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MOTIVATIONS AND BARRIERS FOR THE UTILIZATION OF SIDE-STREAMS FROM PELAGIC FISH PROCESSING FOR FOOD PURPOSES: THE POLISH AND NORWEGIAN PERSPECTIVE

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Abstract: Pelagic fish side-streams are nutritionally rich raw materials that are currently utilised for fishmeal, fish oil, and pet food. This study examined the motivators and barriers to using fish processing side-streams for human consumption in Poland and Norway.
In Norway, the prospect of increased revenue and profit emerged as the primary motivator for enhanced side-stream utilization, whereas in Poland the highest-rated motivators were environmental benefits and waste reduction. Market-related factors were identified as the main barrier in Poland, whereas financial constraints were the primary issue in Norway.
Industry representatives confirmed the technical feasibility of recovering valuable nutrients from side-streams but emphasized the need for proven technologies, investment security, and sufficient market demand to justify the new initiatives.

Keywords: pelagic fish processing, side-stream utilization, new food concepts, sustainable development.

1. INTRODUCTION

The utilization of pelagic fish side-streams for food purposes is gaining attention due to their potential to provide high-value components and improve sustainability in the seafood industry. These side-streams, often considered by-products, include parts like heads, skin, and viscera, rich in proteins, fatty acids, and other bioactive compounds.

This growing interest is set against major global trends. Since 2000, the global population has grown by nearly 2 billion people [World Bank Group 2024], with the expanding middle class – especially in Asia – driving increased demand for aquatic foods [Kidane and Brækkan 2021]. At the same time, fishery production has plateaued at 89.9–91.6 million tonnes, and though aquaculture has expanded significantly, from 17.3 to 35.3 million tonnes in marine and from 25.6 to 59.1 million tonnes in inland aquaculture between 2000 and 2022, it only partly meets this growing demand.

Given the limited biological resources, greater attention is being paid to the role of side-streams throughout aquatic food supply chains. Unlike the term "by-products", which has a legal meaning under EU law [European Parliament 2009], side-streams refer to a broader range of materials – including edible fish parts – with potential food and non-food applications [Falch 2023].

In Norway, side-streams can represent up to 50% of the raw material and are mainly used for fishmeal and oil production [Eysteinsson, Arason and Gudjónsdóttir 2020; Hilmarsdottir et al. 2020]. In Poland, most are also directed toward feed uses, including pet food [Usydus and Szlinder-Richert 2021]. Additionally, whole sprat and fish side-streams are exported to countries like Denmark for fishmeal production [Hryszko 2024]. This is regarded as sustainable, reducing the waste and pressure on wild fish stocks [Boyd, McNevin and Davis 2022; Cappuccinelli et al. 2025].

The current trend has aims beyond basic valorisation, focusing on recovering nutritionally valuable components, such as proteins and lipids for use in functional foods. Pelagic fish side-streams, especially from Atlantic mackerel, contain long-chain omega-3 fatty acids (EPA, DHA), peptides, collagen, and minerals [Välimaa et al. 2019; Eysteinsson, Arason and Gudjónsdóttir 2020; Messina et al. 2022; Siddiqui et al. 2023;]. These compounds have potential applications in health foods, nutraceuticals, and pharmaceuticals. Peptides and proteins also show antimicrobial, antioxidative, and antihypertensive effects [Välimaa et al. 2019; Siddiqui et al. 2023].

Innovative recovery methods, such as pH-shift processing, enzymatic hydrolysis, and membrane filtration, are increasingly applied to enhance extraction efficiency [Cadena et al. 2024; 2025]. These technologies support circular economy principles by converting low-value biomass into high-value products and reducing waste [Hayes and Gallagher 2019; Cadena et al. 2024; 2025].

However, food safety concerns, especially regarding heavy metals, must be carefully addressed [Hayes and Gallagher 2019].

