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Sustainability and innovation across the aquaculture value chain

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Previous research has shown that Norwegian aquaculture firms strongly emphasize environmental and social sustainability, and this study aims to assess if the pattern is consistent across the value chain and consistent independent of suppliers' amount of sales to fish farming. Also, it studies if value chain position and sales to fish farming are associated with innovation activities. Empirically, the study compares survey data between firms in the aquaculture industry and other industries as reference groups. The results show that aquaculture firms across the value chain overall emphasize environmental and social sustainability more than actors in the reference industries. For suppliers, the emphasis is strongest for those with high sales to fish farming. Another finding is that aquaculture firms' innovation activities are relatively strong among firms providing services and input factors, particularly among suppliers with high sales to fish farming.

KEYWORDS

aquaculture, environmental sustainability, social sustainability, innovation, value chain

1 Introduction

It is well known that the aquaculture industry faces several environmental challenges, e.g., pollution in terms of emission of sewages, sea lice, and escapees from pens (Wu, 1991; Hannisdal et al., 2020; Pincinato et al., 2021), which, among stakeholders, has resulted in "widespread environmental and socio-economic concerns with respect to the salmon aquaculture industry" (Bailey and Eggereide, 2020, p. 1). In tandem with these challenges and concerns, research has emphasized environmental sustainability in the aquaculture industry (Neori et al., 2004; Martins et al., 2010; Clark and Tilman, 2017; Georgopoulou et al., 2024), and a recent study showed that is not downplayed by firms in the sector (Aarstad et al., 2023a). On the contrary, aquaculture firms strongly emphasize environmental sustainability, and a potential explanation is their exposure to the industry's challenges. However, if the explanation is valid, one can assume variations in firms' emphasis on environmental sustainability across the value chain since not all industry activities may be equally exposed to the challenges. E.g., firms largely involved in sales of equipment, consulting and research, and feed and fish health products or services are less directly exposed to environmental challenges than those involved in the very production of salmon or trout. A counterpoint is that the knowledge of challenges has diffused across the aquaculture value chain, inducing consistency in environmental sustainability.

Responding to these contrasting arguments, this study investigates if the emphasis on environmental sustainability varies or is consistent across the value chain. Similarly, it investigates if suppliers' sales to fish farming is associated with their emphasis on environmental sustainability. Assuming that exposure to pollution in terms of emission of sewages, sea lice, and escapees from pens has induced aquaculture firms to emphasize environmental sustainability, those suppliers with high sales to fish farming firms may have the strongest emphasis, but we do not rule out that for instance knowledge diffusion has induced a consistent pattern.

In addition to environmental sustainability, research has also emphasized the importance of social sustainability in the aquaculture industry (Valenti et al., 2018; Ferreira et al., 2023; Sannou et al., 2023), which, possibly because actors benefit from their sociocultural proximity to local communities (Hessen, 2022), is neither downplayed by them (Aarstad et al., 2023a). Grounding our study in this research as a further contribution, following the diffusion argument, we investigate whether the emphasis on social sustainability is consistent across the value chain and independent of suppliers' sales to fish farming. Finally, grounding our study in research showing that the Norwegian aquaculture industry is considered a leading R&D-intensive innovative actor internationally (Bergesen and Tveterås, 2019; Cojocaru et al., 2021; Iversen and Hydle, 2023; Afewerki et al., 2023a), we investigate its innovation activities compared to other industries and if they are consistent across the value chain and consistent independent of suppliers' sales to fish farming.

The study defines environmental sustainability as "a proclivity to collaborate with stakeholders concerning environmental improvements, share information with competitors concerning environmental improvements, emphasize environmental improvements rather than short-term economic gains, and emphasize environmental improvements as a means of increasing earnings" (Aarstad and Jakobsen, 2020, p. 1). Social sustainability the literature defines less consistently, but it largely emphasizes local ripple effects, e.g., economic gains for the society at large, including job creation (Carroll, 1979; Gössling and Vocht, 2007; Saeidi et al., 2015). The aquaculture industry's value chain can be understood as firms either being "involved in (1) production and sales of salmon and trout, (2) production and sales of other fish farming species, (3) supply of technological solutions including equipment and consulting services, … [or] (4) supply of other products and services including feed production, fish health products, and transport services" (Aarstad et al., 2023b, p. 133). At last, the study labels innovation activities as firms' propensity to develop "new or improved products, services, or manufacturing processes" or if they have interfirm collaboration concerning those issues (Aarstad and Jakobsen, 2020, p. 2). Connotatively, there may be some overlap between the concepts of environmental sustainability and innovation activities, but we emphasize that in this study, the latter does not explicitly relate to ecological improvements.

