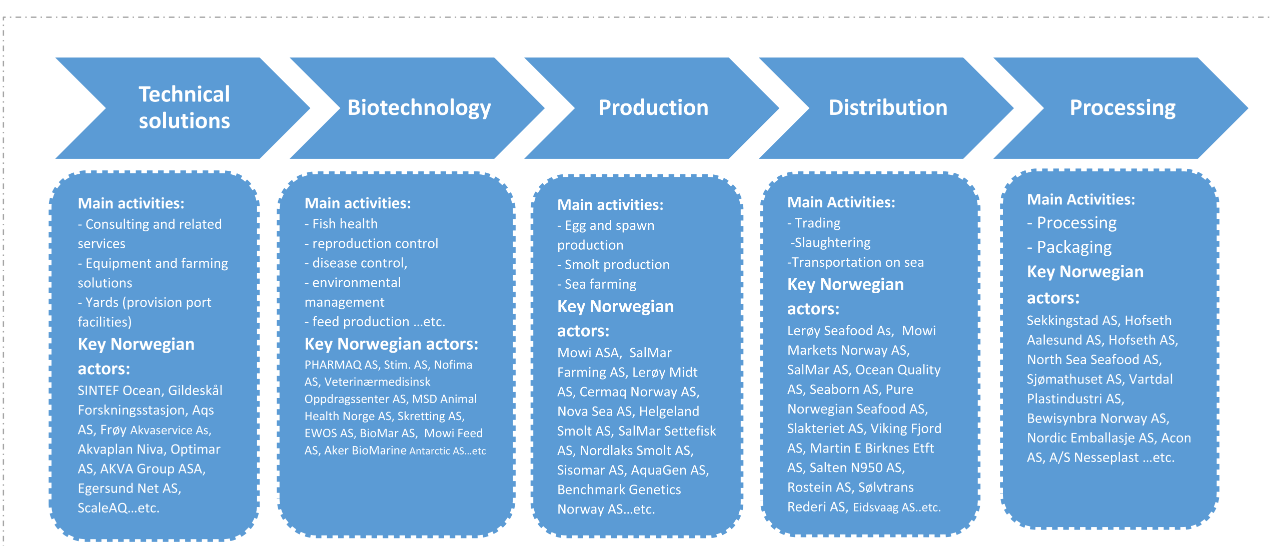

Fig. 1. The Aquaculture value chain, main activities and key Norwegian actors. Authors' own elaboration.

In Norway, the industry is regulated by licences; for instance, the licences determine how much fish can be produced, where it can be produced and the production technology. There are several licencing systems, each with different objectives. The focal point here, namely the development licences, is a special purpose license (in contrast to ordinary licenses) and was a temporary scheme open to applications between 2015 and 2017 [62,39]. Over the last ten years, the value of an ordinary license has increased substantially, with trade (pre-2021) prices between 15 and 20 million USD [39]. However, further expansion has been limited due to due to stricter regulation as a result of increasing environmental and fish welfare concerns [59,55].

The development licences represent an opportunity to develop technology that can address important sustainability challenges for the industry; in addition, these licences can be an opportunity to allow production growth, as development licences remain valid for up to 15 years (to develop and test technology) and are awarded free of charge. The licence owner can apply to convert the licences to ordinary licences after the test period and for a fixed price far lower than its estimated value. It is worth emphasising however that the price should be substantial enough in order for the license owners to be able to qualify for converting these development licenses into full commercial ones. After conversion, there is no criteria regarding the further use of the developed technology [62].

Føre et al. [29], through a systematic content analysis of the different technological concepts involved in the development licensing scheme, have identified substantial variation in terms of scale, locations (sheltered, coastal, open ocean) and types of farm concepts, as well as approaches to addressing sustainability challenges in the sector. Nevertheless, concepts designed for open ocean/offshore locations well as closed concepts designed for both coastal and sheltered areas were identified as the two main emerging aquaculture production technological paths given their success in terms of the awarded development licenses. *Closed facilities* involve impermeable fish enclosures with the aim of separating the enclosed water volume from the surroundings. *Semi-closed systems* also have impermeable enclosures but are designed with a partial isolation (from the surroundings) to enable waste removal. Partly closed facilities combine impermeable and permeable enclosures. Applicants argue that sustainability challenges affecting the sector, including sea lice and escape, can be addressed through such closed technologies. Based on the number of awarded licences, open ocean farming using *semi-submersible platforms (semi-subs)*, which involve rigid platforms with their buoyant elements below the water surface, as well as *rigid floaters* involving permeable nets, have been identified as he most promising technological path [29,77]. In addition, enabled by stronger materials and enclosure structures, the traditional *open net-pen technology* (PE rings) is evolving to be more suitable for farming in the offshore and/or exposed production environment [29,24,77]. These developments, coupled with the emergence of land-based aquaculture technology, are shaping the contours of the Norwegian aquaculture landscape.

4. Development licencing as an innovation policy instrument

In the public policy domain, licencing and permits are key regulation-based policy instruments used by governments to achieve economic, social or environmental goals [66]. Accordingly, the development licencing scheme as a key public policy instrument was designed to address important environmental challenges that provided a good rationale for state interventions and/or innovation policy. Innovation policy, which consists of a range of different policies (and policy instruments), is defined as encompassing policies that have an important impact on innovation [23]. Innovation, which is the result of 'new combinations' [69] of existing knowledge, capabilities and resources, is conceptualised as the introduction of new solutions designed to address social and/or economic challenges and/or opportunities [22]. Innovations are often classified as either radical or incremental. Radical innovations are generally understood to have a high degree of novelty, being substantially new with deep effect on future development including through making dominant rival technologies or processes obsolete. Incremental innovations on the other hand have far less novelty, uniqueness or originality because they are considered mere modifications or refinements of already existing innovations (see e.g., [68]).

In the innovation literature, a differentiation can be made between two types of innovation policy approaches [20]. The first of these approaches, *demand-pull*, involves stimulating demand by incentivising actors to engage in R&D activities and regulations that include market growth targets. On the other hand, the second approach, namely *technology-push*, entails supporting research and development to advance key competencies needed for new technology developments. Technology push strategies may specifically involve government subsidies for actors' R&D activities, initiating public R&D programs and government procurement of new technologies.

In other words, public policy can play an important role in fostering innovations through support for and/or by facilitating the generation of scientific knowledge and technology that addresses societal challenges and opportunities. More specifically, the introduction of the development licencing scheme has been justified by what is commonly referred to in the innovation policy debate as 'market failure'. In the case of the Norwegian aquaculture industry, this is related to both the negative environmental challenges and/or sustainability issues discussed above, as well as sub-optimal resource allocation by firms in R&D, as well as the creation of new knowledge to address these challenges due to the 'public good' nature of knowledge [22]. More specifically, the Norwegian aquaculture firms have had minimal incentive to invest in the creation of ground-breaking knowledge and/or radical innovations that address these challenges. This is because they recognize that the knowledge they create can be accessed and exploited by anyone free of charge, hence reducing the financial returns. It also relates to the diminishing cost of production, increases in salmon prices and the subsequent exponential growth in profits over the last decades of using the traditional farming technology [9,14]**.** Thus, it can be argued that the lacking focus on ground-breaking (radical) innovations in fish-farming technology, resulting from minimal demand for these types of innovations, has in turn affected the availability of complementary knowledge, skills and/or capabilities including financing (albeit related to willingness to invest by the actors involved in the industry) required for such large-scale (ground-breaking) fish-farming technological innovations in the industry. In the innovation policy literature, this is conceptualised as relating to 'structural innovation system failure' (see e.g., [79]).