In light of increasing demand for aquatic food and pressure on natural resources, the effective utilization of side-streams is both necessary and urgent. Therefore, the aim of the study was to investigate the motivations and perceived barriers among pelagic fish processors in Norway and Poland.

2. MATERIAL AND METHODS

The study focused on stakeholders within the pelagic fish supply chain, with particular emphasis on processing companies in Poland and Norway. A mixed-methods approach was adopted, comprising a quantitative online survey and qualitative in-depth interviews.

The quantitative phase used the Computer-Assisted Web Interviewing (CAWI) technique. Conducted in Q4 2024, it involved 26 entities: 16 from Poland and 10 from Norway. Companies were classified by employee numbers: large (Poland: 3; Norway: 2), medium (Poland: 5; Norway: 5), small (Poland: 4; Norway: 2), and micro (Poland: 4; Norway: 1). A simplified categorization system was adopted (micro: <10; small: ≥10 and <50; medium: ≥50 and <250; large: ≥250 employees). Applying the official EU definition [European Commission 2003] was deemed impractical given the production-focused nature of the survey and the involvement of plant managers and technical staff. This streamlined system ensured clarity, reduced response burden, and enabled consistent interpretation across countries.

The questionnaire, prepared in English and translated into Polish and Norwegian by native-speaking researchers, asked the respondents to evaluate the motivations and barriers related to side-stream utilization in pelagic fish processing. Barriers were grouped as follows: knowledge (13), organizational and technological (8), financial (4), market and consumer (6), and legal and administrative (4).

The qualitative phase consisted of eight in-depth interviews (IDIs) with industry representatives between Q4 2024 and Q1 2025 – four per country. Conducted on-site in the English or Polish languages, the interviews lasted 90–120 minutes and included the observation of the production stages, particularly side-stream generation and handling. This immersive approach provided deeper insights into company-level practices and challenges.

Interview transcripts were developed through live note-taking and compiled into case reports. Participants gave informed consent through GDPR-compliant declarations, while the data was reported anonymously. A semi-structured protocol enabled exploration of emergent themes while maintaining comparability. Thematic content analysis was applied to identify key patterns aligned with the study's objectives.

Quantitative data were analysed using Chi-squared tests to assess the associations between categorical variables. Motivations and barriers were rated using Likert-type scales [Likert 1932; Joshi et al. 2015], with non-parametric tests applied: the Mann-Whitney U test for country differences and the Kruskal-Wallis H test (with post hoc comparisons) for enterprise size effects. Analyses were performed using Statistica 10 [StatSoft 2012].

To identify broader motivational factors, Principal Component Analysis (PCA) was conducted using PAST version 5 [Hammer et al., 2001; Hammer 2025], allowing data dimensionality reduction and visualization of cross-country motivational structures.

3. RESULTS

3.1. Quantitative research studies

The comparative analysis of the CAWI survey results on primary motivations for future side-stream utilization in pelagic processing companies in Poland and Norway revealed no statistically significant differences between the countries, indicating broadly similar motivational structures. However, some national variations were observed. Polish respondents ranked environmental benefits highest (4.1 ±0.9), possibly due to stricter regulatory pressures, followed by the desire to enhance corporate image through alignment with Sustainable Development Goals. In contrast, Norwegian companies prioritized economic incentives, particularly profit opportunities from new valorisation pathways (4.3 ±1.3). The least motivating factor in Poland was the development of health-promoting products from side-stream nutrients (3.3 ±1.2), while in Norway it was the reduction of disposal costs (3.4 ±1.8).