Scholars have studied how aquaculture value chains are shaped and developed (Jespersen et al., 2014; Ponte et al., 2014; Kaminski et al., 2018), which, according to Pomeroy et al. (2017, p. 542) "can uncover insights into the linkages and trust … and constraints and challenges that face the sector." Despite these studies, a need has been addressed for further attention on aquaculture value chain research, particularly how the sector contributes "to the sustainable expansion as an increasingly important component of the global food system" (Bush et al., 2019, p. 428).

Aarstad et al. (2023b) recently found that aquaculture firms across the value chain and suppliers with both low and high sales to fish farming were not much affected by the COVID-19 pandemic, but they nonetheless had a strong proactive response to the crisis. In line with the above reasoning, plausible explanations are that knowledge has diffused across the value chain and to suppliers with limited sales to fish farming. Likewise, we do not rule out that the same mechanism has induced aquaculture firms across the value chain and those suppliers with limited sales to fish farming to coherently have adopted a strong emphasis on environmental and social sustainability. Having noted that pollution probably has induced an emphasis on environmental sustainability and that beneficial sociocultural proximity to local communities has induced an emphasis on social sustainability, we accordingly assume that those conducts have similarly diffused across the value chain and to suppliers with limited sales to fish farming.

Above, we asserted that the Norwegian aquaculture industry is internationally considered a leading innovative actor (Bergesen and Tveterås, 2019; Cojocaru et al., 2021; Afewerki et al., 2023a). Possible reasons can be a strong emphasis on sustainability and a long history, but we do not know the extent to which there have been spillover effects concerning innovation activities across the value chain and to suppliers with limited sales to fish farming. I.e., we do not know whether innovation activities occur among particular aquaculture firms, if the pattern is consistent across various value chain actors, or if it is independent of suppliers' sales to fish farming. Following our above arguments, we nonetheless assume that knowledge diffusion may also have induced innovation activities to spread across the value chain and to suppliers with limited sales to fish farming, and the following sections further illuminate this and the other research questions.

2 Materials and methods

Empirically, we merged and compared data from two surveys gathered early in 2021 via telephone interviews by Ipsos, a market consulting firm. Respondents were the firms' CEO or deputy CEO.

The first survey included data from the aquaculture industry, but since candidate firms do not necessarily operate within particular sectors as identified by Standard Industrial Classification (SIC) codes, they were identified by a private research institute knowledgeable about that particular sector. (To validate the identification, later analyses will show how firms in the aquaculture industry were properly classified along its value chain.) Concerning potential suppliers to fish farming, candidate firms had at least 20 percent of their total sales to the sector. Two hundred and one firms identified as being involved with or affiliated with aquaculture responded to the survey (later analyses include 200 firms only due to one with incomplete data). For the identified aquaculture industry, it represents a 15% response rate in the first survey.

The second survey included firms from three other industries: the manufacturing industry, the consulting, finance and insurance industry, and the hospitality tourism and culture industry, 200 in each, with a 25% response rate. The data for the second survey were gathered by the same market research consulting firm as described above, and SIC codes were used to identify each of the three industries: 10-32 for the manufacturing industry, 69-75, and 77-82 for the consulting finance and insurance industry, and 55-56 and 90-93 for the hospitality tourism and culture industry (for details, please see sb.no/en/klass/klassifikasjoner/6).

Table 1A reports items used to measure environmental and social sustainability as dependent variables. Empirically, they were measured on a five-point Likert scale where the respondents could indicate answers varying between "to a very little extent" (coded 1) and "to a very large extent" (coded 5). A few absent or "do not know" answers were coded 3 ("neither nor"). To measure environmental and social sustainability, respectively, as dependent variables, we took the average scores of the items reflecting each construct. Aarstad et al. (2023a) used the same data and also inform about the constructs' validity (i.e., factor loadings) and reliability (i.e., Cronbach's alpha measures).

To measure innovation activities as a third dependent variable, the surveys asked if the firm "in the last three years (1) collaborated with other institutions or companies concerning improvement or development of processes or products, (2) introduced a new or considerably improved process innovation, (3) introduced a new or considerably improved service or product, and (4) if any new service or product was also new for the market" (Aarstad et al., 2023a, p. 3). Responding yes to a question was coded as one and zero otherwise, and we added the score for each respondent to measure the concept. The questions were based on the Community Innovation Survey by Eurostat (OECD/Eurostat, 2005). We modeled innovation activities as an ordinal dependent variable in the regression analyses. In addition, we modeled the concept as a linear control variable when modeling environmental and social sustainability as dependent variables.

