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Unlocking the Potential of Organic Aquaculture in the EU: A Review of Policy Support and Supporting and Constraining Factors

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ABSTRACT

Organic aquaculture remains a niche market within the European Union (EU), despite Europe being one of the regions where it receives most attention. This study aimed to identify the factors limiting its growth by (i) reviewing EU and national policies on organic aquaculture within the Farm-to-Fork strategy context and (ii) examining the supporting/constraining factors influencing organic aquaculture in the EU. Results showed that while EU policy support has increased over time, national implementation remains constrained. Organic aquaculture is incorporated in aquaculture multi-annual strategic plans, but its development is less delineated than conventional sustainable aquaculture, and the same applies to national operational programmes. Globally, there is a need for enhancement in the configuration and execution of organic support, involving all sector actors. Secondly, a literature review identified key impact factors that were categorised as supporting or constraining and analysed quantitatively. Consumer demand for organic aquaculture products appears to be increasing, which could stimulate sector growth. However, significant barriers persist, including price differences between organic and conventional products for consumers, lack of consumer awareness about organic practices/product added-value, and the perceived feasibility of organic aquaculture by farmers. This latter is linked to other constraining factors, such as the high costs and limited availability of organic inputs and complex bureaucracy. To overcome these barriers, the sector requires targeted marketing strategies, financial incentives (both addressed to farmers and consumers), streamlined regulations, and increased research funding to drive innovation. The study also offers insights into the species-specific constraints faced by key farmed species.

1 | Introduction

Within the specific domain of organic aquaculture, the overarching objective is to cultivate ecologically integrated systems that conserve natural environments, bolster biodiversity, adhere to high animal welfare standards, and yield high-quality and nutritious products [1]. Conventional production methods currently in use are facing a number of challenges, including policy obstacles [2], high levels of mortality in animals, associated issues of animal welfare, and environmental pollution resulting

from feed residues [3–5]. This has led to a growing demand for more sustainable aquaculture practices, despite the fact that European aquaculture is overall more sustainable than that in other geographical areas [6]. Moreover, Europe is still highly dependent on imports to cover the seafood demand [7]. In this context, organic aquaculture emerges as a promising strategy for the future advancement of the aquaculture sector [8–12], alongside the development of other sustainable aquaculture productions. Promoting sustainable aquaculture, including organic aquaculture, is a key component of prominent initiatives like the Farm-to-Fork strategy and the European Green Deal [13]. The Farm-to-Fork strategy targets 25% of agricultural land to be designated as organic by 2030, alongside a substantial increase in organic aquaculture.

Displaying a 51% share of worldwide fisheries and aquaculture production in 2022 (excluding plants), aquaculture is the fastest-growing food-producing industry on a global scale [14]. Nevertheless, with 510,050 t produced in 2023 [15] compared to 94.4 million tonnes produced by conventional aquaculture in 2022 [14], organic aquaculture is still a small market. China leads global organic aquaculture production, followed by European nations [15, 16]. Over time, organic aquaculture in Europe has grown from accounting for 3.3% of total aquaculture production in 2012 to 6.4% in 2020 (74,032 t) [16]. The most recent European Market Observatory report for fisheries and aquaculture products [16] states that mussel farming is the primary source of organic aquaculture production in the European Union (EU), with 41,936 t (representing 10% of the EU mussel production), followed by Atlantic salmon (*Salmo salar*; 12,870 t; 75% of the EU Atlantic salmon production), rainbow trout (*Oncorhynchus mykiss*; 4590 t; 2% of the EU rainbow trout production), common carp (*Cyprinus carpio*; 3562 t representing 4% of the EU carp production), oysters (3228 t; 3% of the EU oyster production), and European seabass/gilthead seabream (*Dicentrarchus labrax* and *Sparus aurata*; 2750 t representing 2% of the EU production of these two species). With an output of 18,512 tons, or 47.9% of the total organic aquaculture production, Ireland is the leading producer of organic aquaculture products in the EU. Ireland is followed by Italy, France, and the Netherlands, which display organic production volumes ranging from 5000 to 10,000 t [16]. Despite a steady growth in recent years with a substantial 60% rise from 2015 to 2020, European organic aquaculture's development trajectory is not enough to achieve the EU's Farm-to-Fork Strategy's objective of a major increase in organic aquaculture production by 2030 [17].

From a policy perspective, the practice of organic farming has received support from individual countries since the 1980s and EU-wide since the 1990s [18]. In the last decade, a policy supporting the development of organic aquaculture has been incorporated into the Common Fisheries Policy (CFP) [19], especially in the 2014–2020 and 2021–2027 programming periods. However, despite increasing political support, there is a lack of clarity regarding the adequacy of support provided to foster the growth of the organic aquaculture sector, both at the European and national levels.

Since its inception, the organic aquaculture industry has faced numerous obstacles, such as legislative limitations related to environmental, health, and quality standards. Technical obstacles in the production process have also been highlighted, such as complying with organic regulations for reproduction and incurring additional feed costs. The growth of European organic aquaculture has also been hampered by the lower profitability of organic aquaculture, the low market demand for its products, and competition from other certification programs [11, 16, 20, 21]. Although previous studies have identified various constraining and supporting factors in the literature, some being cited above, there is currently no comprehensive global assessment from which to draw conclusions from the last decades of research at the European level. Such a review would provide a valuable basis for identifying drivers and bottlenecks to facilitate the sustainable development of the organic aquaculture sector and ultimately achieve the goals outlined in the Farm-to-Fork strategy.

The present study had two primary objectives. First, we assessed the evolution of support policies for organic aquaculture over time in the context of the EU's Farm to Fork objectives at both the European and national levels, focusing on a subset of nine selected countries. Second, we looked into the factors that either support or hinder the growth of European organic aquaculture by conducting a quantitative systematic review of the literature. The analysis placed particular emphasis on the most commonly farmed species, including both freshwater and marine species, namely: Atlantic salmon, rainbow trout, common carp, European sea bass, gilthead seabream, and shellfish. This comprehensive overview is essential in identifying the strengths and weaknesses of organic aquaculture from policy, farmer, and market perspectives, thereby facilitating the further development of organic aquaculture in accordance with the objectives delineated in the Farm-to-Fork Strategy.

2 | Organic Aquaculture Policy Overview

The development of European support policies for organic aquaculture started comparatively later than for organic agriculture, but the last decade has seen significant progress in this area. In this study, we carried out a review of support policies for organic aquaculture under the CFP, at the European and at the national levels. The first objective of this policy review was to analyze the regulatory framework under the CFP and the EU Strategic Guidelines for the Sustainable Development of Aquaculture. We also analyzed the financial support available for the development of organic aquaculture, in particular the European Maritime and Fisheries Fund (EMFF) 2014–2020 and the European Maritime, Fisheries and Aquaculture Fund (EMFAF) 2021–2027. A review of national policies was then carried out, with a particular focus on the analysis of national multi-annual strategic plans. The review of implementation at the national level was limited to nine countries (Austria, Croatia, Denmark, France, Germany, Greece, Ireland, Italy and Spain), for which data were available and whose organic aquaculture production represents about 80% of the total European production. This analysis aimed to provide an overview of current policies for the development of the organic aquaculture sector compared to 2014–2020 and to assess how Member States have responded to the EU Commission's organic objectives in the Farm-to-Fork Strategy.