Structural innovation system failures may be related to *infrastructural failures*, which can be a result of lacking and/or insufficient existing physical infrastructures that are crucial for innovation activities. Second, they may be related to c*apabilities failures,* which are associated with a lack of capacity to generate, access and/or exploit new knowledge due to a lack of the right type of competencies and resources amongst firms. Third, n*etwork failures* are related to myopia which inhibits the exploitation of complementary sources of knowledge and processes of interactive learning due to a lack of infusion of new ideas resulting from limited interactions and knowledge exchange with other actors outside a particular industry. Fourth, *institutional failures* are related to both the formal institutional mechanisms that may hinder innovations, including technical standards, labour laws, risk management rules, health and safety regulations, intellectual property rights (IPR)) and the 'wider context of political culture and social value that shape public policy objectives, the macroeconomic policy environment… and the way business is done' [41], p. 613). Overall, it can be said that policies designed to address structural innovation system failures focus mainly on the degree of interaction between different parts of the system, the extent to which some vital component of the system is in need of improvement, or the capabilities of the actors involved [22]. Therefore, by adopting this systemic view, this paper demonstrates how the development licencing scheme has addressed the structural innovation system failures in the sea-farming technology segment of the Norwegian aquaculture industry.

The innovation literature has been criticised for the so-called 'pro-innovation bias' (Rogers 1962, in [32], i.e., for portraying innovation as always desirable behaviour, and for failing to perceive the rational or strategies of non-innovators. *NOvation* is a term coined to refers 'to a series of phenomena and processes that could appear, within the dominant ideology and theories as mindless, sub-rational, not seeing the common good in the innovation and forgoing opportunities' [32], p. 3). Nevertheless, according to the critical views of innovation, choosing not to innovate is considered as a rational strategy. Hence, in this paper, we also shed light on the rationales and/or voices of those who expressed scepticism towards the technological innovation (development) opportunities provided by the development licencing scheme.

5. Re-shaping the Norwegian aquaculture industry and its innovation networks

These emerging technological paths in the Norwegian aquaculture industry have been made possible through the development of new knowledge by the traditional aquaculture companies in the Norwegian aquaculture sector. In other words, the development licencing scheme has been instrumental in instigating reconfigurations of the Norwegian aquaculture value chains and/or innovation networks. This section sheds light on the scheme's impact on actor constellations, specifically the emerging aquaculture innovation networks and/or value chains and the actors (project owners) network development practices and strategies.

One of the main conditions put in place by the Norwegian Directorate of Fisheries in the process of awarding the development licences was that the technology development projects should be qualified as involving 'significant innovation' and 'significant investments'. This implies that the scheme was designed to stimulate technological innovations by actors already positioned in the Norwegian aquaculture sector. Indeed, the most successful projects (measured in terms allocated biomass) are all owned by the major aquaculture actors in Norway (see Table 1). The Norwegian aquaculture industry is structured in such a manner that two thirds of the salmon farming segment in the value chain is dominated by the ten largest companies, the majority of which are MNCs. Almost all of these companies were involved in the applications for the development licence permits, either as sole applicants or as part of larger consortia and/or joint ventures, which frequently are 'temporary coalitions' [19]. These joint ventures (as an ownership structure) often entail creating a separate liability company (around the development projects) wherein an aquaculture company applies as an equal partner with two or three strategic partners, which in most cases are suppliers of key components, such as design and engineering companies (Interview with Supplier (S1 & S2)). The main advantage of these temporary coalitions is that it allows the applicants (mainly the fish farmers) to better manage (and/or minimise) risks associated with project development. These temporary coalitions are, however, as their name indicates, time-bound because they involve agreements for the fish-farming company to buyout the licenses of all the other partners after the completion of the test period (i.e., upon conversion to ordinary permit licences) (Interview with Developer (D)1).

Ownership structure, on the other hand, is also contingent upon the type of technology. In other words (albeit rudimentary), it is the type of technology that determines the composition of the innovation networks. For example, the innovation processes for the semi-submersible platforms (semi-subs) and/or the ones for salmon production in harsh open-ocean conditions (i.e., exposed localities) are often comprised of joint ventures and/or an aquaculture company taking the ownership role with an engineering company (often with a petro-maritime background) as their strategic partners (see Table 1).

Nonetheless, size, which can be understood in terms of turnovers and therefore the availability of financial capital (and in some cases inhouse R&D capabilities), has been a major determinant of success. According to Grünfeld et al. [35], over 75% of the actors that have been granted (84 out of 102) licenses (82%) had a turnover of around USD60 million in 2019. More than half (i.e., 48) of the licenses have been granted to 11 companies which had a turnover of more than one billion kroner in the same year. Accordingly, the major aquaculture companies dominate the development licensing scheme. This may, however, be as expected, given all the risk involved as well as the capital intensity of large (disruptive) technology development projects. On the other hand, size may have enabled these actors to accrue first mover advantages, as demonstrated by Salmar[3] and other large companies. Firms that succeed in enhancing their capabilities and using new or improved technologies and processes, thereby achieving technological leadership, often end up gaining first-mover competitive advantages [16]. First-mover advantages are associated with the development of competitive advantages through cumulative learning dynamics, such as the ability to achieve economies of scope and scale in production and R&D cost spreading [18]; [42]; [16]. First-mover advantages become even more evident when one takes further into consideration one of the main reasons given (by the Norwegian fisheries directorate) to those who had their applications rejected, namely that their concepts were 'not innovative enough' (Interview with D2). According to one particular informant,

Salmar was the winner because they were first [movers]. And if you look at what's going on now, Salmar is first in the next round as well, they've now made something called an outside baseline concession where they think, okay next time we're going out to sea because there's no regulations or system, we've drawn cages and everything, and then we're applying for a license as well, there's going to be an arrangement where they can get a license.… I think they've been fantastically good, they've done it again … (Interview with D1).

5.1. Emerging innovation networks: Knowledge spillovers and the development of new technological capabilities

Another key consequence of the development licenses was strong supplier linkages. Accordingly, although it is reflective of the futures (and/or nature) of the proposed concepts (see above) and thus the type of competence required, the scheme has had a crucial impact on the actor constellations involved the aquaculture value chains, and/or the composition of the Norwegian aquaculture innovation networks (ecosystems).

