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GLOSSARY OF ACRONYMS

Acronym	Definition
BP	By-product
Cat.	Category
D.	Deliverable
EU	European Union
EEA	European Economic Area
EISI	Eco-Intensification Sustainability Index
GAIN	Green Aquaculture Intensification in Europe
(G)VCA	(Global) Value Chain Analysis
HOG	Head-on-gutted
IoA	Institute of Aquaculture
KI	Key Informant
LCA	Life Cycle Analysis
LWE	Life Weight Equivalent
MT	Metric Tonne
NO	Norway/Norwegian
PO	Poland/Polish
PLN	Polish złoty (zł)
S.	Scenario
UoS	University of Stirling
UK	United Kingdom
WP	Work Package
ZUT	West Pomeranian University of Technology (Zachodniopomorski Uniwersytet Technologiczny w Szczecinie)

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Executive summary

The goal of the Green Aquaculture Intensification (GAIN) project is to increase aquaculture output in production and value, while using resources more efficiently, reducing environmental impacts and enhancing societal outcomes. To avoid unintended consequences, an understanding of the value chain is crucial. A value chain analysis (VCA) includes evaluation of each step (node) of a product's value creation. Evaluation of a value chain also includes factors directly involved in the manufacturing process, such as the sourcing of raw materials, production, processing, and distribution costs, but also indirectly linked stakeholders and sustainability characteristics that drive customers' willingness to pay for the final product. The nodes are made up of different actors (e.g., companies, organizations, and individuals) who play important roles in the production and consumption process and are therefore crucial to assess from production to the consumption of the product.

This report is focused on some of the most representative value chains in the EU and European Economic Area, namely those of Atlantic salmon (*Salmo salar*) in Norway, common carp (*Cyprinus carpio*) in Poland, rainbow trout (*Oncorhynchus mykiss*) in Italy and blue mussel (*Mytilus edulis*) and Pacific oyster (*Crassostrea gigas*) in the United Kingdom (UK). The species and culture system combinations were selected based on their unique characteristics, access to data and to reflect the full range of current system intensity. Atlantic salmon production in Norway is intensive and cage-based with well-established domestic and, mainly, export markets (Asche et al., 2013). Rainbow trout production in Europe is considered intensive, with a fifth of the global production in 2018 (EUMOFA, 2019b). In contrast common carp production in Poland is traditionally carried out in extensively managed ponds, supplying mainly the traditional domestic Christmas market (Raftowicz and Le Gallic, 2019). While the Norwegian value chain is characterized by industrial production and efficiency with sustained growth (Torrissen et al., 2011), the Polish common carp value chain indicates opportunities, which we explored by assessing the change of carp processing model to highlight economic opportunities when processing into different product forms. The extensive production of bivalve aquaculture also shows potential, as it provides more than just healthy seafood, but also reinforces ecosystems services (Ferreira and Bricker, 2015).

This report includes four major tasks, (1) Value Chain Analysis (VCA) and Key Informant (KI) survey, in which the latter was developed based on the systematic literature review already published (D3.3), providing a detailed description of the EU and EEA aquaculture value chain (Newton et al., 2019). The scope of D3.3 and the structure and content of the value chain were discussed during an expert workshop meeting in Bremerhaven (Germany) in 2019. This was crucial to develop the sample frame and structure for the VCA KI interviews, (2) data collection and analysis, (3) a carp processing case study to understand the economic potential of full processing instead of traditional sale of live carp, (4) a Delphi survey based on the results obtained from (2) and (3). Due to Covid-19 restrictions, fieldwork was cut short in Poland, completely cancelled in Spain and Italy and delayed in the UK. Despite the unforeseen circumstances, a complete dataset for this report (D4.2) was established for Norway and Poland, with the use of phone calls and emails to obtain additional data. This was also the case of the partners in Italy and the UK, who were able to complete their data collection by email and phone contacts. Value chain insights for European seabass and gilthead seabream were obtained from the MedAID project (MedAID, 2021).

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We present our results (Section 4) in 8 sections. The first focuses on the ability (power/interest) of stakeholders to influence industry change and innovation. The second presents the most important sustainability perceptions identified by the value chain members. Thirdly, the perspectives of the value chain members towards the GAIN innovations are presented. This includes the carp processing case study, which is presented as a separate section (4.3.2.1). Fourthly, the results from the survey and the case study are discussed and used for developing two rounds of Delphi surveys (section 4.5 and 4.6) to assess if there is a consensus about the industry, innovation and sustainability aspects among the stakeholders. The most important Delphi findings are discussed in section 4.7. The last section (4.8) is using literature to gain insight in the value chain of European seabass and gilthead seabream. In summary this report contributes to our understanding of the opportunities and challenges to the eco-intensification of European aquaculture to secure a steady supply of healthy and nutritious seafood produced safely and responsibly.

The VCA KI interview for Norway indicates major sustainability concerns around sea lice, feed ingredients, type of energy use (need for renewables) and regulations (medicine use and production limits). To overcome these challenges innovation is required. However, innovation can be stimulated or limited by the power and interest of certain stakeholders towards changes in the industry. There was a strong relationship between the power and interest, with power rising sharply with corresponding interest to innovate. Our power and interest results indicate that an important cluster of government authorities, NGO's, certifiers, and consumer group associations is considered very powerful and with a medium to high interest in innovation. The processing sector shows a high interest in innovation, but a relatively low score for power, indicating challenges in terms of capacity to push for change in the processing sector. In terms of GAIN innovations, big data for farm management and fish welfare shows a considerable potential and high consensus among the value chain members. The potential contribution of novel feed ingredients such as microalgae and insect to the sustainability of the aquaculture sector was ranked high. However, uncertainty about their suitability to the industry was evident as respondent indicate uncertain around change in feed ingredients affecting health and nutritional value. Additionally, price, availability and quality is a concern, while the potential to reduce environmental impact on an industry scale are relatively unknown.

Key results for common carp in Poland included the current sustainability challenges identified by stakeholders. Climate-change-related extreme weather (e.g., affecting water availability), animal predation on carp, potential for the processing sector to increase output, and the availability and value of EU support funds were the most relevant factors regarding sustainability. The power and interest results did not show consistency among the value chain members. There was high interest, but relatively low power, demonstrated by processors indicating potential bottlenecks in innovation in the carp aquaculture sector. Retailers and NGOs (environmental and ethical groups) showed high power and high interest towards innovation, while farmers, vets, trading companies and government show high power, but low interest to make industry changes. Generally, there was low correlation between the power and interest in Poland and power increased slowly in relation to interest. In terms of the suitability of GAIN innovations, processing by-products for feed scored highly, but with high variability between stakeholder opinion. The potential of centralized slaughter and processing has yet to be adequately assessed on a national and regional level, although the processing sector showed a high interest in such industry changes. Results indicated an increase in economic output on a kilogram basis if by-products were utilized in food, feed and industrial applications.

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Respondents from the Italian trout industry identified Covid-19 (linked to concerns about re-opening food services), climate change (related extreme weather causing concerns about water availability and quality), and market aspects (loss of customer interest towards fresh products and lower price of trout) as the most important sustainability concerns. To overcome these challenges, research and development, especially for small-medium enterprises (SMEs) were considered important.

For the bivalve sector in the UK the most important sustainability challenges identified by stakeholders were governance and, specifically for small companies, water classification, public awareness of bivalve culture and its low environmental footprint. Some stakeholders were uncertain about Brexit, spat availability and future routes to market. Industry stakeholders also believed that the low environmental footprint of bivalves compared to other animal proteins and the potential ecosystem services provided from bivalve culture could be a positive sustainability factor in the future. The power and interest results showed most stakeholder nodes have high interest and high power to make industry changes. The aggregated category of producers showed the highest power and interest. Third parties such as government authorities, certification bodies and consumer groups were scored as having high power but moderate to low interest to make industry changes, whereas research and education stakeholders showed low power and mostly low interest. With regards to GAIN innovations, markets for shells and producing bivalves further offshore scored the highest, with participants highlighting the current industry and personal interest in these innovations.

Within the Delphi survey, questions were asked concerning industry perceptions towards current and potential legislation, support for sustainable growth and important sustainability factors, based on initial VCA KI survey findings. The Norwegian stakeholders seemed to agree on a general trend of increasing production within the salmon sector, preferably in a ''responsible'' way, where environmental impact is considered. Profitability of the industry could be improved by 1) greater application of circular economy and recycling principles, 2) strategic use of novel feed ingredients to substitute a reasonable part of the more expensive marine ingredients, and 3) a focus on quality rather than quantity. In contrast, Polish stakeholders indicated consistent production volumes, but declining financial margins. Appropriate strategies identified to increase the profitability of the carp industry were 1) more efficient predator control, 2) diversification of activities on-farm,3) increased processing, and 4) a focus on quality rather than quantity.

1. Introduction

The value chain can be defined as the interconnected ''actors'', i.e. participants in any action or process, and stakeholders who provide resources, production capability, skills, innovation, and governance to an industry (Bolwig, 2010; Gereffi, 2018). In addition to the ''supply chain'', it includes indirectly affected stakeholders, such as policy makers, academics and consumers who may affect or be affected by the activities within the chain. VCAs and stakeholder mapping exercises are crucial to understand the dynamics of the industry on a national or regional scale. However, as aquaculture shows dependency on global trade of goods and commodities the analysis is often referred to as the Global Value Chain Analysis (GVCA).

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The position and characteristics of any actor within the value chain, their perceptions towards sustainability, and their attitudes towards innovation and eco-intensification measures could have significant impact on the continued sustainability of the industry and the potential to implement innovation; technologically, structurally or politically (Joffre et al., 2017; Obiero et al., 2019; Karim et al., 2020; Lebel et al., 2021). Additionally, specific attitudes of any group of actors towards other actors or stakeholders and innovations in the sector could have unforeseen implications; a comprehensive framework to understand the interconnectedness and relationships between the different value chain actors is therefore required. For example, global trade is increasingly centralised and dominated by brands, supermarkets, and food service companies. These are also called 'lead' firms that control access and determine the terms of trade (Humphrey, 2001). However, the way seafood is advertised at global seafood shows (business-to-business) shows a difference between producing and consuming regions, according to a study by Malcorps et al. (2021a). More specifically, exhibitor booth advertising at Chinese seafood trade shows had less of an emphasis on sustainability compared to seafood shows in Europe and the USA but placed a greater emphasis on food safety and quality than on environmental concerns. In the context of European aquaculture and access to new markets, an understanding of culture, messaging strategies, and interpretation could support better communication of product characteristics between producers, traders, and consumers (Malcorps et al., 2021a), therefore better meeting the consumer demands in e.g., export markets.

The GAIN project undertook two VCA exercises to understand European aquaculture value chains with a focus on Atlantic salmon in Norway, common carp in Poland, trout in Italy trout and bivalves in the UK. The work contained within D4.2 of the GAIN project builds on work from D3.3 and covers the tasks:

- A combined structured and semi-structured VCA survey and Key Informant Interviews focussing on obtaining quantitative and qualitative data on the Norwegian Atlantic salmon, Polish common carp industry, Italian trout and UK bivalves' industries and their perceptions towards sustainability, challenges, and opportunities.
- Delphi survey with two rounds to gain understanding in the consensus and diversity of opinions in the industry following the VCA results (i) and the carp processing model.

Insights in the Polish carp value chain resulted in the development of a carp processing model to understand the potential value addition of complete processing, methodology and results described in 3.3 and 4.3.2.1, respectively.

Planned work in Spain on European seabass and gilthead seabream industries was cancelled but replaced by a summary of similar work being conducted within the MedAID project, described in section 4.8.

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2. Background

Seafood consumption in the European Union (EU) increased by approximately 25% from 2005 to 24.4kg capita^{-1} year^{-1} in 2017 (EUMOFA, 2018; 2019a). People are becoming increasingly aware of the health benefits of seafood consumption, such as providing essential omega-3 fatty acids for neurodevelopment and reducing risk of cardiovascular disease (Willett et al., 2019) amongst others. High animal welfare standards and health awareness in the Europe are driving factors for seafood consumption (Hirvonen et al., 2019). In 2017, the EU supply (14.61 million MT, live weight equivalent) constitutes product from local (EU member states) capture fisheries (28%) and aquaculture production (9%). Additionally, the rest of the supply demand is met by imports from non-EU member states derived from capture fisheries (49%) and aquaculture (14%). Norway (non-EU member, part of EEA) supplies 25% of total seafood imports into the EU. This includes mainly farmed Atlantic salmon which represents 35% of the total estimated consumption of aquaculture products and 15% by volume of all fish and seafood products imported (EUMOFA, 2019a).

Global capture fisheries are close to their production limits, highlighting an important role for aquaculture to fulfil future demand (FAO, 2018). More specifically in the case of Europe, the self-sufficiency ratio, indicating the ratio of domestic production meeting demand, shows a varying trend (between 2009 and 2018) ranging from 41.7% in 2011 up to 45.8% in 2014, slowly declining to 42.5% in 2018 (EUMOFA, 2020). Consequently, the low self-sufficient ratio creates a dependency on finite marine fisheries and global trade for the supply of healthy and nutritious seafood that could have socio-economic and environmental implications and a negative effect on the resilience of the European food system (EUMOFA, 2018).

For the EU to have a self-sufficient seafood supply, its aquaculture needs to expand. It is crucial to develop the aquaculture industry in a sustainable way by means of eco-intensification, using land, water and nutrients efficiently, while minimizing the negative impact on ecosystems and biodiversity (FAO, 2011; Foley, 2011). Thus, a holistic approach towards measuring the socio-economic and environmental sustainability of the aquaculture industry and evaluating the positive impact of innovations is required to avoid problem shifting and unforeseen consequences. Feed provision is a crucial component in the aquaculture intensification process (Ellis et al., 2016) and requires responsible sourcing within Europe and beyond. This is the case of valuable marine ingredients and their potential replacements. Opportunities can be found in the fish processing sector, to supply by-products volume of raw materials as indicated in D2.7 (Malcorps et al., 2020), as individual by-products show interesting nutritional potential (Stevens et al., 2018; Malcorps et al., 2021b). There are also an increasing number of “novel” ingredients on the market, each of which need to be assessed for their performance and sustainability credentials. There is also a need to understand their role from a value chain assessment perspective, and to assess the suitability and role of certain innovations to support the sustainable growth of aquaculture in Europe. Therefore, VCA and LCA are linked and can be integrated to further understanding of value chain stakeholders and practices along the aquaculture supply chains, such as the farm’s input (e.g., feed, brood stock), farm gate, post-harvesting nodes and through to distribution and retail.

A multi-level value chain analysis is required to provide insights into the perceptions of different stakeholders towards industry. This report builds on afindings presented in GAINdeliverables, D3.3, (Newton et al., 2019) and D2.7, (Malcorps et al., 2020).

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3. Methodology

A mixed method approach (Figure 3.1) was used for analysing the value chain of Atlantic salmon (Norway) and common carp (Poland) following the value chain review in D3.3. The first survey (value chain) includes the collection of quantitative and qualitative data on sustainability factors, power and interest towards innovation and suitability of GAIN innovations. The survey data were pre-processed, and results were analysed. In response to new insights in the Polish carp value chain, a processing model was developed covering primary and secondary processing in to obtain insight into the economic opportunities arising from the processing of common carp.

Key findings of the value chain survey were explored in depth with the help of two rounds of a Delphi expert consultation on the Norwegian Atlantic salmon and Polish carp value chains, targeting opinion and consensus around certain practices and perceptions on the two industries. This survey was distributed electronically with assistance from in-country GAIN partners. The Delphi was also used to assess the relevance of EISI (T4.3) indicators to the different industries, where participants from Norway and Poland were asked to score the relative importance of the individual sustainability indicators.

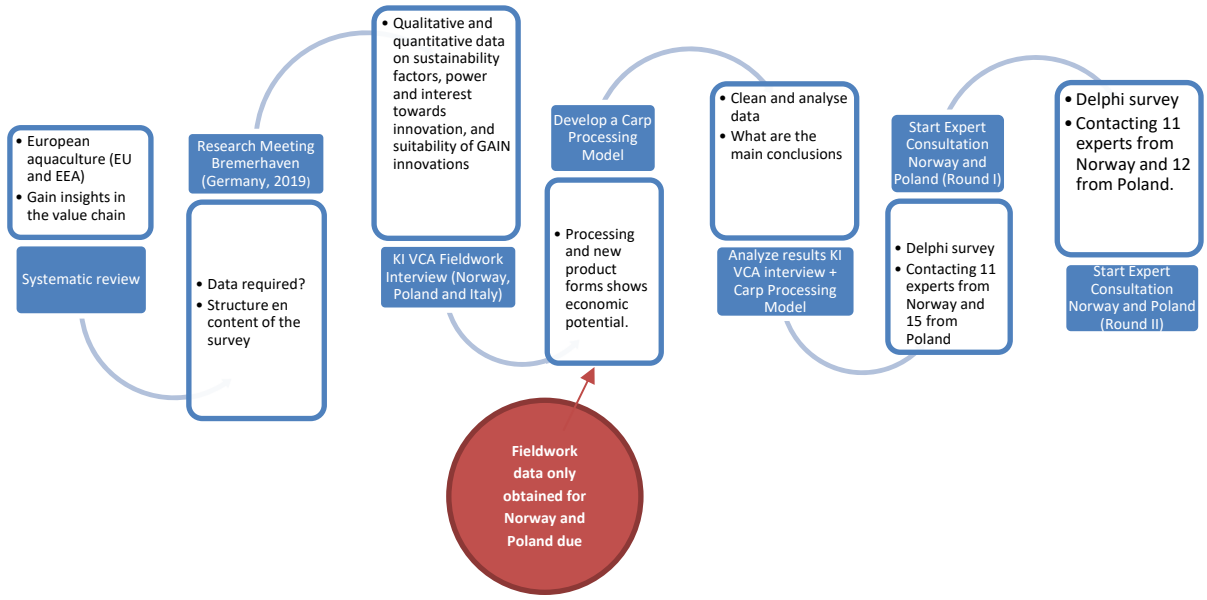

Figure 3.1: Mixed method approach.

In the first stage of the methodology (value chain survey) key points from D3.3 were developed as part of the Typical Farm Workshop held in Bremerhaven (Agribenchmark, 2019), that included GAIN partners (Figure 3.2), who were involved in research on (aspects of) aquaculture value chains. The duration of the expert meeting was 3 days and partners were mixed in multi-disciplinary (socio-economic and environmental expertise) groups to discuss the structure and key players in the value chain for each species. This included presentations on different topics and multiple discussions on aquaculture, sustainability, and value chains to transfer knowledge and create incentives to discuss certain aspects and challenges for the aquaculture industry. Additionally, the typical farm approach was explained, providing examples form a range of the EU and EEA aquaculture species.

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Figure 3.2: Agri benchmark fish and seafood workshop in Bremerhaven, Germany (Agribenchmark, 2019).

These discussions were the starting point of the development of the sample frame (e.g., selection of interviewees based on the validation of each value chain in each country by a GAIN partner) which was finalised and piloted in Norway in July 2019. Adjustments were made according to feedbacks from interviewees. The survey was further adjusted and fit for purpose for the Polish common carp, Italian rainbow trout and UK bivalves. Stakeholders were interviewed face to face, when possible, with the support of GAIN partners at ZUT and GIFAS to overcome language barriers. In response to the Covid-19 restrictions in March 2020 and the cancellation of the fieldwork, the surveys to collect the required data were continued by ZUT through phone calls and email contacts. Trout data in Italy were collected by UNIVE and UK bivalves' data collection was facilitated by AFBI. The value chain surveys are included in Annex 1, 2 and 3 and the stakeholder coverage and timeline can be found in Table 3.1. Obtaining data from the European seabass and gilthead seabream aquaculture industry in Spain was not possible due to travel restrictions. Instead, literature from the MEDAID project was consulted to gather information on these value chains, which are briefly summarized in section 4.8.

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Table 3.1: Surveyed nodes in partner countries for Atlantic Salmon (Norway), common carp (Poland), rainbow trout (Italy) and bivalves (United Kingdom). Not all stakeholders applicable to all countries. Sample size (N) could slight differ per segment of the survey, depending on the awareness or willingness of the stakeholder to answer certain questions. More details on surveyed stakeholders are provided in tables 4.1, 4.2 and 4.3.

Stakeholder	**Aggregated category**	**Norway (June-Sept 2019)**	**Poland (Feb-April 2020)**	**Italy (Dec 2020 – June 2021)**	**United Kingdom (July 2021-September 2021)**
		Atlantic salmon (N=31-34)	**Common carp (N=12-21)**	**Rainbow trout (N=11)**	**Bivalves (N=7-11)**
Brood stock/egg producers	Producers	x		x	
Hatcheries (RAS)		x			
Smolt production (RAS)		x			
Smolt production (flow-through)		x			
(Grow-out) farms		x	x	x	x
(Independent) slaughterhouse and primary processors		x	x	x	x
Independent secondary processors		x		x	x
Value addition processors/smokeries etc.		x	x		x
Integrated companies		x		x	x
By-product processors	Others	x			
Cleaner fish producers	Supporting	x			
(Exporters/import) trading companies		x	x	x	
Retail	Others	x	x		
(Well-boat)/transport*	Supporting	x	x		
Vet/health management companies		x	x		
Feed companies		x	x	x	
Ingredient producers (fish oil, hydrolysates/meals etc)	Others	x			
End users (pet food)		x			
Education groups	Research	x	x		
Research innovation (R&D) companies		x	x		x
Recreational (guide) tour	Others		x		
Trainers		x	x		
Equipment producers	Supporting	x	x		
Government authorities	Others	x	x		x
Certifiers		x	x		
NGOs		x	x		
Consumer groups/associations		x	x		
Carp association			x		
Other support industries/suppliers (ice, chemicals, consumable products etc)		x		x	

**Well-boat only applicable to the Atlantic salmon aquaculture industry in Norway.*

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3.1 Key sections of the VCA

3.1.1 Power and Interest to make industry changes

Based on consolidated stakeholder analysis techniques (Eden and Ackermann, 2011), a power interest matrix was developed, in order to understand the opportunities and barriers for innovation and the characteristics of the industry towards innovation (e.g., stakeholder driven innovation). The "power" of stakeholders is defined as those actors who have the ability to influence change within the value chain, whereas the 'interest' of stakeholders are those actors who are most affected by any change to the value chain. If stakeholders have both high power and high interest, it can be assumed that value chain development is stakeholder driven and there should be a clear relationship between the two. If there is little relationship between power and interest or power rises slowly with interest, then the value chain is not stakeholder driven and change is not meeting the needs of those stakeholders most affected.

The average power and interest were calculated and plotted per stakeholder group to identify stakeholders with high interest and/or high power and establish any relationship between the power/interest dynamic. Their position in the power interest grid was discussed in relation to the sustainability challenges raised by those stakeholders. Due to covid-19 travel restrictions, this was only done Norwegian Atlantic salmon, Polish common carp and UK bivalves.

3.1.2 Sustainability factors and concerns

Participants were asked to identify sustainability factors in their sector, separating out issues which may have a positive or negative effect on the sustainability of the industry going forward and those which they were uncertain about. Each mention of a specific sustainability factor receives one point. Consequently, the sustainability factors in each category (positive, negative, or uncertain) that are more frequently mentioned received more points and are therefore listed at the top as most important sustainability factors. Only for Italian rainbow trout these categories are combined in one table due to low sample size. When applicable, the sustainability concerns are discussed in relation to the specific stakeholders that mentioned it and their respective power/interest towards innovation.

3.1.3 Awareness of GAIN innovations

Survey participants in Norway, Poland and Italy were asked about their awareness of GAIN innovations, such as 'microalgae as a feed ingredient', 'processing by-products for feed' and 'use of big data for welfare'. Awareness was divided in three levels; personal awareness/knowledge, company interest and industry interest towards each innovation listed. Each innovation was scored according to the degree of knowledge or interest across the three levels. The innovations with the highest score are the ones showing most potential to be implemented according to stakeholders, as people are aware and see the benefits for their company/industry.

3.1.4 Statistics

Relationships between stakeholder opinions and the power/interest dynamic were tested statistically.

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1. A regression analysis was applied to test if there was a relationship between power versus interest of the stakeholders overall.
2. A general linear model (GLM) was applied followed up by a Tukey Pairwise comparison (95% confidence).
   (i) To test if there is a significant difference in terms of 'power' or 'interest' between stakeholder categories.
   (ii) To test if there is a significant difference between the scoring of the GAIN innovations between the stakeholder categories.

3.2 Delphi survey

In response to the main findings in the VCA surveys in Norway and Poland, a Delphi survey was developed to add depth into the results of the respective countries. The Delphi surveys included two survey rounds to investigate stakeholder opinion on key sustainability issues, industry trends, innovation, and legislation, and can be found in Annex 5-8.

The first round of the Delphi was distributed through a survey format in February 2021. Most stakeholders' actors from Norway (7 out of 11) and Poland (13 out of 15) also participated in the initial KI value chain survey. A few stakeholders were newly introduced to the first Delphi round to increase the sample size. The individual answers from the expert stakeholder group were analysed, aggregated, and anonymized to inform a second-round list of questions, which was distributed in June 2021. Surveys were distributed to participants from the baseline KI value chain survey (incl. Delphi first round) and their networks, using a Google Forms survey link by email. Additionally, the survey was shared through LinkedIn and aquaculture societies and networks in Norway, Poland, and wider Europe.

In the second round of questions, participants interviewed in the VCA were informed about the main findings of the first Delphi round, and this was followed up by in-depth questions. Some Norwegian (4 out of 11) and Polish (9 out of 12) stakeholder actors in the second Delphi round also participated in the first round. A few other stakeholder actors were introduced to the survey to increase the sample size. The answers from the two Delphi rounds were used to establish a clear variation and/or consensus around different issues in the industry. The answers were then matched with the initial VCA interview to identify similarities and differences in opinions.

3.3 Case study: Common carp processing value addition model

The initial results from the common carp (Poland) VCA KI survey identified opportunities for developing the primary and secondary processing sector in Poland. Common carp in Poland is mostly sold live or sometimes in traditional product forms, such as fillets, slices and sheets (Figure 3.3) and whole carcasses (beheaded and degutted only). Increased processing may lead to an increase in economic output of the industry. This model looks at the added value but does not include costs associated with the utilization of the by-products, such as ice, packaging, and labour.

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Figure 3.3: Common carp sheet (single flap, one side of carcass cut along the spine with skin and ribs on) and carp slice (lateral steaks, carp cut perpendicularly to the spine from the top of the carcass to the ventral part, thickness of approximately 2cm).

To maximize the volume output beyond traditional product forms such as those indicated in Figure 3.3, full processing is desired, which would include the slaughter and removal of the viscera and head (primary processing) and the separation of the fillets and by-products (secondary processing). This shows potential in Poland (Raftowicz and Le Gallic, 2019) from both an economic, environmental and fish welfare perspective, as 1) fish do not suffer, but are slaughtered fast and efficiently according to established protocols; 2) less resources are need as the whole animal is used more efficiently.

Compared to traditional processed product forms, full processing not only results in high value fillets, but also in the additional availability of by-products, such as trimmings and frames. Nevertheless, processing into traditional product forms and fillets results in more by-product availability at the processor level, compared to live or whole fish sales. To understand the additional economic value that might be obtained from these by-products, an Excel spreadsheet model that compared different processing scenarios into various amounts of different product forms was developed. Therefore, it was important to understand the logistics of carp production chains in Poland, to enable structural changes (Lirski, 2020b), and the preferred product/consumption forms (Raftowicz et al., 2019) (Table 3.2). Based on the current preferred product forms (e.g., live carp, sheet, or slices), different processing scenarios were developed representing ''business-as-usual'' scenarios and gradually moving towards a complete (primary and secondary) processing scenario (Tables 3.2 and 3.3). Scenarios 1 to 5 included traditional processing and consumption of carp, such as slice and sheet (Figure 3.3) assuming that by-products are discarded or consumed by human and/or animals at the household level and are marked red (Table 3.3). On the other hand, Scenarios 6 to 10 included new product forms that substitute traditional product forms (e.g., living carp).

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Table 3.2: Description of processing scenarios.

S.	Description of processing scenarios into different product forms
1	Mostly consumption of live common carp with small proportion being processed (by-products at household level) (yield 100%)
2	Common carp gutted (yield 84.3)
3	Carcass[1] - common carp beheaded and gutted (yield 60.3%)
4	Slice[2] - common carp beheaded and gutted (yield 58.1%)
5	Common carp beheaded, gutted and partly de-framed (yield 44.2%)
6	Combination of live sales and processed - 80% live + (20% [3]sheets incl. by-products)
7	Combination of 55% live + (30% filet incl. by-products) + (15% carcass incl. by-products
8	Combination of 40% live + (40% filet incl. by-products) + (20% carcass incl. by-products)
9	Based on an achievable scenario - 20% live + (80% sheets[3] incl. by-products)
10	40% Fillets + (incl. 60% by-products such as heads, frames, trimmings, skin and viscera) - strategic utilization

[1]Carcass: Behead and Gutted

[2]Slice: carp cut perpendicularly to the spine from the top of the carcass to the ventral part, thickness of approx. 2cm. (Figure 3.3)

[3]Sheet: (single flap) one side of carcass cut along the spine with skin and ribs on (Figure 3.3).

The different processing scenarios result in a variety of co-product yields as listed in Table 3.3. The traditional product forms of Scenarios 1 to 5 (in red) assume that by-products are not used, whereas full utilization is assumed in Scenarios 6 to 10. Yields may slightly differ depending on the processing product form and initial yield of the main products. More specifically, in the case of some by-products such as frames, part of the by-product is removed and therefore the share of each by-product may slightly differ depending on the processed product form.