Table 1. The main motivators of future utilization of side-streams in Poland and Norway fish pelagic enterprises

Future utilization of side-streams – motivators	Poland ($\bar{x}$ ± SD)	Norway ($\bar{x}$ ± SD)
Reduction of current disposal costs	3.8 ±1.3	3.4 ±1.8
Increasing revenues and profits from new directions of side-streams utilization	3.8 ±1.3	4.3 ±1.3
Environmental benefits through improved utilization of bioresources and reduced waste	4.1 ±0.9	3.8 ±1.1
Introducing new pro-healthy food products to the market containing ingredients from improved utilization of side-streams	3.3 ±1.2	3.8 ±1.1
Improving the company's image by contributing Sustainable Development Goals	4.0 ±1.1	3.8 ±1.1

Average ratings and standard deviations of motivators, measured on a 5-point Likert-like scale (1 – unimportant, 5 – very important).

Source: own study.

These differences likely reflect the more burdensome compliance environment in Poland compared to Norway, which influences the relative importance assigned to environmental versus financial motivations.

The comparison of key motivators for future side-stream utilization by enterprise size (Tab. 2), based on aggregated data from Poland and Norway, also showed no statistically significant differences ($p > 0.05$). Still, micro-sized enterprises (<10 employees) identified environmental concerns – especially improved bioresource use and waste reduction (3.4 ±1.1) – as their main driver, possibly due to greater sensitivity to efficiency and regulatory constraints. In contrast, small enterprises (10–49 employees) were most strongly motivated by the potential to increase revenues and profits through new side-stream applications (4.3 ±1.2), reflecting a more entrepreneurial focus on innovation and business growth.

Table 2. The main motivators of future utilization of side-streams in fish pelagic enterprises in comparison to their size

Future utilization of side-streams – motivators	Micro enterprises ($\bar{x}$ ± SD)	Small enterprises ($\bar{x}$ ± SD)	Medium enterprises ($\bar{x}$ ± SD)	Large enterprises ($\bar{x}$ ± SD)
Reduction of current disposal costs	2.6 ±1.5	3.8 ±1.6	4.1 ±1.3	3.4 ±1.3
Increasing revenues and profits from new directions of side-streams utilization	2.6 ±1.5	4.3 ±1.2	4.3 ±1.1	4.2 ±0.8
Environmental benefits through improved utilization of bioresources and reduced waste	3.4 ±1.1	4.0 ±1.1	4.1 ±1.0	4.2 ±0.8
Introducing new pro-healthy food products to the market containing ingredients from improved utilization of side-streams	2.4 ±1.3	3.8 ±1.2	3.7 ±1.2	3.6 ±0.5
Improving the company's image by contributing Sustainable Development Goals	3.2 ±0.8	3.7 ±1.4	4.3 ±1.1	4.2 ±0.8

Average ratings and standard deviations of motivators, measured on a 5-point Likert-like scale (1 – unimportant, 5 – very important).

Source: own study.

Among medium-sized (50–249 employees) and large enterprises (≥250 employees), motivations appeared to be more balanced. Both economic (4.3 ±1.1 and 4.2 ±0.8) and environmental drivers (4.1 ±1.0 and 4.2 ±0.8) were rated similarly high, suggesting that large companies are influenced by both sustainability goals and financial considerations. Corporate social responsibility factors, such as enhancing company image through contributions to the Sustainable Development Goals, also received higher ratings in these groups compared to micro and small enterprises,

indicating a stronger strategic alignment with global sustainability frameworks as company size increases.

Although not statistically significant, these tendencies may guide tailored policy support by revealing differing motivations based on enterprise scale and innovation capacity. To explore these patterns further, Principal Component Analysis (PCA) was applied. The PCA plot showed clustering by country, but overlapping 95% confidence ellipses confirmed no significant group separation. Vector lengths indicated the strength of each variable's influence, with environmental motivations emerging as strongly correlated factors (Fig. 1).

