

DISRUPTIONS IN SHORT FOOD AND COLD SUPPLY CHAINS IN FISH PROCESSING

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Purpose: Fish processing is one of the fastest growing sectors of the food industry in Poland. The aim of this article is to analyze and assess the impact of the COVID-19 pandemic on the production of fish products.

Design/methodology/approach: The main research question was formulated as follows: To what extent has the COVID-19 pandemic affected the production of fish products? A research gap has been identified, resulting from limited empirical data, concerning the functioning of the fish processing supply chain in terms of supply and distribution logistics in situations of emergency and prolonged disruption.

Findings: As a result of a diagnostic survey, it was established that during the COVID-19 pandemic, 65.85% of companies reported disruptions in the supply of raw materials and components, while only 34.15% did not feel the effects of the pandemic in terms of supply chain logistics. Deliveries of finished products from the distribution logistics side of fish processing companies were delayed in 43.9% of cases to customers.

Practical implications: Fish processing companies should strive for scenario three, as there are no negative aspects, and there are significant changes in supply and distribution logistics, which directly affect the company's functioning on the market.

Originality/value: The presented analysis and solutions are based on the experience of fishing industry companies and may be considered for application in other industries.

Keywords: fish processing, short food supply chains (SFSC), cold supply chain (CSC), disruption, quality.

Category of the paper: Research paper.

1. Introduction

An important task facing Polish enterprises, especially fish processing companies was to defend themselves against the negative effects of economic crises caused, among other things, by increased uncertainty, rapid climate change, the COVID-19 pandemic (2019-2020) (Olkiewicz, 2022) and the effects of the armed conflict in Ukraine (2022-). The food industry

is the largest manufacturing sector in the European Union in terms of jobs and added value. The strategic nature of the food sector is determined not only by the nature of the products manufactured, but also by the sector's share in global production and gross domestic product (GDP), as well as its importance for the development of the labor market and international trade. In 2022, the economic and financial situation of individual food industry sectors was good. Compared to 2019, there were only minor changes. This demonstrates the sector's high resilience to adverse macroeconomic conditions and its ability to adapt to a changing and unpredictable market environment. The real value of the sector's output accounted for 18.5% of the output of the manufacturing industry (GUS, 2022) and increased by nearly 53% between 2010 and 2021 (Szczepaniak, Juchniewicz, 2024; Drożdż, 2024). The food industry contributes significantly to gross domestic product (GDP), measured by gross value added (GVA) in economics; GVA generated in this sector accounted for between 2.2% and 3% of GVA generated in the entire national economy (GUS, 2023). In Poland, this sector is one of the most important branches of the economy, as in 2022 its share in global production and GDP amounted to 8.5% and 4.2%, respectively, and in the number of people employed in the national economy – 10.3% (Szczepaniak, Drożdż, 2023). The literature on the subject provides several classifications based on the location factors of food industry enterprises. Industries located in the immediate vicinity or as close as possible to the raw material base, which is related to a situation where the transport of raw materials is impossible or difficult due to their perishability, or possibly unprofitable. This group includes, in particular, the sugar, potato, fruit and vegetable, and fish industries (Hryszko, 2023).

Fish processing is one of the fastest growing sectors of the food industry in Poland. The fish and seafood processing sector in Poland is one of the most concentrated sectors of the food industry. Factors influencing changes in the supply chain of fish processing plants in the period 2022-2023 were diverse. The structure of the fish processing sector in Poland should be considered highly fragmented. Although the total number of entities is estimated at around 610-720, a dozen or so of the largest entities account for approximately 75% of total production value. These companies are largely financed by foreign capital. Most entities (around 80%) are small and medium-sized enterprises. The economic and financial situation of the processing plant was good or very good in 2010-2021, but it was highly volatile, mainly due to fluctuations in the purchase prices of raw materials on global markets. The average growth rate of the value of fish products sold in the analyzed period was 10.5% and was significantly higher than in other sectors of the food industry (average growth of 6.4%) (Silvestrini et al., 2023). However, this was accompanied by relatively low profitability. The aim of this article was to analyze and assess the impact of the COVID-19 pandemic on the production of fish products. Over the last two years, the fish sector in Poland has been under pressure from limited demand and declining consumer purchasing power observed both on the domestic market and on foreign markets. Deeper declines in consumption were mitigated to some extent by a reduction in VAT rates on food, and entities in the fisheries and aquaculture sector received financial support for additional

costs incurred as a result of market disruptions caused by Russia's war against Ukraine and its impact on the supply chain. The domestic supply of fish, seafood and processed products amounted to 514,500 tons (in live fish equivalent) in 2023, which was 1.8% higher than in 2022. This was solely due to an increase in net imports, with catches remaining similar to the previous year. The self-sufficiency ratio decreased by 0.5 percentage points.

2. Literature Review

2.1. Short food supply chains (SFSC)

Food trade is essential for achieving food security, and internationally traded food accounts for 19% of calories consumed worldwide (Topczewska et al., 2024). With the growing demand for diverse food products, transportation is a key link in global food supply chains (Tchoukouang et al., 2024; Chandan et al., 2023; Canfora, 2016). Short food supply chains (SFSC) are alternative agri-food systems that include various forms of distribution characterized by few or no intermediaries between consumers and producers, or short geographical distances between them (Szymańska, Lukoszová, 2019; Parker, 2005). SFSC are alternative agri-food systems that include various forms of distribution characterized by few or no intermediaries between consumers and producers, or short geographical distances between them (Mancini et al., 2019). Short supply chains reduce the distance between the producer and the consumer, which can contribute to environmental protection (Bayir et al., 2022). Reducing the number of intermediaries needed to deliver the final product to the consumer ensures better quality resulting from the elimination of storage and repackaging, a lower final price of the product, and a higher share of the producer's profit from the production and sale of the product. Food travels thousands of kilometers thanks to more efficient means of transport, but this comes at a cost to the environment, measured, for example, in food miles (Li et al., 2017). This term refers to the distance food products travel from the place of production to the consumer, indicating the impact of this element of distribution on the environment (Akaichi et al., 2023). Hoehn et al. proposed the term “sustainable development” in short food supply chains. They pointed out that initiatives aimed at changing the food system focus mainly on food waste and circular economy strategies in food production. They emphasize the need to pay attention to the relocation of food markets and greater local consumption (Hoehn et al., 2021). This allows food producers to regain an active role in creating value for the chain and the product itself. The solution eliminates links and intermediaries and shortens the distance food has to travel to reach consumers (food miles).

In terms of logistics, short food supply chains reduce food transportation (Renkema, Hilletofth, 2022). This, in turn, leads to lower transport costs, reduced greenhouse gas emissions, slower wear and tear on local roads, and reduced congestion, i.e., local traffic overload. In this way, economic, environmental, and social benefits are achieved (Raszeja-Ossowska, 2017). The identifier of SFSC value can be quality, and the common feature is the emphasis on the relationship between the producer and the consumer and their role in such a relationship. Similar food products can be the result of both industrial and alternative (short) chains (Tundys, 2015). Identification is extremely important due to the intense competition between them, as well as between different retailers and processors participating in various types of chains, including fish processing companies.