More specifically, in the case of some by-products like frames, part of this by-product is taken in the case of e.g., carp sheet processing (Figure 3.3: single flap, one side of carcass cut along the spine with skin and ribs on). Therefore, the share of each by-product could slightly differ depending on the processed product form. The product forms and related prices were combined to understand the economic potential of the diversification of different product forms. Additionally, by-products could be utilized in a range of applications, from food to feed and industrial applications. Prices were obtained from the carp industry in the local currency (Polish złoty (zł, PLN)) with expert advice from ZUT researchers (Table 3.4). One PLN is equal to 0.22 euro. The estimated prices (Table 3.5) assume that by-products directed into food applications have a higher value, followed by feed applications, especially pet food, and other industrial applications. According to the fish by-product hierarchy pyramid (Stevens et al., 2018), waste reduction and food recovery should have the highest priority, followed up by animal feed and industrial applications. If by-products are not suitable for animal feed or food, or a higher economic value can be generated, industrial applications could be suitable. The lowest value option, that may often incur a charge, is composting or discarding to landfill. It is assumed that if by-products are sold, they are all sold due to economic incentives of higher volume transportation and utilization. We assume that discard of by-products for composting/fertilizer is free, although some farmers indicated that they paid a premium charge to dispose fish by-products into landfill, as part of the use of environmental taxes and charges in the European Union and its member states (EC, 2001). This creates incentives the collection of by-products for free for using in mink or insect farms.

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In total seven utilization pathways were identified based on the price data accessed from farmers, processors, and researchers, namely: 1) market price, 2) average, 3) food, 4) feed, 5) industrial users, 6) composting/fertilizer, and 7) landfill/incineration (Table 3.5). Product yields and market prices were obtained from the literature (Lirski, 2020b) and discussed with researchers from ZUT and slightly adjusted. The prices for the by-products (heads, frames, trimmings, viscera and skin) were obtained from stakeholders in the field and expert opinion of researchers active in the Polish carp value chain. 'Average' represents the average price of food, feed, industrial use, composing/fertilizer, and landfill incineration where individual prices could not be estimated (Table 3.5).

Table 3.3: Scenarios and co-product yields.

Scenario	Co-product yields (%)											
	Live carp	Gutted	Carcass	Slices	Sheet	Fillets	Heads	Frames	Trim-mings	Skin (including scales)	Viscera	SUM (% utilized)
1) Traditional	**100.0**	-	-	-	-	-						**100**
2) Gutted	-	**84.3**	-	-	-	-					15.7	**84**
3) Carcass[1]	-	-	**60.3**	-	-	-	24.0				15.7	**60**
4) Slice[2]	-	-	-	**58.1**	-	-	25.1				16.8	**58**
5) Sheet[3]	-	-	-	-	**44.2**	-	24.0	16.1			15.7	**44**
6) Possible Scenario	**80.0**	-	-	-	**8.8**	-	**4.8**	**3.2**	-	-	**3.1**	**100**
7) Business as Usual (Actual Form[4]	**55.0**	-	**9.0**	-	-	**13.0**	**8.8**	**2.8**	**2.4**	**2.6**	**6.4**	**100**
8) Preferred Scenario[4]	**40.0**	-	**12.1**	-	-	**17.3**	**11.7**	**3.7**	**3.2**	**3.5**	**8.5**	**100**
9) Achievable Future Scenario[4]	**20.0**	-	-	-	**35.4**		**19.2**	**12.9**	-	-	**12.6**	**100**
10) Fully Processed and Utilized[4]	-	-	-	-	-	**43.3**	**17.3**	**9.3**	**8.0**	**8.7**	**13.5**	**100**

In red: underutilized by-products in Scenarios 1 to 5 at processor level or household level: these are discarded.

[1]Carcass: Behead and Gutted.

[2]Slice: carp cut perpendicularly to the spine from the top of the carcass to the ventral part, thickness of approximately 2cm.

[3]Sheet: (single flap) one side of carcass cut along the spine with skin and ribs on.

[4]'Business as usual', 'preferred scenario', 'achievable future scenario' are market based on previous work and conversations with scientist in the field.

Price for whole live carp for 2019 was obtained from the literature in a Polish fish processing magazine (PR, 2021). Additionally, yields and prices (including other costs, such as labour, packaging, ice) of traditional carp products were based on Lirski et al. (2020a) and discussed and adjusted in consultation with researchers from ZUT (Table 3.4).

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Table 3.4: Prices of carp by-product fractions provided by stakeholders of the Polish value chain.

	(Included: prices of labour, ice and packaging)	(Excluded: prices of labour, ice and packaging)						
***By-products (PLN/kg) utilization data**	**Processor 1***	**Proces -sor 1**	**Fish farm 1**	**Fish farm 2**	**Fish farm 3**	**Fish farm 4**	**Resear-cher 1**	**Resear-cher 2**
Heads	5	-2	1.25	0	-0.9	-3	2.5	3
Frames	6.3						2.5	
Trimmings	-						2.5	
Skin (incl. scales)	10						2.5	
Viscera	-						2.5	

**All prices are obtained from the farm gate level. However, the first row are prices that a specific processor obtains by buying whole carp and selling its co-products to the consumers and is therefore considered as value addition. Negative values indicate associated costs with the disposal of the by-products.*

Table 3.5: Carp by-product forms and prices

(By-)product Utilization Pathways								
	Advised		**[3]In 'grey' price (PLN/kg) of by-products obtained at farm or processor level, utilized in different applications**					
[1]Products	**[1]Estimated Yield (%)**	**Market Price (PLN/kg)**	**Average**	**Food (excl. viscera in feed)**	**Feed**	**Industrial Users (excl. viscera in feed)**	**[4]Composting/Fertilizer**	**Landfill/Incineration**
Live carp (fresh)	**100**	**[1]8.83**	-	-	-	-	-	-
Gutted	**84.3**	**[1]10.19**						
Carcass (beheaded and degutted)	**60.3**	**[1]14.25**	-	-	-	-	-	-
Slice	**58.1**	**[1]14.79**	-	-	-	-	-	-
Sheet	**44.2**	**[1]19.44**	-	-	-	-	-	-
Filet	**40.1**	**[1]21.45**	-	-	-	-	-	-
Filet	**[2]43.3**	**[1]21.45**	-	-	-	-	-	-
Heads	**[2]17.3**	**2.8**	**1.6**	**3.5**	**1.3**	**5.0**	**0.0**	**-2.0**
Frames	**[2]9.3**	**2.8**	**1.9**	**3.9**	**1.3**	**6.3**	**0.0**	**-2.0**
Trimmings	**[2]8.0**	**2.8**	**1.0**	**2.8**	**1.3**	**3.0**	**0.0**	**-2.0**
Skin (incl. scales)	**[2]8.7**	**2.8**	**2.9**	**5.2**	**1.3**	**10.0**	**0.0**	**-2.0**
Viscera	**[2]13.5**	**2.8**	**0.4**	**1.3**	**1.3**	**1.3**	**0.0**	**-2.0**

[1]Price for whole live carp for 2019 obtained from the fish processing magazine in Poland (PR, 2021). Yields and prices of traditional carp products (incl. other costs, such as labour, packaging, ice, etc.) are based on (Lirski, 2020a) and discussed and slightly adjusted in consultation with researchers from ZUT. Yields could slightly differ depending on the initial scenario and initial yield of the main products. They could be slightly adjusted to add up to 100% utilization.

[2]Malcorps et al. (2021b)

[3]Prices of Table 2 are allocated in Table 1 based on price expectations for different pathways, e.g., higher price for food compared to feed etc. It is assumed that if by-products are sold, they are all sold due to economic incentives of higher volume transportation and utilization.

[4]Assume that discard of by-products for the use of composting/fertilizer is for free. Collecting for free was indicated by 'fish farm 2' in Table 3.4.

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4. Results

This section provides the results of the value chain survey for the sustainability factors, power and interest grid, and the stakeholder perspectives towards GAIN innovations. The results of a Delphi supplementary survey with two rounds carried out on Norwegian salmon and Polish carp chains are presented in section 4.4.

4.1 Stakeholder power and interest

This section describes the power and interest results for the value chains of Norwegian salmon, Polish carp, Italian rainbow trout and UK bivalves.

4.1.1 Norwegian Atlantic salmon

Table 4.1 shows the number of each type of stakeholder interviewed within the Norwegian salmon value chain. Most stakeholders in the Norwegian industry show high power and high interest in innovation and therefore most of them are grouped in the top right corner of the grid shown in Figure 4.1. Especially important are government authorities, NGOs, certifiers, and consumer group/associations, which are considered very powerful and with a medium to high interest in innovation. Interestingly, the processing sector in Norway shows a high interest in innovation, but a relatively lower score for power to drive the necessary changes.

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Table 4.1: Stakeholder actors active in the Norwegian salmon value chain. Colours (nodes) and numbers (specific stakeholders) refer to figure 4.1.

Nodes	Data label	Stakeholder	Surveyed (n)[1]	Aggr. cat.[2]	Power[3]	Interest[3]
Early life stage	1	Brood stock/egg producers	1	Producers	A	AB
	2	Hatcheries (RAS)				
	3	Smolt production (RAS)	1			
	4	Smolt production (flow-through)				
Grow-out	5	Grow-out farms	3			
Processing	6	Independent slaughterhouse and primary processors	1			
	7	Independent secondary processors	1			
	8	Value addition processors/smokeries etc.				
Integrated	9	Integrated companies				
Processing	10	By-product processors	2	Others	A	B
Grow-out	11	Cleaner fish producers		Supporting	A	B
Trade	12	Exporters/trading companies	1			
	13	Retail		Others	A	B
Health	14	Well-boat/transport	1	Supporting	A	B
	15	Vet/health management companies	3			
Feed (ingredients)	16	Feed companies	3			
	17	Ingredient producers (fish oil, hydrolysates/meals etc)		Others	A	B
	18	End users (pet food)	1			
Education	19	Education groups	2	Research	A	A
	20	Research innovation companies	4			
	21	Trainers	1	Others	A	B
Equipment	22	Equipment producers	2	Supporting	A	B
Third parties	23	Government authorities	1	Others	A	B
	24	Certifiers	3			
	25	NGOs	1			
	26	Consumer groups/associations				
Equipment	27	Other support industries/suppliers (ice, chemicals, consumable products etc)	2			

[1]Total n=34

[2]Aggregated category based on table 3.1

[3]Grouping information using the Tukey method and 95% confidence: Scored Aggregated cat. comparison for power and interest. Aggregated categories that do not share letter(s) in terms of power or interest are significantly different.

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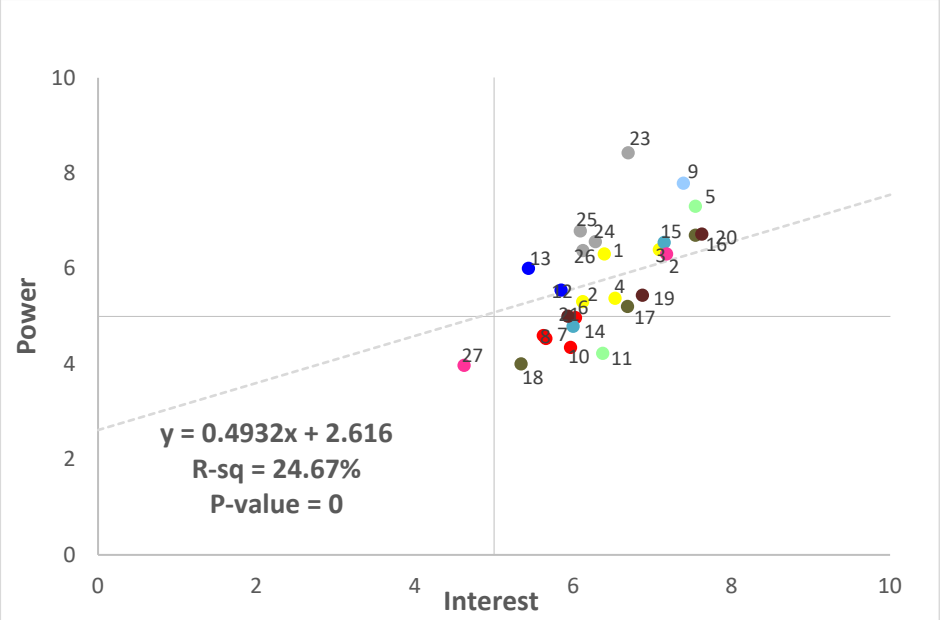

Figure 4.1: Power/interest to make industry changes in Norway.

There was a significant and steep relationship between power and interest overall (P-value<0.0001, R-sq =24.67%) as seen in Figure 4.1. This indicates that the most affected (interested) stakeholders are those with highest ability to affect change (powerful) and that the industry is broadly stakeholder led.

A comparison for interest (Tukey Pairwise Comparisons: Scored Aggregated cat.) indicated a significant difference (p=0.004) between research and all other stakeholders apart from producers (Table 4.1).

4.1.2 Polish common carp

Carp processors show a high interest in innovation (score 7-8), but a relatively low power (score 4-7). Farmers, vets, trading companies and government show high power, but low interest to make industry changes (Table 4.2, Figure 4.2). Interestingly, retailers and NGOs (environmental and ethical groups) showed high power and high interest to make industry changes, which could possibly match with the current trend of moving away from consuming live carp and diversifying products at retailer level.

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Table 4.2: Stakeholder actors active in the Polish carp value chain. Colours (nodes) and numbers (specific stakeholders) refer to figure 4.2.

Nodes	Data label	Stakeholder	Surveyed (n)[1]	Aggr. cat.[2]	Power[3]	Interest[3]
Grow-out	1	Farms	3	Producers	AB	AB
Feed (Ingredients)	2	Feed companies	2	Supporting	A	B
Processing	3	Slaughterhouse and primary processing	1	Producers	AB	AB
	4	Value addition processing				
Trade	5	Important and trading company		Supporting	A	B
	6	Retail company		Others	A	A
Equipment	7	Transport		Supporting	A	B
Health	8	Vet/Health management company	1			
Education	9	Education	5	Research	B	A
	10	Recreational (guide) tour	1	Others	A	A
	11	Research and innovation company (R&D)	4	Research	B	A
	12	Trainer institution		Others	A	A
Equipment	13	Equipment producer, maintenance, and recycling		Supporting	A	B
Third parties	14	Government and representative authorities		Others	A	A
	15	Certification body/organization				
	16	NGOs	3			
	17	Carp associations	1			
	18	Consumer group				

[1]Total n=21

[2]Aggregated category based on table 3.1

[3]Grouping information using the Tukey method and 95% confidence: Scored Aggregated cat. comparison for power and interest. Aggregated categories that do not share letter(s) in terms of power or interest are significantly different.

The stakeholders in Poland show low correlation of power to interest to make industry changes, although there was a significant relationship (P-value=0.034, R-sq =1.46%) (Figure 4.2). However, power does not increase as sharply with interest in the Polish value chain as in the Norwegian salmon industry, indicating that this value chain is not stakeholder driven and there is a lower appetite for change. A pairwise comparison (Tukey) for power and interest between stakeholders indicated that there is a significant difference between 'others', 'supporting', and 'producers' and 'research' (Table 4.2). In terms of interest there is a significant difference between research, others, and producers and supporting.

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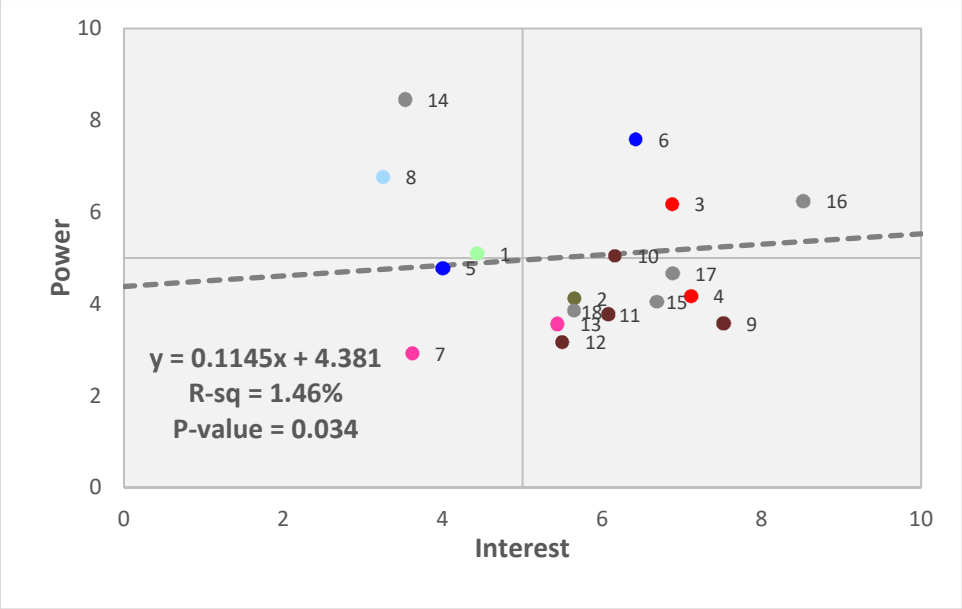

Figure 4.2: Power/interest to make industry changes in Poland

4.1.3 UK bivalves

Table 4.4 shows the different stakeholder nodes of relevance to the UK bivalve sector and the number of each stakeholder interviewed for the power/interest analysis. The power and interest of stakeholders across the UK bivalve sector was mixed but many stakeholders showed high power and interest to make industry changes (Figure 4.3). Stakeholders with the highest aggregated scores for power/interest (>15) included spat hatcheries, shellfish fisheries, primary and secondary processors, retail and grow out farms which had the highest score (18). In general, the category of third parties all had high power (except NGO's) but moderate/low interest. All research category stakeholders showed low power (<5) and varied interest.

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Table 4.3: Stakeholder actors active in the UK Bivalve value chain. Colours (nodes) and numbers (specific stakeholders) refer to figure 4.3.

Nodes	Data label	Stakeholder	Surveyed (n)[1]	Aggr. Cat.[2]
Early life stage	1	Spat fisheries		Producers
	2	Spat hatcheries		
Grow-out	3	Grow-out farms	4	
	4	Shellfish fisheries		
Processing	5	Primary processors	1	
	6	Secondary processors	1	
Trade	7	Exporter/trading companies		Supporting
	8	Retail		Others
	9	Hospitality industry		
Health	10	Vet/health management companies		Supporting
Education	11	Education groups		Research
	12	Research Innovation groups	1	
	13	Trainers		
Logistics/equipment	14	Equipment producers		Supporting
	15	Transport companies		
Third parties	16	Government authorities	1	Others
	17	Certification bodies		
	18	NGOs		
	19	Consumer groups/associations		
Logistics/equipment	20	Other support industries/suppliers (ice, chemicals, consumable products etc)		Supporting

[1]*Total n=11*

[2]*Aggregated category based on table 3.1*

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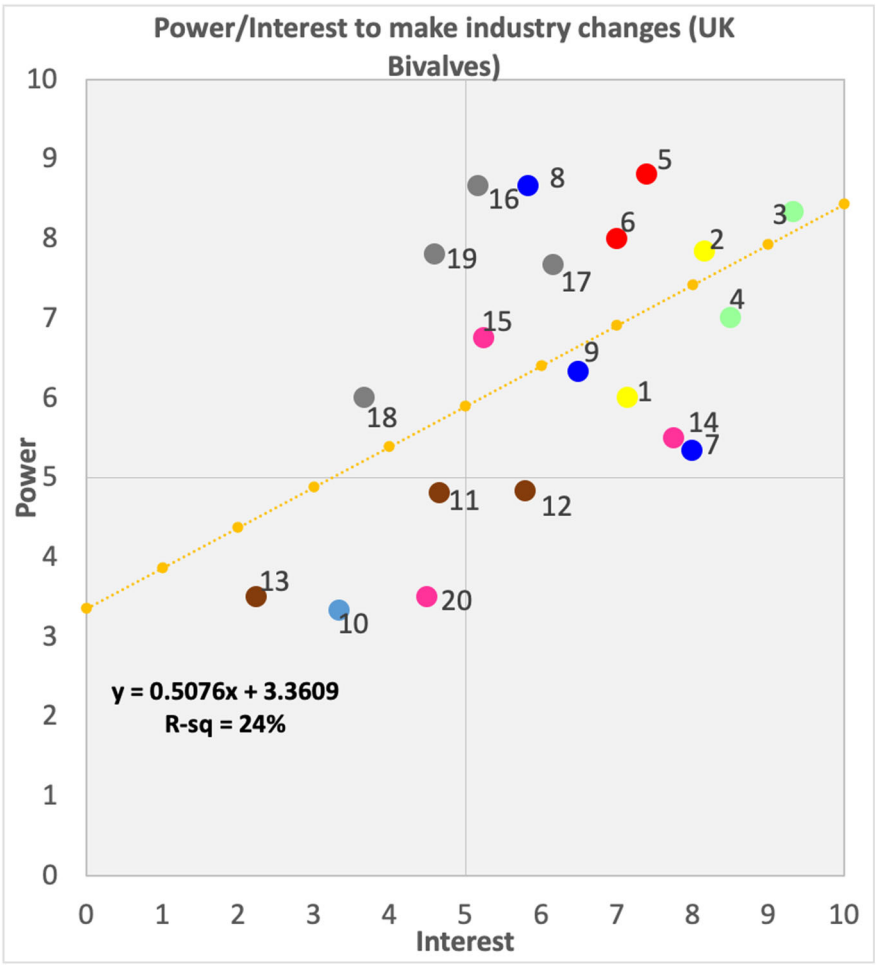

Figure 4.3: Power/interest to make industry changes in the UK bivalve sector.

4.2 Sustainability perceptions

In the following sections the sustainability perceptions of the stakeholders of the value chain of Norwegian Atlantic salmon, Polish Common carp, Italian Rainbow trout and UK bivalves are considered

4.2.1 Norwegian Atlantic salmon

The main (top 3 in terms of count) negative sustainability factors (Table 4.4) concerns fish health in terms of sea lice, including allowances of medicines and chemicals to combat diseases and parasites. Another important issue is the replacement of marine ingredients with plant ingredients, which could also have an effect on the health and final quality of the fish.

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Table 4.4: Count of negative sustainability perceptions, as highlighted by a variety of stakeholders in the Norwegian salmon value chain.

Negative Sustainability Factors	Count
Salmon lice (terms of growth limitations and final product)	4
Limiting allowance/use of medicines and chemicals to combat diseases and parasites	3
Marine ingredient replacement with e.g., plant ingredients can have negative effect on fish (weak health, nutritional value etc).	3
Regulations (government)	3
Feed (e.g., change in ingredients leads to change in nutrition and price)	2
Certification (e.g., ASC) - expensive and too much work and e.g., focus on social issues	2
Sustainability certification seems to favour certain companies and size	2
Operating costs increasing	2
Salmon lice's interaction between farmed and wild salmon	1
Escapees	1
Biological delousing with cleaner fish	1
Environmental footprint	1
Competition for space (e.g., fisherman, anglers, tourism, cabin owners)	1
False perspectives towards sustainability (e.g., fish faeces are bad for the environment)	1
Interaction with community	1
Strict measures (production, medicines, sea lice) to reduce impact on wild salmon (result; loss farm performance)	1
From food from the riches --> Staple food (should go lower in food chain).	1
NGOs intimidates/attacks potential carp consumers through media or before supermarkets.	1
Black swan event (corona virus) disruptive to global markets	1
Climate change	1
Politics and governments (change could affect geopolitics and strength of customer demand)	1

In red most important sustainability factors, orange middle range and in yellow less important sustainability factors.

The main (top 3 in terms of count) positive sustainability factors in 2019 and 2020 in the Norwegian industry is the transition from (diesel) generators located on barges towards a connection to the main electricity grid. Energy from the main electricity net is generated mainly (98%) with hydropower (Government.no, 2016). The other issues in Table 4.5 include the sourcing of traditional and novel feed ingredients. Microalgae oils have recently been introduced into salmon diet formulations (Maiolo et al., 2020b), and its further development is considered a positive development that shows potential to compensate for some of the negative sustainability concerns around marine ingredient replacement shown in Table 4.4. Additionally, the resource efficiency (e.g., feed conversion ratio) of Atlantic salmon farming is considered a positive sustainability factor compared to terrestrial livestock production.

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Table 4.5: Count of positive sustainability factors, as highlighted by a variety of stakeholders in the Norwegian value chain.

Positive Sustainability Factors	Count
Connecting to main electricity net, less energy use	7
Feed ingredients, sourcing, and novel feed ingredients (e.g., algae)	6
Resource efficiency (e.g., FCR) of the industry (compared to e.g., protein - meat)	5
Certification (e.g., ASC, MSC, GlobalGAP) - third party assessment	4
Recycling old equipment	3
No/less/decrease anti-biotics	3
Sea lice delousing system on well-boat (some of them using e.g., thermolizers, no chemicals)	3
Higher quality and bigger smolts (decrease mortalities, less sea lice because of shorter production on sea)	3
Technology (e.g., salmon lice laser, traceability of salmon through value chain)	3
Circular economy principles (zero waste) - use of by-products to increase value and feed output	3
Sea lice combating strategies (coordinating fallow periods farms)	2
Land based (RAS) systems	2
Closed cage systems	2
No/less use of anti-fouling (copper)	2
FM replacement (general) - reduce pressure on marine resources	2
Efficient use of materials	1
Waste management legislation	1
Awareness of sustainability issues/challenges in the industry	1
Less use of chemicals	1
Biosecurity	1
Less interaction with wild fish	1
Sea lice prevention systems (technology)	1
Improvement of fish welfare (including lumpfish)	1
Developing salmon brood stock resistance against diseases	1
Important food production sector (35 million meals a day)	1
Income for 30.000 people in Norway (covering whole value chain)	1
Reinvestment in coastal areas	1
Certified marine ingredient use (e.g., IFFO rs, MSC)	1
FM replacement by plant ingredients	1
FM and plant ingredient replacement by e.g., worms and mushrooms	1
Use of marine by-products	1
Environmental packaging	1
Politics and governments increase pressure on sustainable production practices	1
Global stability and peace	1

In red most important sustainability factors, orange middle range and in yellow less important sustainability factors.

Feed ingredients are included in both the positive as well as the negative sustainability factors (Table 4.4 and 4.5). Consequently, this indicates a level of uncertainty, confirmed by it being the most mentioned uncertain sustainability factor (Table 4.6), especially uncertainty around aquafeed ingredient, such as plant ingredients like soy, which potentially can negatively affect fish health. Additionally, it is acknowledged that novel ingredients show potential, but there are still many uncertainties in the extent and way they can be used at scale. Additionally, (potential future) government regulations on production limits creates uncertainty in the industry, as it is unsure if higher demands for production can be met (fifth in Table 4.6). This explains why it is also considered a negative sustainability factor (Table 4.4). Another uncertain sustainability factor are negative consumer perceptions, which are (according to two KI) created by a bad media image.

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Table 4.6: Count of uncertain sustainability factors, as highlighted by a variety of stakeholders in the Norwegian value chain.

Uncertain Sustainability Factors	Count
Aquafeed ingredients - plant ingredients (e.g., soy affects fish health), while real potential of novel ingredients (algae/insects) relatively unknown.	3
Production limits (government)	2
Consumer perception towards salmon (bad media image)	2
Strict regulations to combat sea lice	1
Higher demands for production	1
Fish welfare	1
Skirts to prevent sea lice (less water refreshment for salmon --> diseases and health problems)	1
Lack of resources brings innovations and push sustainability	1
Standards of ASC certification	1

In red most important sustainability factors, orange middle range and in yellow less important sustainability factors.

4.2.2 Polish common carp

The main (top 3 in terms of count) negative sustainability factors (Table 4.7) concern external factors, such as climate change affecting water resource availability and the negative impression that media and NGOs create around carp farming. Other concerns are related to the characteristics of common carp farming and consumption, including predation, the sale of live carps, mass production to supply a strongly seasonal demand (Christmas market) and a dependency on subsidies. Additionally, the pandemic (COVID-19) is expected to have negative effects on the supply chain and could result in low carp orders from consumers.

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Table 4.7: Count of negative sustainability factors, as highlighted by a variety of stakeholders in the Polish value chain.

Negative Sustainability Factors	Count
Climate change (e.g., relation to water availability)	4
Animal predation (low water surface makes problem worse)	4
Price of water to fill ponds	3
Media - Negative public messaging about carp farming in Poland.	3
Mass production to meet supply in December (leads to bad quality)	3
Dependency on subsidies	2
NGOs activities (creating a negative impression of carp farming and consumption)	2
Live carp sales (e.g., related to welfare issues)	2
COVID-19 affects supply chain (low orders)	2
Lack of governmental subsidies	1
The way we produce (organic) – diseases are easily transmitted into the ponds by e.g., birds	1
Lack of water to fill up ponds (incl. water access restrictions)	1
Import of fishes (Czech Republic), influence on price significant	1
Fisherman got no incentive to go out fishing, as EU supplies them with funding.	1
Processors cannot keep up with new innovations (new packaging, processing line) required by hypermarkets	1
Decreased freshwater fish consumption	1
Decrease in interest in education in fisheries	1

In red most important sustainability factors, orange middle range and in yellow less important sustainability factors.

The main (top 3 in terms of count) positive sustainability factors in the common carp value chain in Poland (Table 4.8) are the EU subsidies to innovate and diversify the industry. There are indications of a dependency on subsidies and is therefore also considered a negative sustainability factor, as indicated in Table 4.7. There is also a link between the sale of live carp (negative factor, Table 4.7) and the opportunity that exist to increase processing output, which could increase output of carp production, while sustaining current production levels (Table 4.8).

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Table 4.8: Count of positive sustainability factors, as highlighted by a variety of stakeholders in the Polish value chain.