When it comes to the actor constellations (and more specifically suppliers) involved in the licensing scheme, a differentiation can be made between the traditional, or the specialised aquaculture suppliers and the non-traditional, or new entrants, the majority of which are registered as design, technical or service-providing firms. Based on the interviews, and in line with Grünfeld et al. [35], it can be argued that the scheme has resulted in much stronger connections between the aquaculture industry and the larger technology and engineering environments in Norway than was previously the case (see below for network development processes and strategies). In addition, different types of actors and competence, including from verification, certification and consulting engineers, have entered or diversified the industry (see Table 1). For example, DNV was described by one informant as one of the major winners of this scheme: *'they have learned [a lot along the way] and have got themselves very well paid for their services even if they had little idea [in the beginning]'* (Interview with S3). This can in turn make an important long-term contribution to the development of a new industrial path in the Norwegian aquaculture sector through the transfer of knowledge and competences from other leading Norwegian sectors,

[3] Salmar originally applied for concession under the green permits for their Ocean Farm 1 concept. However, this was rejected by the Directorate of Fisheries. This in turn led to the company becoming a driving force in the introduction by the government of the development licensing scheme [46].

Table 1
list of concepts and actors involved in the technology development projects.

Developer (Ownership structure)	Project/Concept	Number of liscences awarded	Investment (in MNOK)	Main players involved in the Innovation network	
				Traditional aquaculture suppliers	Non-traditional suppliers (new enterants)*
Akvafuture AS (tidl. AkvaDesign) (SME)	Akvafuture: Closed Containment system (CCS)	2 (1560)	360	O.B.Wiik Xylem Water Solutions Norway Scanship SBS Teknikk Egersund Net Helgeland Plast GPA Flow systems Yara Praxair Veterinærinstituttet NMBU IRIS Høgskulen på Vestlandet Göteborgs Universitet Multitrof akvakultur (MTA) Nord Universitet	Helgeland Marinasystemer Betongsystemer Bygg Tech Force Technology Norway DNV GL
Atlantis Subsea Farming AS (Joint venture between AKVA group ASA, SinkabergHansen AS and Egersund Net AS)	Atlantis: Submersible PE-rings	1 (780)	86,3	Nærøysund Aquaservice Aquastructures Marin Design Aquabyte Lift Up Havforskningsinstituttet SINTEF Ocean Val FoU	KB Storm Imtas Markleen Sperre Partner Plast Viteq Anteo
Cermaq Norway AS (MNC)	iFarm: PE-rings	4 (3120)	663		BioSort
Eide Fjordbruk AS (SME)	Salmon Zero: Closed Containment System (CCS)	2 (1232)	500	Sintef Ocean Aquatec-solutions FishFarming Innovations: Havyard MMC AS Høie Concrete Farm Consortium SUS	Betonmast AS Dr. Techn. Olav Olsen AS Searis Marina Solutions Ulstein Betong Marine AS Amaroq AS
FishGlobe AS (SME) Joint venture between RyFish AS and Grieg Seafood Rogaland (GSFR))	FishGLOBE V6: Closed Containment System (CCS)	2 (1560)	194	Uponor Infra Oy (Uponor) Aquastructures AS Nofima Xylem AS Uni Research	Marine Rådgivningstjenester AS
Grieg Seafood Rogaland (MNC) in a joint venture with Blue Planet AS, RS-X, AKVA Group ASA and Egersund Net AS)	Blue farm: Rigid floater	3 (2340)	523.2	Sintef Ocean AS) Uni Research Polytec	Dr. Techn. Olav Olsen AS DNV/GL/ Noomas AS
Nordlaks- (family owned SME) (aquired from Hydra Salmon Company AS)	Produksjonstank: Rigid floater	4 (3120)	300	Sintef Ocean	Global Maritime
Lerøy Seafood Group AS (MNC)	Pipefarm: Closed Containment System (CCS)	2 (1350)	826	N/A	
Mariculture AS Salmar's (MNC) subsidiary with an O&G background)	Smart Fishfarm: Semi-submersible platform	8 (6240)	1200	Sintef Ocean	Relies mainly on an inhouse Petro maritime competence Involves: DnvGL Global Maritime
MNH Produksjon AS (SME) in a joint venture with Seafarming Systems AS.	Aquatraz: Partly/semi-Closed Containment system (CCS)	4 (3120)	360	Pharmaq Analytiq Norsk institutt for vannforskning Nofima INAQ Xylem Norges teknisk- naturvitenskapelige universitet Nord universitet Aqua Kompetanse Sturla Romstad Moveo PatoGen SINTEF Ocean Aquastructures	Focus Engineering Cefront Technology CFD Marine WI Innovate DNV GL Focus Construction Norsk Heiskontroll Fosen Yard
Mowi Norway AS subsidiary of Mowi ASA Group (MNC)	Marine Donut: Closed Containment System (CCS)	2 (1100)	444	N/A	

(*continued on next page*)

Table 1 (*continued*)

Developer (Ownership structure)	Project/Concept	Number of liscences awarded	Investment (in MNOK)	Main players involved in the Innovation network	
				Traditional aquaculture suppliers	Non-traditional suppliers (new enterants)*
Mowi Norway AS subsidiary of Mowi ASA Group (MNC)	Egget: Closed Containment System (CCS)	4 (3120)	327	N/A	
Måsøval Fiskeoppdrett AS (SME)	Aqua Semi: Semi-submersible platform	4 (3120)	375	Sintef Ocean NMBU NTNU Institutt for maskinteknikk, Akvaplan-Niva, Åkerblå	DNVGL Vard Haugom Technologies
Nekst AS (SME)	Havliljen: Rigid floater	2 (1560)	1000	Fishguard Marine Construction Rostein Rådgivende Biologer	ABB AS Maritime Engineering RGI Inc Risnes Marine Craft AS
Nordlaks Oppdrett AS (SME)	Havfarm 1 og Havfarm 2: Semi-submersible platform	21 (16 380)	2485	Akva Group Selstad Optimar Skarvik Skretting Åkerblå Akvaplan-niva Skarsvaag Sintef Ocean Hordafôr Ocein Blueye Pump Supply Aanderaa/Xylem SAIV SJ Dykk Dykkerkompaniet Veterinærinstituttet	Yantai CIMC Raffles Offshore Ltd Boskalis Siem Offshore DOF Boa Seaworks Seasystems SAP Kongsberg Siemens Scanmatic Techano DNV GL Servi Jotun Rolls Royce Skuld Fearnleys/MIL Shipping Premas NSK Ship Design
Nova Sea AS (SME)	Spidercage: Rigid floater	4 (3120)	415	Aquaknowledge AS MARIN Research Institute HighComp AS	Viewpoint AS ICON Systems AS Moss Maritime AS Aibel AS Stavanger Engineering AS
Norway Royal Salmon ASA (SME)	Arctic Offshore Farming: Semi-submersible platform	8 (5990)	1200	Akva Group ASA Aquastructures AS CageEye AS Geomap Norge AS Bunnundersøkelser Isurvey AS Kompressorer AS Mørenot Aquaculture AS Oceanide Åkerblå AS	ABB AS Elektro Aker Solutions AS Buksér og Berging AS DNV GL Group AS Fearnleys AS Fosen Yard AS Frøy Akvaressurs AS Proactima AS S.Con Inc. Tess AS Safetec Nordic AS Seasystems (Scana Offshore AS) Techano AS Vicinay Marine ÅF Norge AS
Ocean Farming AS: Salmar's subsidiary (MNC)	Havmerden/Ocean Farm 1: Semi-submersible platform	8 (6240)	700	Mørenot Aquaculture AS Emstec GmbH Graintec AS Optimar Stette AS Pump Supply AS MARINTEK Sintef Ocean Euronete S.A.	Global Maritime AS Kongsberg Maritime AS Malm Orstad AS CSIC QWHI DNV GL/Noomas Fugro Oceanor AS Ramnäs Bruk AB Farstad Offshore AS
Reset AS (SME)	Reset: Closed Containment System (CCS)	8 (6240)	1482.8	Merdslippen AS Hardingsmolt AS Bergen university/Uni Research Aquastructures AS	Inventas AS
Salaks AS (SME)	Fjordmax: Rigid floater	6 (4680)	1000	Akvaplan Niva Sea ECO AS SINTEF	NSK ship design DNV GL Multiconsult
Stadion Laks AS (joint venture between LINGALAKS AS AND FRAMO AS)	Stadionbassenget: Closed Containment System (CCS)	3 (1849)	500	N/A	Dr. Techn. Olav Olsen AS