This leads to some very interesting chain mutations. Corporate retailers, wanting to be closer to their customers, are developing distribution channels, for example by ordering goods via the Internet. Local food deliveries are based on short food supply chains, which are considered better from an economic, social, and environmental point of view. As Gonçalves and Zeroual (Gonçalves, Zeroual, 2017) have noted, from an economic point of view, the need for frequent deliveries is associated with high transport costs. One type of short chain is an extended chain involving partnerships in the form of cooperatives or producer associations. This category further extends the reach of the chain, both in time and space. The products are sold to consumers outside the production region, who have no direct or personal contact with producers from the locality or region. In most cases, the products are exported from local or even national markets (Galli, Brunori, 2013, Khodae et al., 2022). In order to minimize the negative environmental impact of short supply chains, they should be seasonal in nature and use environmentally friendly production methods. The seasonal nature of these chains reduces the need for transport and storage.

2.2. Cold supply chain (CSC)

In recent years, the global market for chilled and frozen foods has been growing rapidly, generating demand for the delivery of these types of goods to the farthest corners of the world (Każmierczak, Szymczyk, 2019). These chains deal with the delivery of goods that are sensitive to temperature (especially heat). The organizers of the entire transport process for frozen and refrigerated goods face the challenge of not only ensuring on-time delivery, but above all ensuring the right conditions during transport so that the goods do not lose their quality (Reshetnikova et al., 2021; Awad et al., 2021; Kojder, Klepacki, 2021).

As early as the second half of the 18th century, ice began to be used to ensure longer storage of fish (Kumar et al., 2022). Raw fish, mollusks, and crustaceans are transported over short distances in melting ice or at the temperature of melting ice. Over longer distances, fish are transported as frozen products, foodstuffs that can be stored for long periods at temperatures below approximately -18°C . The freezing process inhibits fat rancidity and stops the growth of microorganisms. During transport of deep-frozen products, the temperature during transport,

loading, and unloading should not deviate by more than $\pm 3^{\circ}\text{C}$, and in the case of frozen products, the deviation should not exceed $\pm 4^{\circ}\text{C}$.

Organizing long-distance transport in the summer to and from countries with warm climates is a particular challenge. The distribution of these types of products therefore requires a cold supply chain. Dry ice is used as a cooling agent to keep frozen goods frozen during transport and transshipment operations. In the logistics of cargo requiring a cold chain, careful planning of the entire transport process is of paramount importance (Yu, Xiao, 2021). The cold chain is an organic combination of four interrelated systems: pre-cooling, storage cooling, refrigerated transport, and marketing, which differ in sequence and timing (Theophilus et al., 2021). A cold supply chain (CSC) is a logistics system that requires a range of equipment to ensure ideal temperature conditions during the transport of goods from their place of origin to their point of sale (Senguttuvan et al., 2021). The CSC also requires appropriate infrastructure, which consists of four main components. The first is the availability of premises where products can be stored for long periods of time, the second link is the facilities where production and preparation for distribution take place, followed by transport, which includes vehicles equipped with control devices and interiors adapted with temperature-maintaining materials. Refrigerated containers are the standard units used to transport frozen fish. They are standardized, thermally insulated containers equipped with a refrigeration unit (compressor or other) to ensure the necessary conditions for transporting perishable cargo. These containers are among the most demanding in terms of construction and handling, and therefore the most expensive of all container units (Sainathan, 2018). In terms of volume, however, they are the second largest group after conventional containers.

The cold chain is exposed to various dangerous situations. Possible events have been divided into four groups of factors according to the cause of the hazard: human, climatic, technical, and random (Mustafa et al., 2024). Chinese cold chain logistics companies emphasize the need to implement low-carbon strategies and smart innovations to address environmental challenges and market needs (Badia-Melis et al., 2018). Domestic policy and financial interventions play a key role in the modernization and standardization of infrastructure, highlighting the importance of the Chinese government's support in the pursuit of sustainable logistics in CCS (Han et al., 2021; Xie et al., 2022). Integrated Cold Chain Management (CCM) effectively demonstrates the complexity of relationships and the collective importance of various components in this category, highlighting their key role in the continuity of food supply, including fish (Alabi, Ngwenyama, 2023). CCM is proving to be a key factor in extending the shelf life of fish as a perishable product, reducing spoilage and ensuring safety.

2.3. Disruption and resilience of supply chains

In the fishing industry, the chain may be disrupted due to weather conditions and other reasons beyond the supplier's control. The supply chains of many companies have been disrupted during crises such as the COVID-19 pandemic (Ivanov, 2022; Han et al., 2023) or

have lost their previous capacity to operate (Michel-Villarreal et al., 2021). The loss of the supply chain's current capacity should be understood in terms of its effects, i.e., the value delivered to the end customer, or the level of customer service (Zhang et al., 2021). The loss of the existing ability to operate may therefore also take the form of incomplete delivery or extended delivery times (WEF, 2013). It should be noted that, in the face of such disruption, the supply chain may not only be unable to deliver value at the same level as before, but may even cause losses on the part of the recipient, which in quantitative terms can be treated as the delivery of negative value (Zamani et al., 2023). In a proactive approach, we deal with increasing the resilience of the supply chain in a manner adequate to the anticipated future threats, and the level of resilience directly depends on the accuracy (quality) of forecasts and is actually verified only during a crisis situation (Christopher, Peck, 2004).

Resilience can be viewed from both a reactive and proactive perspective. In the reactive approach, rebuilding the supply chain's potential after a crisis allows the supply chain to achieve a higher level of resilience and move it to a more stable equilibrium (Sheffi, 2005; Shishodia et al., 2023). Supply chains resilient (SCR) adapt their strategies and operations to changes in the environment in order to reduce the risk of losing their ability to operate (Wieland, Wallenburg, 2013). They are resistant to various types of anomalies, perturbations, effects of failures or malfunctions resulting from a breach of existing operating conditions or disruption of the continuity of material and information flows (Boin et al., 2010). SCRs are those that can avoid disruptions or reduce their severity if they occur, and that adapt their strategies and operations to changes in the environment in order to limit the risk of losing their ability to operate (Välakangas, 2010). Supply chains resilient can be proactive, if appropriate measures are taken in the supply chain before a crisis occurs, or reactive, when measures are taken to restore the original capacity to operate after a crisis has occurred (Szymczak, 2025).

The COVID-19 pandemic was the direct cause of many bottlenecks in supply chains, which manifested themselves in the form of supply shortages, limited or suspended production, and staff shortages (Lund, George, 2020). Research conducted by numerous authors suggests that in 2018, i.e. before the outbreak of the SARS-CoV-2 pandemic, the five largest disruptions to supply chains affected 2000 locations worldwide and caused factories to need as much as 22 to 29 weeks to return to full production capacity (Zaczyk, 2018). The high level of sensitivity of the fish processing sector supply chains, combined with a lack of focus on building resilience, may lead to disruptions in the continuity of basic supply chain processes, and thus to the failure to achieve the set objectives or, in less drastic cases, to their achievement to a lesser extent (Zhao et al., 2023). Resilience is one of the key elements influencing the competitiveness of the supply chain (Dubey et al., 2023). Supply chain resilience should be analyzed from the perspective of a total loss of operational capacity, but in the case of spectacular natural disasters or technical failures, where there is a problem with delivery to the end customer (Ozdemir et al., 2022; Choi et al., 2023).