Positive sustainability Factors	Count
EU funds for innovation/diversification/fisheries/aquaculture support programs and external assistance	5
Increase in output of (primary) processing sector	4
Extensive production - sustainable (in balance with nature/eco-friendly). Limiting waste, little energy use etc. (slow food product)	4
Climate change (e.g., shorter growth cycle)	3
Diversification of income	3
Inclusion of fishponds in small water retention programs	1
Extensive use of ponds complexes as recreational and ecological education objects	1
Presence of universities and institutes conducting research for fisheries sector	1
Increase in production (efficiency)	1
Sustainable local feed ingredients (weed and corn - low carbon footprint)	1
Water environmental program Poland (EU fishery funds) gives money to carp farmers (they need to meet demands for natural areas to get this money).	1
Improve feed formulations. Stop using soy from south America. Low impact as possible	1
Out of season spawning (keep carp on market all year around)	1
Short food supply chain	1
Circular economy in aquaculture	1
Coopetition (building the social capital, sharing economy)	1
New packaging (MAP packaging) vacuum, to deliver fresh and without icing in coming 5 years	1

In red most important sustainability factors, orange middle range and in yellow less important sustainability factors.

Positive sustainability factors are the EU funds and financial support for innovation and diversification activities, and the increase in output of the (primary) processing sector. Climate change is considered an important positive sustainability factor, as the number of days with temperature optimal for growth is likely to increase, thus shortening carp grow-out phase. Water resource, availability, however, could have constraining effects as a negative sustainability factor (Table 4.7) and is also mentioned an uncertainty (trade-offs, such as negative effects of rise in temperature affecting water resources) (Table 4.9). Another uncertainty are the national regulations, which is not keeping up with R&D development in the sector. Additionally, consumer preferences for common carp and other forms of product presentation are considered an uncertainty (Table 4.9).

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Table 4.9: Count of uncertain sustainability factors, as highlighted by a variety of stakeholders in the Polish value chain.

Uncertain sustainability Factors	Count
Climate change (positive/negative trade-offs of rise in temperature, possible fish growth).	3
Policy (national regulations often cannot keep up with R&D, so functions as bottleneck)	2
Consumer preferences relatively unknown	2
Market changes (form of presentation)	2
Live carp not always slaughtered properly (suffering)	2
Subsidy to maintain natural area (natura2000), not sufficient to pay costs	1
Fish farming gets more dependent on public money	1
Extensive carp farming not sufficient to pay costs	1
Prices of table fishes	1
Weather and water conditions	1
New technology	1
Unknown if carp farmers will be included in new water management framework of the government (this prioritizes water users based on needs)	1
Lack of water from the river to fill up ponds	1
Lack of water retention (from precipitation)	1
Eco-groups demanding no sale off for live carp. Could be option for processing	1
Not sure if feed use is eco-friendly unless by-products are used.	1
Government laws forbid sales of live carp, but according to vet guidelines this is allowed. Confusion!	1

In red most important sustainability factors, orange middle range and in yellow less important sustainability factors.

4.2.3 Italian rainbow trout

The covid-19 pandemic is considered the most important sustainability factor, which is linked to concerns about re-opening of restaurants and hospitality facilities (Table 4.10). This is followed up by climate change and related concerns around water availability and quality, as there is a dependency on river water, which is sometimes polluted, or the trout industry is using groundwater, which is also used for drinking water purposes. Other factors are market aspects, such as loss of customer interest towards fresh products and lower price for trout. While this is considered a negative factor, it is also seen by some as a need/opportunity to move away from HOG trout and diversifying towards added value products or other (local) freshwater species.

Research and development were also considered an important factor to overcome sustainability challenges, but is considered a negative sustainability factor, as this is difficult to access for most SMEs which make up the majority of the sector.

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Table 4.10: Count of positive, negative and uncertain sustainability factors, as highlighted by a variety of stakeholders in the Italian value chain.

Positive, negative and uncertain sustainability factors	Count
(End of) Covid-19 (uncertain)	2
Climate change (negative)	1
Water availability and quality (negative)	1
Loss of interest from customers toward fresh products (uncertain)	1
Mature market, low prices for trout (negative)	1
Re-opening of restaurant and hospitality facilities. Market access (positive)	1
Research and development difficult to access for SMEs, which make up the majority of the sector (negative)	1

In red most important sustainability factors, orange middle range and in yellow less important sustainability factors

4.2.4 UK bivalves

A variety of negative sustainability factors were expressed from stakeholders across the UK bivalve sector (Table 4.11). The biggest concern which was indicated by the majority of producers is that governance including the cost and time required for planning and regulatory processes in the UK is challenging, especially for small producers. There were also concerns about water classification, with producers concerned either about their water being downgraded to class B. Concern about the lack of public awareness of the low environmental footprint of bivalves compared to other animal proteins was apparent and the concern of this is that it could reduce market demand or public acceptance which were also highlighted as factors in this assessment. Although it was not one of the highest ranked negative factors, several stakeholders expressed concern about potential implications of climate change such as rising sea level, ocean acidification and increased sea temperature, some of which they expressed had already affected culture in other countries. Disease was also highlighted but only by Northern Irish stakeholders, who expressed concern over the norovirus and herpes diseases.

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Table 4.11 Count of negative sustainability factors, as highlighted by a variety of stakeholders in the UK bivalve value chain.

Negative sustainability factors	Count
Governance challenging for small companies	8
Water classification	5
Lack of public awareness of low environmental footprint	5
UK market demand low	4
Lack of processing facilities in the UK	4
Labour shortages	3
Lack of funding available	3
Disease	3
Licensing constraints	3
Spat availability	3
Increasing sea temperatures	2
Rising sea level	2
Public acceptance of aquaculture	2
Transport costs	2
Ocean acidification	1
Brexit	1
Intensification of UK waters	1

In red most important sustainability factors, orange middle range and in yellow less important sustainability factors

The main positive sustainability factors as highlighted by the UK bivalve industry (Table 4.12) were both the potential for bivalves to provide ecosystem services and the low environmental footprint of bivalve culture. Stakeholders highlighted that the growing trend of consumers considering the environmental footprint of their food could benefit the bivalve industry. Similarly, they felt that greater awareness of ecosystem services of bivalve culture could lead to increased production in the UK. Other factors highlighted, included new equipment and production methods as well as consumer demand and more information available to consumer about safety and preparation of shellfish.

Table 4.12 Count of positive sustainability factors, as highlighted by a variety of stakeholders in the UK bivalve value chain.

Positive Sustainability factors	Count
Ecosystem services	5
Low environmental footprint of bivalve culture	4
Offshore technologies	3
Advancements in equipment	3
More information available to consumers on safety and preparation	3
Consumer demand	3
Increased consumer acceptance of shellfish	1
Consumers learning to cook and handle seafood	1

In red most important sustainability factors, orange middle range and in yellow less important sustainability factors

Several uncertain sustainability factors were highlighted by the UK bivalve sector (Table 4.13) with the top three being routes to market, Brexit and spat availability. Routes to market was identified by four stakeholders. Currently in NI, England and Wales a lot of produce is sold in bulk to EU countries such

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as France, Ireland and the Netherlands, whereas in Scotland the majority of produce goes to UK retail and food service. There were very mixed responses regarding spat availability, with some producers having encountered no issues and others which highlighted this as a major concern, that they have already had to put measures in place to mitigate or believe they might need to in the future. Brexit was indicated in both negative and uncertain factors, with the majority of stakeholder still uncertain about the outcomes of Brexit. Potential concerns from stakeholders regarding Brexit included: water classification for export, border challenges, labour shortages, transport costs, loss of EU funding because of Brexit and potential relaxation of regulation in the UK.

Table 4.13: Count of uncertain sustainability factors, as highlighted by a variety of stakeholders in the UK bivalve value chain.

Uncertain sustainability factors	Count
Routes to market	4
Brexit	4
Spat availability	4
Intensification of farming in UK waters	3
Climate change	2
EU funding withdrawn	1
Pandemics	1
Water classification	1
Increase in vegetarian/veganism	1
Acquiring labour	1
Disease	1

In red most important sustainability factors, orange middle range and in yellow less important sustainability factors

4.3 GAIN innovations

In the following sections the GAIN innovations are discussed, starting first with Norwegian Atlantic salmon, followed up by common carp.

4.3.1 Norwegian Atlantic salmon

The Atlantic salmon industry in Norway shows a high interest and confidence in the use of big data for farm management and welfare (Table 4.14). Additionally, novel feed ingredients, such as microalgae, insect proteins, macroalgae, by-product for feed, FPH and single cell protein show potential. The GAIN innovations are scored quite similarly across the different aggregated groups (table 4.10, column 5 to 8). However, 'by-products for cosmetics/nutraceuticals (12)' shows significant differences between 'research' and 'others', and 'producers', and 'supporting' category.

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Table 4.14: Awareness/interest in the GAIN eco-intensification measures in Norway. Six is the maximum score for each respondent based on a yes (2), uncertain (1) or no (0) score for personal awareness, company interest, industry interest towards each innovation.

	GAIN innovation[1]	Avg[2]	SD[3]	Producers[4]	Research	Others	Supporting
1	Use of big data for welfare	5.52	0.87	A	A	A	A
2	Use of big data management and support	5.27	1.23	A	A	A	A
3	Microalgae as a feed ingredient	5.21	1.78	A	A	A	A
4	Insect protein as a feed ingredient	5.21	1.65	A	A	A	A
5	Macroalgae as a feed ingredient	5.15	1.56	A	A	A	A
6	Processing by-products for feed	5.15	1.50	A	A	A	A
7	Hydrolysed fish proteins	4.61	1.78	A	A	A	A
8	Single cell proteins	4.24	2.17	A	A	A	A
9	Sludge for biogas (as a green energy source)	4.00	1.95	A	A	A	A
10	Mortalities for biogas	3.97	1.91	A	A	A	A
11	Sludge for fertiliser	3.73	2.32	A	A	A	A
12	By-products for cosmetics/nutraceuticals	3.70	2.05	A	AB	AB	B
13	Shells for biofilters	2.48	2.20	A	A	A	A
14	Shells for cement/filler	1.24	1.90	A	A	A	A
15	Shells for packaging	1.09	1.93	A	*	A	A

[1]First column, 'grey' is precision aquaculture, 'green' are novel feed ingredients, 'blue' are by-products and circular economy.

[2]In green (average score between 4.5-6), orange (average score between 3-4.5), yellow (1.5-3) and red (average score between 0-1.5).

[3]Standard deviation

[4]Column 5 to 8 covers grouping information using the Tukey method and 95% confidence. Aggregated categories that do not share a letter are significantly different in their attitudes towards innovations.

**No responses for this category*

4.3.2 Polish common carp

The common carp industry shows relatively less interest in GAIN innovations (Table 4.15) compared with Atlantic salmon in Norway (Table 4.14) and their relative importance is different. In Norway, feed was most important, which is not the case in Poland, of the natural extensive (no to low feed input) production characteristics of the sector. However, there is supplementary feeding and there is relatively high interest in processed by-products for feed. On the other hand, there is medium interest to use by-products for cosmetics and nutraceuticals, and sludge for fertilizer. Additionally, there is awareness/interest in novel ingredients, such as insects, micro and macroalgae, and hydrolysed fish protein. Interestingly, there is medium range awareness/interest in big data management support.

The GAIN innovations are scored quite similarly across the different aggregated groups (table 4.15, column 5 to 8). However, 'sludge for fertiliser (2)' shows significant differences between 'research', and 'producers', and 'others', 'supporting'.

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Table 4.15: Awareness/interest in the GAIN eco-intensification measures in Norway. Six is the maximum score for each respondent based on a yes (2), uncertain (1) or no (0) score for personal awareness, company interest, industry interest towards each innovation.

	GAIN innovations[1]	Avg[2]	SD[3]	Producers[4]	Research	Others	Supporting
1	Processing by-products for feed	4.40	1.76	A	A	A	A
2	Sludge for fertiliser	3.87	2.45	AB	A	B	B
3	By-products for cosmetics/nutraceuticals	3.60	2.32	A	A	A	A
4	Insect proteins	3.53	1.77	A	A	A	A
5	Microalgae	3.13	1.96	A	A	A	A
6	Macroalgae	3.00	1.96	A	A	A	A
7	Sludge for biogas (as green energy source)	2.80	1.97	A	A	A	A
8	Use of big data management and support	2.80	2.40	A	A	A	A
9	Use of big data for welfare	2.67	2.50	A	A	A	*
10	Hydrolysed fish proteins	2.60	2.20	A	A	A	A
11	Mortalities for biogas	1.80	1.93	*	A	A	A
12	Single cell proteins	1.27	1.28	A	A	A	A
13	Shells for biofilters	0.93	1.88	*	A	*	A
14	Shells for packaging	0.93	2.18	*	A	*	B
15	Shells for cement/filler	0.80	1.88	*	A	*	A

[1]First column, 'grey' is precision aquaculture, 'green' are novel feed ingredients, 'blue' are by-products and circular economy.

[2]In green (average score between 4.5-6), orange (average score between 3-4.5), yellow (1.5-3) and red (average score between 0-1.5).

[3]Standard deviation

[4]Column 5 to 8 covers grouping information using the Tukey method and 95% confidence. Aggregated categories that do not share a letter are significantly different in their attitudes towards innovations.

**No responses for this category*

4.3.2.1 Case study common carp: processing value addition model

The carp sector is characterised by traditional farming in large ponds and with a relatively small processing sector, as most carp is sold live during the Christmas period (Raftowicz and Le Gallic, 2019). However, in recent years, fish welfare concerns and opportunities to add value to carp (by-)products are driving an interest towards increased processing. Nevertheless, the economic potential to increase the value output of the industry is relatively unknown.

There are different carp products available on the market (Table 4.4) in a range of prices. Traditionally, by-products originating from the processing of these products are discarded. It is therefore assumed that there is underutilized potential, which could be explored by creating processing scenarios as proposed.

The suggested processing scenarios show the highest production output (based on 1MT whole fish) for the sale of whole/live carp (S1). However, it is then assumed that the whole fish is utilized, including by-products, which is often not the case as these by-products accumulate at the household level. In the case of sc6-10, all co-products are being utilized on a processor level (Figure 4.4). The production forms (S2-5) are assumed to discard all by-products (at household level) and show therefore a lower production output.

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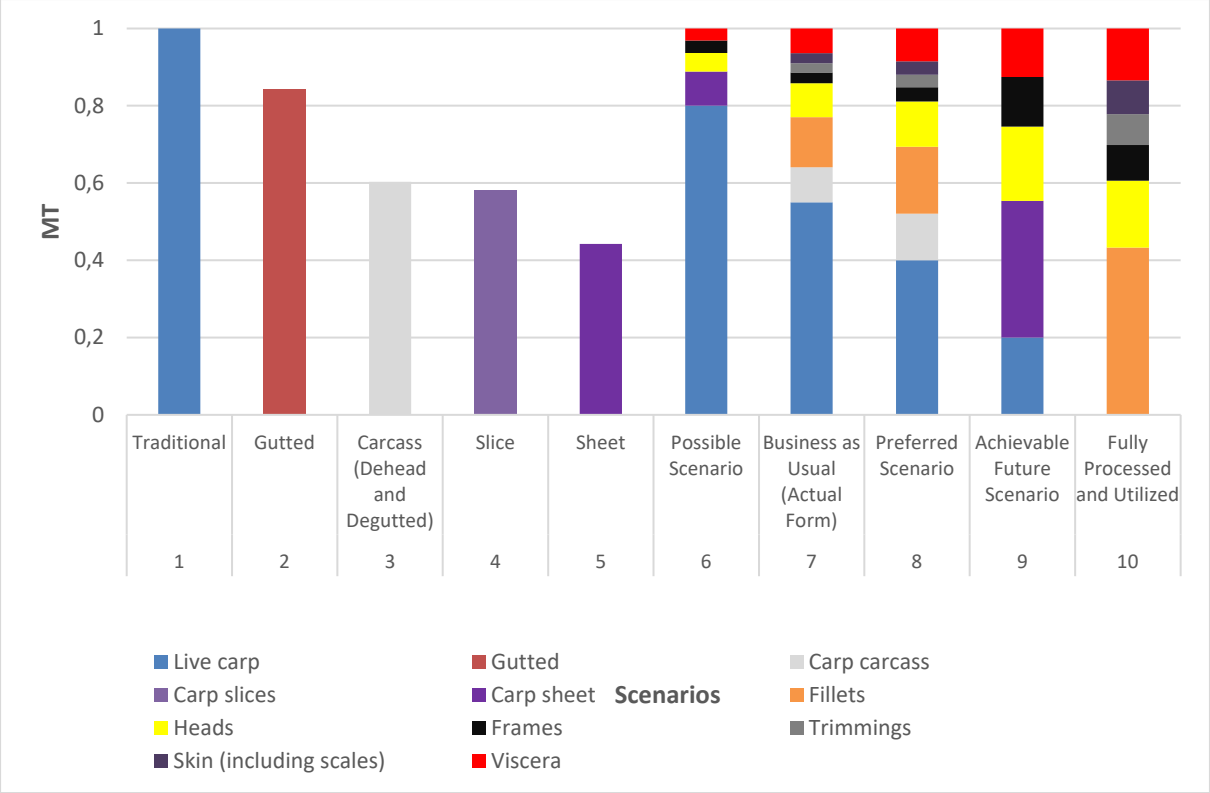

Figure 4.4: Co-product output per MT from common carp aquaculture production in Poland.

The yields and price per commodity differ (Table 3.5) and this could influence the economic output. The potential value output (Figure 4.5) shows a relatively a similar trend compared to the co-product output (Figure 4.4). Interestingly, the high yield of live carp (100%) in combination with a relatively high kilo price indicates incentives to sell it in the traditional product form. Similar profits could be obtained by S6 (Combination of live sales and processed - 80% live + (20% sheets incl. by-products). Consequently, when the use of the by-products increases, the economic output increases with it, as seen from sc7-10, in which scenario 10 is fully processed. However, it is important to consider that in all these scenarios the 'market price' was applied (Table 3.5), which does not include the variability of prices that could be obtained depending on the utilization pathway, as discussed in Figure 4.6.

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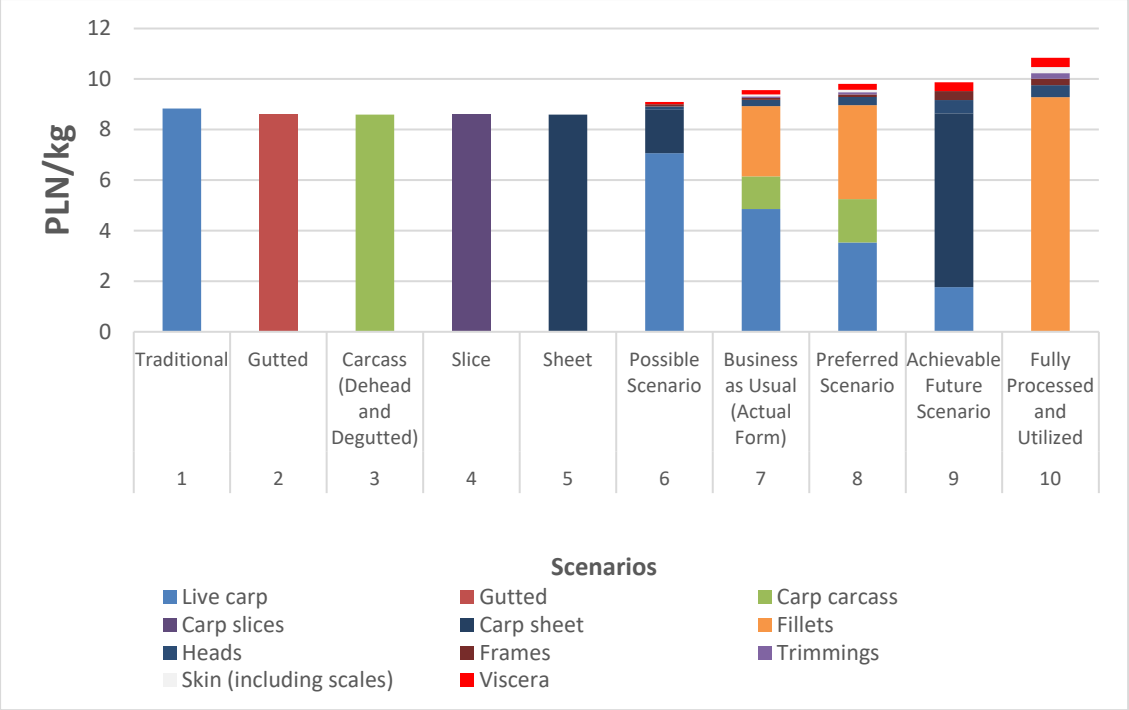

Figure 4.5: Potential value output (PLN/kg) on a kilogram basis on a co-product resolution.

Result indicates a variability in economic output, in which by-products application in food and industrial use show the highest potential (Figure 4.6). The lowest economic potential is associated with dumping by-products on the landfill or incineration, as this has associated with costs. This accounts specifically for S9 (Based on an achievable scenario - 20% live + (80% sheets incl. by-products)) and S10 (40% Fillets + (incl. 60% by-products such as heads, frames, trimmings, skin and viscera) - strategic utilization).

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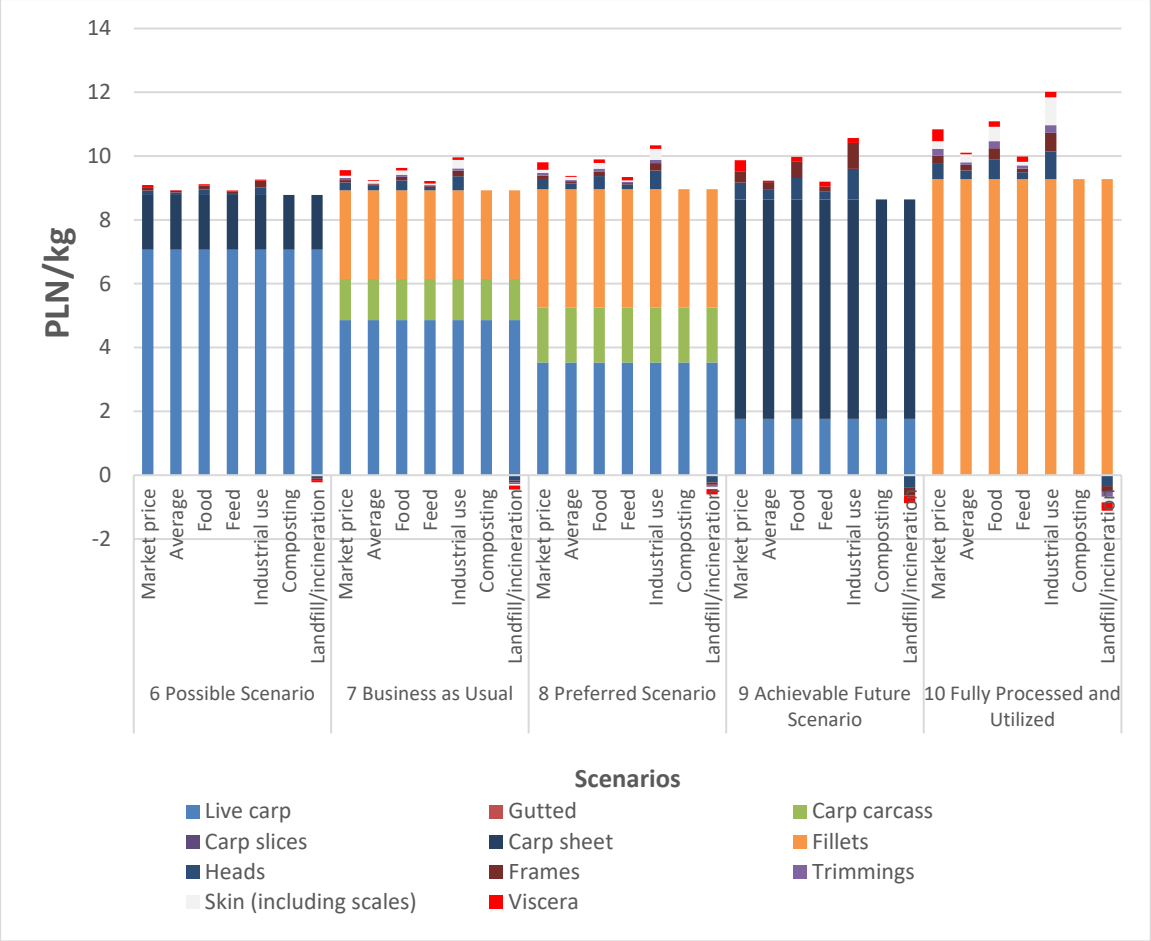

Figure 4.6: Potential value output on a kilogram basis on a co-product resolution (PLN/kg). This figure is an extension of Figure 4.5, including different strategic utilization pathways in scenario 6-10.

4.3.3 Italian rainbow trout

The main trends in the industry are growth and market diversification of trout products. Innovation seems to happen, but stakeholders also indicated that this is limited but changing, as further down discussed (Figure 4.7a). Stakeholders indicate changes in their part of the industry, ranging from novel food, innovation and sustainability, technological innovation an increase customer care (Figure 4.7b). This is also reflected in the answers to the question of the main change in the respondent's company. They indicate a focus on quality preservation, 4.0 (industrial revolution) technology, care for sustainability (Figure 4.7c). Overall, on an industry and company scale, stakeholder actors seem to have a diversified view on the changes that are taking place. When they were asked what sort of factors they could foresee that could have an impact on their farm performance, they mentioned the end of Covid-19 and the reopening of restaurants (Figure 4.7d). Additionally, climate change is also a concern and related availability and quality of water resources, while market aspects such as the trout price and decreasing interest in fresh products is considered impactful to the farm.

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Figure 4.7: a) What are the main trends in the industry (For example: industry growth, different markets, innovation, structural changes, legislative changes)? b) What are the main changes in your part of the industry? c) What are the main changes in your company? Are you planning any changes to become more sustainable/ efficient? d) What factors do you foresee that could positively or negatively affect your farms performance over the next 5 years? Score 1 (negatively) to 5 (positively) or rank.

Stakeholders indicated the potential of utilization trout by-products into cosmetics, nutraceuticals and feed. Relative less interest was shows for the utilization of mortalities into biogas, sludge into biogas and fertiliser (Figure 4.8a). When it comes to technology, most stakeholders indicate that there is not a lot of interest for big data management for fish welfare or farm management support (Figure 4.8b). However, when it comes to the feed ingredients, stakeholder actors indicate industry interest for insects and macroalgae, which is followed up by microalgae, single cell proteins and fish protein hydrolysate (Figure 4.8c).

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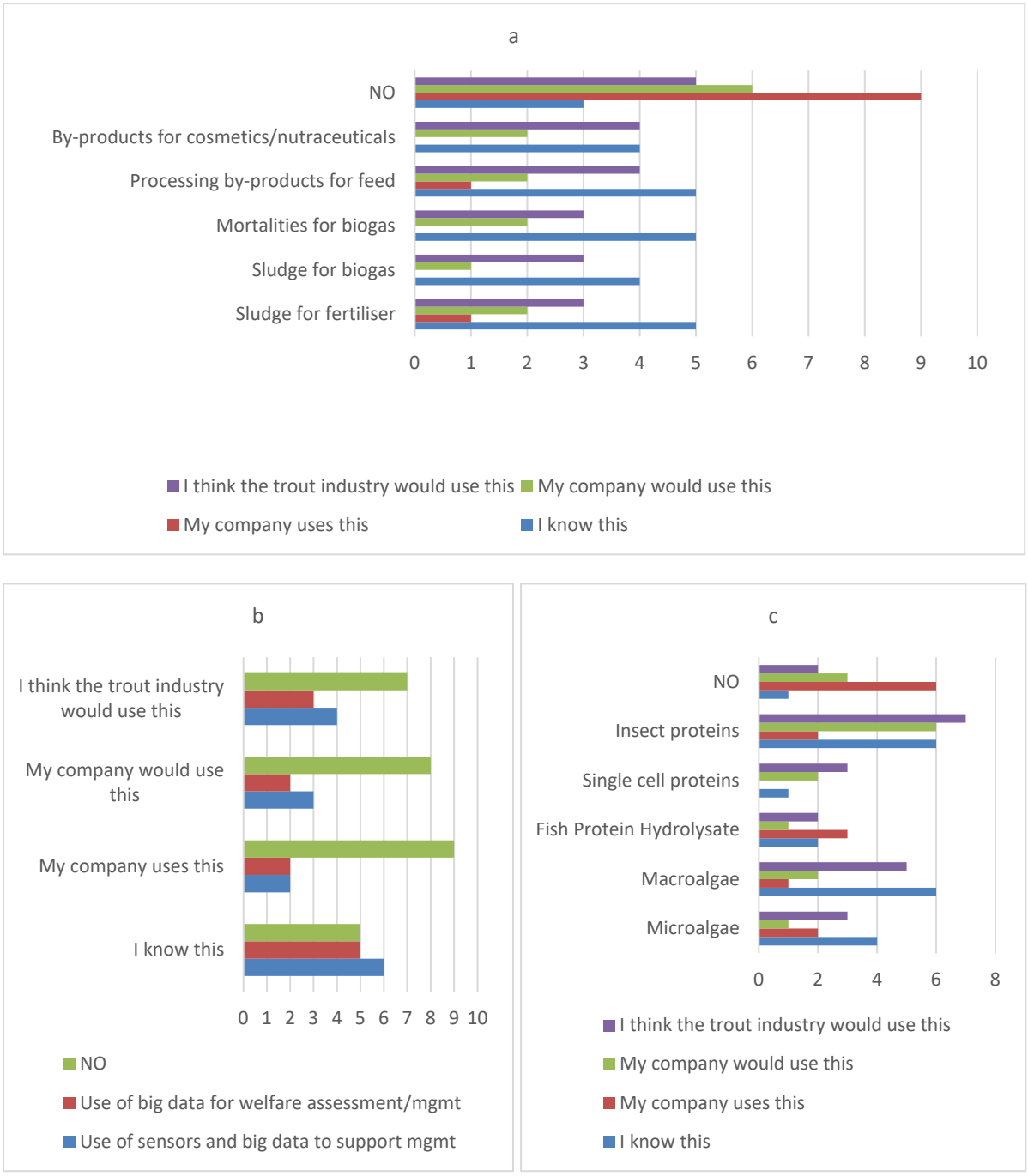

Figure 4.8: a) Interest utilization of by-products and mortalities. b) Interest in big data and sensors to support management. c) Interest in feed ingredients.