*Most of these actors have background from Petro-maritime, construction, design, engineering, ICT…etc.
Source: Føre et al. [29], FDIR & company project documents.

including petroleum:

'This is the problem we are going to solve…using our expertise from oil and gas and our understanding of hydrodynamics, how to design and build structures [made] of steel, how to operate them and things like that…[for us] the scheme has resulted in an engineering dream' (Interview with S4).

Indeed, several of the proposed and awarded development concepts are based on steel and/or concrete constructions (which is predominantly used in the petroleum industry) and were designed and engineered in the form of oil installations [29,77]. The scheme further facilitated the transfer of important knowledge and/or solutions from other ocean-based sectors, including automation, sonar-technology, monitoring and remotely operated vehicles (ROV), etc. Hence, for the traditional suppliers, the scheme has enabled them to enhance their capabilities: *'there is no doubt that we as a company have learned a lot from this, we have had to think a lot, we have been able to try things that we have not tried before…'* (Interview with S5). According to another informant, the scheme has exerted an important impact on their operations: *'you do things in a completely different way, you get other challenges that need to be solved along the way'* (Interview with S6). This is apparent in relation to the type of technological concepts that have been developed:

' … we have used more diving services than we are used to and have to use ROV, since it is as deep as it is, we have to use ROV at greater depths than [usual]. So on the one hand we have been challenged in relation to a standard operation, which is performed inside the net, but which now has to go on the outside of the net' (Interview with S7).

For the traditional and/or established aquaculture suppliers, therefore, it can be further argued that the scheme has played an instrumental role in enhancing their competitive advantage and/or strengthening their position in the sector, as it helped bolster their competences in relation to the development of new capabilities from involvement in the technology development projects (Interview with S8).

As noted above, it is evident that the development of many of the aquaculture concepts was made possible through the involvement of non-traditional actors, mainly from the adjacent petro-maritime industry (see Table 1). This is primarily due to synergies between these sectors. In other words, the size and degree of radical innovations in the technology development projects as well as the type of solutions suggested more closely resemble the form of work and technology requirements that the petro-maritime supplier industry is familiar with. On the other hand, the aquaculture sector (through these projects, and more specifically the licensing scheme) presented an attractive diversification and/or value creation opportunity for the petro-maritime suppliers. According to the interviews with the suppliers, the initiatives of the majority of these suppliers have been strongly driven by the development licensing scheme as well as the conditions in their core market (see below). According to one particular informant (supplier) specializing in the petro-maritime sectors, the development licensing scheme has facilitated entry and/or diversification opportunities for actors '*with a different culture than the aquaculture industry*'. The informant elaborates on what they meant by this statement as follows:

'The aquaculture industry was, at least 5–6 years ago, extra special… I would say that it would have been terribly difficult to find an engineer who worked in aquaculture. And it means that communication has to be done in a slightly different way,. the vast majority of [aquaculture companies] are very [pragmatic] and very concerned about safety and processes and things like that, but still the culture was a bit different' (Interview with S9).

In other words, this is related both to the type of competence and to the less stringent safety and other operational requirements in aquaculture compared to, for example, the petro-maritime sector. This perceived cultural difference has been further amplified by another diversifier:

'In oil and gas, there is a very strong focus on HSE and again of the things that we have brought with us, we have brought that mindset with us through these design processes. It's not like it's an exercise that we do in the end, but it's part of everything you do…' (Interview with S4).

For the aquaculture companies, close cooperation with the petro-maritime suppliers has been crucial, as these suppliers possess knowledge and competences required for the development of technology and structures that are particularly suitable for salmon production in harsh open-sea conditions and/or exposed localities (interview with S1&S4). Furthermore, the scheme was initiated at a time during which the O&G suppliers were also seeking value creation opportunities in adjacent sectors due to the crisis in their core O&G market that started in 2014. Accordingly, as intimated above, the involvement of these suppliers in the technology development projects was very much facilitated by the plunge in O&G prices and the subsequent restructuring imperatives of the O&G-dependent Norwegian economy coupled with the rapid uptick in salmon prices, which provided the aquaculture companies with ample financial liquidity to be able to support such technology development projects in collaboration with these types of actors. For the traditional aquaculture suppliers, the downturn in the O&G market meant that skills became readily available for them to take advantage of:

'…we work a lot with [experienced suppliers] that have got a huge boost. They have hired what they could hire from people at times to be able to take away all the work around it, they have focused on offshore farming and their design around it, so they have been very grateful for what has happened now…they're in big production boost because of the change that's come,. they've tripled their turnover…' (Interview with D2).

Thus, it can be argued that the licensing scheme has succeeded in the re-configuration, and more precisely, the 'renewal', of the Norwegian aquaculture innovation ecosystems thanks to the entry of the new actors into the industry. One particular informant made the following argument:

'…perhaps primarily a result of the link [established] between the aquaculture industry and the technology environment, not necessarily the solutions that have been seen so far, but that the two groups have actually met and sat around the same table… Because there are lots of contacts here and when the industry then gets new challenges and problems, they know [the distance] has become incredibly much shorter. I also think that the industry has learned and will learn terribly much how important it is to have technologists on their side' (Interview with S1).

At a firm level and more specifically for the aquaculture companies, the scheme has played an instrumental role in the realisation of the technology development projects, as it has succeeded in reducing the risks associated with investments in large development projects:

'…even though we are a large player we would never be able to spend so much capital on such an uncertain and risky project, had it not been for that development licenses permits. It is as simple as that. There had been no willingness on either the board or anyone else to do so…. if that license permit hadn't come, ….it may well be that we would have come quite a long way anyway, but it would have taken very much longer and a completely different way of working' (Interview with D3).