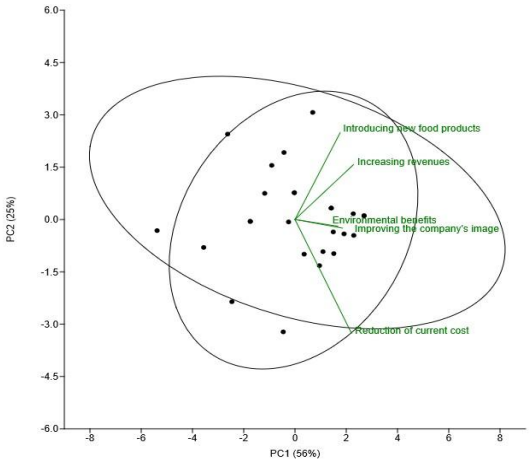


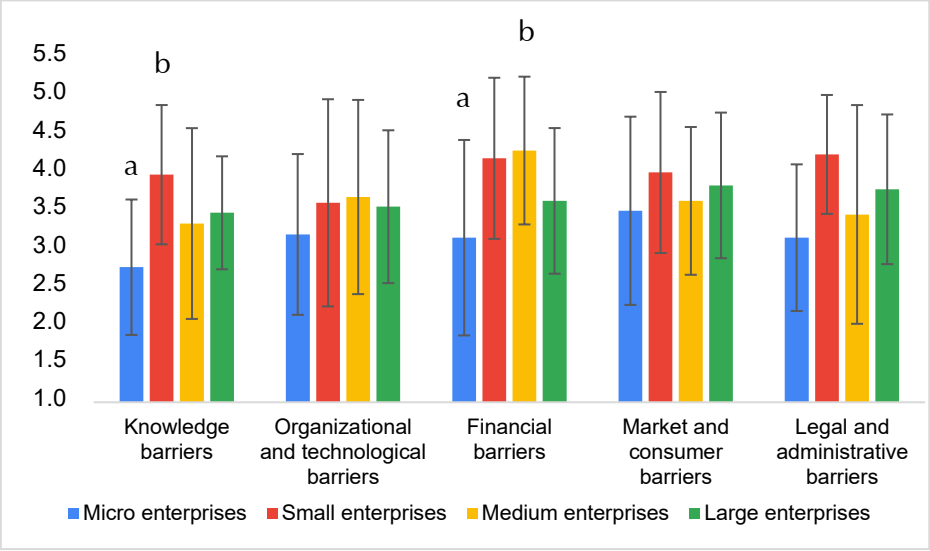
Fig. 1. Principal Component Analysis plot of motivators of better side-stream utilizations in pelagic fish processing plans in Poland and Norway

Source: own study.

When comparing the mean results in the five barrier categories (knowledge, organizational and technological, financial, market and consumer, and legal and administrative) between Poland and Norway, market and consumer-related barriers were rated the highest in Poland (4.0 ±0.9 vs. Norway 3.1 ±1.2), while in Norway financial constraints were the highest (3.8 ±1.1), also important in Poland (3.9 ±1.1). Statistically significant differences occurred only for organisational and technological barriers (PL: 3.6 ±1.1; NO: 3.2 ±1.3; $p = 0.0138$) and market and consumer barriers ($p = 0.000$).

Across enterprise sizes (Fig. 2), significant differences were found only between small and micro enterprises for knowledge barriers, and between micro and medium enterprises for financial ones. In other areas, perceived barriers were broadly similar. Market and consumer barriers were most strongly noted by micro

and large firms, while small enterprises highlighted regulatory and financial constraints. For medium-sized firms, financial barriers were the most relevant.



Average ratings and standard deviations of perceived barriers, measured on a 5-point Likert-like scale (1 – unimportant, 5 – very important).
K-W test results for differences between size of enterprises:
a,b statistical significance $p < 0.05$.

Fig. 2. Results of the importance of different types of barriers, depending on the size of the enterprises

Source: own study.

The results of the CAWI questionnaire are also presented separately for each barrier for each country. Only two knowledge barriers, two organisational barriers and three market and consumer barriers were statistically different.