4.3.4 UK bivalves

The UK bivalve sector showed the highest awareness and interest in new markets for shells (Table 4.16). From discussions, it is clear that this is not relevant to all producers due to their current business models and the lack of processing in most UK nations would make this difficult, alongside the current consumption pattern of bivalves which is based predominantly on live shell in products. However, processors indicated this is currently something they are interested in, and markets included soil conditioner for the agriculture and gardening sectors, as well as chicken farming. Offshore aquaculture, farming at sea rather than on the shore was also an interest to some stakeholders and

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the wider industry. Some stakeholders are already producing bivalves offshore or hoping to trial this technology in the future. Oyster stakeholders highlighted those floating systems for production have been used in other countries and this is something they would consider. This was highlighted as a potential mitigation measure if sea levels were to rise in the future. Many participants were also aware of IMTA: they had concerns about bivalves grown for human consumption with finfish due to contamination but thought that bivalves could be used as an environmental mitigator of finfish farming. Some producers expressed interest in co-growing bivalves and seaweed, which has a variety of potential uses.

Table 4.16: Awareness/interest in GAIN and other eco-intensification measures in the UK bivalve industry. Six is the maximum score for each respondent based on yes (2), uncertain (1) or no (0) score for personal awareness, company interest and industry interest towards each innovation.

GAIN Innovations	Average score[1]	Standard deviation
Markets for shells	3.60	2.00
Offshore aquaculture	3.43	1.68
Integrated multitrophic aquaculture	3.04	0.75
Shellfish grown for nutraceuticals	2.78	2.48
Use of big management support	1.53	1.05

[1]*In green (average score between 4.5-6), orange (average score between 3-4.5), yellow (1.5-3) and red (average score between 0-1.5).*

4.4 VCA KI discussion and conclusion

4.4.1 Norwegian Atlantic salmon

Norway is the largest European aquaculture producer (EU and EEA combined) and production increased from close to 1 million MT to almost 1.4 million MT between 2010 and 2019. Nevertheless, certain consumer segments show a negative attitudes towards farmed salmon, confirmed by a study mapping industry actors and arguments in relation to environmental and socio-economic concerns (Bailey and Eggereide, 2020). Additionally, there are challenges regarding sea lice infection and production limits imposed by the government. There are increased sustainability concerns about the use of certain feed ingredients, such as fishmeal and fish oil, but also about fishmeal and fish oil substitutes, such as plant ingredients, which can negatively affect nutritional value and could result in poor fish health.

Value chain stakeholders clearly indicated the importance of novel feed ingredients. However, there are also many uncertainties around the use of novel feed ingredients. More specifically, the use of novel feed ingredients is challenged by price, quality, (variable) protein content, scalability and supply maintenance (Hua et al., 2019). Overcoming these bottlenecks requires commitment of stakeholders and cross sector collaboration. Our value chain survey indicates that the structure of the industry shows promising characteristics, as it partly considered vertically integrated. Vertically integrated companies show often high power and interest to make industry changes. The industry shows interest

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in novel feed ingredients to reduce environmental impact, feed efficiency, fish welfare and to improve public consumer perception. These concerns are partly described in the study of Hua et al. (2019) highlighting the important of sustainable ingredients in terms of environmental impact and the need to have alternative protein sources to maintain supply. More specifically, according to the stakeholder actors, marine ingredients from fishery processing by-products show potential to reduce environmental impact, feed efficiency and fish welfare. In addition, circular economy/recycling principles and novel feed ingredients are also considered suitable, which is both in line with the study of Stevens et al. (2018) and Malcorps et al. (2021b), indicating the potential of by-products to support the food, feed and economic output of the aquaculture industry.

4.4.2 Polish common carp

Common carp aquaculture production in Poland is considered traditional and extensive, and has a low impact on the environment (Raftowicz and Le Gallic, 2019). Due to its production characteristics, most farms are located in southern Poland, being dependent on different water resources, mainly precipitation and melting snow in the spring. Water availability in the future is uncertain because of climate change and thus production of common carp may be subjected to rapid and unpredictable changes with unknown outcomes. Therefore, based on the hind- and forecast data series collected for freshwater aquaculture in Poland sound mitigation and adaptation measures should be developed for the sector. Interestingly, according to our results, there is medium range awareness/interest in big data management support, even though the industry is extensive and traditional.

The largest demand for common carp is in December during the Christmas period and this results in a large volume (up to 90%) of live common carp on the market. The decentralized nature of the traditional farming locations makes it more difficult to process the common carp efficiently and collect by-products. However, there is also a link between the sale of live common carp and the opportunity that exist to increase processing output, which could increase output of common carp production, while sustaining or increasing current production levels. Our model indicates opportunities to increase profitability by the sales of a different portfolio of commodities and strategic utilization of by-products. Nevertheless, prices are variable, and profitability also depends on the utilization pathway of the by-products. Additionally, consumer preferences towards different carp products forms were considered an uncertainty. This can be explained by the fact that the industry is in transition from traditional live common carp sales towards processed products, driven by the negative consumer perspectives (as a result of negative messaging from NGOs and media) towards the traditional practice. This new area brings uncertainties for farmers, producers and retailers.

Processors in Poland show relatively high power and interest to innovate and diversify their products. Additionally, there is awareness and interest in by-products for feed production and the use of by-products in cosmetics and nutraceuticals. Nevertheless, intensity in processing and the utilization of fish by-products requires collaboration and collective action, which is challenging due to the dispersed power and interest (in innovation) of the different stakeholders. Carp farmers and processors in Poland express interest and readiness in collecting, sorting, storing and even pre-processing of by-products as defined by the ordering companies from the food or cosmetics sector. Nevertheless, it is important to note that the results indicate a weak relationship between those with most interest and those with most power. This could mean that change is not necessarily being directed by those with

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most to gain or lose. This shows the importance to find ways to make sure that aquaculture development is more stakeholder driven (Lasner, 2021).

Common carp in Poland is mostly consumed domestically (Raftowicz and Le Gallic, 2019). However, due to a high interest of some of the common carp farmers (e.g., located in the Barycz Valley), there is also a seasonal increase in common carp consumption by tourists who seek local and natural products. This is in line with the expectations of the consumers within the EU who show great interest in sustainable seafood, in case of the Polish common carp "fresh food". The common carp extensive farming fits perfectly in that picture. However, new obstacles emerged, such as the negative perceptions towards the sale of live common carp should be addressed to meet future consumer demands. This also indicates opportunities to increase the processing intensity and increase food, feed and economic output of the sector. A diversified portfolio of processed carp products could increase the (economic) output of the industry (Stevens et al., 2018; Malcorps et al., 2021b). In addition, stakeholder actors indicate that diversification of activities at the farm (e.g., tourism) could also be an appropriate strategy to increase profitability of the industry, which has been confirmed by findings in the study of Raftowicz et al (2019), and therefore making it less reliant on subsidies from the EU.

4.4.3 Italian rainbow trout

Italian rainbow trout production increased from approximately 35000 MT in 1990 to 45000 around the year 2000. In the last 2 decades the production slightly declined to 33000 MT in 2019 (FAO, 2020) and 34800 MT in 2020 (API, 2021). The decline in production was caused by market saturation and devaluation of the product (Roncarati and Melotti, 2007). In response farmers and increased processing and diversified their products (hamburgers, smoked fish, fish skewers) (Iandoli and Trincanato, 2007), which resulted in small size fish (500g) being sold head-on-gutted, while larger fish (500g up to 1-2 kg) is fully processed in a range of products (Fabris, 2012). Additionally, certain consumers seem to be willing to pay a premium price for organic trout, indicating opportunities for the industry. However, it is important to advertise and communicate these organic characteristics through e.g., advertising campaigns (Disegna and Trevisan, 2009). Nevertheless, the respondents of our survey indicate a current trend of market decline possibly caused by loss of consumer interest and lower price for trout. While some larger rainbow trout is already (partly) processed, increased diversification of trout products and towards the production of other freshwater species, are considered possible solutions to grow the industry. However, the loss in consumer interest could also been caused by the covid-19 pandemic and limiting market access due to closure of restaurants and other hospitality services.

According to PO FEAMP (2020) there are around 310 freshwater farming companies active in the Italian rainbow trout value chain (Maiolo et al., 2020a). Most of these companies (78%) can be found in the Alps and Apennines in North Italy (Fabris, 2012), where optimal growing conditions can be found, such as fast-flowing, high-oxygenated waters with low temperatures (below 21 °C) (Parisi et al., 2014). However, these areas could be affected by climate change resulting in lower water availability and quality, exposing the industry to external factors and affecting its resilience. Additionally, while resilience could be increased by research and development, this is hard to access for most of the trout companies, which are considered small-medium enterprises.

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4.4.4 UK bivalves

Shellfish aquaculture in the UK is valued in excess of £35 million and is dominated by Blue mussel and Pacific oyster production, there is also a small quantity of Native oyster and scallops produced but production volumes are currently low, (Hambrey and Evans, 2016; Adamson et al., 2018). Farmed bivalves are considered a low environmental impact food source (Hillborn et al., 2018) and production is mostly located in rural coastal areas, which provides valuable employment and economic investment to many remote areas of the UK (Black and Hughes, 2017). More recently farming offshore has developed in the UK and offshore technologies were highlighted as a positive sustainability factor, and an area of high interest from stakeholders in this study. Bivalve production is present across all four nations of the UK (Wales, Scotland, England and Northern Ireland), although the structure of these industries is different across the nations. Most notably, the Scottish bivalve industry is largely made up of a co-operative called the Scottish Shellfish Marketing Group which produces shellfish products for UK retail and food service. Elsewhere in the UK, the majority of bivalve products are exported to Europe as either full-grown or half-grown bivalves for further processing or rearing. There is strong political interest in growing the bivalve industry in the UK. Scotland has outlined plans to double its economic value from aquaculture by 2030, which includes plans to increase shellfish production to 21,000 tonnes per annum, according to Scotland Food and Drink (2016). England has also recently set out ambitious plans to increase its aquaculture production by 10-fold, including an increase in bivalve production from 3000 tonnes to 35,000 tonnes in the next 20 years (Huntington and Cappell, 2020).

Seed availability, optimal site availability and water quality issues have been highlighted as potential constraints that would limit the future growth of the industry, according to the Shellfish Centre (2018) and by Hambrey and Evans (2016). These sustainability factors were highlighted as both negative and uncertain challenges by UK stakeholders in this study. Seed availability for oyster production is currently supplied from two hatcheries and although supply is not currently a problem, stakeholders were uncertain on the availability of future supply. Certainly, an increase in production in line with current targets across the UK nations would require large investment and upscale in oyster hatchery capacity (Huntington and Cappell, 2020). Mussel production in the UK mostly relies on wild spat settlement onto suspended ropes or harvested seed which is laid for bottom culture and therefore does not rely on seed from hatcheries. In many farming areas wild spat levels are good and adequate for production, however in some areas, notably in Wales and Scotland producers have seen a decline in wild spat levels. In some regions producers have been forced to fish or develop seed collection sites elsewhere. Governance, in terms of cost and time required for planning and regulatory procedures was shown to be of great concern to several stakeholders. This issue has previously been highlighted as a barrier to industry growth, with calls on the government to actively support and facilitate the industry by streamlining and reducing the cost of these processes, according to the Shellfish Centre (2018) and by Hambrey and Evans (2016).

Stakeholders highlighted that the low environmental footprint of bivalve aquaculture (Hillborn et al., 2018; Gephart et al., 2021) and the potential for bivalves to provide valuable ecosystem services such as water quality regulation, carbon sequestration, coastal protection, habitat creation and supporting local biodiversity (Macleod and Macleod, 2019; Van der Schatte Olivier et al., 2020) could be positive for sustainability of the industry. Although many stakeholders also highlighted that the lack of public awareness of these benefits were potentially negative for the industry. Although lower than many

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other animal foods, the environmental footprint of bivalves is elevated when considering edible portion due to the shell weight (Gephart et al., 2021). Most bivalve shells become waste at processing sites, hospitality venues or at consumer households and these are mostly sent to landfill. There was high interest from UK stakeholders in developing markets for shells especially in the processing sector, however currently the economies of scale are low, and the current consumption pattern of bivalves presents a challenge for innovation in this area. Additionally, potential concerns from stakeholders regarding Brexit included: (1) changes in the water classification requirements for export, (2) border delays, (3) risk of labour shortages, (4) increase in transport costs, (5) withdrawal of EU funding, and (6) the potential for relaxation of regulation in the UK. This was in line with the results from O'hare (2021) which highlighted concerns around loss of trade due to dependency on the EU market and lack of access to alternative markets for UK producers. Additionally, O'hare (2021) reported concerns around the vulnerability of spat supply which was also highlighted as an uncertain and potentially negative sustainability concern by stakeholders in this study.

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4.5 Delphi survey round 1

The results of the Delphi survey for Norway and Poland (annex 5 and 6, respectively) are described in the following section focussing on stakeholders involved, industry perceptions, legislation, sustainable growth support and scoring of the EISI indicators (Table 4.17).

Table 4.17: Industry responses and value chain actors Delphi round 1 and 2

Value chain actor	**Norwegian Atlantic salmon**		**Polish common carp**	
Delphi round	**1**	**2**	**1**	**2**
Brood stock/hatchery		1		
Farm	3	1	2	1
Slaughterhouse and processing		1	1	
Feed	2	3	1	1
Vet/health		1	1	1
Trade		1		
Equipment producers	1			
Recreational			1	
Education, research and academia	3	2	9	5
NGO				1
Certifiers	2			
Government				1
Other		1		2
Total (N)	**11**	**11**	**15**	**12**

4.5.1 Industry perceptions

Norwegian Atlantic salmon

The value chain survey indicated an interest in sustainability and, in particular, the use of more sustainable feed ingredients. This was in line with the Delphi stakeholder actors from Norway, showing a general trend towards increasing the production in a sustainable way (Figure 4.9a). Key aspects of this sustainable transition are the use of sustainable feeds, technically efficient production and high fish welfare standards (Figure 4.9b). This is necessary, as the Norwegian expert group indicated a neutral standpoint on the idea that the industry is sustainable (Figure 4.9c). Contrary, people outside Norway (foreigners) consider the industry already to be sustainable (Figure 4.9d).

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Figure 4.9 a) General trend in the aquaculture industry in Norway? b) Key aspects environmental sustainability of the industry. c) Within Norway, the Norwegian aquaculture industry is perceived as sustainable. d) In Europe, the Norwegian aquaculture is perceived sustainable by the general public.

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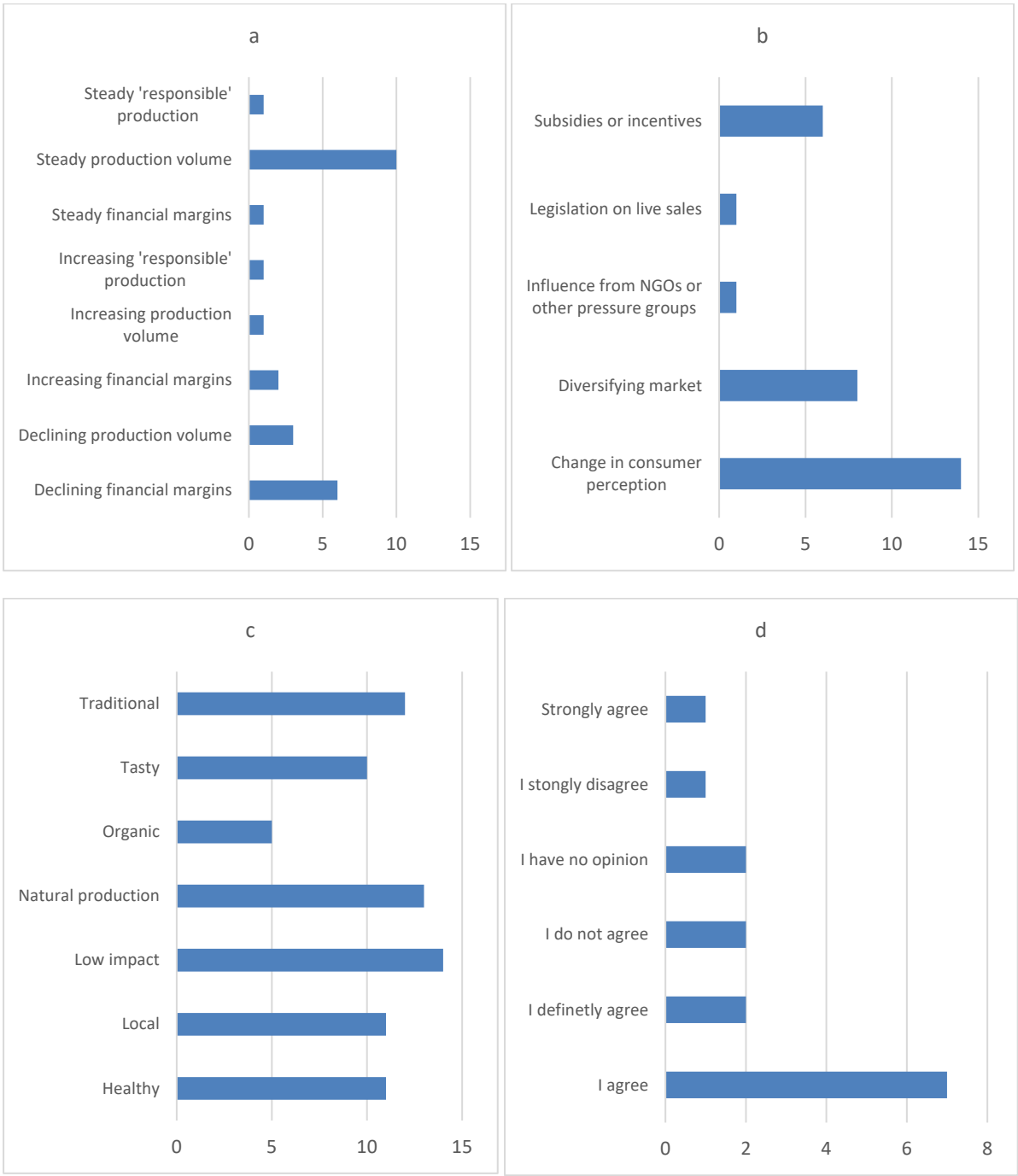
Polish common carp

A general trend in the Polish common carp industry are the steady production volumes and declining financial margins (Figure 4.10a). Common carp slaughter and processing is considered a positive sustainability factor for the industry. However, its implementation could be stimulated by subsidies and incentives, diversification of common carp products and a change in consumer perception (Figure 4.10b). There is a consensus among the Polish participants that the Polish common carp aquaculture industry is sustainable (Figure 4.10d) and that the natural, low impact and traditional aspects of carp farming should be promoted (Figure 4.10c). The Polish participants mentioned not to have an opinion when it comes to the perceptions of Europeans towards the statement if the industry is perceived sustainable (Figure 4.10e).



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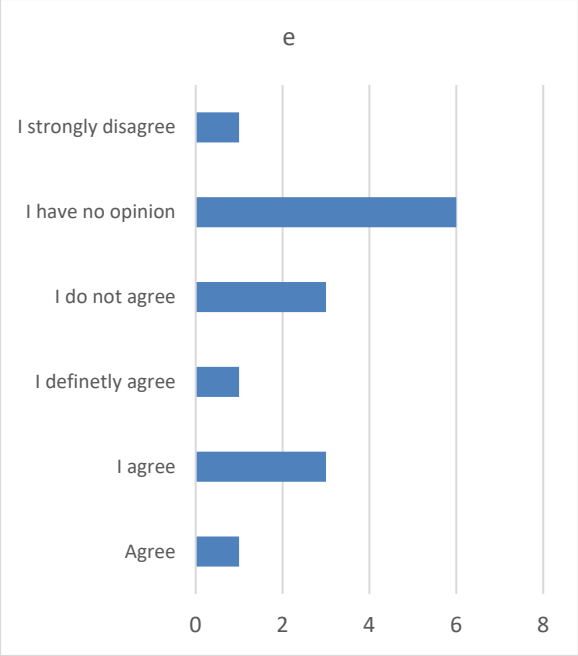

Figure 4.10 a) General trend in the carp aquaculture industry? b) What is needed to increase the processing of carp? c) Aspects of the carp farming industry that should be promoted? d) Within Poland, the Polish carp aquaculture industry is perceived as sustainable. e) In Europe, Polish carp aquaculture is perceived sustainable by the general public.

4.5.2 Legislation

Norwegian salmon

Participants neither agree or disagree on the matter that EU legislation is supporting growth, however, there is a consensus that EU legislation support the industry to become more environmentally friendly (Figure 4.11a and b). National legislation on industry growth and environmental sustainability are supportive according to most participants (Figure 4.11c and d). When it comes to regional legislation, stakeholder actors neither agree or disagree that this is supporting growth, while these policies are supportive to become more environmentally friendly (Figure 4.11e and f).

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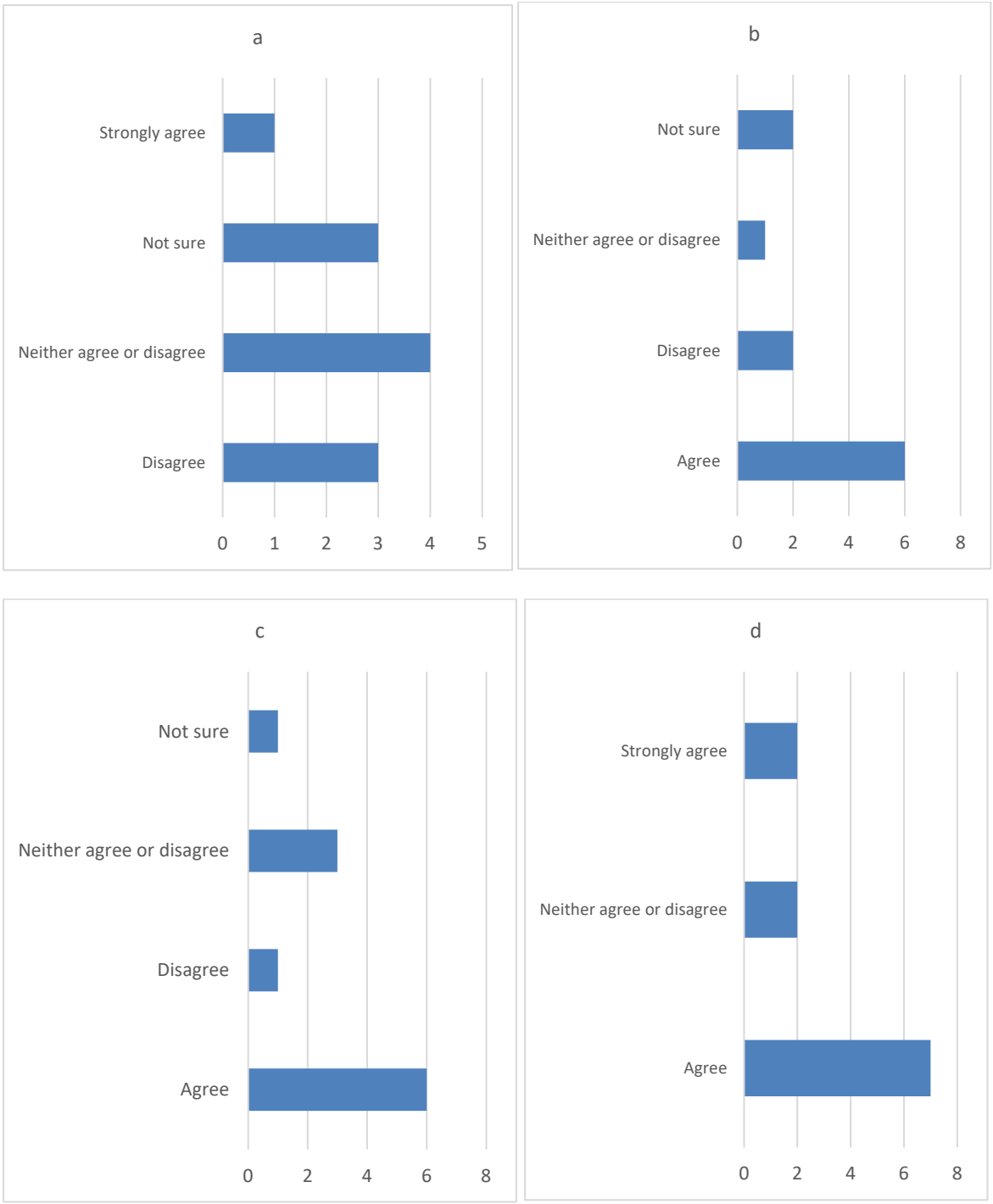

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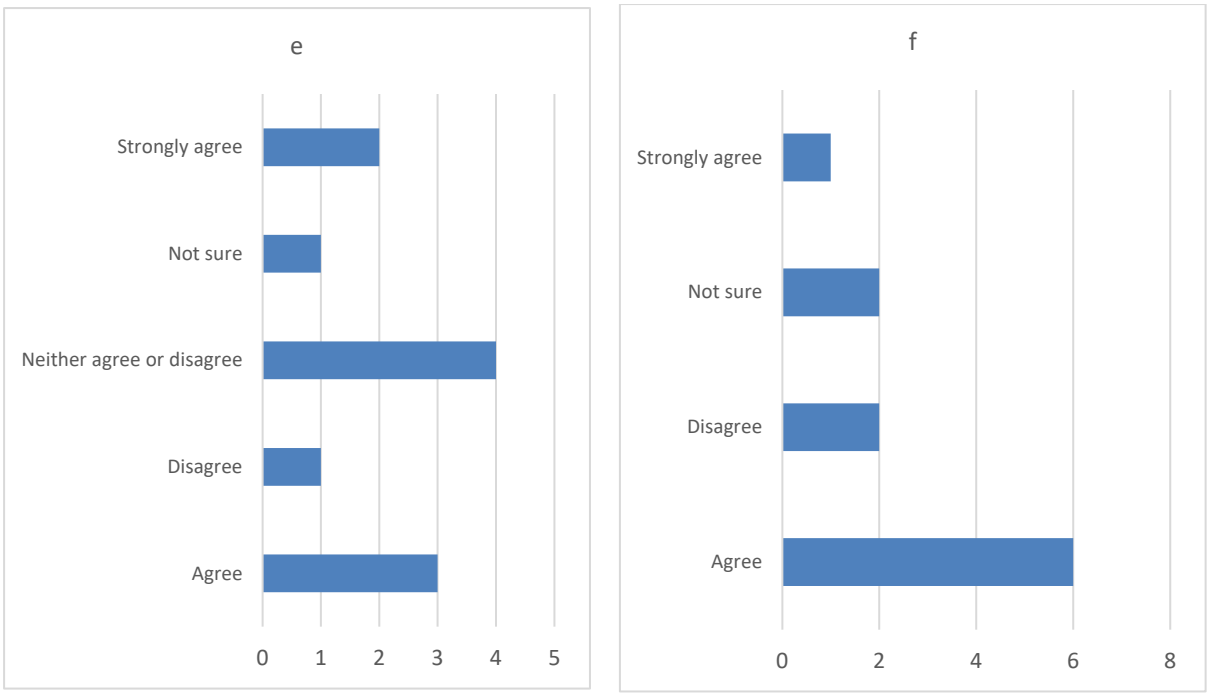

Figure 4.11 a) EU legislation is supporting the growth in production volume output. b) EU legislation is supporting the industry to become more environmentally friendly. c) National legislation is supporting the growth in production volume output. d) National legislation is supporting to become more environmentally friendly. e) Provincial (regioner) is supporting the production volume output). f) Provincial (regioner) is supporting to become more environmentally friendly.

Polish common carp

There is a consensus that EU legislation supports the growth of the sector and efforts to become environmentally more sustainable (Figure 4.12a and b). In contrast national legislation was perceived as not supporting either the growth or environmental sustainability of the industry (Figure 4.12c and d). Participants did not have an opinion when asked if regional legislation support growth and environmental sustainability of the industry (Figure 4.12e and f).