At an industry level, the mapping of the technology development projects (Table 1), as well as the in-depth interviews, indicate that the development licensing schemes have, although to a varying degree, primarily impacted both the technical solutions segment (to a greater extent) and the fish-farming component of production (to a lesser extent) in the Norwegian aquaculture value chains. What can be argued when it comes to the fish-farming segment is that the scheme has apparently helped the leading fish-farming companies in Norway to further strengthen their position in the global aquaculture industry.

However, it is worth noting that some of the aquaculture actors interviewed have expressed some reservations about the scheme. The main point of concern for these actors is that upon commercialisation, these technological developments may contribute to the weakening of their and by implication that of Norway's competitive (leadership) position in the global aquaculture market. Nevertheless, this argument is downplayed by others. For example, one particular informant asserted the following:

'I am absolutely convinced that it makes us stronger as a cluster in Norway. First of all, Norwegian technology is already around the world in aquaculture, globally, so, and suppliers are present everywhere where there is a certain professional way of farming, so that's just the way the world is… I think that we just have to be good and stay ahead and it's just great if we can sell that technology to the rest of the world. And if we kind of say "no, we're going to slow down that development", and that can apply in general or with development licenses, because then we move farming out of Norway and that's just nonsense not true. We have a combination in Norway that is completely unbeatable on the coast and with the competence environments and with the companies … we are going to be at the forefront if we just dare to invest, then we will be at the forefront for a long time' (Interview with D3).

5.1.1. Developers' innovation network development strategies

In the innovation network's development and/or configuration process, the developers (in many cases aquaculture companies) relied on their relational capabilities (i.e., familiarity from earlier collaborations) as opposed to competition. In other words, familiarity (for the traditional suppliers in particular) played an important role in enabling them to gain access to the development projects: *'so the reason we got into the project here is that we have a close cooperation with the developer'* (interview with S8). In innovation and/or new technology development projects, this trust-based practice (as opposed to market-based tendering procedures) is crucial for developers, as this allows them to facilitate close monitoring and reduce transaction costs: *'we have spent much less time on timesheets and all that goes around the process…if you ask someone if they have a tender and ask how many hours are you going to spend on it, they would say I have to spend 800h,. no I don't need 800…'* (interview with S1).

When familiarity could no longer be relied upon, however, a few of the developers used 'speed-dating' as a network development strategy during a large aquaculture conference. Thus, conferences played a significant role as a network development arena for some of the actors involved in the development licensing scheme (interview with D1).

Although the process started informally, the informants indicated that these joint ventures were formalized through the development of cooperation agreements: *'there is a cooperation agreement, a relatively simple cooperation agreement that was written before they started writing the applications and it still applies. It regulates all phases of the project until it is finalized and commercial'* (interview with D1). In addition, the interviews reveal that the network configuration strategies may vary depending on the type of project activities.

6. Discussion

This paper has explored the impact of the development licencing scheme, in terms of re-shaping the Norwegian aquaculture industry and its innovation networks.

As indicated above, despite the number of innovations across the Norwegian aquaculture value chain over the last 40 years, the main technological components of sea-based fish farming have remained largely the same. Consequently, the industry has been experiencing stagnation in production volume and productivity improvements primarily due to environmental and sustainability challenges [34,64,75]. Although it is still too early to argue that the development licencing scheme has permanently addressed the aforementioned challenges, the mapping of the actors involved in all of the technology development projects as well as the in-depth interviews across six selected development projects indicate that the scheme has played an instrumental role in the renewal of the Norwegian aquaculture technological paths. The development licenses have particularly facilitated the emergence of new aquaculture innovation ecosystems (networks), which in this context should be understood as a dynamic innovation network and/or 'evolving set of actors, activities, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors' [33], p. 3). More specifically, the scheme has facilitated the entry of new actors and competences mainly from the adjacent petro-maritime industry and resulted in the enhancement of capabilities among the traditional actors in the industry. In addition, thanks to the introduction of new (non-traditional) actors and competences, the scheme has also had an added value and/or additional positive externality far beyond the development of new technological paths (i.e., product innovations). More specifically, the scheme has further boosted minor incremental innovations or improvements in existing technologies within the technical solutions value chain (e.g., digital technologies such as artificial intelligence, lice counting … etc.), in turn making significant contributions towards enhancing operational activities in salmon farming using the traditional farming technology.

Furthermore, as insights concerning the biological implications of these new technologies (e.g., knowledge concerning how farming in harsh exposed locations affects fish welfare) are currently under development, the scheme may be further expected to foster advancements in the biotechnology segment of the aquaculture value chain.

However, although the scheme was generally well received by many aquaculture actors in Norway, it is worth mentioning that it has also elicited scepticism from some actors involved in the sector. The primary argument posited by these sceptics is that upon commercialisation, these technological developments may contribute to the weakening of their position, and by implication Norway's competitive position in the global aquaculture market. Nevertheless, this argument appears to be integral to the counter-narratives advanced by the proponents of the traditional farming technology or more precisely *NOvators* [32] in the sector (predominantly the small family-owned ventures). This is mainly because the development of new technology that could potentially lead to sectoral renewal and upgrading may mean bankruptcy for the actors who may lack the crucial competences that goes hand in hand with the emerging technological paths (and capacity to upgrade through investments in R&D activities and innovations. Indeed, one of the main assessment criteria for awarding licences, i.e., 'significant investments' (which in turn is crucial for 'significant innovations') may have had exclusionary effect on the small aquaculture companies. However, taking into consideration the importance of these actors for their local communities, subsequent government policies should incorporate measures that specifically target (include) these types of actors.

Nonetheless, our findings indicate that the scheme (by reducing developmental risks) has played an important role in fostering the development of new knowledge and the enhancement of the technological capabilities of the domestic aquaculture industry through the entry of new actors and the development of new innovation ecosystems (see above). More specifically, the large R&D investments that have been induced by the scheme have established Norway as a competence hub. This access to strong and innovative industrial environments has the potential to give a lasting competitive advantage to the country. Forging closer ties between the aquaculture industry and the innovative environments can form the basis for the establishment of new strong clusters, or innovation ecosystems (networks), that can dominate the global markets for sustainable farming technology for many years to come.

Accordingly, it can be further argued that through this technology-push innovation policy, the Norwegian government has contributed to enhancing the country's global leadership position as opposed to weakening it. As discussed above, this can be explained by what is referred in the strategic management literature as the notion of first-mover advantages (see [16], [43]). Here, a parallel can be drawn with the Norwegian oil industry wherein the capabilities the industry developed through years of learning and experimentation and therefore the development of capabilities in the North Sea was leveraged in other parts of the world, as this turned Norway into one of the leading exporters of offshore technology, based on this knowledge-intensive O&G sector, led by the state-owned enterprise Equinor (formerly Statoil). Another example is Denmark in the emerging Offshore Wind Industry (see [2]; [1]).