Choi et al. determined that actions are possible through close cooperation with suppliers, which will enable the creation of buffer solutions, just-in-time segmentation, and increased visibility of resources in the supply chain, including those in transit (SYME, 2024). The transmission of disruptions means the emergence of negative risk effects in an increasing number of entities in the supply chain, which is a result of their mutual cooperation, and the channels of transmission of disruptions are determined by the relationships between entities. Preventing the transmission of disruptions and preventing them from amplifying in the supply chain therefore means modeling the cooperation between entities in these structures.

3. Methods

In 2020, there were 785 companies in Poland involved in the processing and preservation of fish and fishery products, which was an increase of 10.56% compared to 2019, where the decline to 2018 was 4.44%. Fish processing is mainly concentrated in the coastal belt – the West Pomeranian Province (184), Pomeranian Province (214) and Warmian-Masurian Province (35). In the following years, a decline was recorded: 652 entities in 2021, 645 in 2022, and 641 entities at the end of 2023, employing 18,831 people (SYME, 2024). According to data from the Central Statistical Office, however, these dozen or so large plants employed 67% of all workers in the sector and generated 69% of the industry's sales value. Approximately 45% of the plants are located in two coastal provinces. The vast majority (77%) were entities employing up to 9 employees (443 entities), and only 9% (54 entities) were large companies with more than 49 employees (including 9 with more than 249 employees). According to the ownership criterion, domestic capital clearly prevails, with only 28 entities characterized by exclusive foreign ownership and an additional 8 with a predominance of this source of financing. However, these entities are crucial for the sector, as they account for approx. 60% of revenues and employment. Most entities operate as sole proprietorships (231), followed by limited liability companies (182) and civil law partnerships (113). Only 8 entities are joint-stock companies. At the end of June 2024, the number of entities in the REGON register was 569 (9 fewer than in the same period of the previous year).

Breakdown of fish product manufacturing:

- frozen sea fish and fillets,
- salted fillets,
- smoked fillets,
- fresh or chilled sea fish fillets,
- fish fillets in breadcrumbs or batter,
- preserved, marinated or pickled fish and fish products.

Table 1.
Production of fish products in the period 2020-2023

| Specification | 2020 | 2021 | 2022 | 2023 |
|--|-------|-------|-------|-------|
| Frozen & chilled fish (including fillets) | 80.7 | 95.8 | 86.1 | 127.8 |
| Salted fillets | 15.3 | 15.7 | 17.9 | 16.9 |
| Smoked fish (including fillets) | 98.0 | 113.0 | 104.0 | 103.1 |
| Filets of marine fish, fresh or chilled | 113.4 | 102.9 | 97.0 | 99.3 |
| Fish fillets in breadcrumbs, including fish fingers | 12.0 | 15.6 | 12.9 | 14.1 |
| Fish and fish preparations, tinned, pickled and preserved | 189.5 | 159.6 | 171.7 | 166.6 |

In the first half of 2024, the production of fish and fish products in medium and large fish processing plants (with more than 49 employees) amounted to 269,600 tons and was 5.9% higher than in the previous year. The increase in production was mainly recorded in the range of frozen meat (by 39.7%), smoked fish (by 27.5%, including salmon by 35.2%) and fresh or chilled fillets (by 11.5%). The production of processed and canned products decreased by 1.4%, with a decline in the supply of marinades (by 10.0%) and canned and preserved products (by 1.9%), while there was a significant increase in products such as delicatessen and culinary products, salads, spreads, fish sticks and fish spreads (by 7.3%). The production of processed and preserved salmon decreased by 7.1%, and that of herring by 5.0% (Drożdż, Hryszko, 2024).

Table 2.
Exports and imports of fish and shellfish by the combined nomenclature (CN) in thousand tonnes

| Specification | 2020 | 2021 | 2022 | 2023 |
|---------------|--------|--------|--------|--------|
| Export | 214.16 | 234.71 | 224.74 | 210.94 |
| Import | 562.00 | 600.73 | 559.08 | 582.23 |

China remains the world's largest producer of fish and other aquatic organisms (catches and aquaculture, including aquatic plants), followed by Indonesia (9.9%), India (7.1%), Vietnam (3.9%), Peru (2.5%) and Russia (2.4%). With a turnover of approximately USD 3.5 billion in both imports and exports, Poland ranked 15th and 16th in the global ranking in 2023.

This study focuses on analyzing and assessing the impact of the COVID-19 pandemic on the production of fish products. The following stages were identified as part of the research process:

- Stage 1 – analysis of international literature on supply chains, with particular emphasis on the fishing industry.

- Stage 2 – identification of research methodology, including research gaps, hypotheses, selection of research tools, and research sample.
- Stage 3 – validation of the research tool.
- Stage 4 – conducting qualitative research using an opinion poll based on a proprietary survey questionnaire.
- Stage 5 – analysis, evaluation, and modeling of the obtained data.

An important element of the research was to identify disruptions in the fish sector supply chain in Poland and their attributes in the supply chain. The aim was to identify which elements affect the resilience of the supply chain and to develop an appropriate resilience framework in the context of the COVID-19 pandemic and future data analysis, e.g., the impact of military actions between Ukraine and Russia. The cognitive process involving the analysis of literature and statistical data allows us to conclude that, despite the growing interest in supply chains, there is still no significant data relating to the fish sector in the context of logistical disruptions. This has identified a research gap regarding the functioning of fish processing supply chains in terms of supply and distribution logistics in emergency situations and during prolonged disruptions. This is particularly important from the point of view of maintaining the resilience, safety, and continuity of cold supply chains for products that quickly lose their safety date for use and consumption. It is worth noting that the analytical research conducted on resilient supply chains is scattered and, to date, only a small segment of resilience related issues has been addressed, with individual cases indicating disruptions to a stable network. Therefore, the lack of adequate quantitative research led to the formulation of the following research question: To what extent did the COVID-19 pandemic affect the production of fish products? In order to achieve this goal, the main research hypothesis was formulated:

COVID-19 had a negative impact on the production of fish products.

The following auxiliary hypotheses were also put forward:

- H1. Disruptions in the supply chain of raw materials occurred on the supply side regardless of the distance of the source of supply.
- H2. Disruptions in the supply chain to customers occurred among all fish product manufacturers in Poland.
- H3. There was a change in inventory levels in the surveyed fish processing companies.