For knowledge-related barriers (Tab. 3), all mean scores in Poland ranged between 3.1 and 3.7, while in Norway they varied between 2.6 and 3.8. Statistically significant differences were observed for only two knowledge barriers. This indicates that Norwegian companies generally do not perceive the lack of knowledge related to side-stream utilization and nutrient recovery from them as major obstacles to the utilization of pelagic fish side-streams.

In contrast, Polish companies identified them as important barriers. Norwegian respondents highlighted insufficient knowledge about tax incentives and limitations in human and material resources as key obstacles. The absence of scientific project outcomes was not considered a major barrier in either country, as scientific institutions are not commonly regarded as the primary sources of innovative solutions by processing companies.

Table 3. Knowledge barriers of better side-stream implementation for food purposes

Knowledge barriers **Lack of knowledge…**	**Poland** **($\bar{x}$ ± SD)**	**Norway** **($\bar{x}$ ± SD)**
…about possibilities of side-streams utilization	3.4 ±0.8*	2.7 ±1.2*
…about the nutritional ingredients in side-streams	3.3 ±0.8	2.7 ±0.9
… about the recovery of nutritional ingredients from side-streams	3.5 ±1.0**	2.6 ±1.0**
… about the results of scientific projects of side-streams utilization	3.3 ±0.9	2.8 ±1.0
… of how to produce a new product with nutrients recovered from side-streams	3.7 ±1.1	3.2 ±1.2
… of the legal aspects of side-stream ingredients application for food purposes	3.4 ±1.3	3.2 ±1.5
… of how to label a new product with nutrients recovered from side-streams	3.2 ±1.0	3.0 ±1.3
… of what personal and material resources, the company needs to have to improve utilization of side-stream	3.2 ±0.8	3.6 ±1.3
… of what financial resources the company needs to have to improve utilization of side-stream	3.1 ±0.9	3.6 ±1.2
… of how to obtain public funding for the implementation of the new solutions	3.6 ±1.0	3.4 ±1.1
… about tax incentives for implementing new solutions	3.5 ±1.0	3.8 ±1.2
… about market demand for the nutritional substances recovered from side-streams and food products with them	3.6 ±1.0	3.5 ±1.4
… of how to market a new product	3.6 ±1.0	3.2 ±1.6

Average ratings and standard deviations of perceived barriers, measured on a 5-point Likert-like scale (1 – unimportant, 5 – very important).
U test results for differences between countries:
* statistical significance $p < 0.1$,
** statistical significance $p < 0.05$.

Source: own study.

In the category of organizational barriers (Tab. 4), the most important obstacle reported by Polish companies regarding improved utilization of side-streams was the lack of professional training in this area and the shortage of specialists in the market. These barriers showed a statistically significant difference between Poland and Norway, as Norwegian companies identified the seasonality of side-stream volume generation as the most critical organizational barrier, since it hinders efficient processing in highly automated facilities.

Table 4. Organizational and technological barriers for the better side-stream utilization for food purposes

Organizational and technological barriers	Poland ($\bar{x}$ ± SD)	Norway ($\bar{x}$ ± SD)
Lack of technological solutions (including equipment) for improved utilization of company side-streams	3.9 ±1.0	3.6 ±0.8
Lack of specialists in the market for the utilization of side-streams	3.9 ±0.8*	3.2 ±1.2*
Lack of professional trainings in side-streams utilization	4.1 ±0.9**	3.0 ±1.2**
Spatial limitations of the company for improved utilization of company side-streams	3.8 ±1.0	3.6 ±1.2
Difficulties in collecting, protecting and logistics of side-streams and their components	3.2 ±1.1	3.1 ±1.4
Not sufficient volume of side-stream (or component) for new solutions implementation	3.3 ±1.4	2.9 ±1.7
Seasonality of side-streams volume generation	3.9 ±1.3	4.1 ±1.1
Seasonal variations of side-streams chemical composition	3.2 ±1.3	2.5 ±0.7

Average ratings and standard deviations of perceived barriers, measured on a 5-point scale (1 – unimportant, 5 – very important).
U test results for differences between countries:
* statistical significance $p < 0.1$,
** statistical significance $p < 0.05$.