To identify each aquaculture firm's value chain position, the respondents could indicate between ten activities they had been involved in the last year (listed in Table 1B). It was possible to indicate more than one activity. Based on that raw data, we next used Breiger et al.'s (1975) CONCOR (convergence of iterated correlations) methodology in the Ucinet (Borgatti et al., 2002) social network program to identify four structurally equivalent blocks of value chain activities representing 79.2% variation compared to each activity individually. Overall, the four blocks represent value chain activities that relate to "the production and sales of salmon and trout (Block 1), production and sales of other fish farming species (Block 2), supply of technological solutions including equipment and consulting services (Block 3), and supply of other products and services including feed production, fish health products and transport services (Block 4)" (Aarstad et al., 2023b, p. 136).

Moreover, respondents reporting activities in Block 3 or 4 were also requested about the percentage in sales to fish farming. Those numbers were categorized into two dummy variables labeled as less than or equal to 50% sales or more than 50% sales to fish farming.

The study controls for (1) firm size in the number of employees, (2) whether the firm has major ownership locally or regionally, nationally beyond the region, or internationally, and (3) whether the firm has international engagements (i.e., in the last year had production in another country, ownership in another country, or sales to another country). We include the variables to control for unobserved heterogeneity in the data that the other variables may not account for.

3 Results

Model 1 in Table 2 shows that firms in the aquaculture industry emphasize environmental sustainability significantly more than those in the three other industries merged into one reference group (the reason they were merged is Aarstad et al. (2023a) showing that firms in all three reference industries emphasized environmental sustainability consistently and significantly less than in the aquaculture industry). Model 2 moreover shows that firms in

TABLE 1A Environmental and social sustainability.

Environmental sustainability	We consult collaboration partners, authorities, or interest groups about environmental improvements. We collaborate with other actors about environmental improvements. We carry out development and innovation efforts to reduce our environmental footprint. We apply R&D-based knowledge to reduce our environmental footprint. Environmental improvements strengthen our earnings. We are more concerned about environmental challenges than other enterprises in the industry. Environmental improvements have greater importance than short-term economic gains.
Social sustainability	We are concerned about local ripple effects of our business (jobs, purchase of goods and services, tax revenues). Local jobs have greater importance than short-term economic gains. We are concerned about dialogue with those who are affected by our business (for instance, the local community, environmental organizations). We give economic support to voluntary activities in the local community (sports organizations, cultural events, etc.). We are more concerned about creating jobs than other firms in the industry.

TABLE 1B Results of block modeling.

Block 1	Production of salmon or trout. Production of eggs or smolt. Slaughter or processing of salmon/trout. Sales of salmon/trout.
Block 2	Production of other fish farming species than salmon or trout.
Block 3	Production and sales of equipment for the fish farming industry Consulting and/or research services aimed at the fish farming industry.
Block 4	Production of feed. Production and sales of fish health products or services (including production of cleaning fish). Transport services for the fish farming industry (well boats, etc.).

the aquaculture industry across the value chain, as identified in the four structurally equivalent blocks of actors, consistently and significantly emphasize environmental sustainability more than those in the three other industries merged into one reference group. Model 3 shows that suppliers to fish farming emphasize environmental sustainability significantly more than those in the merged reference group, independent of the amount of sales. However, the effect is stronger for those with the highest sales (the number of observations is lower in Model 3 than in the two previous models because it only includes firms from the aquaculture industry that operate in Block 3 or 4). Table 2 also informs that innovation-active firms emphasize environmental sustainability relatively much. Finally, Table 2 informs that firms with many employees tend to emphasize environmental sustainability relatively much, but the effect is only borderline significant in two of the three models.

Model 1 in Table 3 shows that firms in the aquaculture industry emphasize social sustainability significantly more than those in the three other industries, again merged into one reference group (the reason being the same as described in the paragraph above). However, the social sustainability effect is less marked than the environmental sustainability effect. Model 2 shows that the firms in the aquaculture industry across the value chain, except for those involved with the production and sales of equipment and doing consulting or research activities (Block 3), emphasize social sustainability significantly more than those in the three other industries. Model 3 shows that only suppliers with high sales to fish farming emphasize social sustainability significantly more than those in the merged reference group. Table 3 finally informs that innovation-active firms and those with many employees emphasize social sustainability relatively much.