To confirm the correct identification of the research methodology, a survey was conducted on five entities (fish processing) located in the Central Pomeranian region in the first quarter of 2022. As part of the evaluation and analysis of the survey data, weighted averages of the variables were indicated: new forms of sales (0.15), market position (0.07), delay/expedited order fulfillment (0.23), cooperation with industry players (0.15), company operations (0.2), growth potential (0.15), and quality of cooperation with suppliers (0.05) were identified, which allowed, in the final stage, to build scenarios (models) for assessing the impact of variables on the proper functioning of supply chains according to the balanced impact index $BII = \text{weight} \times (\text{rating} - 3 (\text{neutral}))$, where the rating of variables according to Likert: 1 – very negative impact,

2 – negative impact, 3 – no impact, 4 – moderate impact, 5 – very high impact, were defined as: 1-2 = BII negative (negative impact), 3 = BII = 0 (neutral), 4-5 = BII positive (positive impact).

The main elements of the research methodology defined in this way allowed for the appropriate selection of the method of obtaining primary data. The sample selection was purposive, as the authors decided to study fish processing entities and obtained their results using a diagnostic survey conducted via questionnaire in 2022-2023 in the West Pomeranian and Pomeranian provinces. The survey was sent to 96 entities, but 41 companies participated in the study: micro-enterprises accounted for 31.71%, small enterprises for 17.07%, medium-sized enterprises for 26.83%, and large enterprises for 24.39%, which constituted a representative research sample (6.4% of all fish processing enterprises). In terms of ownership, 4.88% were joint-stock companies, 41.46% were limited liability companies, 31.7% were sole proprietorships, 17.07% were general partnerships, and the remaining 4.89% were other types of companies. The research results obtained were evaluated, allowing for an assessment of the strength and direction of the impact of variables (BII) on the creation of scenario variants (models): current state, positive (after ad hoc changes), and target.

4. Results and Discussion

During the Covid-19 pandemic, 65.85% of companies reported disruptions in the supply of raw materials and only 34.15% did not feel the effects of the pandemic in terms of supply chain logistics. Figure 1 shows disruptions in the supply of raw materials across the country.

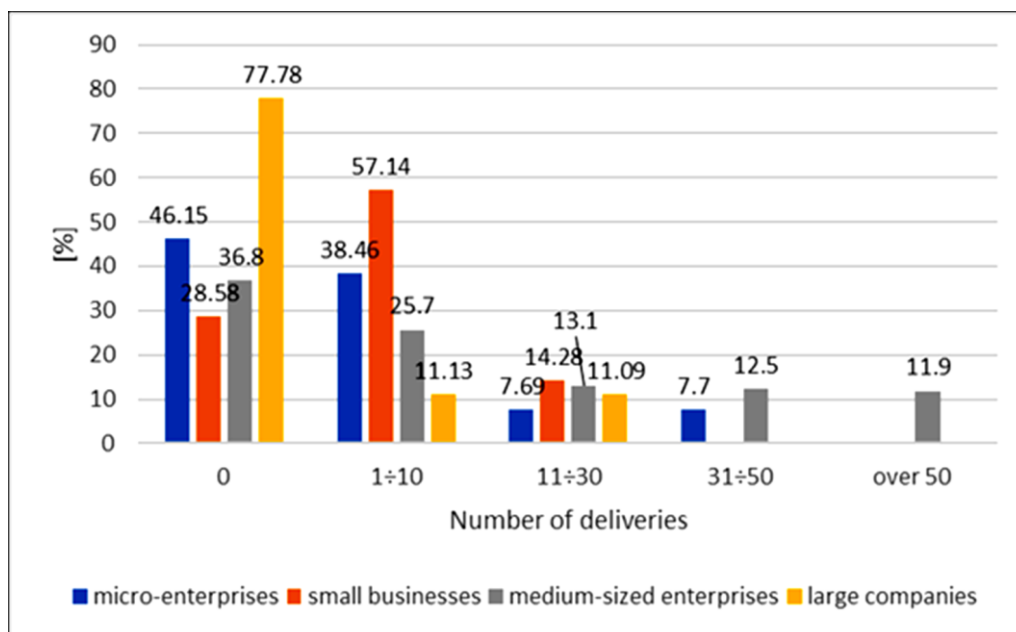


Figure 1. Disruptions in the supply of raw materials and other materials during the Covid-19 pandemic.

Above 30 deliveries, 24.4% were recorded by medium-sized enterprises, small companies with up to 10 deliveries recorded as much as 57.14%, and micro-enterprises in the same range recorded 38.46%. Large companies only recorded delivery delays of 22.22% in the range up to 30 deliveries. Figure 2 shows supply disruptions in the reference period for raw materials and materials from the European Union.

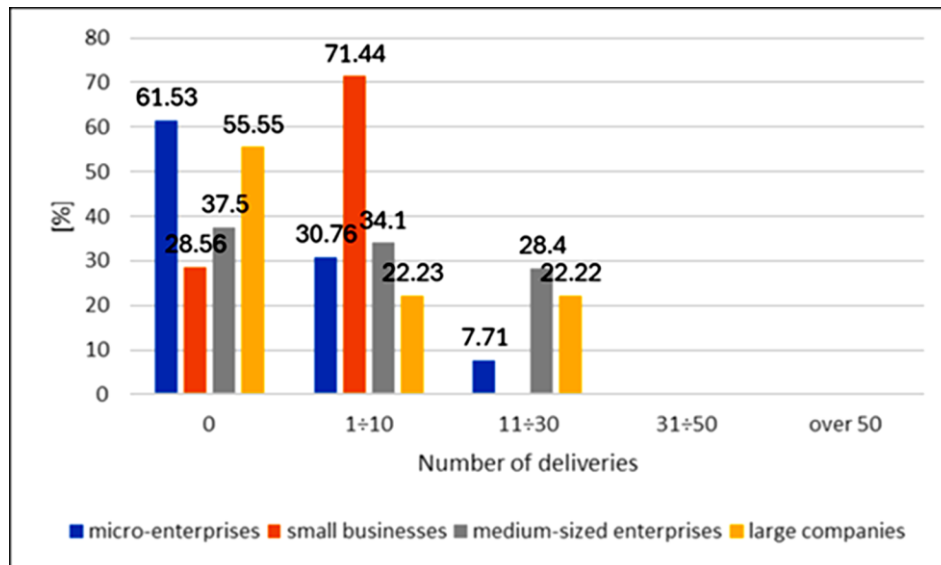


Figure 2. Disruptions in the supply of raw materials and materials during the Covid-19 pandemic from the EU.

Small enterprises in 71.44% had problems with up to 10 deliveries of raw materials and supplies during the pandemic. Micro-enterprises reported 30.76% of delayed deliveries up to 10 and 7.71% in the range above 30. Medium-sized companies in 62.5% reported delays from within the EU. Large enterprises in 55.5% had no problems with deliveries. Figure 3 shows disruptions in the supply of raw materials and supplies from outside the EU, mainly from China.