Source: own study.

Financial barriers (Tab. 5) were rated as highly relevant by respondents in both Poland and Norway. In Poland, the most critical financial obstacles were the high investment costs associated with the implementation of new solutions and the high maintenance costs of these solutions. In Norway, the most important financial barriers were the challenges related to obtaining (public) funding for the implementation of new solutions and the high investment costs involved.

Table 5. Financial barriers for the better side-stream utilization for food purposes

Financial barriers	Poland ($\bar{x}$ ± SD)	Norway ($\bar{x}$ ± SD)
High investment costs for implementing new solutions	4.1 ±1.1	3.9 ±1.0
Challenges obtaining (public) funding for implementing new solutions	3.9 ±1.1	3.9 ±1.1
High maintenance costs of new solutions	4.1 ±1.1	3.4 ±1.3
Lack of tax incentives for implementing new solutions	3.6 ±1.3	3.7 ±1.3

Average ratings and standard deviations of perceived barriers, measured on a 5-point scale (1 – unimportant, 5 – very important).

Source: own study.

Market and consumer-related barriers (Tab. 6) in the pelagic sector were perceived as considerably more important in Poland than in Norway. Statistically

significant differences were observed in several areas, including retailer's reluctance to introduce new food concepts, consumer reluctance to purchase food products based on side-streams, and difficulties in marketing new products. These barriers were consistently rated as more significant by Polish respondents compared to their Norwegian counterparts.

Table 6. Market and consumer barriers for the better side-stream utilization for food purposes

Market and consumer barriers	Poland ($\bar{x}$ ± SD)	Norway ($\bar{x}$ ± SD)
Concerns about insufficient demand for new food concepts containing ingredients from side-streams	3.9 ±1.1	3.2 ±1.3
Lack of objective consumer knowledge regarding the nutritional ingredients from side-streams which can be used for food production	4.0 ±1.0	3.4 ±1.1
Consumer reluctance to purchase food products made from side-streams ingredients due to concerns about their quality or safety	4.3 ±0.9**	2.7 ±1.2**
Too high retail price for consumers of new products based on side-streams	4.0 ±0.9	3.1 ±1.5
Retailers reluctance to introduce new food concepts	4.1 ±0.9**	3.0 ±1.2**
Difficulties in marketing new products containing ingredients from side-streams	4.0 ±0.9*	3.2 ±1.1*

Average ratings and standard deviations of perceived barriers, measured on a 5-point scale (1 – unimportant, 5 – very important).
U test results for differences between countries:
* statistical significance $p < 0.1$,
** statistical significance $p < 0.05$.

Source: own study.

The importance of legal and administrative barriers (Tab. 7) was quite similar for Polish and Norwegian companies. In both countries not the legislation itself but the lack of uniform interpretation of the laws and complex administrative procedures were more important barriers in the better utilization of side-streams.

Table 7. Legal and administrative barriers concerning the better side-stream utilization for food purposes

Legal and administrative barriers	Poland ($\bar{x}$ ± SD)	Norway ($\bar{x}$ ± SD)
European law requirements	3.4 ±0.9	3.2 ±1.4
National legislation requirements	3.4 ±0.9	3.4 ±1.5
Lack of uniform interpretation of laws	3.9 ±1.1	3.6 ±1.3
Complex administrative procedures by food safety authorities	3.9 ±1.1	3.5 ±1.6

Average ratings and standard deviations of perceived barriers, measured on a 5-point scale (1 – unimportant, 5 – very important).

Source: own study.

Comparing the results given for barriers in the CAWI research in Poland and Norway, the most important ones for Norwegian processors were related to the seasonal collection of side-streams and obtaining the money for investments. Polish processors most often indicated market and consumer barriers, such as consumer concerns about the quality or safety of products from the side-stream, which could be an important disincentive to purchase such products.