2.1 | European Policy Support

2.1.1 | Regulatory Framework: CFP And Organic Aquaculture Legislation

At European level, the CFP has provided political support for the development of organic aquaculture, particularly in the 2014–2020 and 2021–2027 programming periods. The CFP was reformed in 2013 and aims to ensure the long-term environmental, economic, and social sustainability of fisheries and aquaculture. This requires the involvement of all actors along the value chain, from authorities and consumers to all industrial actors [22]. The CFP's integration of environmental, social, and economic sustainability objectives contributed to the European Green Deal and its associated strategies. The European Green Deal further bolstered the CFP approach by underscoring the pivotal contributions of fisheries and aquaculture to the economy and employment in coastal regions, ensuring food security within the European Union, and safeguarding the marine environment [22]. The Farm-to-Fork approach thus recognizes the close relationship between people's well-being, thriving communities, and the planet's health. It further emphasizes the imperative to ensure the livelihoods of primary producers in facilitating the transition of the EU's food system towards sustainability. While the Farm-to-Fork strategy has set specific targets for organic aquaculture (i.e., substantial augmentation in organic aquaculture), the CFP promotes organic aquaculture indirectly through its broader objectives of supporting sustainable practices that align with the goals of organic aquaculture production.

In this context, the CFP offers a range of tools designed to enhance the appeal of careers in fisheries and aquaculture and to promote sustainable aquaculture, encompassing organic aquaculture. The CFP's strategy includes the promotion of producer organisations, the provision of vocational training programmes, the enhancement of labour rights, and the encouragement of digital transformation in the workplace. The CFP also aims to bridge technological gaps through research and the promotion of technological innovation [22, 23]. The support for organic aquaculture is also reflected in the Strategic Guidelines for the Sustainable Development of EU Aquaculture (see Section 2.1.2) adopted by the EU in 2013 [24] and 2021 [25], which served as a basis for member states to define national goals in their multi-annual strategic plans. Member States have been encouraged, also in the context of the EU Organic Action Plan 2021–2030 under the European Green Deal, to incorporate the expansion of organic aquaculture as an objective within their revised multi-annual national strategic plans for aquaculture (see Section 2.2). In addition, the EU budget provides significant financial support (e.g., European Maritime Fisheries and Aquaculture Fund [EMFAF], Community-Led Local Development funding) to increase the overall resilience of the aquaculture sector (European Commission, 2023b; see Section 2.1.3). Overall, as a result, the policy framework for the support of organic production in the EU has been strengthened in the CFP for the period 2021–2027. The functioning of the CFP was evaluated in 2023 in order to identify achievements, delays in implementation and efforts that are still needed to reach full potential [22]. The evaluation concluded that the CFP remains an adequate legal framework, but that various challenges impede its full implementation, necessitating a faster and more structural transformation. Consequently, an extensive stakeholder consultation was initiated to propose future directions for fisheries and aquaculture policies within the framework of a 'Pact for fisheries and oceans' [22]. Additionally, a public consultation was launched in January 2025 to gather concerns, ideas and opinions on the effectiveness of the CFP.

Beyond the CFP, the governance of organic aquaculture in Europe is currently overseen by Regulation 2018/848 [26], which establishes standards for organic production. Implemented in 2022, this regulation has repealed previous council regulations and has taken into account various recommendations made for specific organic production rules by the Expert Group for Technical advice on Organic Production [27]. This regulatory framework has two objectives: firstly, to contribute to the protection of the environment and, secondly, to promote animal welfare. The regulation established a set of guidelines pertaining to the practices of organic aquaculture production, encompassing the utilization of inputs (including feeds and juveniles), the administration of veterinary treatments, and the maintenance of husbandry conditions. Comprehensive details concerning organic aquaculture production and labeling regulations can be found in Busacca and Lembo (2019) [28]. The public authorities of each EU country are in charge of managing aquaculture and enforcing the organic regulations, with the aim of assisting producers in adhering to EU competition rules and related regulations.

2.1.2 | EU Strategic Guidelines (2013–2020 and 2021–2030)

As mentioned above, the EU strategic guidelines under the CFP are a tool to promote the development of sustainable aquaculture, including organic aquaculture. In 2013, the European Commission published the first strategic guidelines [24]. The purpose of these guidelines was to provide EU Member States and other pertinent stakeholders with a shared vision for the development of sustainable EU aquaculture. They aimed at helping Member States to define national targets. At that time, the main objectives of those guidelines were to simplify administrative procedures, secure growth of sustainable aquaculture through coordinated spatial planning, enhance competitiveness, and promote a level playing field for EU operators. The revised and updated strategic guidelines for a more competitive and sustainable EU aquaculture for the years 2021–2030 were adopted by the Commission in 2021 [25]. These guidelines emphasized several priorities, including the promotion of a competitive and resilient aquaculture sector (e.g., through a reduction in environmental impact, the integration of suitable aquaculture activities into protected areas, a focus on fish health and welfare), participation in the green transition (e.g., development of a circular economy, implementation of life-cycle approach analyses, use of sustainable feeds), fostering social acceptance, giving customers clear and accurate information about aquaculture methods and goods, and promoting innovation and knowledge growth in the aquaculture industry. The European Commission has called upon all EU Member States to ensure that the appropriate means are in place for the implementation of these guidelines and actions. Of particular note, the Commission invited EU Member States to give due consideration to the priorities outlined in these guidelines when allocating support to the sector

from both EU and national funds. The European Commission also released two documents online in April 2024 with the goal of encouraging the expansion of sustainable aquaculture in EU nations. One of the documents concerned the regulatory and administrative framework for aquaculture [29] and the other document regarded the planning of space and access to water for marine aquaculture [30]. They aimed at providing guidance on best practices for administrative procedures and for planning space and water access for freshwater, marine, and land-based aquaculture. By 2029, an evaluation of the new Strategic Guidelines will be made, assessing the guidelines' efficiency, effectiveness, coherence, relevance, and EU added value, in order to support the decision on the next steps after 2030.

Despite the emphasis on sustainable aquaculture practices, the majority of the priorities outlined in the guidelines align with organic principles, and consequently the EU Organic Regulation. The guidelines support the goals of the Farm-to-Fork Strategy, especially the significant increase in organic aquaculture and the decrease of antimicrobial sales. Additionally, they emphasize the regulatory framework for EU aquaculture and the specific legislation for organic production, which, through certification and labeling, encourage aquaculture to adhere to more rigorous production standards with regard to environmental impact and animal welfare, while also imposing limits and regulations on external inputs. Finally, the guidelines support the adoption of spatial planning policy, which should guarantee that particular areas are made available for organic aquaculture.

2.1.3 | European Funds for Fisheries and Aquaculture

Another tool to support the development of organic aquaculture is the availability of European and national funding. The European Maritime Fisheries Fund (EMFF) [31] was the financial instrument to implement the objectives of the reformed CFP between 2014 and 2020. The EMFF focused on the long-term objectives of the Europe strategy for smart, sustainable and inclusive growth for the period 2014–2020. It aimed to contribute to sustainable and competitive fisheries and aquaculture and to the balanced and inclusive territorial development of fisheries and aquaculture areas. The EMFF missions were to: (i) assist fishermen in the transition to sustainable fishing, (ii) encourage coastal communities' economic diversification, (iii) fund projects that create jobs and improve the quality of life, (iv) promote the development of sustainable aquaculture, (v) facilitate access to finance, and (vi) support the implementation of the Maritime Policy [31]. The total budget of 6.4 billion euros for the period 2014–2020 was managed and implemented by both the European Commission (11%) and Member States (89%), with the allocation of funds based on the size of each member state's fishing industry. Member states managed this fund through operational programmes which, once approved by the Commission, allowed national authorities to decide on the projects selected for funding. A common monitoring and evaluation system was set up to monitor EMFF operations financed under shared management and a technical assistance team (Fisheries and Aquaculture Monitoring and Evaluation) was made available to member states. The amount of EMFF funds committed has gradually increased over the years, as has the amount of funds actually spent by beneficiaries (Figure 1). According to the latest EMFF implementation report [32], 6 billion euros had been committed by the end of 2023 (108% of the total EMFF funds available under shared management), although there were large differences in the commitment rates between member states, with a large part of the operations supported by the EMFF concentrated in Spain and Italy (Figure 2). However, it should be noted that beneficiaries continued to receive payments from the managing authorities in 2024 and therefore the final balances will change slightly in the final EMFF report. Of the 1047 million euros allocated to the European Union's Priority 2 ('Promotion of environmentally sustainable, resource-efficient, innovative, competitive and knowledge-based aquaculture'), 112.6% has been committed, representing 20% of total commitments, of which 85% has been spent and declared by beneficiaries at the end of 2023. Looking at the EMFF operational programmes of the selected Member States (https://oceans-and-fisheries.ec.europa.eu/funding/emff-operational-programmes-2014-2020_en), European and national funds have been mobilised for the global development of sustainable aquaculture under the Union's Priority 2 in all Member States studied (Figure 3). In addition, clear support for the development of organic aquaculture can be found in the description of the operational programmes. Specific initiatives could be mentioned, such as the adoption of measures to better inform consumers about the origin of the product, such as organic production, in Austria, or the availability of subsidies for investments in organic aquaculture production facilities in Denmark. The organic aquaculture production from selected project pipelines had a target of 10,103 t, and from fully implemented projects, 65.1% of the target had been implemented (6577 t), according to the Cohesion Open Data Platform (last accessed 6 February 2025). However, it should be noted that the updating of the EMFF by Member States in relation to specific common indicators is often incomplete, which is a source of difficulty in assessing the use of funds for organic aquaculture purposes.