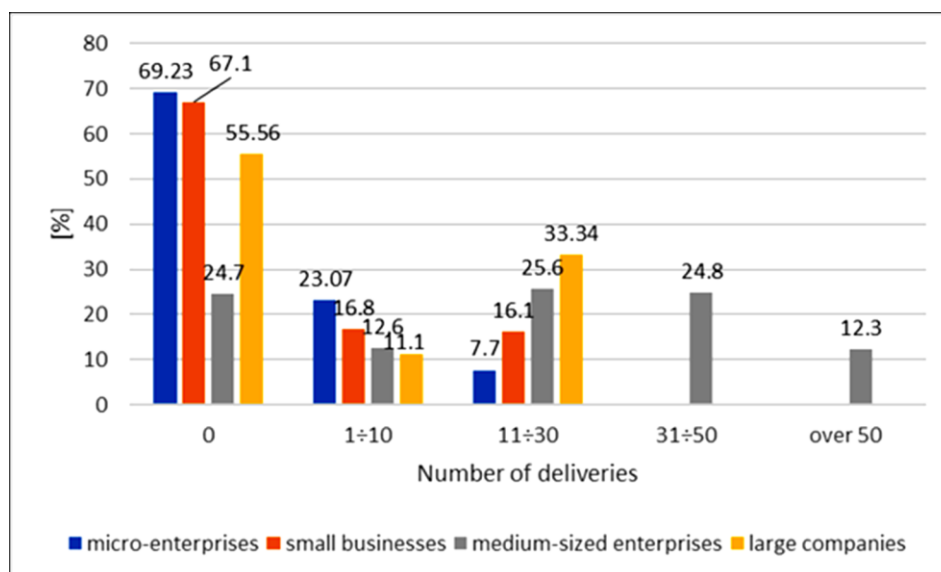


Figure 3. Disruptions in the supply of raw materials and materials from outside the EU during the Covid-19 pandemic.

Micro-enterprises in 30.17% had problems with raw material supplies, while small companies in 32.9% reported delays. Medium-sized enterprises had the most problems with raw material supplies, with as many as 37.1% reporting more than 30 deliveries, and 38.2% reporting disruptions in up to 30 deliveries. Delayed deliveries in large companies accounted for 44.44%.

When analyzing deliveries from the distribution logistics side, 43.9% of companies experienced delays to customers. Figure 4 shows the problems with deliveries to domestic customers.

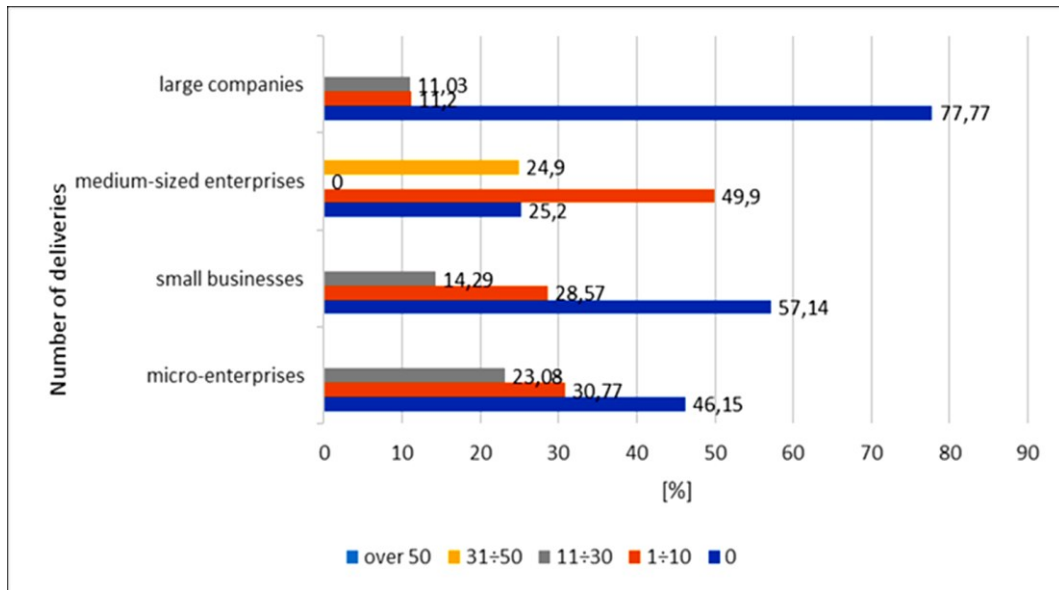


Figure 4. Disrupted deliveries of finished products during the Covid-19 pandemic in the country.

Micro-enterprises in 53.85% had problems with deliveries to their customers. Small enterprises in 42.86% of cases failed to deliver finished products to customers on time. Medium-sized enterprises reported the greatest disruptions in the supply of fish products, with 74.8% of deliveries to domestic customers affected. Large fish processing companies on the domestic market delivered 77.77% of their orders without any problems. Figure 5 shows disrupted deliveries of finished products within the European Union.

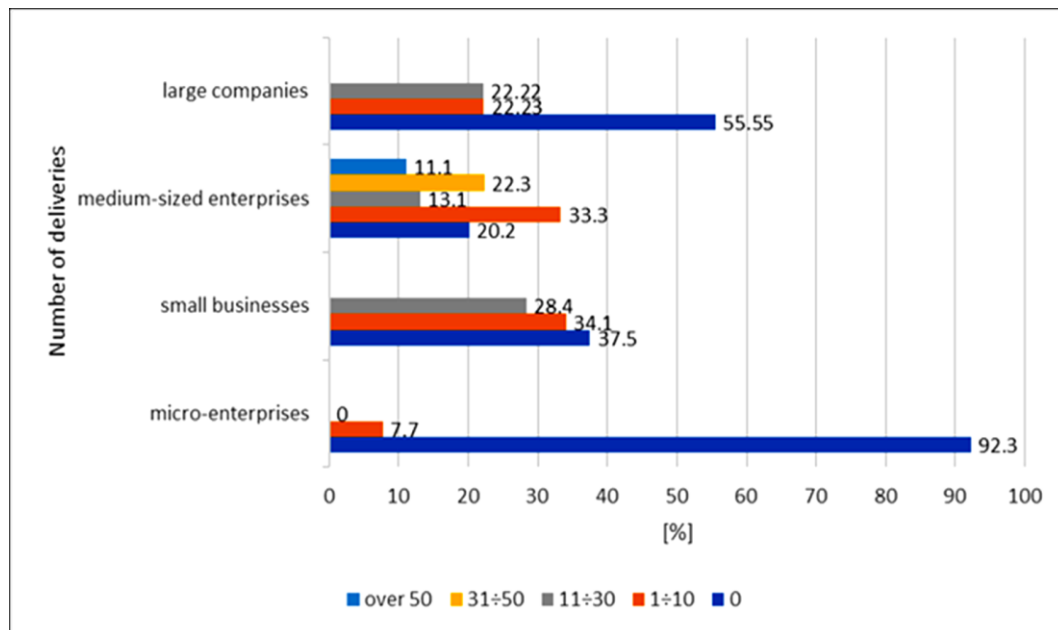


Figure 5. Disruptions Disrupted supplies of fish products in the EU during the Covid-19 pandemic.