3.2. Qualitative research studies

The interviews revealed a nuanced set of motivations and barriers shaping how pelagic fish processors in Poland and Norway approach the utilization of solid side-streams. Economic considerations emerged as the main driver in both countries. The participants highlighted the importance of financial viability – whether through reducing disposal costs or generating new revenue. A Polish respondent noted, "primary motivations are purely economic – to reduce current disposal costs and gain higher profits from such by-products as heads and viscera". Several firms expressed dissatisfaction with current low-value uses, such as fishmeal, and showed interest in recovering edible meat from trimmings for food-grade applications – provided that the processing costs are justified.

Some also mentioned corporate image and sustainability as secondary motivators. For medium and large companies, the idea of zero-waste operations was associated with environmental responsibility and market positioning. In Norway, where most off-cuts are already converted into fishmeal and oil, some executives stated there was "no extra motivation" to modify a working system. However, others saw potential in further development – particularly for human consumption – if aligned with existing processes and profitability.

Interviewees in both countries acknowledged potential reputational and strategic benefits in developing higher-value uses for side-streams, particularly in the context of circular economy trends. Yet these aspirations were tempered by significant practical barriers. The most commonly cited was limited access to knowledge and proven technologies. Many companies were unaware of food-grade applications beyond fishmeal or lacked guidance on how to implement new processes. As one Polish processor put it: "Our company has no knowledge of what market exists for components recovered from side-streams".

Managers also stressed the absence of clear demand. Without buyer interest or partnerships, few were willing to risk investing in side-stream utilization. Respondents noted a lack of market signals and explained that they typically adopt innovations only when ready-made solutions are presented. Scientific research was often seen as too theoretical and disconnected from operational needs, with preferences leaning toward turn-key technologies from customers or suppliers.

Operational and logistical challenges further hindered progress. Limited space in older or smaller plants, particularly in densely built or tourist-adjacent areas,

restricted equipment installation. One Polish company had even ceased fishmeal production due to odour concerns and now requires any side-stream innovation to be odour-neutral. Additionally, high-throughput pelagic lines, especially during peak seasons, make in-process sorting difficult. One Norwegian manager noted that unless automation can match the speed of production, selective refinement is unfeasible.

Resource allocation within companies was another issue. Side-stream initiatives often compete with more immediate investments such as cold storage or filleting lines, making them less attractive unless mandated or clearly profitable. Furthermore, seasonality adds complexity: intense harvest periods for herring or mackerel require either intermittent processing or complex storage solutions for highly perishable side-streams.

In summary, processors showed cautious interest in more advanced side-stream utilization. Some companies, having already minimised waste through fishmeal production, focus on incremental gains driven by image and market potential. Small and medium enterprises remain more reactive and open to opportunities if market partners or ready solutions are available but generally risk-averse and under-resourced. Norwegian firms benefit from structured valorisation systems and experience less pressure to change, while Polish processors – facing greater uncertainty – expressed stronger aspirations but also confronted more severe constraints. Despite these differences, core motivators and obstacles were shared across both countries, reinforcing that practical and economic logic remains the key to innovation in side-stream use.

4. DISCUSSION

The results on motivations and barriers to advanced utilization of pelagic fish side-streams in Poland and Norway revealed only minor differences, suggesting similar innovation approaches. Polish companies more often emphasized lacking know-how on nutrient recovery and applications, while Norwegian firms highlighted seasonal fluctuations in side-stream volumes as a key constraint. Case studies from Bar [2015] in Norway, Denmark, Iceland, and Germany identified barriers, such as knowledge gaps, consumer requirements, and financial constraints, many of which were echoed in this study through both surveys and in-depth interviews (IDIs).