Model 1 in Table 4 shows that firms in the aquaculture industry are significantly more innovation-active than those in the reference industries, except for the manufacturing industry, where the difference is borderline significant (the findings are illuminated by showing negative effects for the reference industries when the aquaculture industry is modeled as default). Model 2 similarly shows that firms in the aquaculture industry are significantly more innovation-active than firms in the two merged consulting, finance, and insurance industry and the hospitality, tourism and culture industry as a reference group. Model 3 shows that the innovation activities are significant and consistent across the value chain, but the effect is not particularly strong for aquaculture firms involved in the production of salmon or trout, the production of eggs or smolt, the slaughter or processing of salmon or trout, or sales of salmon or trout (Block 1). Model 4 shows that only firms with strong sales to fish farming are significantly more innovation-active than firms in the merged reference group. Finally, Table 4 informs that firms with many employees and international engagements are relatively innovation-active.

TABLE 2 Ordinary least square regressions with robust standard errors in parentheses.

	Model 1	Model 2	Model 3
Control variables			
Number of employees (log)	.045† [.059]	.045† [.059]	.032
	(.025)	(.025)	(.027)
Major ownership locally or regionally[a]	-.102	-.102	-.202† [-.074]
	(.124)	(.124)	(.122)
Major ownership nationally beyond the region[a]	.123	.116	-.025
	(.156)	(.155)	(.158)
International engagements	-.071	-.069	-.054
	(.067)	(.066)	(.073)
Innovation activities	.243*** [.371]	.244*** [.372]	.241*** [.372]
	(.022)	(.022)	(.023)
Independent variables			
Aquaculture[b]	.563*** [.268]		
	(.069)		
Block 1[b]		.564*** [.159]	
		(.105)	
Block 2[b]		.718*** [.137]	
		(.152)	
Block 3[b]		.555*** [.183]	
		(.106)	
Block 4[b]		.475*** [.112]	
		(.134)	
Less than or equal to 50%[b]			.386* [.079]
			(.188)
More than 50%[b]			.536*** [.200]
			(.097)
R-square/R-square adj.	.246/.241	.248/.239	.224/.217
F-value	52.6***	35.9***	35.0***
Max./avg. VIFs	2.25/1.52	2.26/1.36	2.25/1.45
Number of observations	800	800	717

Two-tailed tests of significance for regression coefficients. Beta values for significant regressors in brackets. † p <.10; * p <.05; ** p <.01; *** p<.001. Intercepts omitted. [a]Default is major ownership internationally. [b]Default is the merged (1) manufacturing industry, (2) consulting, finance and insurance industry, and (3) hospitality, tourism and culture industry. Dependent variable is environmental sustainability.

4 Discussion and policy implications

Motivated by research showing that Norwegian aquaculture firms strongly emphasize environmental and social sustainability (Aarstad et al., 2023a), this study aimed to assess whether the pattern is consistent across the value chain and consistent independent of suppliers' sales to fish farming. Motivated by

TABLE 3 Ordinary least square regressions with robust standard errors in parentheses.

	Model 1	Model 2	Model 3
Control variables			
Number of employees (log)	.058* [.096]	.056* [.094]	.061* [.098]
	(.023)	(.022)	(.025)
Major ownership locally or regionally[a]	.354** [.162]	.363** [.167]	.339** [.155]
	(.114)	(.112)	(.124)
Major ownership nationally beyond the region[a]	.195	.210	.145
	(.147)	(.144)	(.158)
International engagements	-.113* [-.072]	-.096† [-.061]	-.119† [-.075]
	(.058)	(.058)	(.063)
Innovation activities	.117*** [.225]	.118*** [.227]	.122*** [.236]
	(.018)	(.018)	(.019)
Independent variables			
Aquaculture[b]	.251*** [.151]		
	(.060)		
Block 1[b]		.289** [.103]	
		(.097)	
Block 2[b]		.399** [.097]	
		(.121)	
Block 3[b]		.085	
		(.091)	
Block 4[b]		.408*** [.122]	
		(.095)	
Less than or equal to 50%[b]			.148
			(.161)
More than 50%[b]			.206* [.096]
			(.080)
R-square/R-square adj.	.090/.083	.099/.089	.083/.074
F-value	13.8***	10.8***	10.1***
Max./avg. VIFs	2.25/1.52	2.26/1.36	2.25/1.45
Number of observations	800	800	717

Two-tailed tests of significance for regression coefficients. Beta values for significant regressors in brackets. † p <.10; * p <.05; ** p <.01; *** p<.001. Intercepts omitted. [a]Default is major ownership internationally. [b]Default is the merged (1) manufacturing industry, (2) consulting, finance and insurance industry, and (3) hospitality, tourism and culture industry. Dependent variable is social sustainability.

research showing that the Norwegian aquaculture industry is considered a leading innovative actor internationally (Bergesen and Tveterås, 2019; Cojocaru et al., 2021; Afewerki et al., 2023a), the study further aimed to assess if the firms' value chain position and suppliers' sales to fish farming were associated with their innovation activities. To study the research questions, we compared survey data between firms in the aquaculture industry and other industries as reference groups.