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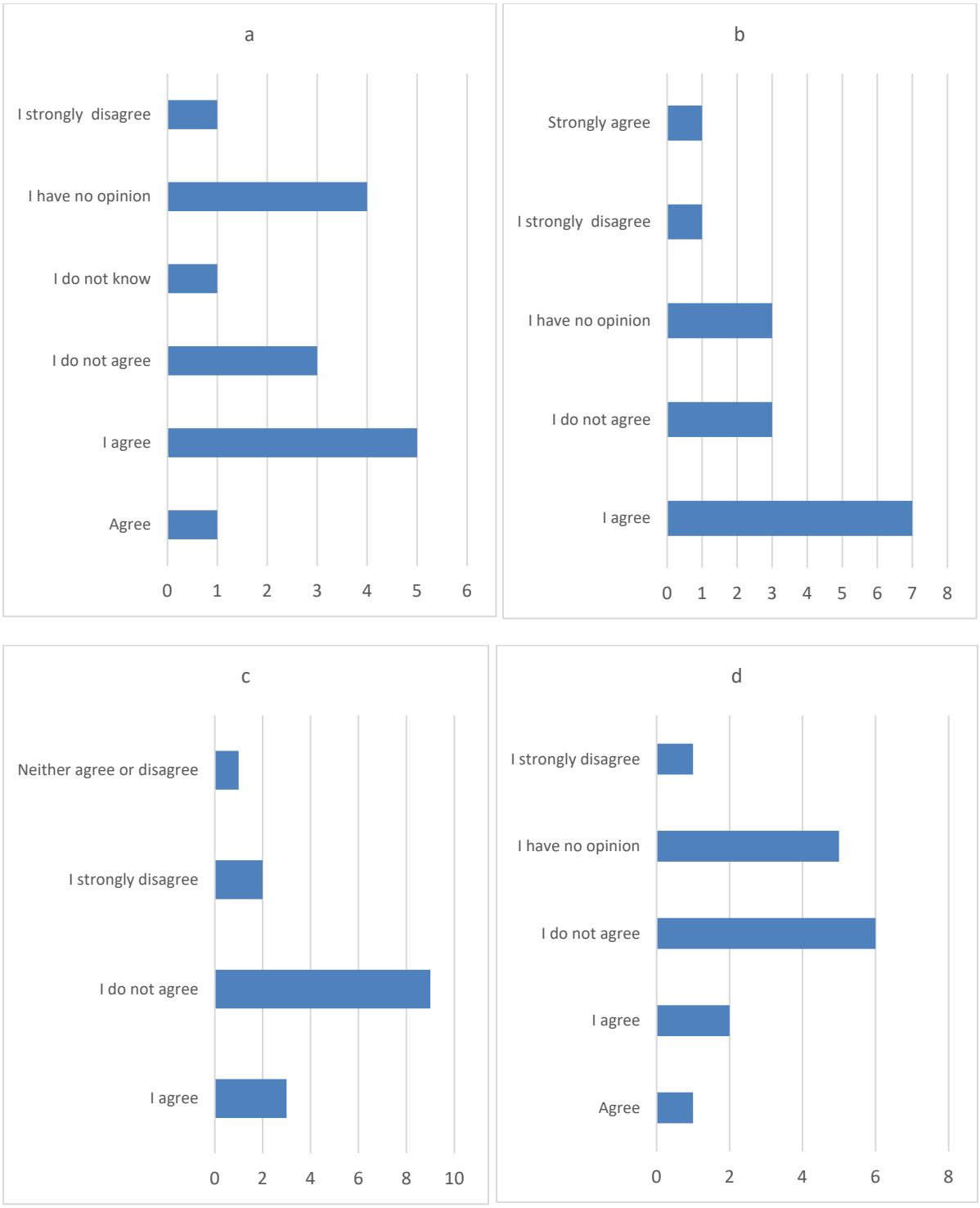

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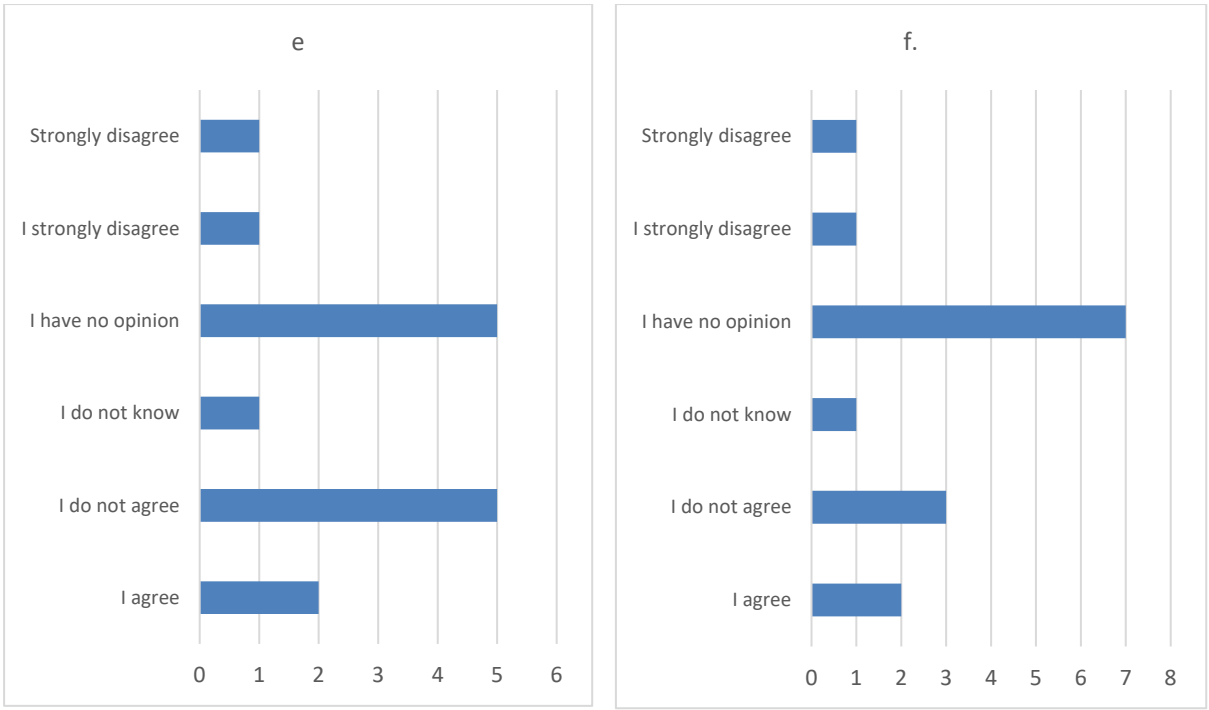

Figure 4.12 a) EU legislation is supporting the growth in production volume output. b) EU legislation is supporting the industry to become more environmentally friendly. c) National legislation is supporting the growth in production volume output. d) National legislation is supporting the industry to become more environmentally friendly. e) Provincial (voivodeship) legislation is supporting the growth in production volume output. f) Provincial (voivodeship) legislation is supporting the industry to become more environmentally friendly.

4.5.3 Sustainable growth support

Norwegian Atlantic salmon

There is an overall consensus that collaboration between stakeholders and government support in the form of R&D is needed to support sustainable growth of the Norwegian aquaculture industry (Figure 4.13a). Appropriate strategies include the adoption of circular economy principles and the use of novel feed ingredients. Additionally, there is contradictory views among the focus of increased production and a focus on quality rather than quantity (Figure 4.13b). The substitution of marine ingredients with novel feed ingredients, circular economy principles media promotion and increased transparency are considered suitable strategies to improve public perception towards the aquaculture industry in Norway (Figure 4.13c).

Sea lice is considered the biggest sustainability challenges for the industry. Suitable mitigation strategies are physical sea lice exclusion technologies, closed or semi-closed containment systems, cleaner fish, and data sharing between farms (Figure 4.13d).

Environmental performance and efficiency could be improved through different feed ingredients. All experts agree that most novel feed ingredients show potential, especially over plant ingredients as alternative to partly substitute marine ingredients, which have the lowest score (Figure 4.13e and f).

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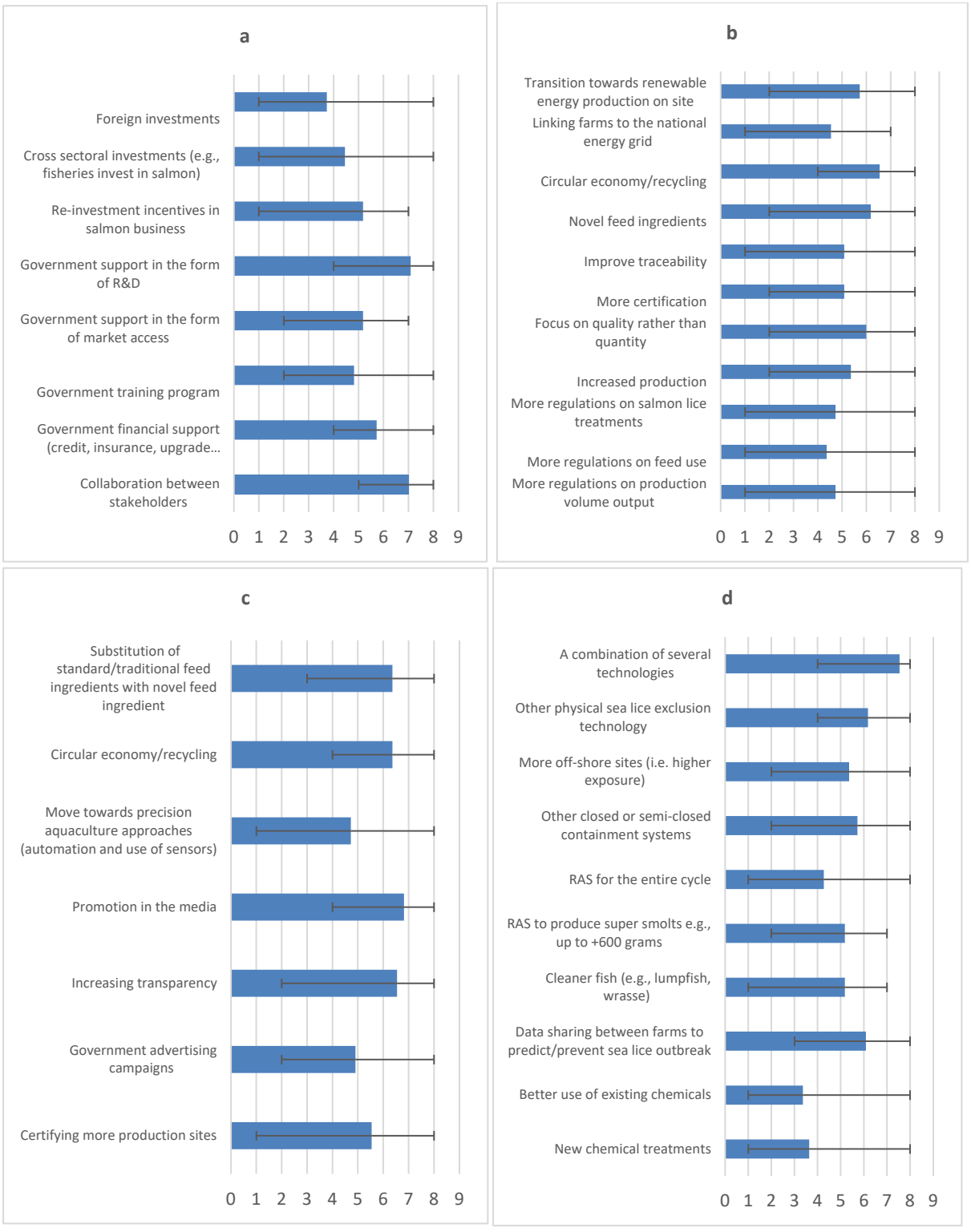
Similar, these ingredients show also potential to improve fish welfare and to improve public consumer perception (Figure 4.13g and h).



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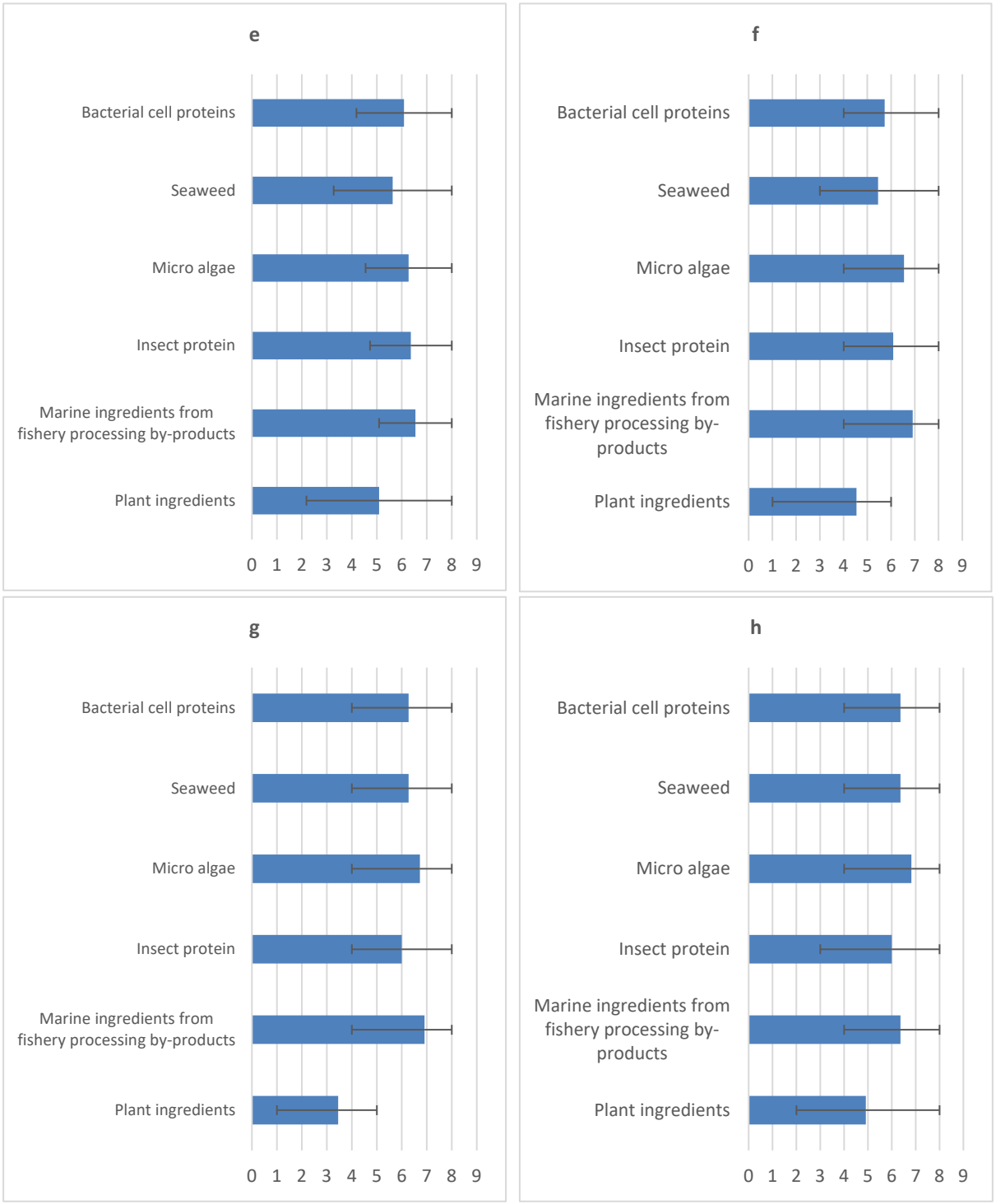

Figure 4.13 a) Needs to support sustainable growth? b) Strategies to increase the profitability? c) Strategies to improve public perception towards the aquaculture? d) Potential technologies to combat sea lice? e) Potential of novel feed ingredients to improve environmental sustainability? f) Potential of novel feed ingredients to improve feed efficiency? g) Potential of novel feed ingredients to improve fish welfare? h) Novel feed ingredients show potential to improve public consumer perception of farmed fish? (Score: 1 low potential, 8 highly potential).

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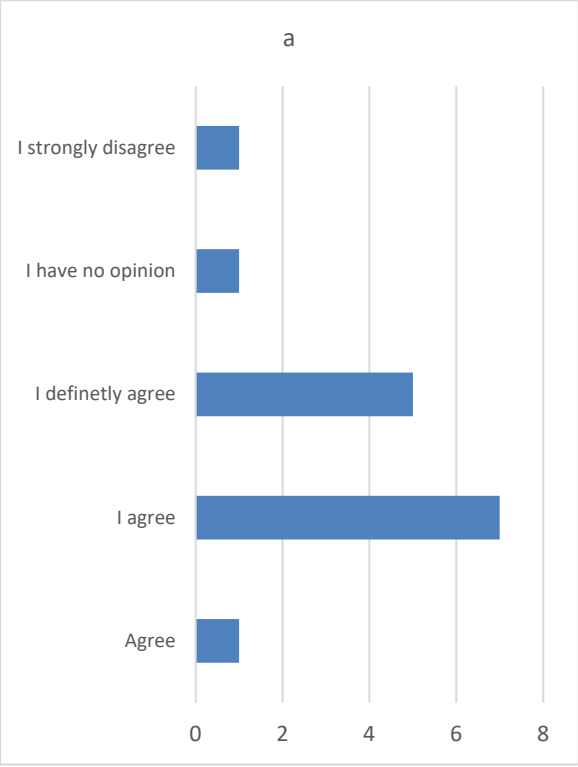
Polish common carp

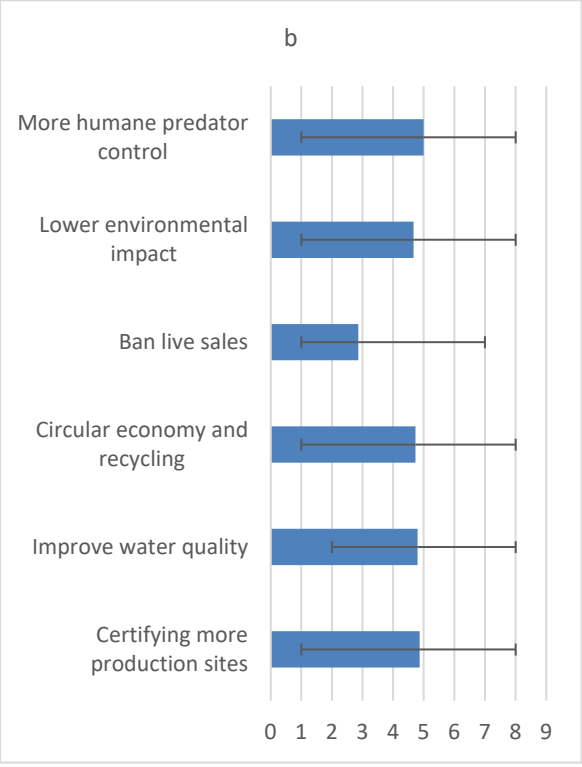
Most participants agree that carp processing could increase the profitability of the industry (Figure 4.14a). Actions that could improve the perception towards the industry are human predator control (e.g., scarecrows), 'awareness of' lower environmental impact compared to other aquaculture species, circular economy, and recycling, improving water quality and certifying more production sites (Figure 4.14b). This should be promoted through marketing campaigns (financially) supported by the government and media promotion (Figure 4.14c). To support the sustainable growth of the aquaculture industry, government support in form of finance and R&D, EU funds and collaboration between stakeholders, are considered important by the stakeholders (Figure 4.14d).

Suitable strategies to improve the sustainability of the industry are diversification of the activities at the farm, efficient predator control and increased processing (Figure 4.14e). The latter is important, as processing into fillets is considered the most profitable aquaculture product (Figure 4.14i).

The year around appeal for carp can be improved by other investments to promote carp consumption throughout the year, such as EU funds to promote carp consumption, marketing and advertising campaigns, organizing promotion events, consumer perception change, diversify carp products (Figure 4.14f). Appropriate strategies to improve the image of Polish carp aquaculture are increasing awareness, education, and more processing (Figure 4.14h).

Challenges, such as water availability because of climate change is the main negative sustainability concern. This could be mitigated by engineering solutions (channels), record keeping, improved water quality monitoring, and the more efficient use of water resources (Figure 4.14g).





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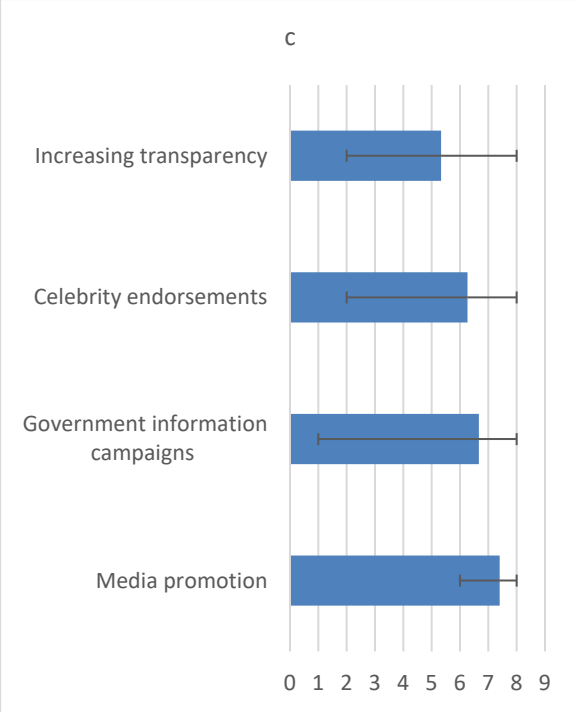

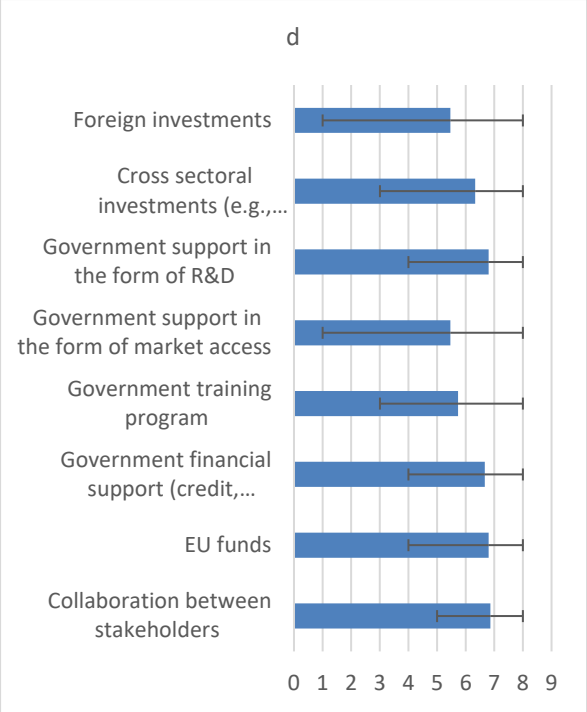

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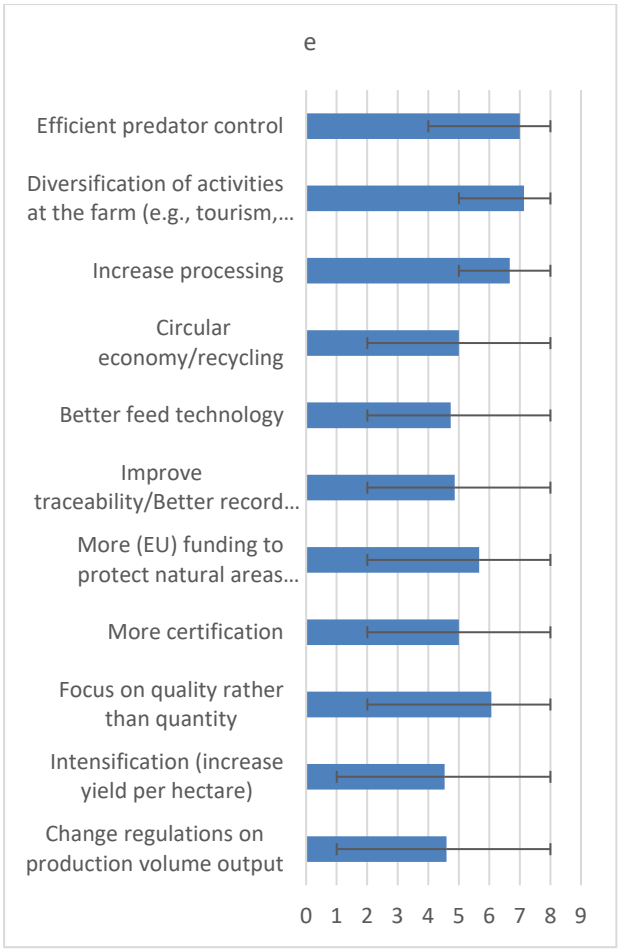

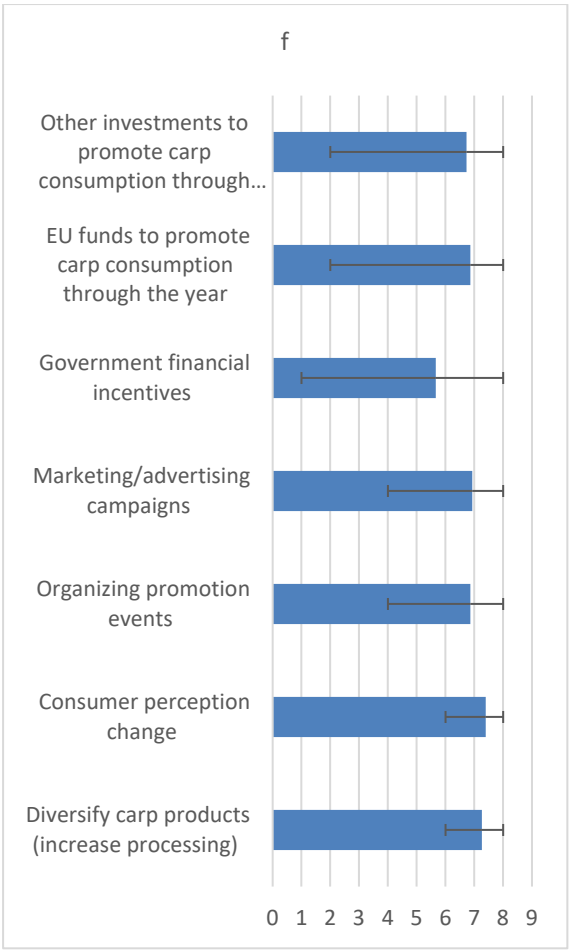

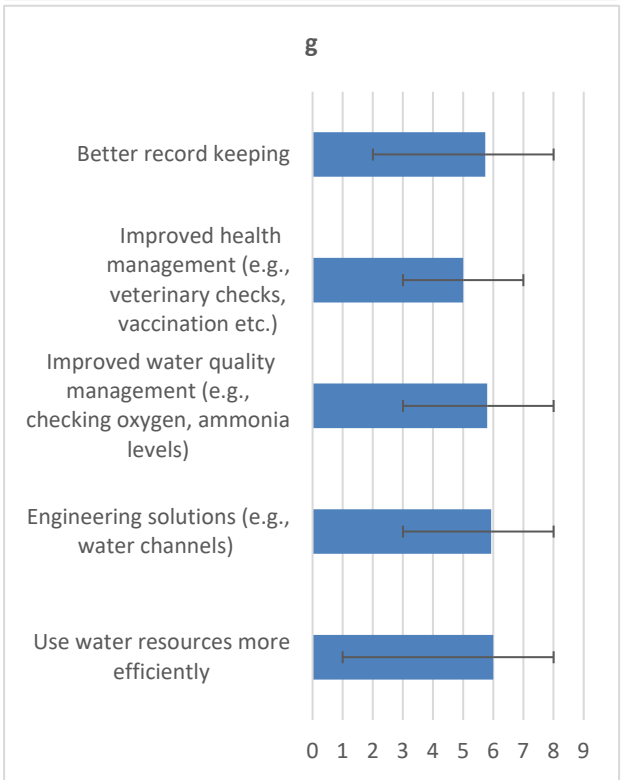

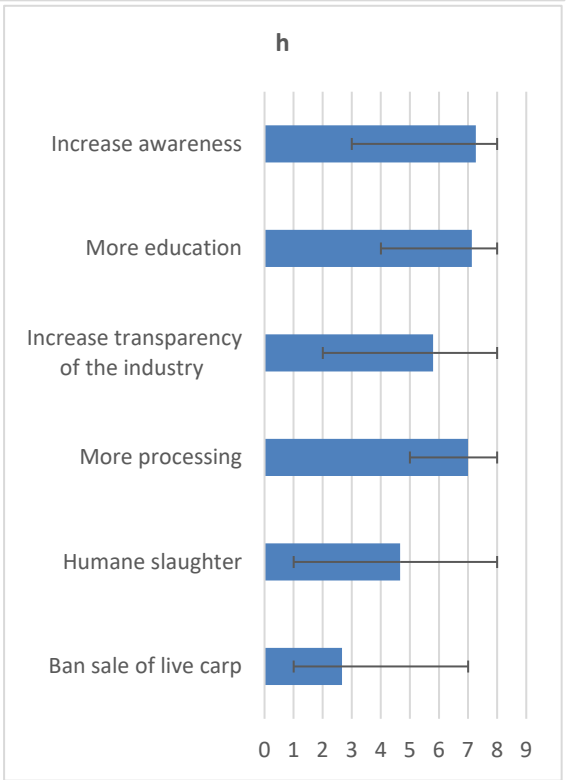

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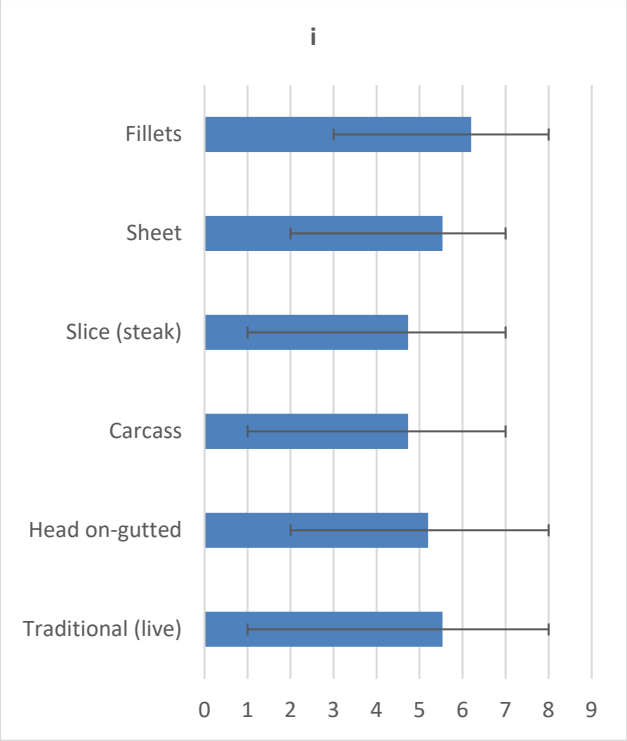

Figure 4.14 a) Carp processing could increase profitability? b) Actions to improve perception towards aquaculture? c) In terms of marketing and promotion, what could be done to improve perception towards aquaculture? d) What is needed to support the sustainable growth? e) Strategies to increase the profitability? f) How can the year around appeal for carp being improved? g) Suitable mitigation strategies against the effects of climate change? h) Appropriate strategies to improve the image of carp farming? i) Most profitable carp product? (Score: 1 low, 8 high).