Building on the experience and lessons learnt from the EMFF, the EMFAF [33] was launched in 2021 for the period 2021–2027 to support the EU CFP in ensuring food security and the growth of a sustainable blue economy. This fund also contributes to achieving the objectives of the European Green Deal and the United Nations Sustainable Development Goal 14 ('Conserve and sustainably use the oceans, seas and marine resources'). This fund has a total budget of 7.9 billion euros, the majority of which is under shared management (i.e., national programmes co-funded by the EU budget and EU countries). The second priority of the fund consists in 'fostering sustainable aquaculture activities, and processing and marketing of fishery and aquaculture products, thus contributing to food security in the Union', for which 981.9 million euros have been earmarked. This priority includes two sub-objectives: '2.1 Promoting sustainable aquaculture activities, especially strengthening the competitiveness of aquaculture production, while ensuring that the activities are environmentally sustainable in the long term' and '2.2 Promoting marketing, quality and added value of fishery and aquaculture products, as well as processing of those products.' As data on the use of this fund is still limited, the results are still preliminary, but by mid-2024, a relatively small amount of the fund had been committed (17.6%) or spent (2.4%), but it has been slowly increasing over time (Figure 1), particularly in Denmark (45.7% decided, 8.6% spent), Austria (32.5%

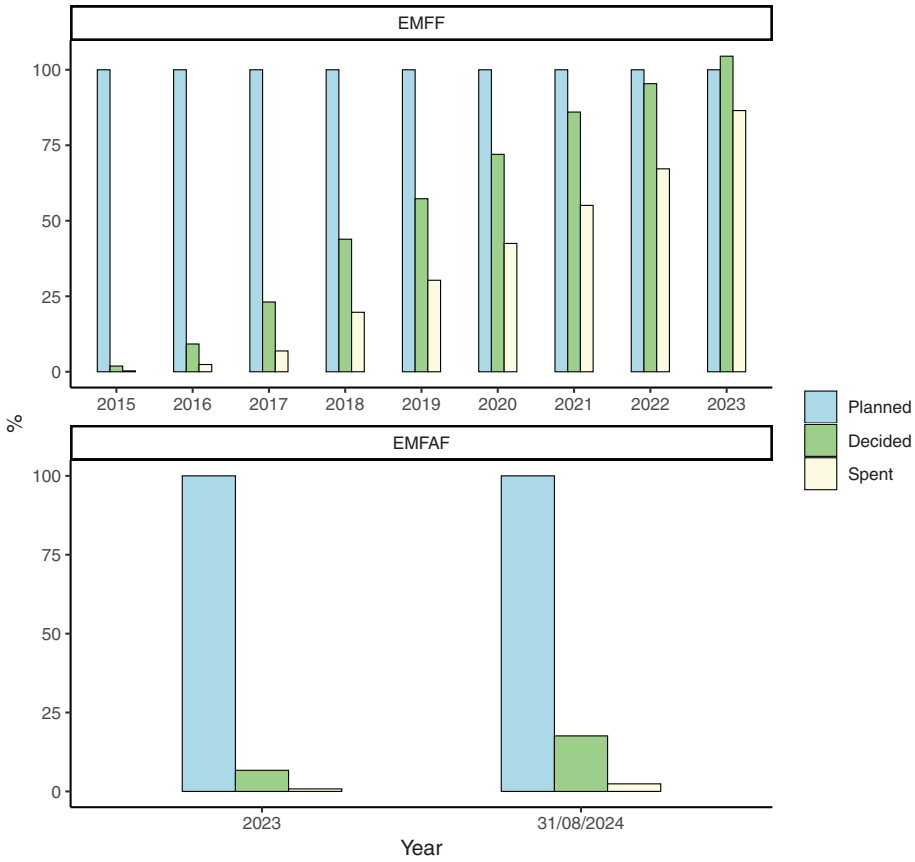

FIGURE 1 | Investment progress (share of original budget) of the EMFF (between 2015 and 2023; in euro) and EMFAF (between 2021 and 2023 and between 2021 and the August 31, 2024; in euro) funds according to three variables: The total planned investment volume including EU and national financing ('planned', in blue, in %), the total financial resources allocated to selected projects ('decided', in green; in %), and the total investment expenditure reported to the programmed managers by the selected projects ('spent', in yellow; in %). Data originate from the Cohesion Open Data Platform; https://cohesiondata.ec.europa.eu/funds/emff/14-20#finance-implementation; accessed on February 5, 2025).

decided, 11.2% spent) and Germany (32.1% decided, 9.4% spent) (Figure 2). Looking at the operational programs for the EMFA of the different Member States analysed (https://oceans-and-fisheries.ec.europa.eu/funding/emfaf-programmes-2021-2027_en), organic aquaculture is supported through the priorities set to develop a sustainable aquaculture as all member states studied allocated European and national funds to the EMFAF priority 2 (Figure 3). In addition, in some cases, there are explicit references to the development of organic aquaculture in the operational programmes. For example, the operational programmes of Austria, France, Ireland, Italy, Greece and Croatia include the objective of promoting the implementation of organic aquaculture. In addition, the Austrian and Spanish operational programmes also set the objective of raising consumer awareness of organic products and their added value, while the French, Italian, Spanish and German programmes mention support for the conversion and certification of organic production. Finally, as a last example, the French and Italian operational programmes mention support for research in organic aquaculture.

Overall, the objectives and actions to support the development of organic aquaculture, whether under the EMFF or the EMFAF, are not very detailed compared to those for the development of sustainable conventional aquaculture. Moreover, the lack of consolidated data on the specific use of these funds for specific objectives limits the assessment of the funds dedicated to the development of organic aquaculture. The absence of individual consideration of organic aquaculture within the context of these financial resources, in contrast to the manner in which it is addressed within the agricultural sector, renders the acquisition of precise data on the extent of support for organic aquaculture in the European Union a challenging endeavour. Nevertheless, the funds allocated to aquaculture in general have increased in all Member States in the EMFF 2021–2027 compared to the EMFF 2014–2020, apart from Denmark (Figure 3). The increasing support of organic aquaculture in the EMFAF operational programmes, compared to the EMFF operational programmes, appears to be in accordance with the updated Strategic Guidelines for Aquaculture, the Organic Action Plans, and the Farm-to-Fork objectives. However, it is important to note that this increase in the funds available for aquaculture development does not necessarily result in effective expenditure, as the many local authorities responsible for expenditure are not always in a position to support the development programmes and/or may be encouraged to change their expenditure priorities.