The in-depth interviews have indeed confirmed that several of the suppliers that have participated in the earlier development projects have subsequently received orders from other similar projects. In addition, other countries may be able to build cages (including replicas of these concepts), but on a practical level, success is determined, in addition to the suitable natural conditions ideal for salmon farming and access to risky capital (that Norway is endowed with), by the existence of other crucial expertise including but not limited to net design and net handling (i.e., the innovation system). Aspects related to biology and other systems on farming as well as the regulatory framework are important as well. In other words, as discussed above, the existence of sectoral and regional and/or national [22,50,31], and more precisely, a technological innovation ecosystem (networks), is pivotal. At present, the Norwegian aquaculture technological regime further strengthened by these emerging (sustainable) technological solutions is at an advanced stage in comparison with the rest of the world.

Nevertheless, in the long run, sustaining competitive advantages and a market (industry) leadership position will be contingent upon the ability of the developers, namely aquaculture companies' as well as suppliers, to continuously reduce costs and enhance firm-specific capabilities, such as their ability to optimise cost-capability ratios [17]. The aquaculture companies can achieve this through various firm-specific innovation and/or production network configuration strategies, including the following: intra-firm coordination (i.e., through in-house activities), inter-firm control (i.e., through outsourcing), inter-firm-partnership (i.e., through collaborations and strategic partnerships with highly capable suppliers) and extra-firm bargaining (i.e., through pushing and lobbying for the creation of conducive institutional environments and/or garnering government support) (see [17]).

At a macro level, the success of the development licencing scheme as an innovation policy instrument will ultimately be defined by the commercial viability of the new technologies. In other words, this will be based on their ability to outcompete the traditional farming technologies, which are currently extremely cheap, in addition to their ability to enable production from areas which the current technology is not suited for. In the latter case, new technology may also lead to the availability of licence permits which are highly coveted. In addition, there is no requirement for the continued use of the concepts upon conversion to ordinary licence. permits. Hence, there is a need for the government to continue to play an instrumental role in ensuring a level playing field between the different strands of technologies. This could, for example, be done by implementing more stringent environmental and/or sustainability requirements (than the existing ones) for traditional farming technologies as well as the development of conducive framework conditions, including continued support for the emerging sustainable technological paths until cost parity is achieved. Such requirements could complement the already-existing auction-based licensing procedures in the industry. This could help the sector to retain the actors that have diversified from other highly profitable industries, by enhancing the legitimacy of these emerging technologies [49]. This should be further complemented by the development of safety requirements and/or standards that reflect biological production activities using these new concepts [75,74].

7. Conclusion

This paper provides important new insights regarding the role of government policy in innovations in the Norwegian aquaculture industry. More specifically, going beyond the neoclassical market failure approach and building on the innovation systems perspectives (i.e., taking a systemic view), the paper demonstrates how the development licencing scheme has addressed challenges related to structural innovation system failures in the fish-farming technology segment of the Norwegian aquaculture industry.

Thus, based on in-depth interviews with actors involved in the technology development projects and a mapping of the technology development projects, the paper argues that in the short term, the government innovation policy through the development licensing scheme appears to have succeeded in addressing the structural innovation system failures primarily associated with *capabilities* and *networks,* as it clearly played a crucial role in facilitating both the development of new knowledge and capabilities among the traditional aquaculture actors and the reconfiguration of the Norwegian aquaculture innovation networks. This is mainly because the scheme has facilitated the entry of new actors and competences from adjacent sectors and has strengthened ties between the actors involved in the networks. In other words, it is apparent that the scheme has succeeded in fostering radical fish farming-related technological innovations through the creation of new innovative ecosystems and/or networks.

However, the long-lasting effects of the development licencing scheme on the Norwegian aquaculture sector remain to be seen. Nevertheless, the overall success of the innovation policy instrument may ultimately hinge upon sufficiently addressing some aspects of the institutional failures in the sector. More specifically, as the current regulatory framework in the industry has developed with a focus on traditional technology, it has been very much challenged by the emergence of these new concepts. In addition, there is no requirement for the continued used of the technological concepts upon conversion to ordinary (commercial) licenses. Thus, it is necessary for the current regulatory framework to be adapted to the new developments in the sector. In the short run, this may specifically include continued support until the emerging concepts can compete with the traditional low-cost technology. This may further require defining clearer goals of sustainability, a strong enforcement of these and disincentives surrounding technology that fails to adhere to these goals. In light of this, future research could focus on the challenges and opportunities related to the commercialization and/or diffusion of these emerging technologies in the context of regulation of the aquaculture industry both in Norway and other salmon-producing countries.

Furthermore, the paper focused on the aquaculture production technology segment of the industry. Nevertheless, the overall sustainability of the sector is contingent on the sustainable activities in the other segments in the aquaculture value chain as well. Therefore, there is a need for policy intervention to promote sustainability across all aquaculture production stages starting from feed, juvenile production, food fish production, harvesting, processing, logistics, etc.

Data Availability

Data will be made available on request.

Acknowledgements

We would like to thank the two reviewers for helpful and constructive comments. The work for this paper was financed by the "Development licenses as a driver for innovation in fish farming - Effects on technology, industry and regulation" project, Norwegian Research Council no. 301486.

References

[1] S. Afewerki, Firm agency and global production network dynamics, Eur. Plan. Stud. 27 (8) (2019) 1483–1502.
[2] S. Afewerki, M. Steen, Gaining lead firm position in an emerging industry: a global production networks analysis of two Scandinavian energy firms in offshore wind power, Compét. Change (2022), https://doi.org/10.1177/10245294221103072.
[3] S. Afewerki, F. Asche, B. Misund, T. Thorvaldsen, R. Tveteras, Innovation in the Norwegian aquaculture industry, Rev. Aquac. 15 (2) (2023) 759–771.
[4] K.A. Alexander, A social license to operate for aquaculture: reflections from Tasmania, Aquaculture 550 (2022), 737875.