Polish and Norwegian firms frequently mentioned a shortage of qualified staff, limited awareness of new solutions, and low internal motivation for change. Bar [2015] also noted that innovation is largely driven by consumer expectations, a finding still relevant today, as well as by goals like reducing labour dependency, increasing cost efficiency, and ensuring regulatory compliance. In the present study, these drivers were particularly visible among Norwegian firms.

Bar [2015] further emphasized the lack of economic resources as a barrier to innovation – a concern still evident in Norway. In contrast, Polish firms have seen

better access to innovation funding in recent years. While automation was once an enabler for green innovation, its widespread implementation now often presents itself as a structural constraint. Alam et al. [2011], studying Malaysian SMEs, found financial barriers significantly limited growth – a pattern also observed in Poland and Norway, where small and medium companies heavily rely on external support for side-stream valorisation. Beyer [2022] classified innovation barriers as internal (organizational, HR, financial) and external (legal, financing, market), all of which were ranked high in this study. Successful innovation, according to the respondents, must be well-resourced, market-oriented, and led by skilled personnel. Kozludzhova [2023] distinguished between general barriers (e.g., lack of innovation structure, market inertia, financing gaps) and specific ones (e.g., fear of change, unclear commercialisation paths). Both types were confirmed in the present IDIs. Similarly, Torres de Oliveira, Gentile-Lüdecke and Figueira [2021] stressed that external knowledge sourcing is vital to innovation success; yet most surveyed firms still relied on customers and the internet, with little engagement from academia. Coad, Pellegrino and Savona [2015] also ranked the lack of qualified personnel as a key productivity constraint, behind financial limitations – a view widely shared among Polish and Norwegian processors. While many innovation barriers persist over time due to structural limitations, motivators for side-stream valorisation are increasingly shaped by shifting regulations and consumer demands, which vary by country and enterprise size.

5. CONCLUSIONS

The combined findings from surveys and interviews provide a detailed picture of the circularity prospects in pelagic fish processing. In both Poland and Norway, processors increasingly recognize the value of side-streams but remain driven by economic rationales. Companies are most likely to invest in valorisation when it results in cost savings or opens new market opportunities.

A promising pathway is the outsourcing of nutrient recovery technologies, especially for SMEs that lack in-house capacity. This model supports circular economy goals while offering economic and environmental benefits. However, its success depends on both internal adjustments – such as improved segregation and hygiene practices – and external coordination, including regional logistics systems that ensure consistent side-stream supply to specialized facilities.

Companies currently not valorising side-streams expressed strong interest in change, provided it is practical and economically justified. In contrast, firms already producing fishmeal or fish oil showed a more cautious, incremental approach, focusing on higher-value applications, such as human-grade ingredients.

Despite this interest, significant knowledge and market barriers persist. Many companies lack awareness of the available technologies or end-user markets.

Bridging these gaps requires collaboration between industry, academia, and public institutions. Demonstration projects and matchmaking efforts can foster trust and accelerate uptake.

Strategic priorities differ by company size. Large companies tend to integrate valorisation into long-term planning, while SMEs emphasize short-term gains. This highlights the need for targeted policy tools – such as subsidies, co-investment mechanisms, and tax incentives – to lower the barriers to entry, especially for smaller processors. Simultaneously, consumer awareness and labelling schemes could help build demand for side-stream-derived products.

Beyond valorisation, opportunities exist in maximizing edible yield, such as through mechanically separated fishery products (MSFP) [European Parliament 2004], and using underutilized parts like bones and skin to develop functional foods and nutraceuticals. However, legal and administrative complexity remains a major hurdle, particularly in Norway. Harmonizing legislation and offering regulatory guidance would ease compliance and encourage broader industry participation.

In conclusion, the shift toward a circular, knowledge-based bioeconomy in pelagic fish processing is feasible. Achieving it will require innovation, regulatory reform, and both financial and organizational support. Most importantly, building strategic partnerships across the value chain is essential to scale solutions and realize shared value from side-stream utilization.

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