2.2 | Multi-Annual National Strategic Plans for Aquaculture and Organic Aquaculture

Within the remit of the CFP, EU Member States are obligated to formulate a multi-annual national strategic plan, which

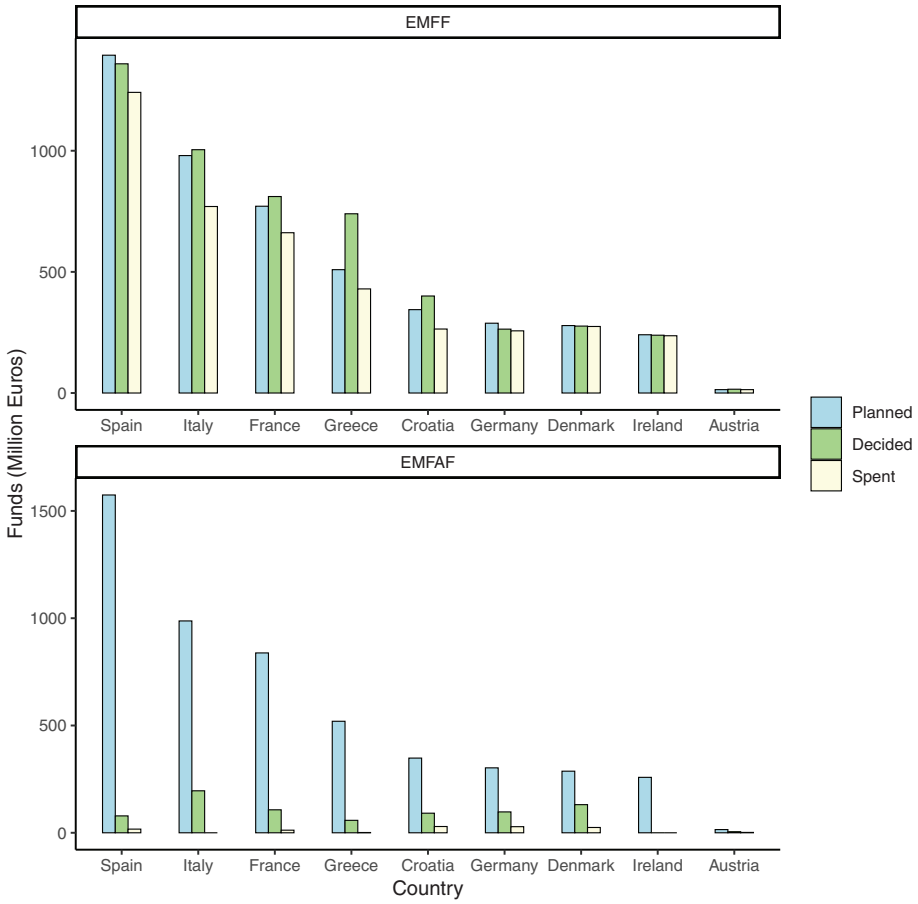

FIGURE 2 | Investment progress of the EMFF (2014–2023; in million euros) and EMFAF (between 2021 and August 2024; in million euros) funds in the nine selected countries according to three variables: The total planned investment ('planned', in blue, in million euros), the total financial resources allocated to selected projects ('decided', in green; in million euros), and the total investment expenditure reported to the programmed managers by the selected/decided projects ('spent', in yellow; in million euros). Data originate from the Cohesion Open Data Platform; https://cohesiondata.ec.europa.eu/funds/emff/14-20#finance-implementation; accessed February 6, 2025).

incorporates objectives in conjunction with the financial, administrative, and other measures to be taken to achieve the expected results. Support for organic aquaculture has been demonstrated by the European Commission encouraging Member States to include the development of organic aquaculture among the objectives of their revised 2021–2027 national strategic plans for aquaculture. We here examined the support for organic aquaculture in the Multi-Annual Plans of Austria, Croatia, Denmark, France, Germany, Greece, Ireland, Italy, and Spain, covering the periods 2014–2020 and 2021–2027. A potential limitation of the analysis is the restriction to documents available in the respective countries' official languages. In some cases, the translation process performed using the DeepL tool may not have adequately captured the meaning of the texts.

Looking at the period 2014–2020, specific references to organic aquaculture were made in the different multi-annual national strategic plans (Table 1), except for Croatia and Germany, although concrete measures are poorly developed. Measures specific to organic aquaculture appear more detailed in the 2021–2027 multi-annual action plans compared to those relative to the 2014–2020 period (Table 1). This discrepancy is particularly evident in the case of Croatia, where references to organic aquaculture appeared in the 2021–2030 action plans. Furthermore, a considerable increase in the number of measures that are explicitly aimed at organic aquaculture is evident in the 2021–2030 plans of member states, for instance in Denmark and Ireland (Table 1). This suggests a potential escalating emphasis on the advancement of organic aquaculture among member states. However, a general observation of the Multi-Annual National Aquaculture Plans of the countries under scrutiny is that the analysis of the status of organic aquaculture is globally underdeveloped. This is evident in the limited emphasis placed on identifying objectives and activities that promote the development of organic aquaculture when contrasted with the considerable resources allocated to the analysis and promotion of key actions for the development of sustainable conventional aquaculture. Despite the European Commission's 2021 adoption of the new strategic guidelines for the sustainable development of European aquaculture, which assign greater priority to organic aquaculture, the analysis of national aquaculture plans indicates that countries are paying more attention to other forms of sustainability. It is noteworthy that two of the multi-annual national plans analysed, namely Denmark and Ireland, explicitly called for a review of certain aspects of the prevailing regulation on organic aquaculture in their current multi-annual national strategic action plans (Table 1).