[5] V.S. Amundsen, From checking boxes to actual improvement: a new take on sustainability certification, Aquaculture 548 (2022), 737672.
[6] V.S. Amundsen, T.C. Osmundsen, Becoming certified, becoming sustainable? Improvements from aquaculture certification schemes as experienced by those certified, Mar. Policy 119 (2020), 104097.
[7] J.L. Anderson, F. Asche, T. Garlock, Economics of aquaculture policy and regulation, Annu. Rev. Resour. Econ. 11 (2019) 101–123.
[8] F. Asche, Farming the sea, Mar. Resour. Econ. 23 (4) (2008) 527–547.
[9] F. Asche, K.H. Roll, R. Tveterås, Innovations and Productivity Performance in Salmon Aquaculture, IFIP International Conference on Advances in Production Management Systems, 2012.
[10] F. Asche, M. Sikveland, D. Zhang, Profitability in Norwegian salmon farming: the impact of firm size and price variability, Aquac. Econ. Manag. 22 (3) (2018) 306–317.
[11] F. Asche, J. Bronnmann, A.L. Cojocaru, The value of responsibly farmed fish: a hedonic price study of ASC-certified whitefish, Ecol. Econ. 188 (2021), 107135.
[12] F. Asche, K. Roll, H. Sandvold, A. Sørvig, D. Zhang, Salmon aquaculture: larger companies and increased production, Aquac. Econ. Manag. 17 (3) (2013) 322–339.
[13] F. Asche, H. Eggert, A. Oglend, C.A. Roheim, M.D. Smith, Aquaculture: externalities and policy options, Rev. Environ. Econ. Policy 16 (2) (2022) 282–305.
[14] O. Bergesen, R. Tveterås, Innovation in seafood value chains: the case of Norway, Aquac. Econ. Manag. 23 (3) (2019) 292–320.
[15] S.-L. Billing, Using public comments to gauge social licence to operate for finfish aquaculture: lessons from Scotland, Ocean Coast. Manag. 165 (2018) 401–415.
[16] A.D. Chandler, Scale and Scope: The Dynamics of Industrial Capitalism, Belknap Press of Harvard Univ. Press, Cambridge, MA, 1990.
[17] N.M. Coe, H.W.-C. Yeung. Global Production Networks: Theorizing Economic Development in an interconnected world, Oxford University Press, Oxford, 2015.
[18] A. Davies, T. Brady, Organizational capabilities and learning in complex product systems: towards repeatable solutions, Res. Policy 29 (2000) 931–953.
[19] S. Dawley, D. MacKinnon, R. Pollock, Creating strategic couplings in global production networks: regional institutions and lead firm investment in the Humber region, UK, J. Econ. Geogr. 19 (2019) 853–872.
[20] G. Di Stefanoa, A. Gambardella, G. Verona, Technology push and demand-pull perspectives in innovation studies: current findings and future research directions, Res. Policy 41 (2012) 1283–1295.
[21] Directorate of Fisheries. (2021). Utviklingstillatelser. Retrieved 21 September 2021, from https://www.fiskeridir.no/Akvakultur/Tildeling-og-tillatelser/Saertillatelser/Utviklingstillatelser.
[22] J. Edler, J. Fagerberg, Innovation policy: what, why, and how, Oxf. Rev. Econ. Policy 33 (1) (2017) 2–23.
[23] C. Edquist, Design of innovation policy through diagnostic analysis: Identification of systemic problems (or failures), Ind. Corp. Change 20 (2011) 1–29.
[24] EY, The Norwegian Aquaculture Analysis 2019, EYGM Limited, Oslo, 2020.
[25] EY, The Norwegian Aquaculture Analysis 2020, EYGM Limited, Oslo, 2021.
[26] FAO, The State of World Fisheries and Aquaculture: Towards Blue Transformation, Food and Agriculture Organization of the United Nations, Rome, 2022.
[27] A. Fløysand, S.-E. Jakobsen, Industrial renewal: narratives in play in the development of green technologies in the Norwegian salmon farming industry, Geogr. J. 183 (2) (2017) 140–151.
[28] H.M. Føre, T. Thorvaldsen, Causal analysis of escape of Atlantic salmon and rainbow trout from Norwegian fish farms during 2010–2018, Aquaculture 532 (2021), 736002.
[29] H.M. Føre, T. Thorvaldsen, T.C. Osmundsen, F. Asche, R. Tveterås, J.T. Fagertun, H.V. Bjelland, Technological innovations promoting sustainable salmon (*Salmo salar*) aquaculture in Norway, Aquac. Rep. 24, (2022) 1–10.
[30] H.E. Froehlich, J.Z. Koehn, K.K. Holsman, B.S. Halpern, Emerging trends in science and news of climate change threats to and adaptation of aquaculture, Aquaculture 549 (2022), 737812, https://doi.org/10.1016/j.aquaculture.2021.737812.
[31] B. Godin, National innovation system: the system approach in historical perspective, Sci., Technol., Hum. Values 34 (*4*) (2009) *476–501*.
[32] B. Godin, D. Vinck, Critical Studies of Innovation: Alternative Approaches to the Pro-innovation Bias, Edward Elgar, Cheltenham, UK, 2017.
[33] O. Granstrand, M. Holgersson, Innovation ecosystems: a conceptual review and a new definition, Technovation (2020) *90–91*.
[34] M. Greaker, I. Vormedal, K. Rosendal, Environmental policy and innovation in Norwegian fish farming: resolving the sea lice problem? Mar. Policy 117 (2020), 103942.
[35] L. Grünfeld, C. Lie, M. Basso, O. Grønvik, A. Iversen, Å. Espmark, M. Jørgensen, Evaluering av Utviklingstillatelser for Havbruksnæringen og Vurdering av Alternative Ordringenr for Fremtiden, Menon Economics, Oslo, 2021, pp. 2–118.
[36] B. Hersoug, Why and how to regulate Norwegian salmon production? – The history of maximum allowable biomass (MAB), Aquaculture 545 (2021), 737144.
[37] B. Hersoug, One country, ten systems–the use of different licensing systems in Norwegian aquaculture, Mar. Policy 137 (2022), 104902.
[38] B. Hersoug, E. Mikkelsen, K.M. Karlsen, "Great expectations"–Allocating licenses with special requirements in Norwegian salmon farming, Mar. Policy 100 (2019) 152–162.
[39] B. Hersoug, M. Olsen, A. Gauteplass, T. Osmundsen, F. Asche, Serving the industry or undermining the regulatory system? The use of special purpose licenses in Norwegian salmon aquaculture, Aquaculture 543 (2021), 736918.
[40] R. Kelly, G.T. Pecl, A. Fleming, Social licence in the marine sector: a review of understanding and application, Mar. Policy 81 (2017) 21–28.
[41] R. Klein Woolthuis, M. Lankhuizen, V. Gilsing, A system failure framework for innovation policy design, Technovation 25 (2005) 609–619.
[42] S. Klepper, Entry, exit, growth, and innovation over the product life cycle, Am. Econ. Rev. 86 (1996) 562–583.
[43] S. Klepper, Industry life cycles, Ind. Corp. Change 6 (1997) 145–182.
[44] G. Kumar, C.R. Engle, Technological advances that led to growth of shrimp, salmon, and tilapia farming, Rev. Fish. Sci. Aquacult. 24 (2) (2016) 136–152.
[45] P. Leith, E. Ogier, M. Haward, Science and social license: defining environmental sustainability of atlantic salmon aquaculture in South-Eastern Tasmania, Australia, Soc. Epistemol 28 (3–4) (2014) 277–296.
[46] G. Lilleng, (2020). Kollektivt entreprenørskap. En studie av ordningen med utviklingstillatelser i norsk havbruksnæring. [Master thesis]. The Arctic University of Norway.
[47] E.T. Lindfors, Radical path transformation of the Norwegian and Tasmanian salmon farming industries, Reg. Stud., Reg. Sci. 9 (1) (2022) 757–775.
[48] D.C. Little, J.A. Young, W. Zhang, R.W. Newton, A. al Mamun, F.J. Murray, Sustainable intensification of aquaculture value chains between Asia and Europe: A framework for understanding impacts and challenges, Aquaculture 493 (2018) 338–354.
[49] D. MacKinnon, S. Afewerki, A. Karlsen, Technology legitimation and strategic coupling: a cross-national study of floating wind power in Norway and Scotland, Geoforum 135 (2022) 1–11.
[50] F. Malerba, Sectoral systems of innovation and production, Res. Policy 31 (2) (2002) 247–264.
[51] C. Mather, L. Fanning, Social licence and aquaculture: towards a research agenda, Mar. Policy 99 (2019) 275–282.
[52] Meld St. 16 (2014-2015), Forutsigbar og miljømessig bærekraftig vekst i norsk lakse- og ørretoppdrett (Meld. St. 16 (2014–2015), Ministry of Trade Industry and Fisheries, 2015.
[53] A.U. Misund, From a natural occurring parasitic organism to a management object: historical perceptions and discourses related to salmon lice in Norway, Mar. Policy 99 (2019) 400–406.
[54] B. Misund , & R. Tveterås, (2020). Economic rents in Norwegian aquaculture. NORCE Report 39/2020. https://norceresearch.brage.unit.no/norceresearch-xmlui/handle/11250/2837743.
[55] R.L. Naylor, R.W. Hardy, A.H. Buschmann, S.R. Bush, L. Cao, D.H. Klinger, D. C. Little, J. Lubchenco, S.E. Shumway, M. Troell, A 20-year retrospective review of global aquaculture, Nature 591 (2021) 551–563.
[56] M.J. Newton, T.A. Farrelly, J. Sinner, Discourse, agency, and social license to operate in New Zealand's marine economy, Ecol. Soc. 25 (2020) 1.
[57] T. Nyrud, E. Mikkelsen, Familieeierskap i Oppdrettsnæringen, NOFIMA, Tromsø, 2021.
[58] A. Oglend, V.H. Soini, Implications of entry restrictions to address externalities in aquaculture: the case of salmon aquaculture, Environ. Resour. Econ. 77 (2020) 673–694.
[59] T. Osmundsen, M. Olsen, T. Thorvaldsen, The making of a louse - constructing governmental technology for sustainable aquaculture, Environ. Sci. Policy 104 (2020) 121–128.
[60] T. Osmundsen, M.S. Olsen, A. Gauteplass, F. Asche, Aquaculture policy: designing licenses for environmental regulation, Mar. Policy 138 (2022) 1–12.
[61] T.C. Osmundsen, P. Almklov, R. Tveterås, Fish farmers and regulators coping with the wickedness of aquaculture, Aquac. Econ. Manag. 21 (1) (2017) 163–183.
[62] T.C. Osmundsen, V.S. Amundsen, K.A. Alexander, F. Asche, J. Bailey, B. Finstad, M. S. Olsen, K. Hernández, H. Salgado, The operationalisation of sustainability: Sustainable aquaculture production as defined by certification schemes, Glob. Environ. Change 60 (2020), 102025.
[63] L. Pal, Case Study Method and Policy Analysis, in: I. Geva-May (Ed.), Thinking like a policy analyst: policy analysis as a clinical profession, Palgrave Macmillan, New York, 2005, pp. 227–257.
[64] L. Pal, Beyond Policy Analysis – Public Issue Management in Turbulent Times, Nelson Education, Toronto, 2014.
[65] R.B. Pincinato, F. Asche, K.H. Roll, Escapees in salmon aquaculture: a multi-output approach, Land Econ. 97 (2) (2021) 425–435.
[66] I.V. Poel, The transformation of technological regimes, Res. Policy 32 (1) (2003) 49–68.
[67] J. Schumpeter, The Theory of Economic Development, Harvard University Press, Cambridge, MA, 1934.
[68] M. Sikveland, R. Tveteras, D. Zhang, Profitability differences between public and private firms: the case of Norwegian salmon aquaculture, Aquac. Econ. Manag. 26 (4) (2022) 414–438.
[69] S.G. Sjøtun, A. Fløysand, H. Wiig, J.Z. Hopp, Multi-level agency and transformative capacity for environmental risk reduction in the Norwegian salmon farming industry, Front. Hum. Dyn. (2022) *48*.
[70] M.D. Smith, C.A. Roheim, L.B. Crowder, B.S. Halpern, M. Turnipseed, J. L. Anderson, F. Asche, L. Bourillón, A.G. Guttormsen, A. Khan, L.A. Liguori, A. McNevin, M.I. O'Connor, D. Squires, P. Tyedmers, C. Brownstein, K. Carden, D. H. Klinger, R. Sagarin, K.A. Selkoe, Sustainability and global seafood, Science 327 (5967) (2010) 784–786.
[71] L. Stien, K. Størkersen, S. Gåsnes, Analyse av Dødelighetsdata fra Spørreundersøkelse om Velferd hos Rensefisk, Havforskningsinstituttet, Bergen, 2020.
[72] K. Størkersen, Fish first: Sharp end decision-making at Norwegian fish farms, Saf. Sci. 50 (2012) 2028–2034.
[73] K. Størkersen, T. Osmundsen, L. Stien, C. Medaas, M. Lien, B. Tørud, T. Kristiansen, K. Gismervi, Fish protection during fish production. Organizational conditions for fish welfare, Mar. Policy 129 (2021), 104530.