4.6 Delphi round 2

4.6.1 Perceptions

This second subject includes the stakeholder actors from the second Delphi round starting first with Norwegian Atlantic salmon, followed up by common carp (annex 7 and 8, respectively)

Norwegian Atlantic salmon

Stakeholders indicate a perception from EU consumers that Norwegian salmon is pristine and high standard. However, they also indicate different perceptions on sustainability (Figure 4.15).

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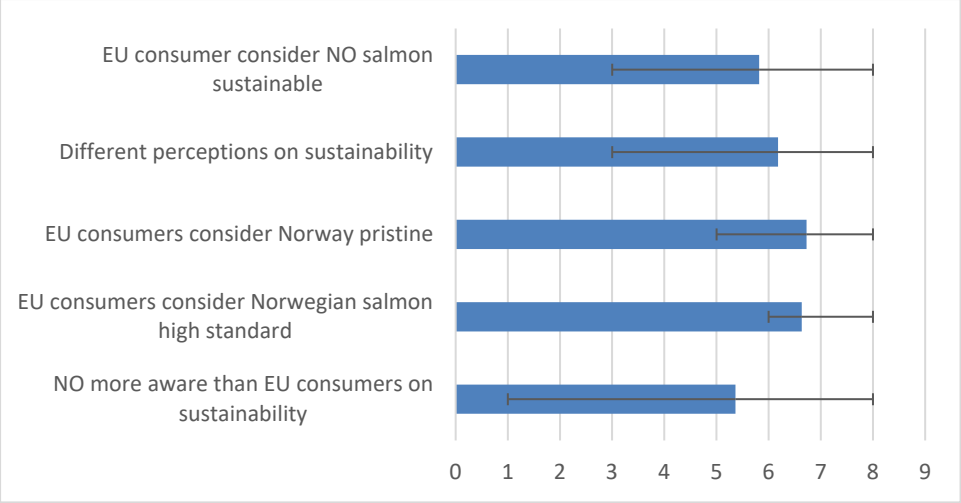

Figure 4.15: In round 1 (see graphs) we asked about the environmental impact of the Norwegian aquaculture industry. Stakeholders indicated that they perceived that EU consumers regarded Norwegian aquaculture to be more sustainable than Norwegian consumers did. What can explain these different perceptions?

In the previous round stakeholders indicated that novel feed ingredients are considered a key strategy to increase profitability and sustainability. However, stakeholders indicated that novel feed ingredients use is constraint by price, availability, consistency of nutritional content, and quality, identified as the most important challenge for novel feed ingredients (Figure 4.16).

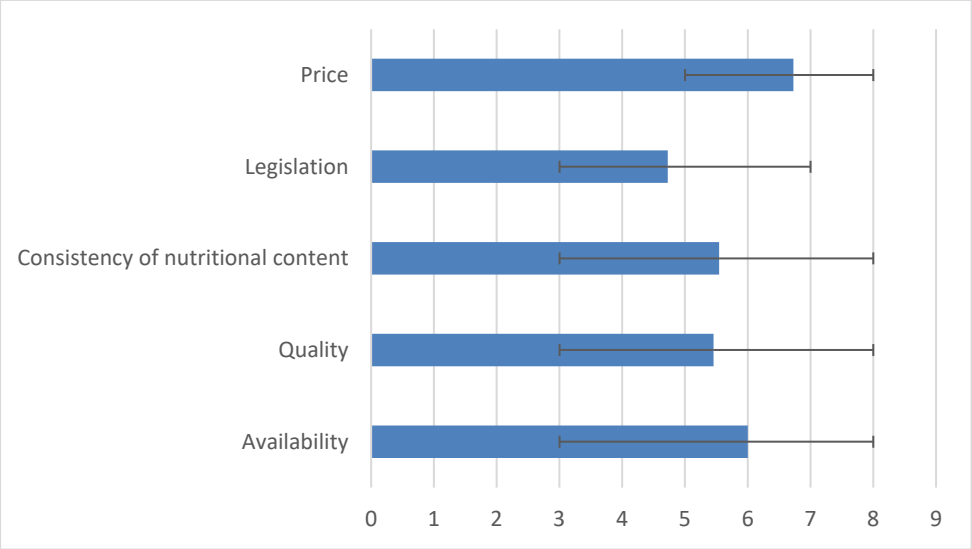

Figure 4.16: In round 1 we asked about general trends in the aquaculture industry in Norway. Stakeholders highlighted a trend towards responsible production. Stakeholders also indicated that novel feed ingredients were considered a key strategy to increase profitability and sustainability. What are the main challenges of novel feed ingredients?

Stakeholders indicated that important strategies to support fish welfare are the implementation of training in fish welfare (Figure 4.17). Additionally, monitoring of water quality and fish condition are also important strategies to support fish welfare. The one with a lower priority seems to be feed quality assurance, predator control and regulator veterinary checks.

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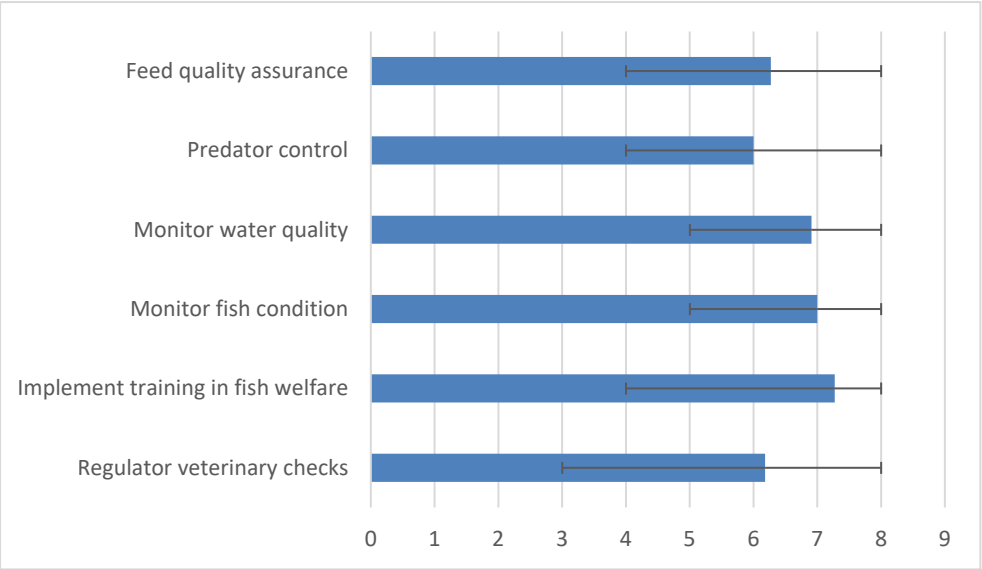

Figure 4.17: In round 1 we asked about environmental sustainability (graph below, red bar). In addition to sustainable feeds and technically efficient production, stakeholders highlighted the importance of high fish welfare. What are key strategies to support fish welfare?

Stakeholders in the first round indicated that collaboration between stakeholders is considered most important to support sustainable growth. This could be in the form of sharing farm performance data, R&D on sustainable feeds, area warning system for sea lice (Figure 4.18).

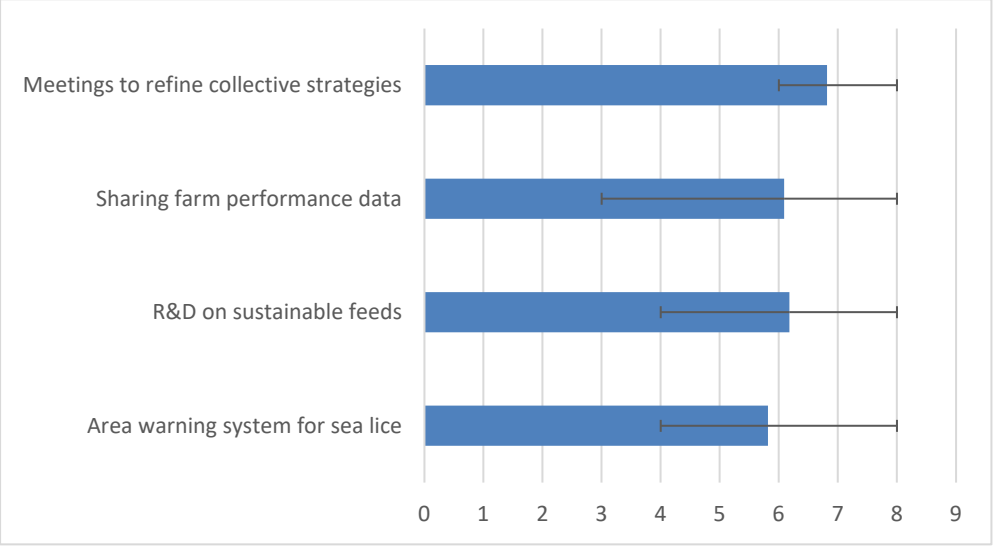

Figure 4.18: In round 1 we asked about the needs to support sustainable growth. Stakeholders indicated that collaboration between stakeholders is very important to support sustainable growth. What type of collaboration is most important?

In the previous round, stakeholders had mixed views about legislation in terms of supporting the growth of the industry. Legislation to achieve sustainable growth should be focussed on maximum standing biomass regulation, planning site selection, financial instrument for innovations, legislate on environmental footprint. Stakeholders also indicate, but with less importance, the reduction of feed use regulation, reduction of salmon lice treatment regulation, replacing regulation with private standards (Figure 4.19).

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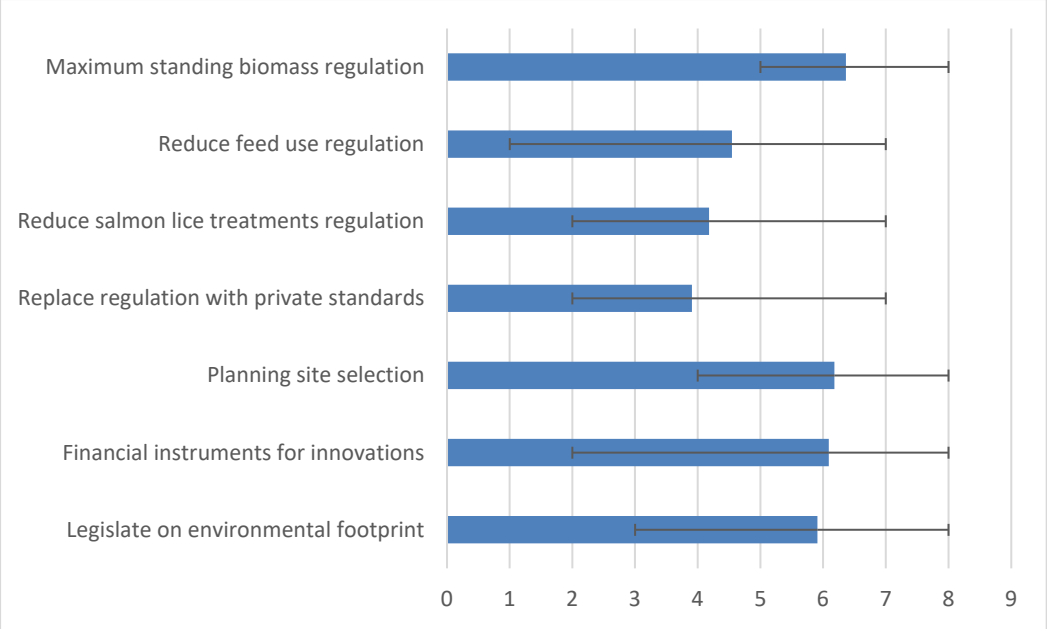

Figure 4.19: In round 1 we asked if current EU and provincial (regioner) legislation is supporting growth (production volume output) of the Norwegian aquaculture industry. Stakeholders had mixed views about legislation in terms of supporting the growth of the industry. Where should legislation focus to achieve sustainable growth?

Polish common carp

In the first-round stakeholder actors identified a perception of reduced profit margins. This could have been caused by higher production costs and low carp prices. Stakeholders also indicated that environmental challenges, such as the lack of water, also have reduced the production and therefore the profitability (Figure 4.20).

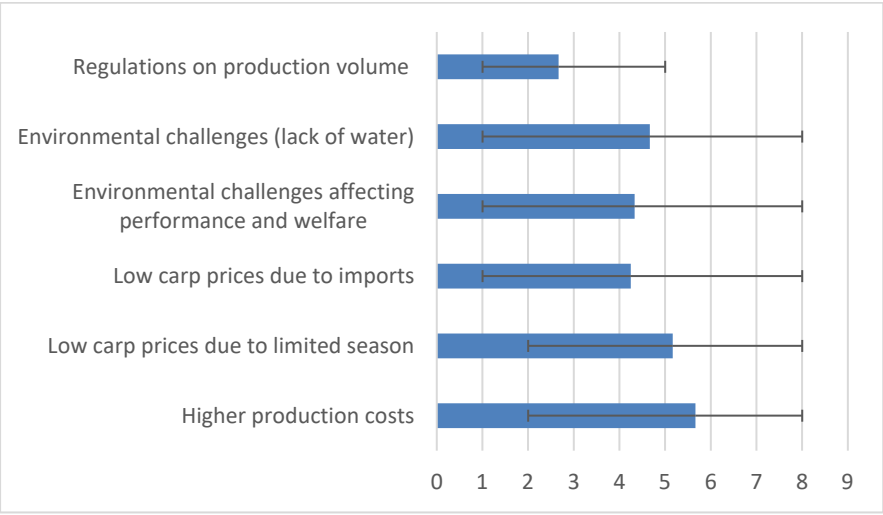

Figure 4.20: In round 1 we asked about the general trends in the carp aquaculture industry in Poland. In addition to a steady production volume, stakeholders identified a perception of reducing profit margins (graph below). What has caused the declining financial margins?

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Stakeholders in the first round indicate that carp processing shows potential to increase the profitability of the Polish aquaculture industry. However, this requires a consumer perception change towards processed carp. According to the stakeholders this could be achieved by advertising differentiated products, promotion of the natural production characteristics of the Polish carp industry, advertising all year consumption of carp products (Figure 4.21).

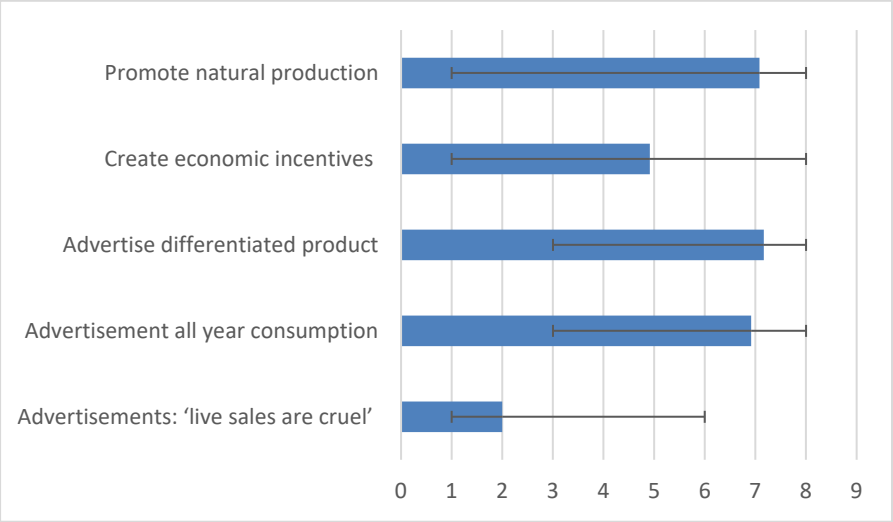

Figure 4.21: In round 1 we asked if carp processing could increase the profitability of the Polish aquaculture industry. Stakeholders indicate that carp processing could increase the profitability of the industry. What is the best strategy to change consumer perceptions towards processed carp?

According to the stakeholder actors, supportive legislation (provincial/national) on sustainable carp production should have a wide focus, but high priority should be put on financial instruments to promote carp products year-round, financial instruments to develop short supply chains and to support small processing plants. Financial instruments could also be used to stimulate innovation. Other legislation should focus on protecting carp ponds as an environmental asset. Lower priority was accorded to legislation aiming to increase carp farms on state-owned land, tightened regulation of veterinary standards or around carp harvesting, or implementation of government food quality standards (Figure 4.22).

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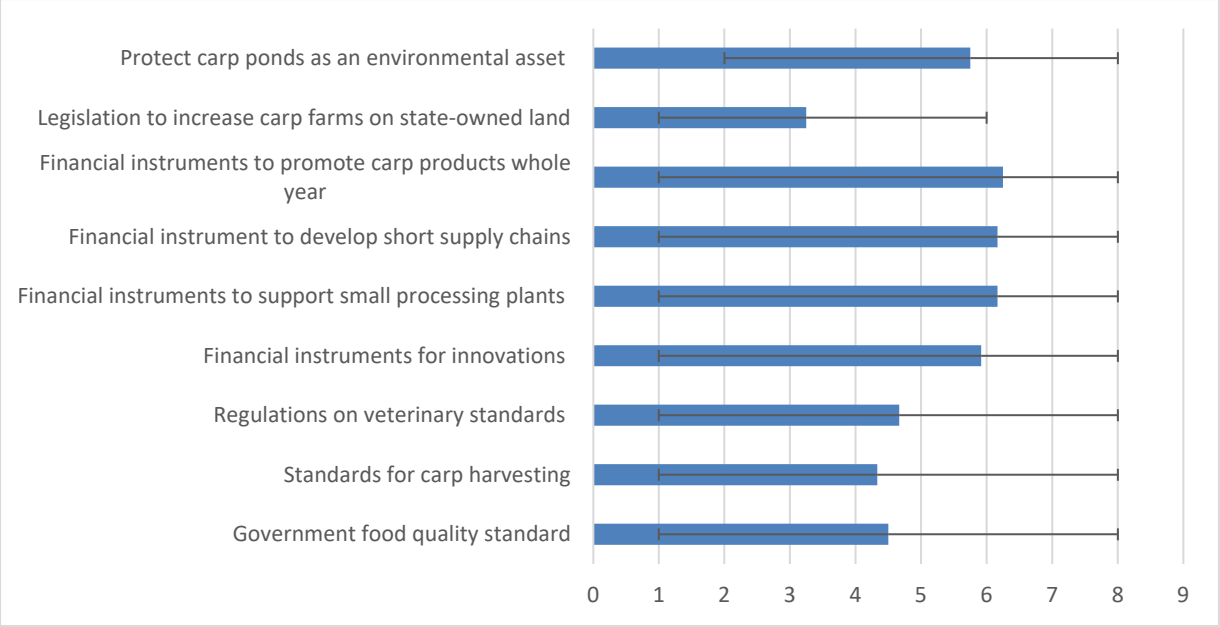

Figure 4.22: In round 1 we asked if current provincial (voivodeship) legislation is supporting the sustainable growth of the Polish carp aquaculture industry. Stakeholders had no opinion or disagreed that legislation supported sustainable growth of the industry, indicating disengagement between the industry and policy. What topic should legislation (provincial/national) be focussed on to promote sustainable carp aquaculture.

The results from the first-round show that there is a weak relationship between those with most interest and those with most power, meaning change is not necessarily being directed by those with most to gain or lose. Aquaculture development could be me more stakeholder- driven if there is support from the government and representative authorities for innovation in the industry, especially if funding was directed through multi-stakeholder platforms. Other initiatives could be a government fund for stakeholder joint R&D initiatives and government funding for academia and industry initiatives (Figure 4.23).

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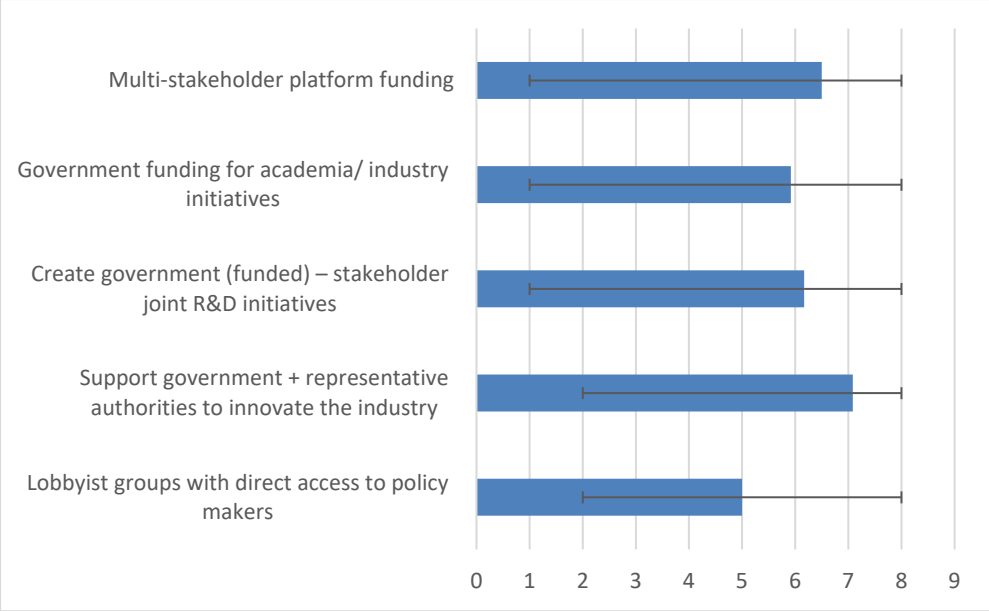

Figure 4.23: During the value chain survey, participants were asked to score the power (ability to make change) and level of interest (affected by change) that different stakeholders have within the aquaculture industry. The results below show that there is a weak relationship between those with most interest and those with most power, meaning change is not necessarily being directed by those with most to gain or lose. How can we make sure that aquaculture development is more stakeholders driven?

4.7 Delphi conclusion

4.7.1 Norwegian Atlantic salmon

The Norwegian respondents seem to agree that the the general trend is to increase the production in a sustainable way. Our results indicate that Norwegians are neutral on the sustainability of the industry today, while people outside Norway consider the industry to be sustainable. Nevertheless, the Norwegians stakeholder actors identified sustainable feeds as an important step towards a more sustainable production. Nevertheless, the use of these novel feed ingredients is exposed to challenges such as price and availability, which was also highlighted in the study of Hua et al. (2019). the use of fish by-products (e.g., trimmings and viscera) to support fishmeal and fish oil production, in combination with novel feed ingredients such as micro-algae show potential to contribute positively to health and welfare of fish, accordign to Hua et al. (2019). This clearly indicates that our results of the Norwegian stakeholder actors and their focus on fish welfare, quality rather then quantity, and product efficiency could be supported by the use of novel feed ingredients. Therefore indicating potential to support the sustainable growth of the industry.

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4.7.2 Polish common carp

Our results indicate that most stakeholder actors agree on the general trend of steady production volumes and declining financial margins. This clearly indicates that increase 'full' processing of carp could not only increase the production volume by using the whole carp more efficient, but also shows potential to increase the financial margins by diversifying the product portfolio. This could lead to more food, feed and economic output, as stated in the papers of Stevens et al. (2018) and Malcorps et al. (2021b), showing potential to support the sustainable growth of the industry. Nevertheless, obtaining more value requires processing and new consuming trends, such as year-round consumption, direct selling to restaurants and people and promoting origin of the product (Raftowicz and Le Gallic, 2019). This could be achieved by legislation from an EU level, as stakeholders show a consensus that this could show potential to support growth and environmental sustainability of the industry. More specifically, support and investments to promote carp consumption throughout the year, diversifying carp products promoted through marketing and advertising campaigns and events. However, this suggest a massive engagement of public resources into the carp economy, which might not be the way forward, according to (Lasner, 2021). These implementations might not lead to an increase in demand in carp products. Therefore, it might be wise to develop the market through other channels, by means sustainability certification to highlight the natural characteristics of carp farming (Feucht and Zander, 2018). This study concluded potential for new carp products in Germany and Poland by identifying new product forms (e.g., bone cut carp filet), increase availability, and provide in combination with non-traditional recipes (Feucht and Zander, 2018). Additionally, certain consumers show willingness to pay more for sustainable/organically produced products and product labels are an excellent opportunity to emphasize the traditional and natural characteristics of carp farming. However, communication strategies in the form of packaging or certifications could differ per country and need to be short and concise in order to achieve its goal of convincing the consumer to purchase the product and pay a premium price (Zander et al., 2018). Enabling carp aquaculture access to certain certifications could open the door to large retailers demand such type of certification, but this would be associated with extra costs, which in the longer term will be paid by the consumer. This is risky, as consumers do not always understand labelling well, and in combination with a premium price could drive certain consumers away from the product (Ólafsdóttir et al., 2018).

Consumer perceptions could also be changed by long term investments in education. Carp has a cultural value in certain areas and integrating carp culture in history and biology in the schedule of public school could increase awareness. Additionally, introducing carp farming and its products by means of other service, like recreation and tourism (Lasner, 2021).

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4.8 European seabass and gilthead seabream

This section provides insight in the most important aspects in the value chain of farmed European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) in the Mediterranean. Due to the Covid-19 pandemic, the research was carried out by means of a literature research. Most of the results are based on the project deliverables from the MedAID project (MedAID, 2021). More specifically, we will focus on the sustainability aspects and opportunities and barriers for eco-intensification highlighted in the deliverable reports of this project (Cidad et al., 2018; Gartzia et al., 2018; Stancu et al., 2018; Aguilera et al., 2019; Fernández Polanco et al., 2019; Fernández Polanco et al., 2020; Fernández Sánchez et al., 2020; Llorente et al., 2020b; Roque et al., 2020; Massa and Fezzardi, 2021).

European Seabass and gilthead seabream are often farmed together in Europe, mainly in the Mediterranean. The aquaculture production of European seabass in Europe account for almost 83.000 metric tonne in 2019, with Greece, Spain, Croatia and Italy being the top producers, producing more then half of the volume (FAO, 2020). Farmed gilthead seabream accounted for approximately 91.000 metric tonnes, with simarlar countries as top producers compared to European seabass (FAO, 2020). On a Mediterranean perspective, Aguilera et al. (2019) reported that in 2016 more then 90% of the seabass and seabream aquaculture production was located in Turkey, Greece, Egypt, Spain, Tunisia, France and Italy, while hatchery production representing 93% of the production was mainly located in Greece, Turkey, Spain, Italy and France. In comparison, European (EU countries) produce 44%, while non-EU countries produce 56% of the total Mediterranean aquaculture production. This is reversed for the hatchery production, from which 64% of juvenelis are produced in EU countries and 36 in non-EU countries. Mediterranean seabass and seabass aquaculture is considered heterogeneous as a result of adaptation to their environmetnal and business models (Aguilera et al., 2019).

In terms of processing, currently both species are often purchased whole or head-on gutted, as a large part of production is only primary processed (Malcorps et al., 2020). Therefore, there is significant potential for both species to add value by utilising viscera for the production of fish oil and hyrolysates (Malcorps et al., 2020; Malcorps et al., 2021b). According to a survey conducted by Gartzia et al. (2018), European seabass and gilthead seabream processors produce most often chilled, fresh and frozen products. Nevertheless, the lack of secondary processing results in missed opportunities regarding the utilisation of heads, frames and trimmings (Malcorps et al., 2020). This opportunity was also confirmed by Gartzia et al. (2018) stating a rising demand for differentiated, processed and high added-value fish products that are ready to prepare or eat. Nevertheless, full processing is not taking place in most cases and by-products often accumulate at the household level, rather then the processing level, which makes utilisation difficult. Nevertheless, this indicates the potential of full processing (primary and seconary processing) resulting in the availability of heads, frames, trimmings, skin and viscera at the processing level. These by-products and their nutritional value shows potential to be utilised in food, feed or industrial applications, which could increase the volume and output of aquaculture production (Stevens et al., 2018; Malcorps et al., 2021b)

The economic analysis indicated that the 2008 and 2014 period was characterized by negative economic returns, as a result of adjustments in production structure, increased feed and energy prices, and reduction in fish consumption. The industry consolidated from small and large companies

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towards medium-size companies (Cidad et al., 2018). The market for seabass and seabream is unstable and experiences periodical shocks and price volatility, as a result of changing domestic demand and international trade (Fernández Polanco et al., 2019). This is caused by elastic demand and price variability, which are related to each other in a way that consumer will increase their purchase when price drops or when their income increases, therefore purchasing larger volumes. This process could also have the reversed effect in a situation of economic decline. Nevertheless, at the farm level, supply is inelatsic with associated financial risk if price decreases (Fernández Polanco et al., 2019). The largest impact in terms of profitability are the unit sales price, followed by survival rate, harvested weight parameters in hatcheries and by survival rate, feed cost and FCR in grow-out facilities. The lowest impact on profitability in relation to the hatchery facility are feed units costs and feed conversion ratios, while harvested weight and fingerling unit costs show the lowest impacts on profits in the grow-out facility (Fernández Sánchez et al., 2020). Nevertheless, the model of Llorente et al. (2020b) indicated that farmers on average could reduce their inputs into the farms by 16-29% without decreasing their output, or produce 16-29% more output without increasing the input, indicating room to increase efficiency of farming, which has improved over the period 2008 and 2016 but shows more potential. More specifically, according to some studies on aquaculture sea cage (incl. Atlantic salmon in Norway) farming, economic of scale have an impact, as larger farms achieve higher technical efficiency and are therefore more profitable then smaller ones (Asche et al., 2013; Asche et al., 2018; Llorente et al., 2020a).