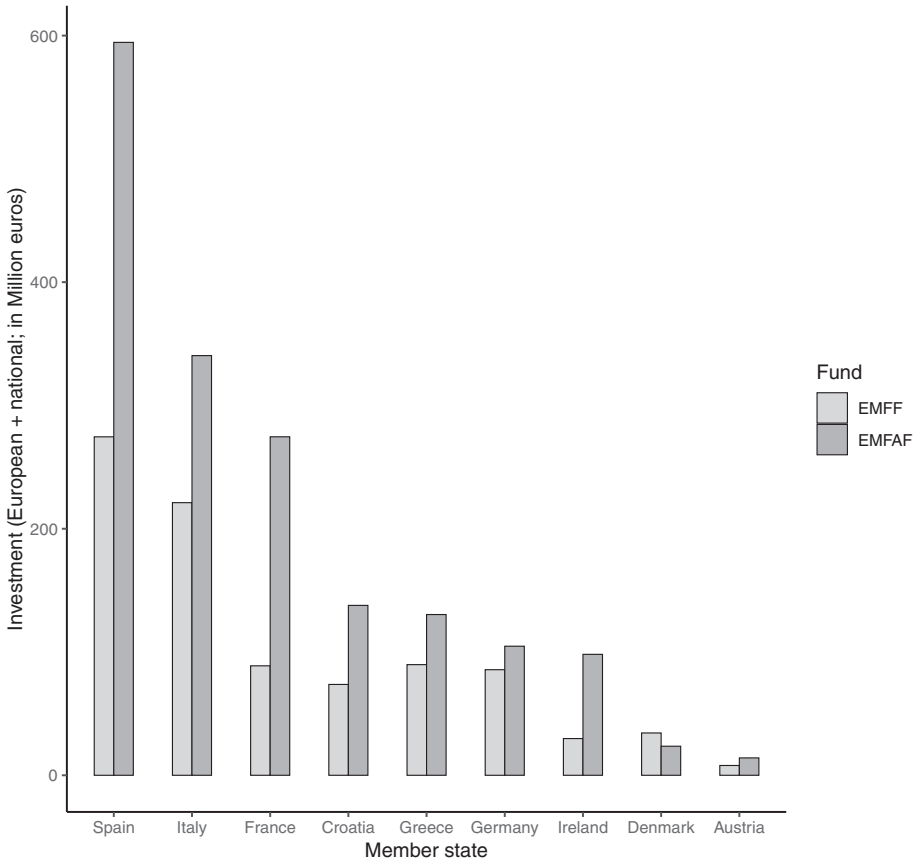

FIGURE 3 | Total investment (European and national contributions; in million euros) planned for the development of sustainable aquaculture under the EMFF (2014–2020, under the European Union's Priority 2—'Promotion of environmentally sustainable, resource-efficient, innovative, competitive and knowledge-based aquaculture'; in light grey) and the EMFAF (2021–2027, under the Priority 2—'Fostering sustainable aquaculture activities, and processing and marketing of fishery and aquaculture products, thus contributing to food security in the Union'; in dark grey) per member state. Data for the EMFF were extracted from the factsheets of the EMFF operational programmes of each Member State (https://oceans-and-fisheries.ec.europa.eu/funding/emff-operational-programmes-2014-2020_en). Data for EMFAF were extracted from the Cohesion Open Data Platform (https://cohesiondata.ec.europa.eu/d/hgyj-gyin/visualization; last accessed on February 7, 2025).

3 | Review of Constraining and Supporting Factors for the Organic Aquaculture Development

In this section, a quantitative systematic literature review was carried out with the aim of identifying and analyzing the factors that either constrain or enable the development of European organic aquaculture. The study focuses in particular on the species most farmed in European organic aquaculture, including both freshwater and marine species, namely Atlantic salmon, rainbow trout, common carp, European sea bass, gilthead seabream, and shellfish.

3.1 | Methodology

3.1.1 | Data Collection

The overall search strategy was based on the PRISMA protocol (http://www.prisma-statement.org/). Due to the limited number of documents available on organic aquaculture, our search strategy was deliberately designed to be inclusive, ensuring the incorporation of all relevant literature on the subject, including both peer-reviewed articles and grey literature. Specific search terms were used in Web of Science (WoS, Clarivate Analytics, PA, USA, TS = ('organic aquacultur*')) and in Scopus (TITLE-ABS-KEY('organic aquacultur*')) and queries were made in early 2023. The search conducted on WoS yielded 77 documents, while the Scopus search resulted in 93 documents (Figure 4; Appendix S1). From the initial pool of 170 documents identified in WoS and Scopus, duplicates were removed, resulting in a total of 101 unique documents (Figure 4). These documents were then screened for eligibility, resulting in the exclusion of 44 documents due to non-English language, inaccessibility (i.e., only abstracts available) or lack of relevant data (Appendix S1). This process resulted in a total of 57 peer-reviewed documents. In addition, 11 relevant documents known to the authors but not included in the initial search were added, and seven were kept after analysis, resulting in a selection of 64 documents (Figure 4; Appendix S1).

In addition, a manual search was conducted using the EU platform Cordis, Google, and the EUMOFA website to identify relevant grey literature. This supplementary search yielded 12 pertinent documents for inclusion (out of 14 analysed): six deliverables from the FP7 research project OrAqua (2014–2016; https://www.oraqua.eu/), two deliverables from the H2020 project FutureEUAqua (2018–2023; https://futureeuaqua.eu/), two reports from EUMOFA, one position paper from the Federation

TABLE 1 | References to organic aquaculture in the 2014–2020 and 2021–2027 national strategic plans for aquaculture of targeted countries (data extracted from the Multi-annual National Strategic Plans of each targeted country; https://aquaculture.ec.europa.eu/country-information).

Country	2014–2020 multiannual national strategic plans	2021–2027 multiannual national strategic plans
Austria	Achievement of a satisfactory standard in the domain of quality production, encompassing the production of organic fish.	'It is important that novel technologies are developed and promoted in the domains of production, processing and marketing, with a particular emphasis on organic production. It is stated as essential to allocate additional financial resources to the management of organic ponds. Finally, it is specified a need to expand organic production'.
Croatia	No reference on organic aquaculture was reported	'Growth of organic aquaculture is required. Increased use of better practices and management systems is necessary, in accordance with public and private quality standards and certification schemes, particularly those for organic food. Development of new products offering higher added value in aquaculture should also be encouraged. Activities contributing to the development of organic aquaculture will also be supported, extending from conventional to organic production and eco-schemes. Finally, increased investment in local value-added products that meet public and/or private quality standards is also recommended, including designations of origin and organic products, and investment in local farm-to-fork initiatives with creative/productive partnerships between producers, tourism organizations and restaurants'.
Denmark	Aim for up to 10% of seafood production to be organic by 2020. Prioritised investment in organic production.	'The Strategy for a Sustainable Aquaculture Sector 2021–2027 is based on six benchmarks, four of which include specific actions for organic aquaculture. **Benchmark 3**: Need for the development of organic aquaculture despite challenges posed by EU organic rules and for the improvement of consumer awareness of organic aquaculture. Grants will be available for investments in climate solutions and purification technology to reduce the aquaculture sector's climate footprint and emissions to the surrounding environment and for development projects, including in organic aquaculture. Work will be made to change EU rules for organic aquaculture on to allow greater use of technological solutions in production. **Benchmark 4:** Need for research, development and innovation in organic production **Benchmark 5:** Need for marketing campaigns for new products such as organic aquaculture products. **Benchmark 6:** Need for better knowledge on organic production and animal welfare in fish farming'.
France	It was recommended that investments be made to facilitate the transition to organic aquaculture. It was also advised that support measures be consolidated through the provision of environmental services, with a particular focus on organic aquaculture. It was further recommended that all initiatives aimed at improving the image of aquaculture products whose origin and quality are guaranteed, including organic aquaculture, be supported. The organization of technical routes for obtaining quality labels or organic aquaculture labels was also suggested to be encouraged.	'The promotion of the production of quality-labelled products is of paramount importance. For instance, meals served in collective catering and in all establishments entrusted with a public service mission must include 50% quality and sustainable products, of which at least 20% must be organic, as of January, 1, 2022. The promotion of French aquaculture products that meet consumer demand is also crucial, through the development of official quality labels, environmental certification and organic production. The implementation of compensation for conversion from conventional to organic production in fish farming is to be supported. Investments in organic aquaculture production are to be supported. Investments in collective projects to improve the quality of coastal waters by developing organic shellfish farming are to be supported'.

(Continues)

TABLE 1 | (Continued)

Country	2014–2020 multiannual national strategic plans	2021–2027 multiannual national strategic plans
Germany	No reference on organic aquaculture was reported	'The National Strategic Plan for Aquaculture in Germany 2021/2030 makes only a limited reference to organic aquaculture. According to the Strategic Plan, the concept of certified organic aquaculture is currently only considered by a small percentage of consumers as a viable alternative to conventional products, and this segment of the market only accounts for a very small share of the aquaculture product sector in Germany. In this context, the Strategy proposes a series of initiatives to foster greater consumer acceptance of organic aquaculture. Chief among these is the implementation of 'transparent production' models, complemented by comprehensive consumer education efforts, including the implementation of advertising campaigns. In this regard, it is evident that a reorientation of current strategies is necessary, with the existing strategies requiring a comprehensive review and possible revision to achieve the desired outcomes. One of the strategies that is poised to assume an even more pivotal role in the future is the consistent labelling of local products regarding their origin and form of production (organic)'.
Greece	The introduction of organic aquaculture methods and the conversion of conventional aquaculture production to organic aquaculture were supported.	'The Greek Multi-Annual National Strategic Plan for the Development of Aquaculture (2021–2030) makes only a minor reference to organic aquaculture. It has been reported that the multi-annual plan will provide support for organic (biological) aquaculture and other systems with an even lower environmental footprint, such as recycled water systems and integrated multi-trophic systems'.
Ireland	Action 3 'Promotion of organic aquaculture practices and certification'. Significant support for the development of organic aquaculture was also foreseen through Action 5 'Foster knowledge, innovation and technology transfer' and Action 8 'Support best husbandry and disease management practice'.	'The National Strategic Plan for the Sustainable Development of Aquaculture 2030 identifies as a key activity the improvement of transparency and traceability of organic products using digital tools. Irish aquaculture should continue to move towards organic seafood production where possible, meeting the highest standards available to EU producers and in line with Ireland's objectives to increase organic production under the Organic Strategy. In conjunction with the National Strategic Plan for the Sustainable Development of Aquaculture 2030, other actions have been taken under the current Irish Organic Action Plan 2019–2025: promoting organic aquaculture products in new and existing markets, exploring the potential for Irish organic mussels in export markets, organising technical seminars to improve producers' knowledge of organic systems and legislation, highlighting the need for organic feed and feed ingredients and exploring the potential for Irish sources of organic feed, identifying and securing sources of organic juveniles and ova. Finally, research endeavours into the application of principles of organic agriculture to aquaculture have identified that a significant proportion of these principles, which pertain to soil-based agriculture, necessitate further consideration to ensure their applicability to aquatic systems'.