[74] S. Tveteras, Norwegian salmon aquaculture and sustainability: the relationship between environmental quality and industry growth, Mar. Resour. Econ. 17 (2) (2002) 121–132.
[75] R. Tveterås, M. Hovland, T. Reve, B. Misund, R. Nystøyl, H. Bjelland, et al., Verdiskapingspotensialet og veikart for havbruk til havs, Stavanger, 2020, pp. 14–118.
[76] I. Vormedal, M. Larsen, K. Flåm, Grønn Vekst I Blå Næring? Miljørettet Innovasjon I Norsk Lakseoppdrett, Fridtjof Nansen Institute, Lysaker, 2019.
[77] K.M. Weber, H. Rohracher, Legitimizing research, technology, and innovation policies for transformative change: combining insights from innovation systems and multi-level perspective in a comprehensive "failures" framework, Res. Policy 41 (2012) 1037–1047.
[78] R.K. Yin, Case Study Research and Applications, SAGE Publications Inc, California, 2018.
[79] N. Young, C. Brattland, C. Digiovanni, B. Hersoug, J.P. Johnsen, K.M. Karlsen, H. Thorarensen, Limitations to growth: social-ecological challenges to aquaculture development in five wealthy nations, Mar. Policy 104 (2019) 216–224.
[80] T. Ytrestøyl, T.S. Aas, T. Åsgård, Utilisation of feed resources in production of Atlantic salmon (Salmo salar) in Norway, Aquaculture 448 (2015) 365–374.
[81] D. Zhang, R. Tveterås, Influence of price variability and financial ratios on business failure in the Atlantic Salmon industry, Mar. Resour. Econ. 37 (2) (2022) 183–200.