The productivity of the seabass and seabream industry started to increase since 2011, while overall production started to increase steadily during 2015 and 2016, when the average profitability of investment and equity was positive, according to Cidad et al. (2018). This trend continue, as trade data in 2017 shows increased exports of the main producers. Nevertheless, despite the rise in demand for seafood and fishing being at unsustainable levels, European Mediterranean aquaculture should be expected to grow, while still lagging behind the performance of countries such as Egypt, Tunisia and Turkey (Aguilera et al., 2019). This might be explained by the lack of genetically improved fish, poor feed performance, inadequate health management, possible environmental factors, increased competition for coastal use, low public perception towards aquaculture and complex administrative frameworks, which function as barriers for the development of the aquaculture sector in the EU (Aguilera et al., 2019). Public perceptions are influenced by media, and regarding aquaculture are mostly focussed on economic issues, human health and environment, in which health and environment often include a negative perception or tone towards aquaculture (Fernández Polanco et al., 2020). It is important to distinguish the product from the sector itself in terms of acceptability, and focus on the specific stakeholders to unlock the potential for the sustainable development of the sector by using local social structures, understanding issues and visions of the different stakeholders. More specifically, ensuring consumers are bought closer to the product and educated about aquaculture, and encouraging NGOs towork in the field with the aquaculture sector should be normalised. Further authorities should support farmers and associates to improve public perceptions of aquaculture, scientific work targeted to increase knowledge around aquaculture, and clear definitions of the quality ofaquaculture products agreed. Conclusively, everyone should be involved to build a public image, not just the farmers and a focus on the offerings of the sector, such as provided ecosystem services, food securiy and socio-economicbenefits to local communities should be prioritised (Massa and Fezzardi, 2021).

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The sector is challenged by health, social and environmental issues. Briefly, both species are affected by infections, most commonly bacterial infections for European seabass and gill fluke for gilthead seabream. It is recommended to have standardised diagnostics, surveillance and proper communication in place to detect diseases at early stage. This is especially important due to the characteristics of Meditterranean aquaculture where transportation of live animals is a common practice, with associated health risks (Cidad et al., 2018). In the last 5 years, the most important developments according to the interviewed participants in the study of Gartzia et al. (2018) are sustainability (environmental, regional certifications, organic, welfare and labelling), R&D development (products, diverisification, packaging, shelf-life, convenience, processing/technologies) (Gartzia et al., 2018). When it comes to welfare, increased concern is observed in the aquaculture industry. Briefly, animal welfare can be assessed by the so called operational welfare indicators (OWI) covering the 5 freedoms: ’freedom from hunger, malnutrition and thirst‘, ’freedom from fear and distress‘, ‘freedom from physical and thermal discomfort‘, ’freedom from pain, injury and disease‘, ’freedom to express normal patterns of behaviour‘ (Brambell, 1965). Nevertheless, the OWI indicators should be expaneded, integrated and specified towards the species, production system, specific life cycle and environmental conditions (Roque et al., 2020).

Quality and safety were considered the most important developments (Gartzia et al., 2018). This is also in line with most of the consumer expectations of future aquaculture products, in which the main drivers for consumption are healthiness and nutritional value and convenience in relation to easy cooking, no bones and high value-added products (Gartzia et al., 2018). According to a survey by Stancu et al. (2018) on 1500 consumers, 34% is considered an adventurous food consumer, which regularly consumes fish and are considered responsible consumers (e.g., sustainable choice), indicating oppertunities to diversify towards sustainable products. Interests in new aquaculture fish products is also applicable for the rational food consumer representing 20% of the respondents (Stancu et al., 2018).

Respondents described the challenging complexity of administrations and regulations in the sector, e.g., time to get a production license. This is seen as a barrier for further developments of the sector. The majority of the respondents also think that is is important to provide capacity to adopt new technologies and farm practices. Other important factors are the need for transparency in governance processes, while relatively high confidence was shown towards local and national institutions (Cidad et al., 2018).

When it comes to the environmental impact, most of the environmental impact in Meditterranean aquaculture is caused by feed production and consumption and related feed conversion ratio. It is therefore crucial in the future to improve feeds‘ performance and to find new sustainable sources of ingredients with lower environmental impact (Cidad et al., 2018). Interestingly, the report shows a high variability in the results of the life cycle asssessment (LCA), indicating that there is no common production method for Meditterranean European seabass and gilthead seabream production (Cidad et al., 2018). Nevertheless, 40% of respondents indicated that they think that the public perception of aquaculture is 'bad' to 'very bad'. Interestingly, 70% of the respondents consider their communication sufficient enough to adress professionals, but they pointed out the misconception of aquaculture by the public. Respondents indicated that they had a positive relationship with most stakeholders, while more then a third suggested a 'bad' to 'very bad' relationship with stakeholders in tourism, environmental NGOs and recreational activities. (Cidad et al., 2018)

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When it comes to social impact, most farmers assessed the the MeDAID project are aware of social responsibility and have policies in place to guarantee social equality, this is especially the case for Spain (Cidad et al., 2018).

The data collection, as part of the MEDaid project, was challenging just as our own data collection at farms in Norway and Poland. Most of the farms couldn't provide satisfactory data to ensure a robust dataset benefiting the quality of the study. This could affect the results of this study together with the relatively small sample size, lack of proper categorisation, especially in relation to understand country-to-country variation. These are important insights for future data acquisition (Cidad et al., 2018).

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5. A value chain comparison

This chapter compares the different aquaculture value chains in the EU ranging from extensive (traditional) carp farming to industrial scale salmon farming. In the following sections we will dive deeper into the sustainability challenges and opportunities.

The Norwegian salmon aquaculture industry is an example where full processing takes place (Malcorps et al., 2020). Most of the by-products (heads, frames, trimmings, skin, and viscera) are utilised, but mixing is still a common practice which dilutes the nutritional value of the individual by-products, indicating potential to increase the economic output through their strategic utilisation in food, feed and industrial applications (Stevens et al., 2018; Malcorps et al., 2021b). This potential includes for example their reuse in aquafeeds in Europe. Stakeholders identified this as a good strategy to increase profitability, improve environmental sustainability, feed efficiency, fish welfare and public consumer perception towards farmed fish. Additionally, if safety regulations allow, more by-products could also be utilized in direct human consumption such as, salmon heads in soup (Stevens et al., 2018). This could support the sustainable growth of the industry, while staying within production limits and regulations imposed by the government, which is considered a negative and uncertain sustainability factor by the Norwegian stakeholders.

In the case of other species farmed in Europe, such as common carp, by-products are often discarded at the processing or household level (Malcorps et al., 2020). Certain carp by-products show potential for food, feed and industrial purpose (Malcorps et al., 2021b), which could create processing and utilization incentives, enabling the Polish aquaculture industry to diversify its products and increase the (economic) output of the sector. This was identified by some stakeholders, especially the processors, who have relatively high power and interest to innovate and diversify their products. Most respondents also showed awareness and interest in by-products for feed production, cosmetics, and nutraceuticals. This is mainly driven by the fact that a higher price could be obtained for processed fish, as highlighted by Raftowicz and Le Gallic (2019). Nevertheless, this could be challenging due to the variable power and interest of the other stakeholders along the value chain. Additionally, respondents indicate uncertainty around new product forms in relation to consumer preferences, which could be a barrier for the intensification of the processing sector.

According to a survey conducted by Gartzia et al. (2018), European seabass and gilthead seabream processors produce most often chilled, fresh and frozen products, but highlights a rising demand for differentiated, processed and high added-value fish products that are ready to prepare or eat. This indicates that European seabass and gilthead seabream is not fully processed, which is also confirmed by the study by Malcorps et al. (2020) showing a lack of secondary processing results in missed opportunities regarding the utilisation of heads, frames and trimmings. This lack of processing is also the case for turbot in which the derived by-products show interesting nutritional characteristics for a variety of applications (Malcorps et al., 2020; Malcorps et al., 2021b). The lack of full secondary processing is also applicable to the Italian rainbow trout value chain (Malcorps et al., 2020). Italian respondents indicate a loss of interest towards fresh products and low prices for trout. In response farmers and increased processing and diversified their products (hamburgers, smoked fish, fish skewers) (Iandoli and Trincanato, 2007). However, this opportunity could be further exploited by further diversifying its products and produce ready to eat products, while utilizing some by-products

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into feed, cosmetics, and nutraceuticals, as indicated by respondents. Overall, Southern European aquaculture shows potential to increase the (economic) output of the aquaculture sector by means of full (primary and secondary) processing. Nevertheless, this imposes other challenges, such as consumption preferences, which can vary greatly across Europe from whole fish compared to various processed forms of different species (EUMOFA, 2017).

The use of novel feed ingredients shows most potential in the Norwegian salmon industry due its volumes and industry structure. Norwegian respondents show interest in novel feed ingredients to reduce environmental impact, feed efficiency, fish welfare and to improve public consumer perception. However, they also acknowledge that the use of novel feed ingredients is constrained by price, availability, consistency of nutritional content, and quality, which are identified as the most important challenges for novel feed ingredients. More specifically, the three feed companies questioned identified price as the main challenge, followed up by availability and quality. This shows some overlap with the study of Hua et al. (2019) and Pelletier et al. (2018) highlighting similar challenges as identified by our stakeholders. Overcoming these challenges requires strategies such as R&D and investment at scale to increase availability and reduce price, while at the same time ensuring quality is maintained. The industrial scale of the Norwegian salmon value chain shows characteristics that could overcome these challenges. More specifically, in terms of interest in innovation, capacity and resources, the most affected Norwegian stakeholders, which are the one with the highest interest in innovation are those with highest ability to affect change (powerful). This indicates that this industry is stakeholder led, which makes the implementation of new innovations easier in comparison with other value chains, such as Polish common carp. The latter doesn't show much interest in novel feed ingredients due to extensive and traditional production characteristics but shows additional constrains regarding innovation; power does not increase as sharply with interest, indicating that this value chain is not stakeholder driven and that there is a lower appetite for change compared to the Norwegian value chain.

Climate change was mentioned by the Norwegian, Italian and Polish stakeholders' respondents. However, it seems that it was of greatest concern for Italian rainbow trout and Polish carp farmers due to their dependency on freshwater resources. Availability and quality of freshwater could be affected by climate change and this was also mentioned by the study of Maiolo et al. (2020a) and Lasner et al. (2020) for rainbow trout and common carp, respectively. Overcoming these challenges requires a comprehensive action plan together with other industries that share the same water resources. This could be supported by national and European policies. In the case of the Polish carp value chain, national legislation was perceived as not supporting either the growth or environmental sustainability of the industry, while there was consensus that EU legislation supported the growth of the sector and efforts to become environmentally more sustainable. In the case of the Italian trout value chain, stakeholders perceived the industry could be supported by research and development, but that currently the outputs were largely inaccessible for most small and medium size trout farmers, indicating a need to better align research and industry interests to innovate the industry.

The UK bivalve industry is the only non-finfish species assessed in this study, but shows interesting characteristics that could not only benefit nutritional outcomes in the EU, but also environmental benefits. Bivalve aquaculture has a low environmental footprint (Hillborn et al., 2018; Gephart et al., 2021) compared to other animals foods, but the environmental footprint of bivalves is elevated when considering edible portion due to the shell weight (Gephart et al., 2021). Nevertheless, they also

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provide valuable ecosystem services such as water quality regulation, carbon sequestration, coastal protection, habitat creation and supporting local biodiversity (Macleod and Macleod, 2019; Van der Schatte Olivier et al., 2020). Sector stakeholders indicated that there is currently a lack of awareness on these valuable ecosystem's services. This indicates a potential for the sector to grow, but this is currently challenged by low economies of scale and current consumption patterns. Additionally, respondents indicate that 20% of the production weight is lost during harvest, indicating a potential to increase production by improving harvest efficiencies.

Overall, the aquaculture industry could grow significantly if the European Union wants to become more self-sufficient regarding their seafood supply. Nevertheless, the industry is challenged by sustainability challenges, a range of consumer perceptions towards different products forms (EUMOFA, 2017), origin (wild vs farmed) (Bronnmann and Hoffmann, 2018), and climate change. The latter is especially relevant in both ways, first by reducing the environmental impact of aquaculture, secondly by adapting to climate change to increase resilience to external environmental shocks (Ahmed et al., 2019). In terms of mitigating the environmental impact, feed use is responsible for the majority of the environmental impact (Bohnes et al., 2018) and substituting part of the diet with ingredients that do not add additional pressure on marine and terrestrial resources is considered part of the solution (Newton and Little, 2018; Malcorps et al., 2019). This is crucial, as unintended consequences of shifts in feed type used may occur along the entire value, indicating the importance to take a larger food systems approach into account (Cook et al., 2015). Different novel feed ingredients are proposed, but some are constrained by price, quality, (variable) protein content, scalability and supply maintenance (Hua et al., 2019). Nevertheless, a re-evaluation of the potential to increase the supply of marine ingredients from under-utilised by-product resources has received far less attention, and should be explored (Malcorps et al., 2021b). Aquaculture policies, especially in the Nordic countries, seem to have a focus on fed aquaculture to reduce negative impacts. However, there is a need to incorporate general measures to reduce impacts from pollution, spread of pathogens, use of high-grade food resources and energy consumption (Luthman et al., 2022). Challenges, such as disease outbreaks and fish welfare concerns could be addressed by increased collaboration between stakeholders, with the use of big data for example. This was especially indicated by Norwegian stakeholders from the more industrialized salmon aquaculture industry, while relatively less interest towards big data was shown by the Polish carp, Italian trout and UK bivalve industry.

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Annex 1: VCA KI interview Norway (Atlantic salmon)

Structured questions and checklist (as used in Norway July – September 2019)

Introduction and verbal consent

My name is …… and I am working for …….

We have a research project "GAIN – Green Aquaculture INtensification in Europe" to support the ecological intensification of aquaculture in EU and the EEA. The objectives are to increase production and competitiveness of the industry while ensuring sustainability and compliance with EU regulations on food safety and environment.

Part of this project is to assess the consumers and stakeholders' acceptance of eco-intensification measures for which we are conducting a survey for the key players along the value chain.

Would you be happy to participate in this survey and discuss your opinions/vision and your business plan regarding aquaculture intensification, it will take approximately 30 minutes? Yes/No

Company/business and interview details

What is the main activity of this company, which sector this company can be classified (farming, processing, feed ……)?

What is your position/responsibility in this company?

How many years are you working in aquaculture?

How many years are you working for this company?

Value chain information

Total industry production (MT - feed, grow out, smolts etc)

Type of products or activities (Producer, R&D, education etc depending on stakeholder)

Comparison to other companies

Number of companies in Norway

Company production as % of total

Main markets of total industry (domestic, international)

Transportation methods (% air/sea/land of total industry).

What are the main trends in the industry (growth, markets, practices, innovation, structural, managerial, consolidation, integration, new players, diversification, value addition)?

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What are the main changes in your part of the industry?

What are the main changes in your company?

1.1 Can you rate the power and interest of the following stakeholders in terms of their power to make industry changes/innovate and how it could affect them? Score 1 (barely any influence) to 10 (highly influential)

Stakeholder	**Power**	**Interest**
Brood stock/egg producers		
Hatcheries (RAS)		
Smolt production (RAS)		
Smolt production (flow-through)		
Grow-out farms		
Independent slaughterhouse and primary processors		
Independent secondary processors		
Value addition processors/smokeries etc.		
Integrated companies		
By-product processors		
Cleaner fish producers		
Exporters/trading companies		
Retail		
Well-boat/transport		
Vet/health management companies		
Feed companies		
Ingredient producers (fish oil, hydrolysates/meals etc)		
End users (pet food)		
Education groups		
Research innovation companies		

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Trainers		
Equipment producers		
Government authorities		
Certifiers		
NGOs		
Consumer groups/associations		
Other support industries/suppliers (ice, chemicals, consumable products etc)		

1.2 Do you participate in the following?

	No.	Length relation	Description
Association membership			
Workshop attendance			
R & D with academia/NGO			
R & D with commercial			
Government programme			
Other …..			

1.3 What stakeholders do you have most interaction with?

Name	Type (NGO, feed mill,..)	Relationship (customer,…)	Number meetings/yr	Years of relationship

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Knowledge, attitudes and perceptions regarding aquaculture intensification and sustainability

By intensification, we mean producing more with fewer resources at all stages along the VC

How do you see intensification in aquaculture (positives/negatives/impacts)?

Does your company have a vision/plan for sustainable intensification?

What are the current topics / processes on sustainability that you are currently working on?

1.4 What factors do you foresee that could positively or negatively affect your farms performance over the next 5 years? Score 1 (negatively) to 5 (positively) or rank.

	Sustainability Factor	Overall Rank/score	Response
Negative			
Positive			
Uncertain			

Within GAIN project we are proposing the following eco-intensification measures, for each of these measures we would like to know your opinion and acceptance and if your company already applying or willing to adopt in the future. Please remember the following QS may not be applicable to all the measures bellow.

For each measure, please ask the following QS:

Have you heard about this measure?

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Do you have any example of it being applied?

1.5 Production and Environment

Measure	Microalgae	Macroalgae	Hydrolysed fish proteins	Single cell proteins	Insect protein
Knowledge					
Company interest					
Industry interest					
Comment					

1.6 Enhancement of secondary outputs

Measure	Sludge for fertiliser	Sludge for biogas	Mortalities for biogas	Processing by-products for feed	By-products for cosmetics/nutraceuticals
Knowledge					
Company interest					
Industry interest					
Comment					

1.7 Enhancement of secondary outputs

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Measure	Shells for biofilters	Shells for packaging	Shells for cement/filler	Use of big data management support	Use of big data for welfare
Knowledge					
Company interest					
Industry interest					
Comment					

Do you think there is enough information available for the awareness of sustainable aquaculture intensifications?

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Annex 2: VCA KI interview Poland (common carp) (distributed in English and Polish)

Introduction and verbal consent

My name is ……(Code…..) and I am working for …….

We have a research project "GAIN – Green Aquaculture INtensification in Europe" to support the ecological intensification of aquaculture in EU and the EEA. The objectives are to increase production and competitiveness of the industry while ensuring sustainability and compliance with EU regulations on food safety and environment.

Part of this project is to assess the consumers and stakeholders' acceptance of eco-intensification measures for which we are conducting a survey for the key players along the value chain.

Would you be happy to participate in this survey and discuss your opinions/vision and your business plan regarding aquaculture intensification, it will take approximately 30 minutes? Yes/No

Company/business and interview details

What is the main activity of this company, which sector this company can be classified (farming, processing, feed ……)?

What is your position/responsibility in this company?

How many years are you working in aquaculture?

How many years are you working for this company?

Value chain information

Who is producing?

How much are they producing?

Where are they producing?

Where is the value added?

Where are the products going?

Total industry production (MT - feed, grow out, etc)

Type of products or activities (Producer, R&D, education etc depending on stakeholder)

Comparison to other companies

Number of companies in Poland

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Company production as % of total

Main markets of total industry (domestic, international)

Transportation methods (% air/sea/land of total industry).

What are the main trends in the industry (growth, markets, practices, innovation, structural, managerial, consolidation, integration, new players, diversification, value addition)?

What are the main changes in your part of the industry?

What are the main changes in your company?

1.1 Can you rate the power and interest of the following stakeholders in terms of their power to make industry changes/innovate and how it could affect them? Score 1 (barely any influence) to 10 (highly influential)

Stakeholder	Power	Interest
Farms		
Feed companies		
Slaughterhouse and primary processing		
Value addition processing		
Import and trading company		
Retail company		
Transport		
Vet/Health management company		
Education		
Recreational (guide) tour		
Research and innovation company (R&D)		
Trainer institution		
Equipment producer, maintenance and recycling		
Government and representative authorities		
Certification body/organization		

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NGO		
Carp associations		
Consumer group		

1.2 Do you participate in the following?

	No.	Length relation	Description
Association membership			
Workshop attendance			
R & D with academia/NGO			
R & D with commercial			
Government programme			
Other …..			

1.3 What stakeholders do you have most interaction with?

Name	Type (NGO, feed mill,..)	Relationship (customer,…)	Number meetings/yr	Years of relationship

The project has received funding from the European Union's Horizon 2020 Framework Research and Innovation Programme under GA n. 773330

Knowledge, attitudes and perceptions regarding aquaculture intensification and sustainability By intensification, we mean producing more with fewer resources at all stages along the VC

How do you see sustainable intensification in aquaculture (positives/negatives/impacts)?

Does your company have a vision/plan for sustainable intensification?

What are the current topics / processes on sustainability that you are currently working on?

1.4 What factors do you foresee that could positively or negatively affect your farms performance over the next 5 years? Score 1 (negatively) to 5 (positively) or rank.

	Sustainability Factor	Overall Rank/score	Response
Negative			
Positive			
Uncertain			

Within GAIN project we are proposing the following eco-intensification measures, for each of these measures we would like to know your opinion and acceptance and if your company already applying or willing to adopt in the future. Please remember the following QS may not be applicable to all the measures bellow.

For each measure please ask the following QS:

Have you heard about this measure?

Do you have any example of it being applied?

1.5 Production and Environment

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Measure	Microalgae	Macroalgae	Hydrolysed fish proteins	Single cell proteins	Insect protein
Knowledge					
Company interest					
Industry interest					
Comment					

1.6 Enhancement of secondary outputs

Measure	Sludge for fertiliser	Sludge for biogas	Mortalities for biogas	Processing by-products for feed	By-products for cosmetics/nutraceuticals
Knowledge					
Company interest					
Industry interest					
Comment					

1.7 Enhancement of secondary outputs

Measure	Shells for biofilters	Shells for packaging	Shells for cement/filler	Use of big data management support	Use of big data for welfare
Knowledge					

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Company interest					
Industry interest					
Comment					

Do you think there is enough information available for the awareness of sustainable aquaculture intensifications?

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Annex 3: VCA KI interview Italy (Rainbow trout) (distributed in Italian)

Introduction and verbal consent

My name is ……(Code…..) and I am working for …….

We have a research project "GAIN – Green Aquaculture INtensification in Europe" to support the ecological intensification of aquaculture in EU and the EEA. The objectives are to increase production and competitiveness of the industry while ensuring sustainability and compliance with EU regulations on food safety and environment.

Part of this project is to assess the consumers and stakeholders' acceptance of eco-intensification measures for which we are conducting a survey for the key players along the value chain.

Would you be happy to participate in this survey and discuss your opinions/vision and your business plan regarding aquaculture intensification, it will take approximately 30 minutes? Yes/No

Company/business and interview details

What is the main activity of this company, which sector this company can be classified (farming, processing, feed ……)?

What is your position/responsibility in this company?

How many years are you working in aquaculture?

How many years are you working for this company?

Value chain information

Brood stock and Hatcheries

-Do you have your own bloodstock, or purchase eggs from hatcheries? Is this practice usual within the industry?

-If you purchase eggs from hatcheries, do you prefer using monosex culture of females or triploids or mixed sex haploid?

Do you sell fingerlings or eggs to other farms? What % of production?

Production

What is the production system of your company? RAS, raceways, cages and ponds?

-How much of Italian production is taking place in RAS, raceways, cages and ponds (%)? Estimate.

RAS Raceway Cage Pond

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-Number of companies in Italy producing rainbow trout? Make an estimation of the proportion of company sizes producing rainbow trout?

Company size	Number/ %
Small	…
Medium	…
Large	…

-Are these companies located in a certain area of Italy (clusters?)?

-Are there any features of your company that are different compared to other companies producing trout in Italy?

Feed

-How many feed companies in Italy?

-Do you import any feed from other countries (if yes from where and why?)

Processing

What are the product forms (portion size, large, filleted, smoked, other)?

-What type of trout products are available on the market and what is their proportion of the total?

Product forms	Share of product of total production (%)
Whole portion size	
Fillets	
Smoked…	
….	

-What are the opportunities for adding value through processing? Diversification of products?

-Where are the products going (countries/regions, other industries for further processing)?

1.1 Can you rate the power and interest of the following stakeholders in terms of their power to make industry changes/innovate and how it could affect them? Score 1 (barely any influence) to 10 (highly influential)

Stakeholder	Power	Interest
Brood stock/egg producers		
Hatcheries (RAS)		
Hatcheries (flow-through)		

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Grow-out farms		
Independent slaughterhouse and primary processors		
Independent secondary processors		
Value addition processors/smokeries etc.		
Integrated companies		
By-product processors		
Exporters/trading companies		
Retail		
Vet/health management companies		
Feed companies		
Ingredient producers (fish oil, hydrolysates/meals etc)		
End users (pet food)		
Education / training groups		
Research innovation companies		
Equipment producers		
Government authorities		
Certifiers		
NGOs		
Consumer groups/associations		
Other support industries/suppliers (ice, chemicals, consumable products etc)		

1.2 Do you participate in the following?

	No.	Length relation	Description
Association membership			

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Workshop attendance			
R & D with academia/NGO			
R & D with commercial			
Government programme			
Other …..			

1.3 What stakeholders do you have most interaction with?

Type (NGO, feed mill,..)	Relationship (customer,…)	Number meetings/yr	Years of relationship

Knowledge, attitudes and perceptions regarding aquaculture intensification and sustainability by intensification, we mean producing more with fewer resources at all stages along the VC

-What are the main trends in the industry (For example: industry growth, different markets, new innovation, structural changes, legislative changes)?

-What are the main changes in your part of the industry?

-What are the main changes in your company? Are you planning any changes to become more sustainable/ efficient?

-What factors do you foresee that could positively or negatively affect your farms performance over the next 5 years? Score 1 (negatively) to 5 (positively) or rank.

	Sustainability Factor	Overall Rank/score	Response
Negative			

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Positive (score 4,5)			
Uncertain (score 3)			

Within GAIN project we are proposing the following eco-intensification measures, for each of these measures we would like to know your opinion and acceptance and if your company already applying or willing to adopt in the future.

FEED INGREDIENTS

Measure	Microalgae	Macroalgae	Hydrolysed fish proteins	Single cell proteins	Insect protein
Knowledge					
Company interest					
Industry interest					
Comment					

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Enhancement of secondary outputs

Measure	Sludge for fertiliser	Sludge for biogas	Mortalities for biogas	Processing by-products for feed	By-products for cosmetics/nutraceuticals
Knowledge					
Company interest					
Industry interest					
Comment					

Measure	Use of sensors and big data management support	Use of big data for welfare assessment/ management
Knowledge		
Company interest		
Industry interest		
Comment		

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Annex 4: Company data collected and consent

Company/organization name?

Position in the company/organization?

Sector within the aquaculture industry?

a. Hatchery
b. Farms (grow-out)
c. Feed
d. Slaughter and/or Processing
e. Certifiers
f. Education, Research and Academia
g. Governments
h. Vet and Health Management
i. Recreational
j. NGO
k. Carp associations
l. Trading company
m. Trainer Institutions

I have read the 'Participation Information Sheet' and agree and tick all the boxes in the 'Electronic Consent Form'.

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Annex 5: Delphi survey Norway (Atlantic salmon) Round I

MULTIPLE ANSWERS POSSIBLE

1. What is the general trend in the aquaculture industry in Norway?

A. Increasing production volume
B. Steady production volume
C. Declining production volume
D. Increasing financial margins
E. Steady financial margins
F. Declining financial margins
G. Increasing 'responsible' production
H. Steady 'responsible' production
I. Declining 'responsible' production

2. Key aspects of environmental sustainability of the Norwegian salmon industry are…?

A. Use of sustainable feeds
B. Supporting and invigorating isolated coastal communities
C. Technically efficient production
D. High fish welfare
E. Good site selection
F. Moving to offshore for grow-out
G. Greater use of RAS technology
H. Integrated Health management strategy
I. Minimizing escapes

LIKERT SCALE (CHOOSE 1)

3. Within Norway, the Norwegian aquaculture industry is perceived as sustainable.

A. Strongly agree
B. Agree
C. Neither agree or disagree
D. Disagree
E. Strongly disagree
F. Not sure

4. In Europe, the Norwegian aquaculture is perceived sustainable by the general public.

A. Strongly agree
B. Agree
C. Neither agree or disagree
D. Disagree
E. Strongly disagree
F. Not sure

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5. EU legislation is supporting the growth (production volume output) of the aquaculture industry.