(Continues)

TABLE 1 | (Continued)

Country	2014–2020 multiannual national strategic plans	2021–2027 multiannual national strategic plans
Italy	It was seen as imperative to promote initiatives that foster the development of highly environmentally friendly aquaculture. This encompasses various forms of multitrophic aquaculture and organic aquaculture. Conversion of conventional aquaculture production methods to organic aquaculture was also to be promoted.	'The promotion and support of the creation and development of sustainable aquaculture systems is of paramount importance, with a particular emphasis on those systems that provide environmental services, including through support for organic certification. A higher priority is to be given to actions for the mitigation of environmental impacts, through the creation and/or modernisation of aquaculture systems with reduced greenhouse gas production and with CO_2 sequestration functions. In order to priorities such actions, companies that have obtained or are pursuing sustainability certifications (e.g., organic certification) will be rewarded. Furthermore, the promotion and encouragement of the adoption of sustainable, highly eco-compatible production models by aquaculture farms is to be encouraged, with the aim of offering environmental services based on the efficient use of resources, thereby improving the environmental performance of production activities (e.g., organic certification). Finally, support is to be given for the conversion of conventional aquaculture production methods towards organic aquaculture'.
Spain	The promotion of organic aquaculture was to be achieved by the provision of financial assistance to facilitate the transition from conventional aquaculture production methods to organic aquaculture methods.	"The plan is intended to encourage the development of a more sustainable and efficient aquaculture industry, thereby contributing to the preservation of the environment. The utilisation of optimal practices will be promoted in domains such as energy or water consumption, or the exploration of innovative feeding methods that are less intensive in the use of fish meal/oil, as well as the promotion of practices that are more environmentally responsible, including organic production. The development of shellfish farms that are certified as organic will also be encouraged. Furthermore, studies on organic aquaculture will be promoted'.

of European Aquaculture Producers, and one scientific report from the Organic Eprints repository (Appendix S1). Furthermore, some grey literature documents, provided by national partners, were retrieved in their respective national languages and translated into English using the DeepL tool (Appendix S1). Six documents were kept (out of seven analysed), bringing the final number of documents analysed to 82 (Figure 4; Appendix S1).

3.1.2 | Definition of Impacts Factors

In this study, we defined 28 different impact factors (IFs) that can either support or constrain the development of organic aquaculture in the EU (Table 2). These IFs were conceptualised to capture the interplay between farmers and the institutional environment, based on Michelsen's [34] framework, which views society as consisting of three key components: the state (based on political authority), the market (based on economic competition) and civil society (based on civil solidarity within families and social groups). We have further delineated distinctions between societal levels, with society as a whole representing the macro level, individual farmers operating at the micro level, and organizations operating at the meso or sectoral level mediating interactions between the macro and micro levels. Within this framework, civil society represents the farming community domain, the state represents the aquaculture policy domain, and the food market represents its own domain. Organizations within the farming community domain typically revolve around farmers' solidarity and serve to organise their interests, including training, extension services, and advocacy for organic farming. The aquaculture policy domain involves interactions between public authorities and farmers through regulations and support schemes. In the food market domain, farmers interact with companies that demand different food products for processing and marketing. Each IF was assigned to a specific level (micro, meso or macro), system element (e.g., farming community, food market, aquaculture policy and civil society), subsystem element (e.g., farmers, research and development, processors and/or retailers, consumers, policy action/support, environment and international organic markets), and its connection with other system elements (Table 2; Appendix S1). As can be seen in Table 2, some factors appear in both the constraining and enabling categories. This does not imply contradictory impacts, but rather suggests that these factors can operate in opposite directions depending on the context and circumstances. They should not be considered as solely constraining or solely enabling. Their effect depends on the prevailing conditions.

Each mention of the different IFs was extracted from the 82 documents and categorised as supporting or constraining. In addition, each IF was categorised into one of the following three subcategories based on the content of the document: (i) 'Supporting/Constraining but insufficient' (i.e., when the authors did not explicitly refer to the IF as supporting/constraining but it was implicit, when there was a specific caveat mentioned by the authors

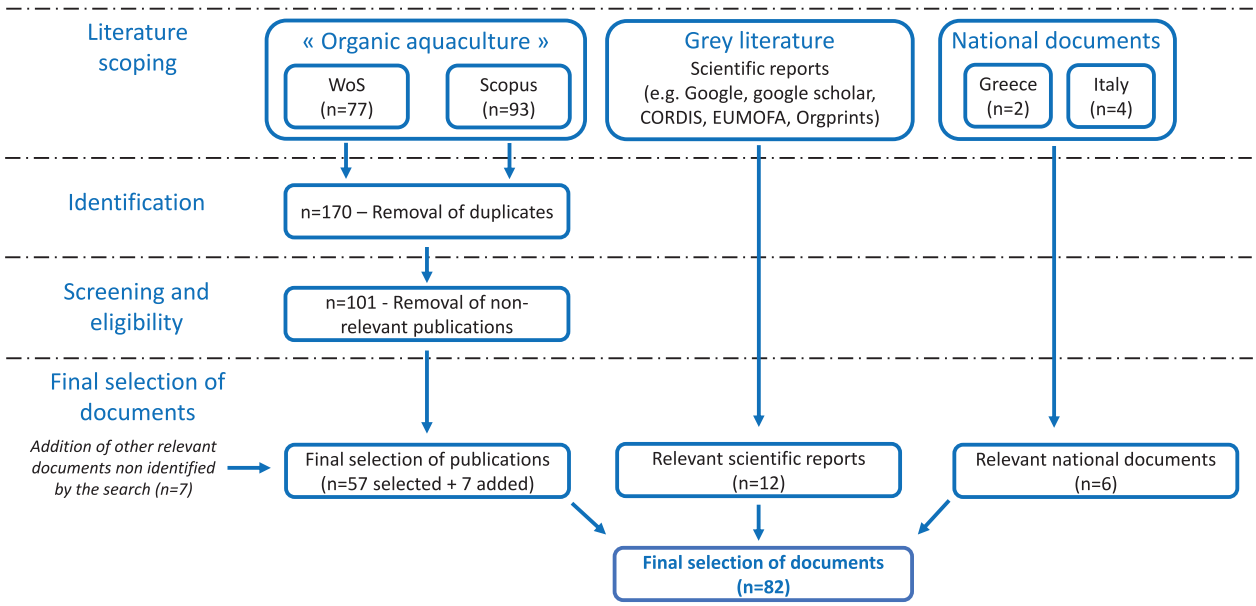

FIGURE 4 | Selection of documents for the systematic literature review according to the PRISMA diagram.