The results showed that aquaculture firms across the value chain overall emphasize environmental and social sustainability more than actors in the reference industries, and among suppliers, the emphasis is strongest for those with high sales to fish farming. Another finding was that aquaculture firms' innovation activities are relatively strong among firms providing services and input factors, particularly among suppliers with high sales to fish farming.

A theoretical implication of the findings is that learning appears to have diffused across the value chain as firms are coherently concerned with environmental sustainability independent of their explicit exposure to pollution. Another theoretical implication is that firms in the industry coherently emphasize social sustainability independent of value chain position.

A policy implication of the study is observing that the aquaculture industry's strong emphasis on environmental and social sustainability is consistent across the value chain. The findings communicate that the overall industry indeed takes its environmental social responsibility seriously, and the findings need to be communicated to policymakers in particular.

To our knowledge, this is the first study comparing aquaculture firms' emphasis on environmental sustainability, social sustainability, and innovation activities across the value chain with firms operating in other industries as reference groups. Also, it is the first study comparing how suppliers' sales to fish farming affect sustainability and innovation activities. Concerning our findings, it is not unlikely that a relatively strong emphasis on environmental and social sustainability across the value chain may be due to the diffusion of learning and resources, but a limitation is that we did not explicitly investigate this issue. Therefore, future research should emphasize why there is a fairly strong consistency in environmental and social sustainability across the aquaculture value chain. Also, future research should further address why suppliers with high sales to fish farming seem to emphasize sustainability and innovation activities relatively strongly.

Related to the above, it should be noted that, due to strong environmental concerns, regulations regarding so-called green licenses, development licenses, and eco-technology licenses have been proposed in the Norwegian aquaculture industry (Osmundsen et al., 2022), which we do not deny may have influenced this study's survey responses. Acknowledging this potential explanation, we encourage future research to unpack the extent to which the license proposals may have contributed to the aquaculture industry's overall positive emphasis on environmental sustainability our research has shown. Similarly, we acknowledge that local

TABLE 4 Ordinal logistic regressions with robust standard errors in parentheses.

	Model 1	Model 2	Model 3	Model 4
Control variables				
Number of employees (log)	.260***	.233***	.225***	.170***
	(.059)	(.066)	(.067)	(.076)
Major ownership locally or regionally[a]	-.278	-.241	-.219	-.222
	(.315)	(.452)	(.471)	(.497)
Major ownership nationally beyond the region[a]	-.025	-.099	-.131	.276
	(.402)	(.567)	(.584)	(.590)
International engagements	.711***	.594**	.549**	.671**
	(.155)	(.183)	(.188)	(.211)
Independent variables				
Manufacturing[b]	-.325†			
	(.195)			
Consulting, finance, and insurance[b]	-1.03***			
	(.198)			
Hospitality, tourism, and culture[b]	-.961***			
	(.201)			
Aquaculture[c]		1.01***		
		(.183)		
Block 1[c]			.539*	
			(.255)	
Block 2[c]			.917*	
			(.441)	
Block 3[c]			1.25***	
			(.265)	
Block 4[c]			1.47***	
			(.356)	
Less than or equal to 50%[c]				.455
				(.480)
More than 50%[c]				1.43***
				(.249)
Wald χ^2	104.4***	72.2***	77.7***	75.5***
Max./avg. VIFs	2.27/1.70	2.33/1.64	2.34/1.44	2.34/1.55
Number of observations	800	600	600	517

Two-tailed tests of significance for regression coefficients. † p <.10; * p <.05; ** p <.01; *** p<.001. Intercepts omitted. [a]Default is major ownership internationally. [b]Default is the aquaculture industry. [c]Default is the merged consulting, finance, and insurance industry and the hospitality, tourism, and culture industry.
Dependent variable is innovation activities.

authorities showing goodwill, e.g., by granting access to fish farming, may have influenced the social sustainability scores, which we also encourage future research to investigate. Finally, as the license proposals were aimed at leveraging innovations (Tveterås et al., 2020; Grünfeld et al., 2021; Afewerki et al., 2023b), we encourage future research to investigate the extent to which they may have influenced our findings concerning that concept.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

JA: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. SJ: Conceptualization, Funding acquisition, Project administration, Writing – review & editing. AF: Data curation, Funding acquisition, Project administration, Writing – review & editing. OK: Formal analysis, Methodology, Software, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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