Micro-enterprises delivered on time in practically 92.3% of cases, while small enterprises had problems with deliveries of their products in 62.5% of cases. Medium-sized enterprises recorded as many as 79.8%, and 11.1% made more than 50 deliveries to a single recipient. Large enterprises delivered their products late in 44.45% of cases. Figure 6 shows deliveries of fish products by companies operating in Poland to customers outside the EU, mainly to customers in the United States.

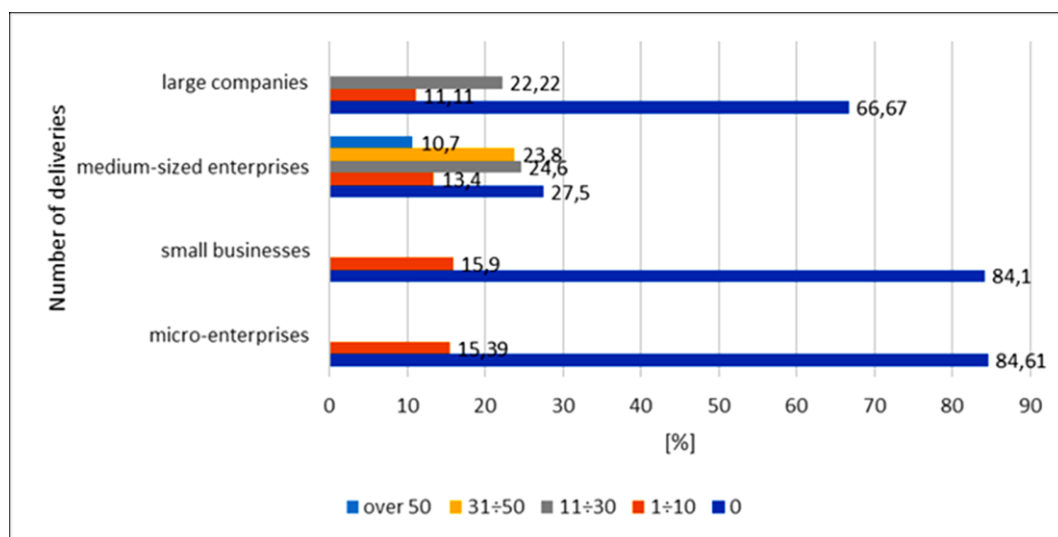


Figure 6. Timeliness of fish product deliveries to customers outside the EU.

Micro and small enterprises reported approximately 15% of disruptions in the delivery of their products. Medium-sized fish processing enterprises reported as many as 72.5% of disruptions, with 10.7% of deliveries delayed by more than 50 deliveries. Large enterprises delivered fish products on time to 66.67% of customers outside the EU, with delays accounting for 33.33%. The Covid-19 pandemic has caused changes in the operating model of many fish

processing companies. Figure 7 presents an analysis of micro-enterprises. Rating 1 – very negative impact, 2 – negative impact, 3 – no impact, 4 – moderate impact, 5 – very high impact.

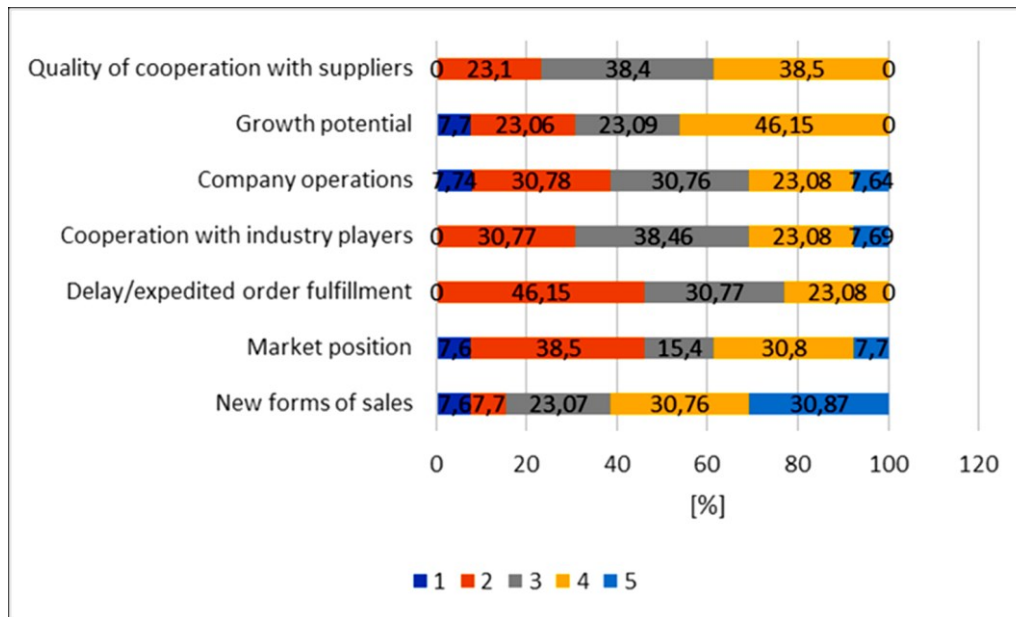


Figure 7. Impact of the Covid-19 pandemic on the functioning of micro-enterprises during the Covid-19 pandemic.

In the case of micro-enterprises, it had a positive impact on their development (30.87%). In 46.15% of cases, it affected their position on the local market, and 38.5% of micro-enterprises changed their form of sales to online sales. It had a negative impact on supply and distribution disruptions and the functioning of the company, as well as on cooperation with entities from the industry in 30.77% of cases. Figure 8 shows the impact of the Covid pandemic on changes in the functioning of small fish processing companies.

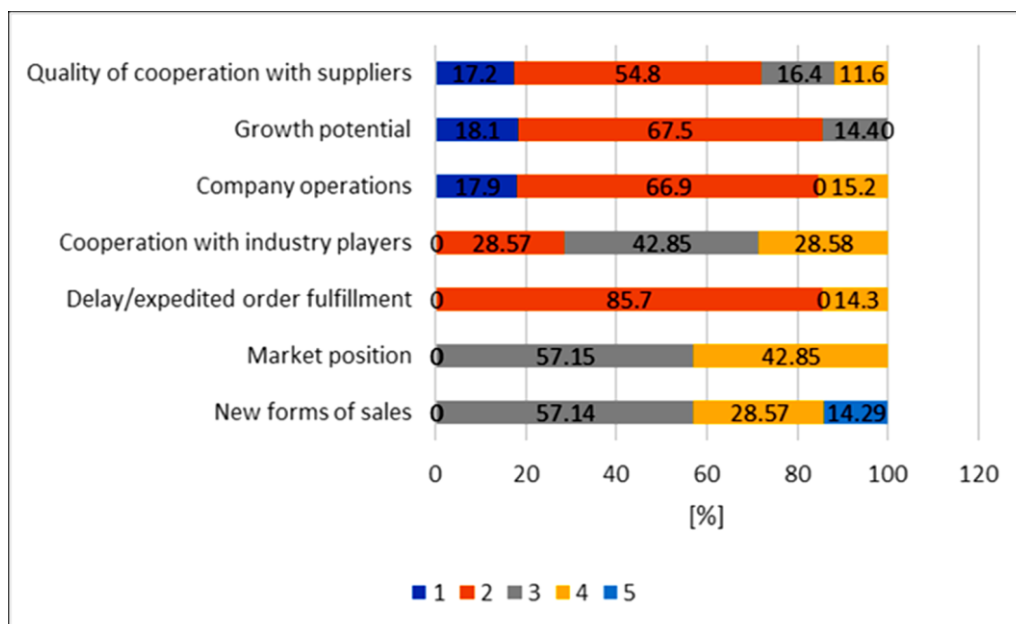


Figure 8. Impact of the Covid-19 pandemic on the functioning of small enterprises during the Covid-19 pandemic.