A. Strongly agree
B. Agree
C. Neither agree or disagree
D. Disagree
E. Strongly disagree
F. Not sure

6. EU legislation is supporting the aquaculture industry to become more environmentally friendly.

A. Strongly agree
B. Agree
C. Neither agree or disagree
D. Disagree
E. Strongly disagree
F. Not sure

7. National legislation is supporting the growth (production volume output) of the aquaculture industry.

A. Strongly agree
B. Agree
C. Neither agree or disagree
D. Disagree
E. Strongly disagree
F. Not sure

8. National legislation is supporting the aquaculture industry to become more environmentally friendly.

A. Strongly agree
B. Agree
C. Neither agree or disagree
D. Disagree
E. Strongly disagree
F. Not sure

9. Provincial (regioner) legislation is supporting the growth (production volume output) of the aquaculture industry.

A. Strongly agree
B. Agree
C. Neither agree or disagree
D. Disagree
E. Strongly disagree
F. Not sure

10. Provincial (regioner) is supporting the aquaculture industry to become more environmentally friendly.

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A. Strongly agree
B. Agree
C. Neither agree or disagree
D. Disagree
E. Strongly disagree
F. Not sure

SCORE 1 to 8 (1 not important, 8 highly important)

11. What is needed to support the sustainable growth in aquaculture

A. Collaboration between stakeholders
B. Government financial support (credit, insurance, upgrade grants etc.)
C. Government training program
D. Government support in the form of market access
E. Government support in the form of R&D
F. Re-investment incentives in salmon business
G. Cross sectoral investments (e.g., fisheries invest in salmon)
H. Foreign investment

12. What are appropriate strategies to increase the profitability of the salmon industry?

A. More regulations on production volume output
B. More regulations on feed use
C. More regulations on salmon lice treatments
D. Increased production
E. Focus on quality rather than quantity
F. More certification
G. Improve traceability
H. Novel feed ingredients
I. Circular economy/recycling
J. Linking farms to the national energy grid
K. Transition towards renewable energy production on site

13. What could be done to improve public perception towards the aquaculture industry and its products?

A. Certifying more production sites
B. Government advertising campaigns
C. Increasing transparency
D. Promotion in the media
E. Move towards precision aquaculture approaches (automation and use of sensors)
F. Circular economy/recycling
G. Substitution of standard/traditional feed ingredients with novel feed ingredient

14. Which of these technologies show most potential to combat sea lice?

A. New chemical treatments
B. Better use of existing chemicals
C. Data sharing between farms to predict/prevent sea lice outbreak
D. Cleaner fish (e.g., lumpfish, wrasse)
E. RAS to produce super smolts e.g., up to +600 grams

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F. RAS for the entire cycle
G. Other closed or semi-closed containment systems
H. More offshore sites (i.e. higher exposure)
I. Other physical sea lice exclusion technology
J. A combination of several technologies

15. **How much potential do the novel feed ingredients for salmon diets below show for improving the environmental sustainability?**

A. Plant ingredients
B. Marine ingredients from fishery processing by-products
C. Insect protein
D. Microalgae
E. Seaweed
F. Bacterial cell proteins

16. **How much potential do the novel feed ingredients for salmon diets below show for improving the feed efficiency?**

A. Plant ingredients
B. Marine ingredients from fishery processing by-products
C. Insect proteins
D. Microalgae
E. Seaweed
F. Bacterial cell proteins

17. **How much potential do the novel feed ingredients for salmon diets below show for improving the fish welfare?**

A. Plant ingredients
B. Marine ingredients from fishery processing by-products
C. Insect proteins
D. Microalgae
E. Seaweed
F. Bacterial cell proteins

18. Which novel feed ingredients show most potential to improve the public consumer perception of farmed fish?

A. Plant ingredients
B. Marine ingredients from fishery processing by-products
C. Insect proteins
D. Microalgae
E. Seaweed
F. Bacterial cell proteins

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We have conducted a sustainability assessment of the industry and have collected data for the following indicators. We wish to weight the sustainability indicators based on the importance for the industry. We want to know what the industry thinks! Please SCORE each indicator from 1-8 from least important to highly important as a sustainability indicator.

Economic:

1. Number of fish rejected at processing plant
2. Feed efficiency
3. Farm operating costs
4. Renewable energy production within farm
5. Domestic/export market destination
6. Mortality at farm
7. Diversity of products (e.g., fillets, smoked, value add)
8. Market destinations (e.g., restaurants, retail)

Environment:

1. Renewable energy use on the farm
2. Antibiotic use
3. Chemical use
4. Regular water quality checks
5. Oxygen demand (COD/BOD)
6. Suspended solids in the water column
7. Benthic impact
8. Recycling by-products in other industries (e.g., feed)
9. Greenhouse gasses/carbon footprint
10. Freshwater consumption
11. Acidification
12. Nutrient release in the environment
13. Land footprint
14. Energy consumption
15. Feed efficiency
16. Fish-in-fish-out
17. Presence of impact reduction mitigation (e.g., drain traps)

Social:

1. Labour and wage structure
2. Number of employees per unit output
3. Output value per employee
4. Employee risk to hazardous/chemicals
5. Employee safety and risk reduction
6. Certification (e.g., ASC)

Welfare:

1. Amount of emergency harvests
2. Cleaning of the nets (frequency)
3. Number (%) of farm mortalities in cycle

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4. Observation of body damage
5. Humane slaughter of fish
6. Anti-predator measures (e.g., seal scarers)
7. Average stocking density
8. Fish welfare training for employees
9. Health management plan

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Annex 6: Delphi survey Poland (common carp) Round I (was distributed in Polish)

MULTIPLE ANSWERS POSSIBLE

1. What is the general trend in the carp aquaculture industry in Poland?

A. Increasing production volume
B. Steady production volume
C. Declining production volume
D. Increasing financial margins
E. Steady financial margins
F. Declining financial margins
G. Increasing 'responsible' production
H. Steady 'responsible' production
I. Declining 'responsible' production

2. What is needed to increase the processing of carp?

A. Change in consumer perception
B. Diversifying market
C. Legislation on live sales
D. Influence from NGOs or other pressure groups
E. Subsidies or incentives

3. **What aspects of the carp farming industry should be promoted?**

A. Low impact
B. Natural production
A. Organic
B. Traditional
C. Local
D. Tasty
E. Healthy

LIKERT SCALE (CHOOSE 1)

4. Within Poland, the Polish carp aquaculture industry is perceived as sustainable

G. Strongly agree
H. Agree
I. Neither agree or disagree
J. Disagree
K. Strongly disagree
L. Not sure

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5. In Europe, the Polish carp aquaculture is perceived sustainable by the general public.

G. Strongly agree
H. Agree
I. Neither agree or disagree
J. Disagree
K. Strongly disagree
L. Not sure

6. EU legislation is supporting the growth (production volume output) of the aquaculture industry.

G. Strongly agree
H. Agree
I. Neither agree or disagree
J. Disagree
K. Strongly disagree
L. Not sure

7. EU legislation is supporting the aquaculture industry to become more environmentally friendly.

G. Strongly agree
H. Agree
I. Neither agree or disagree
J. Disagree
K. Strongly disagree
L. Not sure

8. National legislation is supporting the growth (production volume output) of the aquaculture industry.

G. Strongly agree
H. Agree
I. Neither agree or disagree
J. Disagree
K. Strongly disagree
L. Not sure

9. National legislation is supporting the aquaculture industry to become more environmentally friendly.

G. Strongly agree
H. Agree
I. Neither agree or disagree
J. Disagree
K. Strongly disagree
L. Not sure

10. Provincial (voivodeship) legislation is supporting the growth (production volume output) of the aquaculture industry.

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G. Strongly agree
H. Agree
I. Neither agree or disagree
J. Disagree
K. Strongly disagree
L. Not sure

11. Provincial (voivodeship) legislation is supporting the aquaculture industry to become more environmentally friendly.

G. Strongly agree
H. Agree
I. Neither agree or disagree
J. Disagree
K. Strongly disagree
L. Not sure

12. Carp processing could increase profitability of the industry?

A. Strongly agree
B. Agree
C. Neither agree or disagree
D. Disagree
E. Strongly disagree
F. Not sure

SCORE 1 to 8 (1 not important, 8 highly important)

13. What actions could be done to improve perception towards the aquaculture industry?

H. Certifying more production sites
I. Improve water quality
J. Circular economy and recycling
K. Ban live sales
L. Lower environmental impact
M. More humane predator control

14. In terms of marketing and promotion, what could be done to improve perception towards the aquaculture industry and its products?

A. Media promotion
B. Government advertising campaigns
C. Celebrity endorsements
D. Increasing transparency

15. What is needed to support the sustainable growth in carp aquaculture?

A. Collaboration between stakeholders
B. EU funds
C. Government financial support (credit, insurance, upgrade grants etc.)

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D. Government training program
E. Government support in the form of market access
F. Government support in the form of R&D
G. Cross sectoral investments (e.g., fisheries invest in carp aquaculture)
H. Foreign investments

16. What are appropriate strategies to increase the profitability of the carp industry?

A. Change regulations on production volume output
B. Intensification (increase yield per hectare)
C. Focus on quality rather than quantity
D. More certification
E. More (EU) funding to protect natural areas (e.g., Natura 2000)
F. Improve traceability/Better record keeping
G. Better feed technology
H. Circular economy/recycling
I. Increase processing
J. Diversification of activities at the farm (e.g., tourism, other aquaculture species)
K. Efficient predator control

17. How can the year around appeal for carp being improved?

A. Diversify carp products (increase processing)
B. Consumer perception change
C. Organizing promotion events
D. Marketing/advertising campaigns
E. Government financial incentives
F. EU funds to promote carp consumption through the year
G. Other investments to promote carp consumption through the year

A. **What are suitable mitigation strategies against the effects of climate change for Polish carp aquaculture?**
B. Use water resources more efficiently
C. Engineering solutions (e.g., water channels)
D. Improved water quality management (e.g., checking oxygen, ammonia levels)
E. Improved health management (e.g., veterinary checks, vaccination etc.)
F. Better record keeping
G. Breeding programs for resilience

18. What are appropriate strategies to improve the image of carp farming

A. Ban sale of live carp
B. Humane slaughter
C. More processing
D. Increase transparency of the industry
E. More education
F. Increase awareness

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19. What is the most profitable carp product? (Score: 1 low profitability, 8 high profitability)?

A. Traditional (live)
B. Head on-gutted
C. Carcass
D. Slice (steak)
E. Sheet
F. Fillets

We have conducted a sustainability assessment of the industry and have collected data for the following indicators. We wish to weight the sustainability indicators based on the importance for the industry. We want to know what the industry thinks! Please SCORE each indicator from 1-8 from least important to highly important as a sustainability indicator.

Economic:

1. Farm operating costs
2. Renewable energy production within farm
3. Domestic markets vs export markets
4. Diversity of products/market destinations

Environment:

1. Renewable energy use
2. Chemical use
3. Regular water quality checks
4. Greenhouse gasses/carbon footprint
5. Freshwater consumption
6. Acidification
7. Nutrient release in the environment
8. Land footprint
9. Energy consumption
10. Impact reduction mitigation (e.g., bird nets)
11. Cleaning of ponds and chemicals used

Social:

1. Labour structure (proportion of e.g., workers, managers)
2. Jobs created per unit output
3. Employee risk to hazardous/chemicals
4. Employee safety and risk reduction
5. Certification (e.g., ASC)

Welfare:

1. Amount of emergency harvests
2. Number of mortalities on farm
3. Observation of body damage

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4. Humane slaughter of fish
5. Predation measures (e.g., bird nets)
6. Average stocking density

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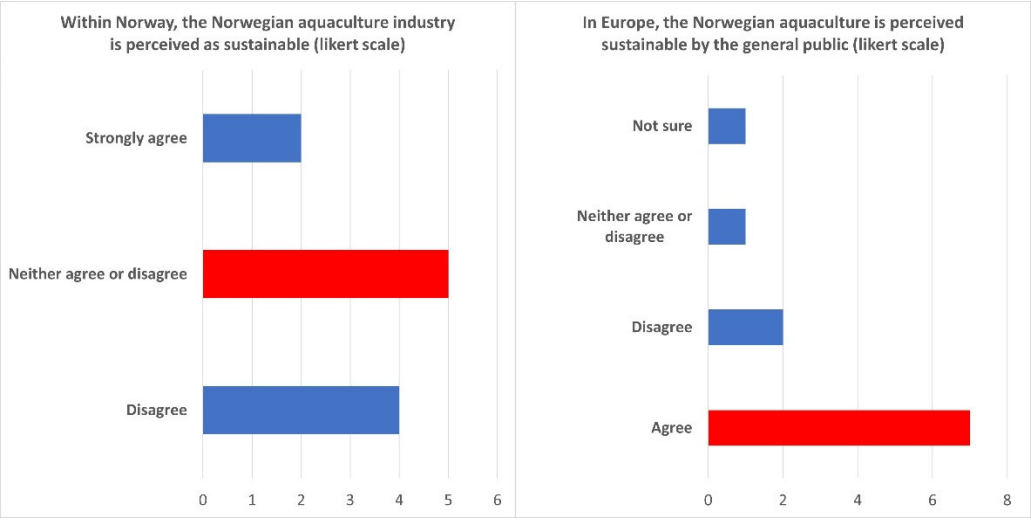
Annex 7: Delphi survey Norway (Atlantic salmon) Round II

Score: 1 not important, 8 highly important

1. In round 1 (see graphs) we asked about the environmental impact of the Norwegian aquaculture industry. Respondents indicated (red bar in graphs) that they perceived that EU consumers regarded Norwegian aquaculture to be more sustainable than Norwegian consumers did. What can explain these different perceptions?



   a. Norwegians are more aware than EU consumers on seafood's sustainability challenges

   b. EU consumers consider Norwegian salmon to be of uniformly high standard

   c. EU consumers think that Norway has a pristine environment

   d. Perceptions on the definition of sustainability differs

   e. EU consumers consider Norwegian salmon sustainable compared to their own local products

2. In round 1 we asked about general trends in the aquaculture industry in Norway. Respondents highlighted a trend towards 'responsible' production (graphs below, red bar). Respondents also indicated that novel feed ingredients were considered a key strategy to increase profitability and sustainability. What are the main challenges of novel feed ingredients?

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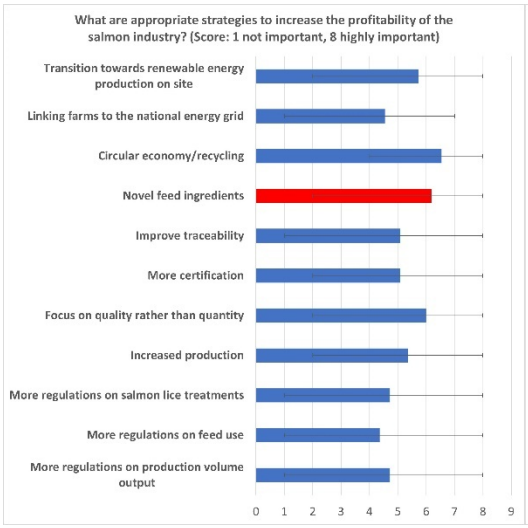
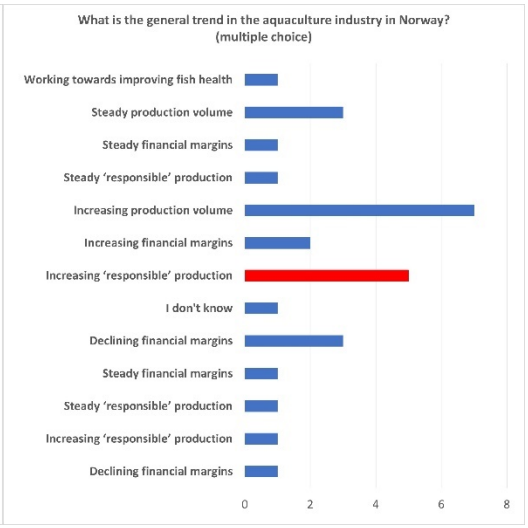
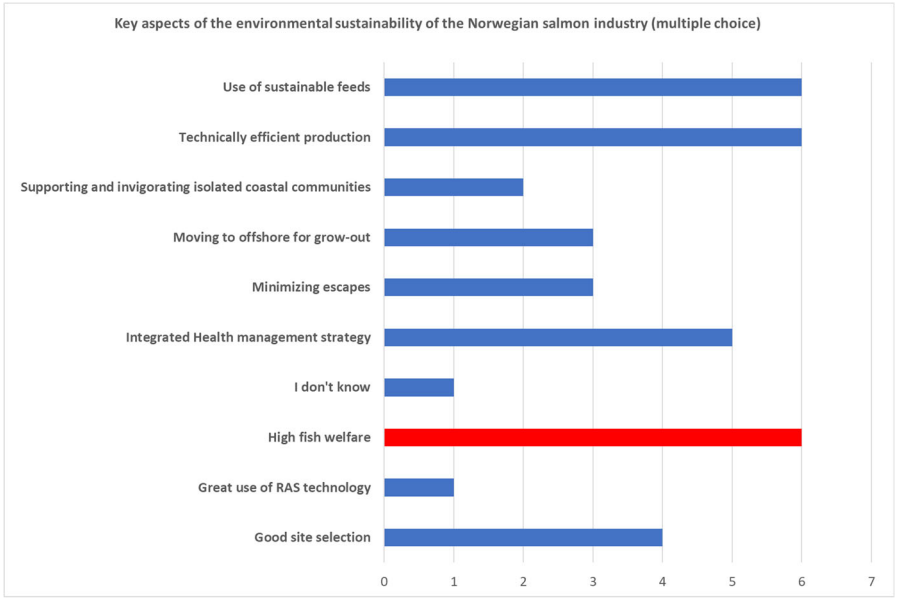




a. Availability
a. Quality
b. Consistency of nutritional content
c. Legislation
d. Price

3. In round 1 we asked about environmental sustainability (graph below, red bar). In addition to sustainable feeds and technically efficient production, stakeholders highlighted the importance of high fish welfare (red bar). What are key strategies to support fish welfare?



a. Regulator veterinary checks
b. Implement training in fish welfare
c. Monitor fish condition
d. Monitor water quality (temp, pH etc)
e. Predator control
f. Feed quality assurance

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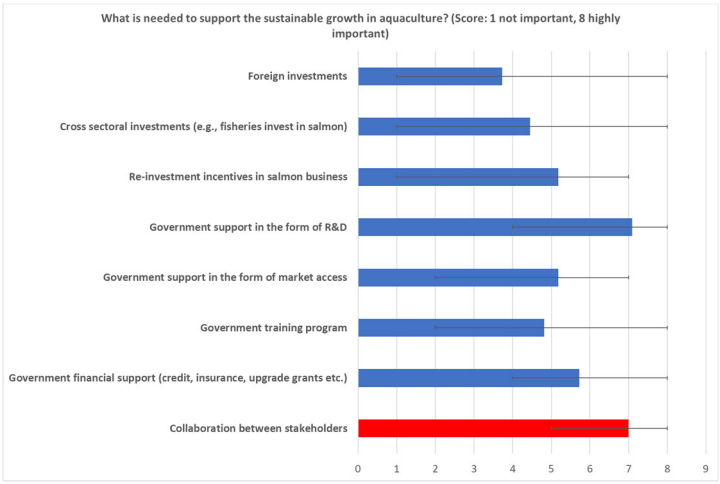
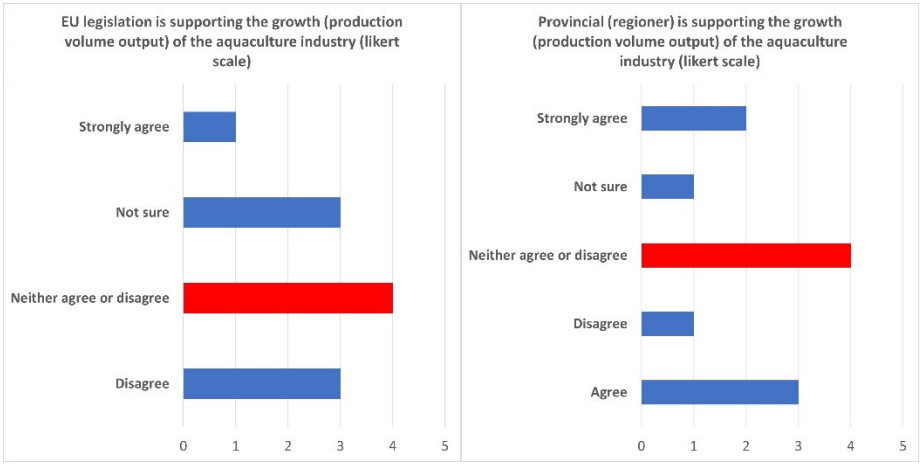
4. In round 1 we asked about the needs to support sustainable growth. Respondents indicated that collaboration between stakeholders is very important to support sustainable growth (graph below, red bar). What type of collaboration is most important?



a. Implementing an area warning system for sea lice
b. R&D on sustainable feeds
c. Sharing farm performance data
d. Regular producer meetings to refine collective strategies

5. In round 1 we asked if current EU and provincial (regioner) legislation is supporting growth (production volume output) of the Norwegian aquaculture industry. Respondents had mixed views about legislation in terms of supporting the growth of the industry (graphs below, red bar). Where should legislation focus to achieve sustainable growth?



a. Legislate on environmental footprint, e.g., carbon
b. Financial instruments (e.g., subsidies, incentives, tax benefits) for innovations
c. Improving the planning for new site selection
d. Replace government regulation with private standards (e.g., ASC or GlobalG.A.P.)
e. Reduce regulation on salmon lice treatments
f. Reduce regulation on feed use
g. Site or context specific regulation on maximum standing biomass

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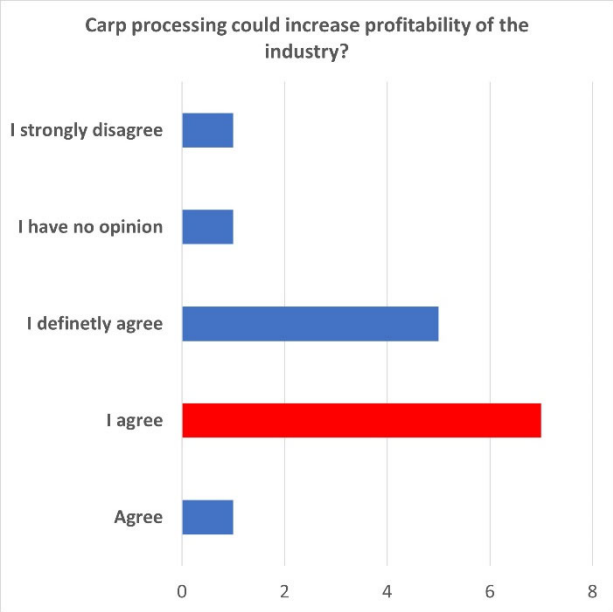
Annex 8: Delphi survey Poland (common carp) Round II (was distributed in Polish)

Score: 1 not important, 8 highly important

1. In round 1 we asked if carp processing could increase the profitability of the Polish aquaculture industry. Respondents indicate that carp processing could increase the profitability of the industry (red bar). What is the best strategy to change consumer perceptions towards processed carp?



a. Advertisements: 'live sales are cruel'
b. Advertisement to stimulate people to eat processed carp all year
c. Better advertising campaign for differentiated carp products
d. Create economic incentives (tax cuts or subsidies on processed carp products)
e. Industry promotion of natural production characteristics of processed carp products

2. In round 1 we asked about the general trends in the carp aquaculture industry in Poland. In addition to a steady production volume, respondents identified a perception of reducing profit margins (graph below). What has caused the declining financial margins?

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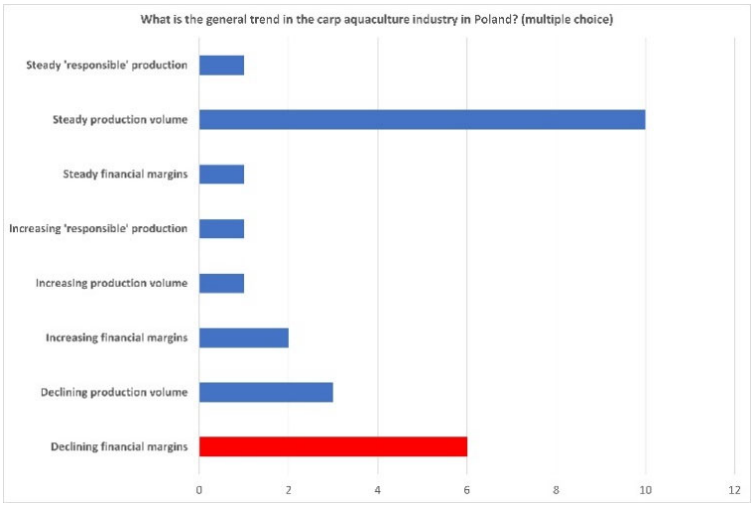
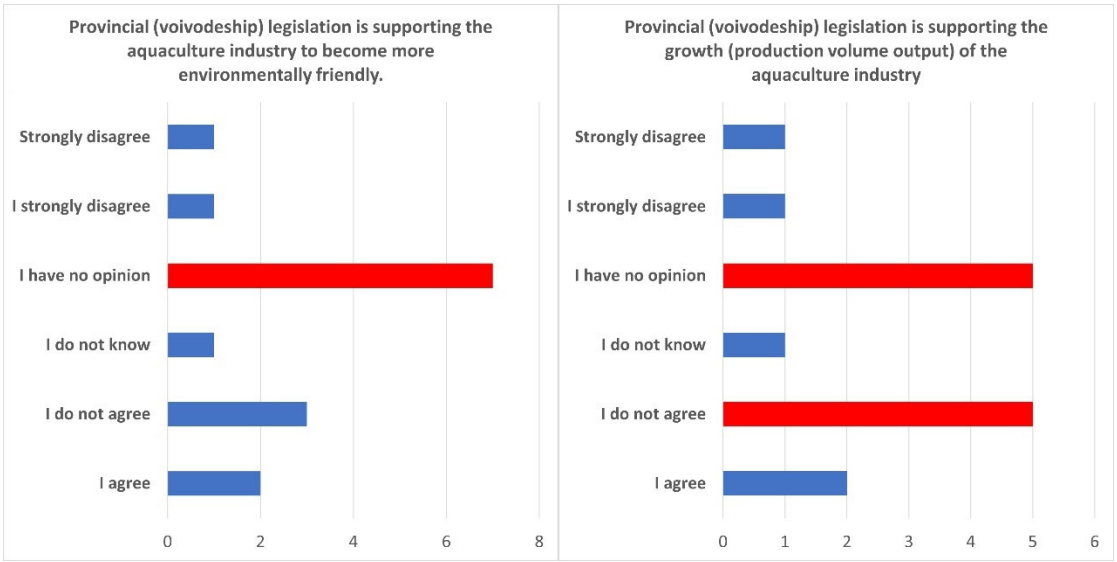


a. Higher production costs
b. Low carp prices due to limited season window (Christmas sale)
c. Low carp prices due to imports of carp
d. Environmental challenges leading to welfare and performance issues
e. Environmental challenges leading to lack of water resources
f. Regulations on production volume

3. In round 1 we asked if current provincial (voivodeship) legislation is supporting the sustainable growth of the Polish carp aquaculture industry. Respondents had no opinion in terms of provincial legislation to support sustainable practices, while respondents indicate to disagree/no opinion regarding provincial legislation supporting the growth of the industry (graphs below, red bar). Additional, respondents clearly disagreed that national legislation support the sustainable growth of the industry. What topic should legislation (provincial/national) be focussed on increase financial margins and to promote carp as being low impact.



a. Legislate on environmental footprint, e.g., carbon
b. Fish processing

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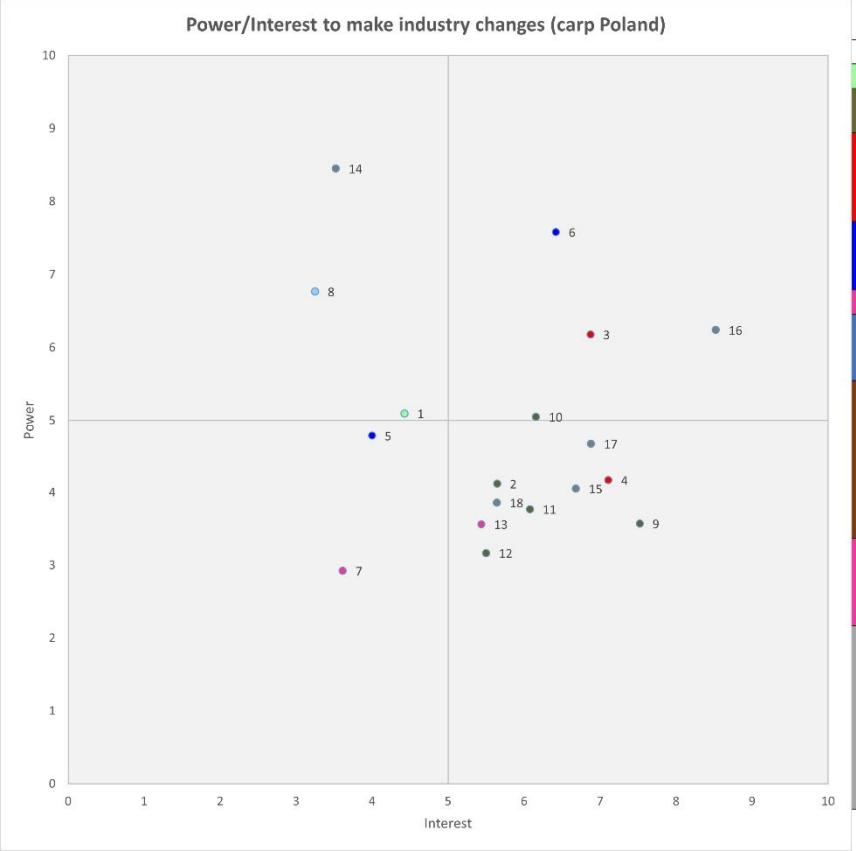
c. Financial instruments (e.g., subsidies, incentives, tax benefits) for innovations
d. Increase the amount of land available to farm carp
e. Organic certification
f. Other certification
g. Less regulation on production output
h. Supporting regulations to protect carp ponds as an environmental asset

4. During the value chain survey, participants were asked to score power/interest of other stakeholders towards making an industry change/innovation. These values were grouped in a stakeholder grid to find patterns of stakeholders with high interest and high power most likely to initiate industry changes (graph below). Barriers for innovation can be found in the low interest and high-power grid, or high interest and low power grid. For the Polish carp industry, respondents indicate that the industry innovation is not stakeholder led. How can the industry become better industry led?



Nodes	No.	Stakeholder
Grow-out	1	Farms
Feed (Ingredients)	2	Feed companies
Processing	3	Slaughter house and primary processing
	4	Value addition processing
Trade	5	Important and trading company
	6	Retail company
Equipment	7	Transport
Health	8	Vet/Health management company
Education	9	Education
	10	Recreational (guide) tour
	11	Research and innovation company (R&D)
	12	Trainer institution
Equipment	13	Equipment producer, maintenance and recycling
Third parties	14	Government and representative authorities
	15	Certification body/organization
	16	NGO
	17	Carp associations
	18	Consumer group

a. Increase the power of processors to make industry changes
b. Increase the interest of government and representative authorities to innovate the industry
c. Increase the power and interest of farms to innovate the industry
d. Increase the power of education and research to drive innovation
e. Increase the power of certifiers to set a standard and drive innovation

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