in relation to the IF, or when the support for the IF in the paper was considered to be low), (ii) 'Supporting/Constraining' (i.e., where the authors explicitly identified the IF as supportive or constraining), or (iii) 'very supportive/constraining' (i.e., where the authors explicitly identified the IF as a major supportive or constraining factor for the development of organic aquaculture). For each IF, additional data were collected from all documents for several variables: geographic region (Africa, Asia, Europe, North America, Oceania, or South America), specific country, aquaculture type (e.g., freshwater or marine), species group (fish, shellfish), species, and time period (1990–1999, 2000–2009 or 2010-present). If data for a given variable were not specified in the document, it was coded as 'not specified'. The countries considered as part of Europe are the EU-27, Norway and the United Kingdom. Norway was included in the analysis because it is part of the European Economic Area, and the United Kingdom was retained because it was part of the EU for most of the data collection period. For each document, if the IF was mentioned several times, it was only retrieved once at the highest level mentioned (e.g., very supportive > supportive > supportive but insufficient). If the IF was mentioned twice in the document, but in relation to different monitored variables (e.g., different regions or species), it was retrieved twice, specifically in relation to one or other of the variables mentioned. For example, if the IF referred to a constraining factor for the development of organic aquaculture for both Europe and Asia, it was coded twice as a constraining factor for each geographical region. Each document was first reviewed by a single co-author to minimise technical variability in the interpretation of results. Subsequently, each IF assignment was performed by two co-authors. Any discrepancies in classification were resolved by consensus between the two readers. The final table of all collected data used for data analysis is provided in Appendix S1.

3.1.3 | Data Management and Quantitative Analysis

Following the collection of all IFs, data management and quantitative analysis was carried out using R 4.3.1 [35]. First, the dataset was examined at a global level to obtain a comprehensive overview including all literature and to identify regions and species for which sufficient data were available. Based on this initial overview, two quantitative analyses were performed at the European level to analyses the IFs at different levels: (1) at the European level, aggregating all species, and (2) at the European level, by major farmed species. One specific IF, namely 'Harmonisation/diversity of certification standards' ($n = 12$ mentions), was excluded from the European level analyses due to its obsolescence following recent changes in European organic aquaculture regulations. For species-specific analyses within Europe, separate analyses were carried out for each major farmed species: Atlantic salmon, common carp, rainbow trout, European sea bass/seabream and shellfish (mussels and oysters). Sea bass and seabream were analysed together due to similarities in farming practices and highlighted IFs. Similarly, IFs related to oyster and mussel farming were analysed together as a shellfish group due to similarities in farming practices and a relatively low number of IFs.

3.2 | Review Results

3.2.1 | Global Overview: Literature at the World Level

Among the 82 documents examined, a total of 630 IFs were retrieved. The data collection revealed a paucity of literature concerning organic aquaculture prior to 2000, with only one document available. The literature between 2000 and 2009 was also found to be relatively scarce, comprising 15 documents with a total of 56 IFs retrieved (Figure 5). However, since 2010, there has been a substantial increase in the number of publications, with 73 relevant documents retrieved, accumulating 572 IFs out of 630 (Figure 5). The majority of these documents pertain to European aquaculture, constituting 71.1% of the total dataset (54 documents) and amassing 448 IFs out of 630, followed by Asia (19 documents, 77 IFs) (Figure 5). Conversely, there were significantly fewer citations related to Africa (5 documents, 9 IFs) or

TABLE 2 | List of the different impact factors retrieved from the literature review.

Level	System element	Subsystem element	Connection with other system element(s)	Impact factor	Definition	Type
Micro level	Farming community	Farmers		Values, identities, beliefs and interest towards organic aquaculture	This IF includes the ethical, cultural and personal principles of the farmers, as well as their enthusiasm and commitment to organic aquaculture practices.	Supporting or constraining
Micro level	Farming community	Farmers		Status of knowledge, skills and advice/training related to organic aquaculture	This IF refers to the level of understanding, knowledge and practical skills of farmers involved in organic aquaculture. This could result from the provision of resources aimed at providing guidance, knowledge and skills development to farmers involved in organic aquaculture.	Supporting or constraining
Micro level	Farming community	Farmers	All	Perceived feasibility of organic aquaculture	Subjective assessment made by farmers of the practicality, feasibility and ease of adoption and implementation of organic aquaculture practices. This includes, for example, the feasibility assessment of practices (e.g., lower densities, no hormones, and feed composition)/ equipment changes (e.g., spatial separation) or the price the product can achieve given the market situation.	Supporting or constraining
Micro level	Farming community	Farmers		Group pressure and social norms among farmers	This IF encompasses the collective expectations, attitudes and behaviours within the farming community that can either encourage or discourage adherence to organic principles and practices (peer-to-peer effect).	Supporting or constraining
Micro level	Farming community	Farmers	Research & development	Applicability of social and technical innovations in organic aquaculture	It refers to the extent to which new technologies and practices developed through research and innovation efforts are suitable and effective for integration into organic aquaculture operations from the farmer's perspective (e.g., through research transfer).	Supporting or constraining

(Continues)

TABLE 2 | (Continued)

Level	System element	Subsystem element	Connection with other system element(s)	Impact factor	Definition	Type
Micro level	Farming community	Farmers		Availability and costs of organically produced inputs	This refers to the (in)accessibility and/or cost to farmers of aquaculture inputs that comply with organic regulations (e.g., animal seeds and raw materials for feed).	Supporting or constraining
Micro level	Farming community	Farmers	Processors and/or retailers	Accessibility to organic markets	This IF refers to the ease with which organic aquaculture farmers can enter, participate and effectively access markets that prioritise and demand organic aquaculture products (e.g., availability of market infrastructure and distribution channels).	Supporting or constraining
Meso level	Farming community	Research & development	Farmers	Research towards technical solutions and innovations for organic aquaculture	This IF refers to the level of research effort on the development of new methods, technologies and practices specifically designed to address the challenges related to organic aquaculture.	Supporting or constraining
Meso level	Food market	Processors and/or retailers	Consumers	Diversification of organic aquaculture products and assortments	This IF refers to the expansion of the variety of products offered to the market in order to meet market demand.	Supporting or constraining
Meso level	Food market	Consumers	Processors and/or retailers + Farmers	Price difference between organic and conventional products	This IF corresponds to the level of price difference between aquatic products produced by organic aquaculture and those produced by conventional aquaculture.	Supporting or constraining
Meso level	Food market	Farmers	Consumers + Processors and/or retailers	Supply chain relationships	This IF refers to the interconnected network of interactions and collaborations between different stakeholders within the organic aquaculture industry, including farmers, consumers, processors and retailers.	Supporting or constraining
Meso level	Food market	Consumers	Farmers	Competition and/or confusion with other labels	This IF refers to the existence of multiple labels/certifications (e.g., Friend of the Sea, Aquaculture Stewardship Council) which can lead to consumer confusion.	Constraining

(Continues)

TABLE 2 | (Continued)