Small fish processing companies did not feel the impact of the Covid-19 pandemic on their market position (57.15%) or on the implementation of new forms of sales (57.14%), but 42.86% implemented changes in their sales. Delivery delays in 85.7% of cases had a negative impact on the quality of cooperation with suppliers (72%), development opportunities (85.6%) and disruptions in the functioning of the company (84.5%). Figure 9 shows the impact of the Covid pandemic on changes in the functioning of medium-sized fish processing companies.

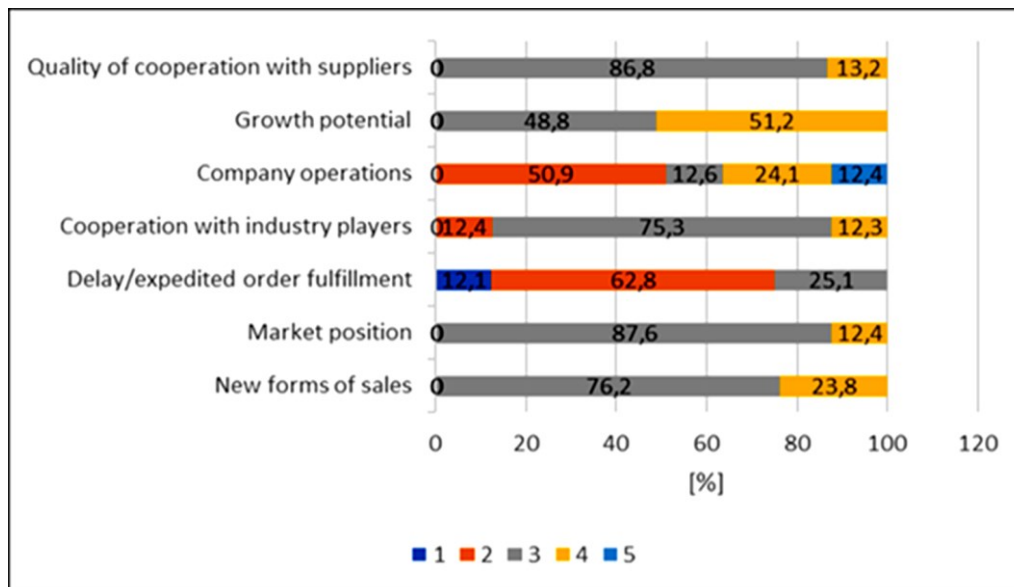


Figure 9. Impact of the Covid-19 pandemic on the functioning of medium-sized enterprises during the Covid-19 pandemic.

The COVID-19 pandemic had no impact on medium-sized enterprises in terms of the quality of cooperation with suppliers, new forms of sales, market positions (48.8%) and cooperation with entities from the fish industry. In 51.2% of cases, medium-sized companies stated that it had a positive impact on their market positions and in 36.5% on cooperation with entities from the fish industry. Figure 10 shows the impact of the Covid pandemic on changes in the functioning of large companies in the fish processing sector.

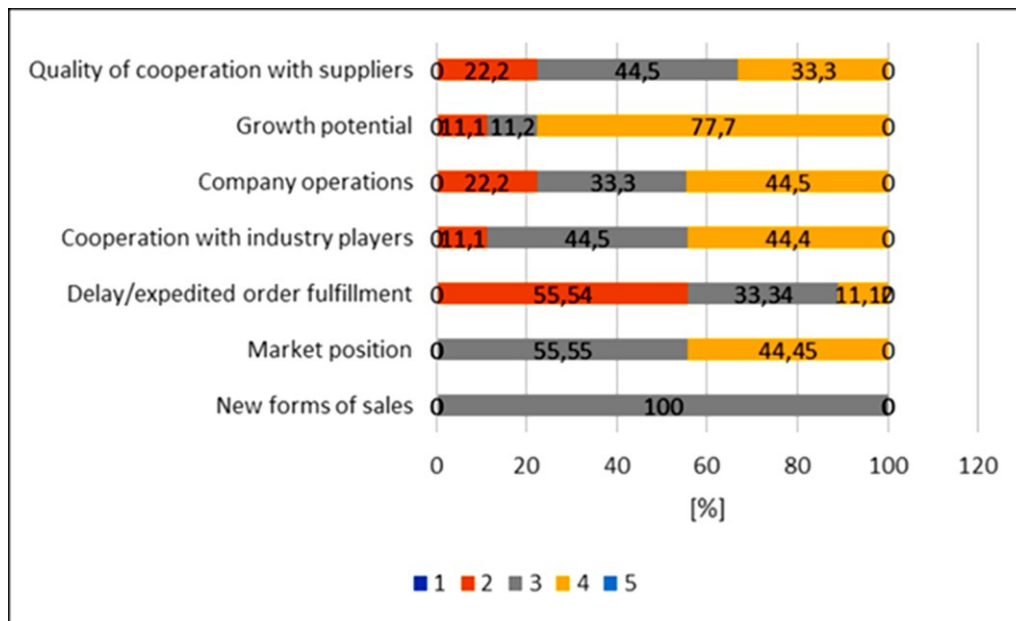


Figure 10. Impact of the Covid-19 pandemic on the functioning of large enterprises during the Covid-19 pandemic.

Large enterprises affected by the Covid-19 pandemic did not change their sales methods, assessed their growth opportunities positively (77.7%), strengthened their market position, improved their operations and cooperation with suppliers.

The analysis of the variables influencing the impact of the Covid-19 pandemic on the functioning of entities is the result of the functioning of fish processing supply chains in terms of supply logistics and distribution in situations of long-term disruptions. This allowed us to develop three scenario variants.

The first, identifying the current state, indicates a negative balanced impact index that arose suddenly and unexpectedly (Covid-19), as evidenced by the variables:

1. New forms of sales / -0.3 / strong negative.
2. Market position / -0.07 / neutral.
3. Delay/expedited order fulfillment / 0.46 / strong positive.
4. Cooperation with industry players / -0.15 / medium negative.
5. Company operations / 0.2 / medium positive.
6. Growth potential / -0.15 / medium negative.
7. Quality of cooperation with suppliers / -0.1 / neutral.

Data analysis indicates that two variables strongly determine the current functioning of supply chains and organizations. Almost all the others (except for neutral ones) have a negative impact on the current operations of organizations. It should be noted that new forms of sales have a strong negative impact, as in the current situation, changing to an untested, unprepared form of sales may increase costs and bring no benefits.

The second variant, presenting dependent variables that have a small but positive impact on the balanced impact indicator ($BII > 0$, i.e., 0.49), results from ad hoc changes in the management of the organization, i.e., changes in short supply chains (or short periods), increased stockpiling, sourcing goods from new sources, etc., after the pandemic was confirmed to be continuing and developing. The variables were assigned the following values:

1. New forms of sales / 0 / neutral.
2. Market position / -0.07 / neutral.
3. Delay/expedited order fulfillment / 0.46 / strong positive.
4. Cooperation with industry players / 0 / neutral.
5. Company operations / 0.2 / medium positive.
6. Growth potential / 0 / neutral.
7. Quality of cooperation with suppliers / -0.1 / neutral.

In the second scenario, despite delays in deliveries from fish processing companies, there are negative changes in market position and the quality of cooperation with suppliers.

The third scenario, generated for the purposes of the disruptions in supply chains that do not guarantee, among other things, the security and continuity of operations of entities, is the target variant. This is the variant that all entities under study should strive for in this particular situation. In the target variant, the variables positively shape a balanced impact index at the level of $BII = 1.07$, with the following variable values:

1. New forms of sales / 0.3 / strong positive.
2. Market position / 0.07 / neutral.
3. Delay/expedited order fulfillment / 0 / neutral.
4. Cooperation with industry players / 0.15 / medium positive.
5. Company operations / 0.4 / strong positive.
6. Growth potential / 0.15 / medium positive.
7. Quality of cooperation with suppliers / 0 / neutral.

Data analysis indicates that organizations should focus primarily on those variables that achieved the highest growth between variants 1 and 3, as they represent growth potential. In the case of delivery delays in the first scenario, new forms of sales have a strongly negative impact. In the case of the third scenario, the change will be due to the absence of negative options, the very positive functioning of the company, and new forms of sales.

Figure 11 is presented for a better presentation of the development of variants and dependent variables.

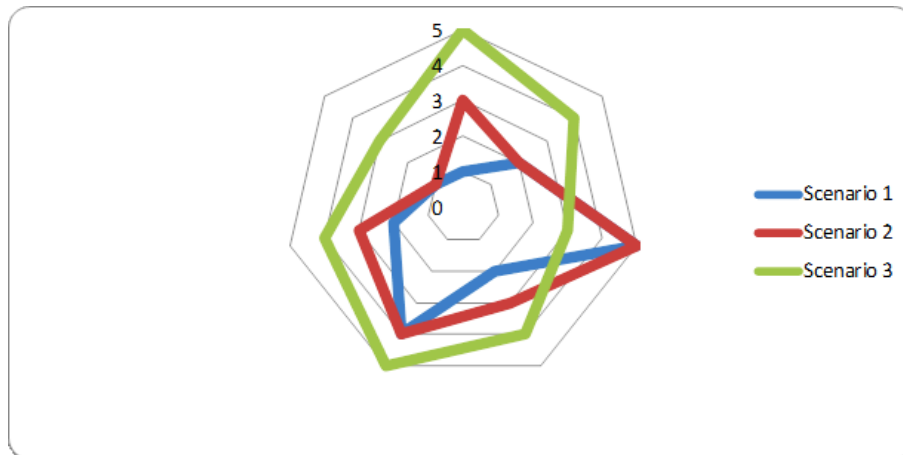


Figure 11. Comparison of impact assessment scenarios (provide data labels).

Analysis of the figure indicates that the best scenario for the companies surveyed would be option 3, which is also confirmed by the BII, in which new forms of sales are caused by the entry of e-commerce into the market, increasing the number of distribution channels. The changes may affect the functioning of companies in the fish processing industry.

5. Discussion and Conclusions

The processing of fish products constitutes a significant part of the food sector. Research on fish product supply chains has been conducted by researchers from various academic institutions and focuses on the implementation of new blockchain and IoT technologies (Ismail et al., 2023). Other authors characterize global supply chains in the fishing industry as an extensive network of artisanal fishermen, small-scale fish farmers, processors, exporters, importers, and wholesalers, including various distribution channels (Cromwell et al., 2025). The authors publish articles on the need to integrate tracking practices into fisheries improvement projects, where they highlight the importance of ensuring that companies operating in the global fisheries supply chain adhere to responsible sourcing policies (Rahman et al., 2021). Due to the pandemic, the fisheries sector has significantly expanded controls to ensure food safety (Jamwal, Phulia, 2021). The research findings presented in the article highlight changes in supply chains within Polish fish processing companies, a topic previously absent from both Polish and international publications. Although the research provides important information on the impact of the COVID-19 pandemic on the fish processing industry, several limitations can be identified:

- The analysis focuses primarily on the pandemic period and a brief comparison with the pre-pandemic situation. It lacks a long-term perspective that would allow for an assessment of the sustainability of the observed changes.

- Regional differences (e.g., access to ports and logistics infrastructure) that may significantly impact the operations of companies in the fish processing sector were not taken into account.
- The classification into small, medium, and large companies does not account for other important factors, such as the level of vertical integration, supplier diversification, or the degree of automation.
- Increases in inventory or delays in deliveries have direct financial consequences, which were not explored in depth due to a lack of information on the subject.

The research provides significant insights into the functioning of the fish processing sector. It confirms the high vulnerability of supply chains, and even the globally developed fish industry has proven susceptible to disruptions, regardless of the distance from raw material sources. Companies in the sector under study have begun to increase their inventory levels, marking a shift away from just-in-time models toward greater resilience. Medium and large companies have been particularly hard hit, which may be due to the larger scale of their operations and more complex supply chains.

The research findings are significant not only for the fish processing sector but also, more broadly, for the entire food industry, and they contribute to the development of resilient supply chains. The research reflects the growing importance of building resilient and flexible supply chains, which is crucial in the context of global crises. Problems with the availability of raw materials highlight the need to diversify supply sources and strengthen domestic production capacity in the fish processing sector.

For over a decade, the fish processing industry has been considered one of the fastest growing sectors of the food industry in Poland. It also plays a significant role in supplying the European Union market with fish products. However, there are many threats to its continued operation, which lie both in the fish and seafood market itself and in its environment. The current problems facing the domestic fish processing industry have very diverse origins, e.g. problems with raw material supplies, which were already apparent before accession to the EU and now seem to be decisive for the survival and continuity of many businesses. As the study shows, the COVID-19 pandemic has significantly affected the behavior of fish processing companies in terms of raw material purchases and deliveries to customers compared to the pre-pandemic period.

COVID-19 had a negative impact on the production of fish products due to significant delays in the supply of raw materials to fish processing companies. There were disruptions in the supply chain of raw materials regardless of the distance of the source of supply, with medium and large companies being particularly affected. All groups of fish processing companies experienced delays in deliveries of finished products to customers, prompting companies to increase their stocks on the supply and distribution side. Future studies should take into account changes in supply chains on the supply and distribution side under the influence of subsequent crises and the changes developed in response to them.

Fish processing companies should strive for scenario three (BII 3), as there are no negative aspects and there are significant changes in supply and distribution logistics, which directly affect the company's functioning on the market.

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