Level	System element	Subsystem element	Connection with other system element(s)	Impact factor	Definition	Type
Meso level	Food market	Processors and/or retailers + Farmers	Consumers	Marketing strategies for organic products	This IF refers to the specific tactics and approaches used by farmers, processors and retailers to promote and sell organic products to consumers.	Supporting or constraining
Meso level	Food market	Farmers	Aquaculture policy	Relationship with aquaculture policy stakeholders	This IF refers to the interactions/ cooperation between farmers and regulators/policy makers.	Supporting or constraining
Meso level	Food market	Consumers		Consumer attitude and beliefs	Personal beliefs and values held by consumers regarding organic aquaculture products. This includes the influence of peer groups and prevailing societal attitudes on individuals' purchasing decisions and consumption patterns.	Supporting or constraining
Meso level	Food market	Consumers		Purchasing power/ Willingness to buy	Financial capacity and willingness to pay (e.g., premium price) for organic aquaculture products	Supporting or constraining
Meso level	Food market	Consumers	Mass media	Awareness and knowledge about organic aquaculture practices and product added value	Level of understanding and information that consumers have or receive from media or marketing campaigns about the principles, methods and benefits of organic aquaculture and the added value of organic aquaculture products.	Supporting or constraining
Meso level	Food market	Consumers		Consumer demand	Consumer willingness/interest to purchase organic aquaculture products on the market	Supporting or constraining
Meso level	Food market	Farmers	Processors and/or retailers	Accessibility to marketing campaigns	Extent to which farmers have easy access to marketing and promotional activities related to organic aquaculture products/practices	Supporting or constraining
Meso level	Food market	Consumers	Processors and/or retailers + Farmers	Accessibility to organic products	Ease of access and purchase of organic aquaculture products by consumers (e.g., distance to organic markets, availability in supermarkets/fishmongers).	Supporting or constraining

(Continues)

TABLE 2 | (Continued)

Level	System element	Subsystem element	Connection with other system element(s)	Impact factor	Definition	Type
Meso level	Food market	Farmers	Processors and/or retailers	Risks associated to low-scale production	Small-scale production faces more risks than large-scale production due to economies of scale (i.e., limited production volumes), financial vulnerability (e.g., in case of financial crisis) and market competition.	Constraining
Meso level	Aquaculture policy	Policy Action/Support	Farmers + Consumers	Availability of incentives	Refers to the availability of financial support to stakeholders to promote organic farming (e.g., eco-premiums for farmers, subsidised prices for consumers).	Supporting or constraining
Meso level	Aquaculture policy	Policy Action/Support	Farmers	Level of bureaucracy complexity and applicability of organic aquaculture rules	Level of complexity and/or applicability of regulations for organic aquaculture	Supporting or constraining
Meso level	Aquaculture policy	Policy Action/Support	Farmers	Willingness to pay certification costs	This IF refers to the costs of certification, which may exceed the available budget of farmers.	Constraining
Meso level	Aquaculture policy	Policy Action/Support	Research & development	Funding availability for organic aquaculture research and development	The availability and accessibility of financial resources to support scientific research, technological development and innovation.	Supporting or constraining
Meso level	Food market	Processors and/or retailers	Farmers + Consumers	Harmonisation/Diversity of certification standards	This IF refers to the extent of the range of criteria, rules and requirements set by different certifying bodies and organizations for organic aquaculture practices and products.	Supporting or constraining
Macro level	Civil society	Environment		Environmental benefit and ecosystem services	Positive effects or benefits of organic aquaculture on the natural environment (e.g., reduced water pollution, improved habitat conservation, increased biodiversity).	Supporting or constraining
Macro level	Civil society	Environment		Site availability for organic aquaculture development	Existence and suitability of sites where organic aquaculture can be established and operated.	Supporting or constraining
Macro level	Food market	International organic markets		Trade regulations	Rules governing international trade in organic aquaculture products.	Supporting or constraining

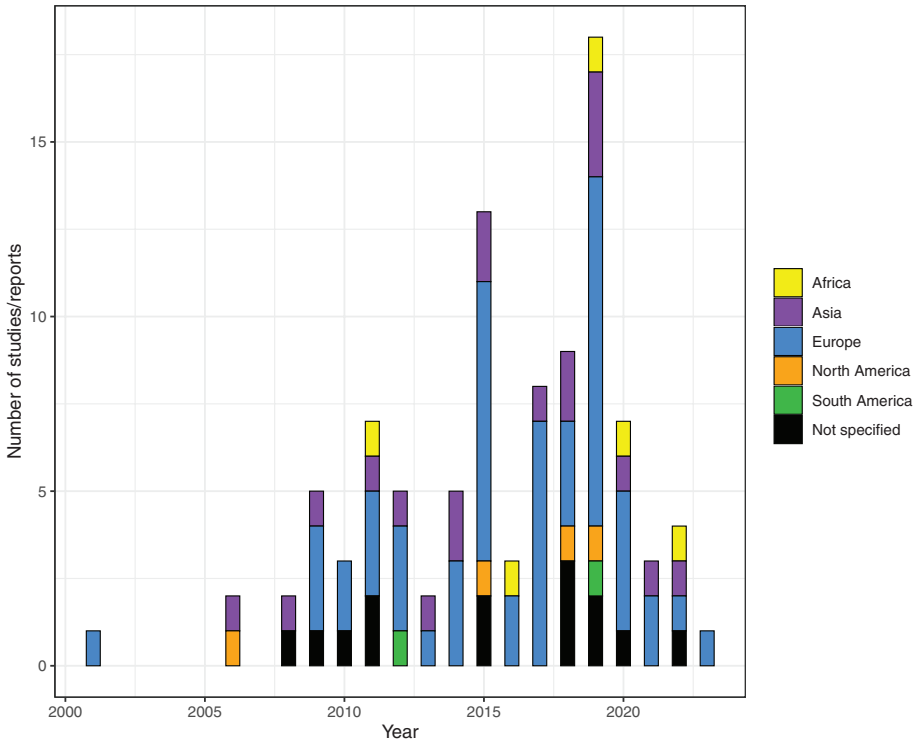

FIGURE 5 | Region focused on the different documents reviewed over the years.

North America (4 documents, 7 IFs) and South America (2 documents, 3 IFs), limiting the potential insights from these regions for the advancement of organic aquaculture. Furthermore, 86 IFs did not specify a particular geographic region. The collected documents encompassed various topics, including but not limited to reviews on the organic sector (e.g., practices, economic market, prospects, challenges in member countries and/or the EU), specific studies on consumer preferences, and innovations in practices directed toward specific species.

Of the 630 IFs retrieved, 124 pertained to freshwater aquaculture, 145 were associated with marine aquaculture, while the majority of mentions ($n = 361$) did not target a specific aquaculture sector. Within these documents, although most mentions were not directed toward a specific species group ($n = 332$) or individual species ($n = 377$), a significant portion (37.6%, $n = 237$) focused on fish farming, particularly European sea bass/gilthead seabream ($n = 92$ IFs), common carp ($n = 44$ IFs), Atlantic salmon ($n = 27$ IFs), and rainbow trout ($n = 26$ IFs) (Figure S1). Additionally, there were few mentions of Nile tilapia ($n = 2$ IFs), rohu ($n = 1$), catfish ($n = 4$), or Atlantic cod ($n = 4$) (Figure S1). Shellfish garnered 61 IFs, notably shrimps ($n = 24$) and mussels ($n = 11$), with sporadic mentions of oysters ($n = 1$), clams ($n = 1$), crab ($n = 3$), and prawns ($n = 13$) (Figure S1).

3.2.2 | Results on Factors of the Development of European Organic Aquaculture

In the documents reviewed, the primary supporting factors identified for the development of organic aquaculture in Europe were mostly within the meso-level and were 'marketing strategies for organic products' ($n = 29$), followed by 'consumer demand' ($n = 24$), 'availability of incentives' ($n = 18$), 'consumer attitude and beliefs' ($n = 18$), and 'research towards technical solutions and innovations for organic aquaculture' ($n = 18$) (Figure 6). Additionally, other significant supporting factors (with more than 10 mentions) included 'awareness and knowledge about organic aquaculture practices and product added value' ($n = 16$), 'price difference between organic and conventional products' ($n = 13$), 'environmental benefit and ecosystem services' ($n = 13$), and "purchasing power and willingness to buy' ($n = 11$) (Figure 6).

On the contrary, the five most frequently mentioned constraining factors to the development of organic aquaculture in the EU in the reviewed documents were belonging to the micro and meso levels and were the 'perceived feasibility of organic aquaculture' ($n = 31$), the 'price difference between organic and conventional products' ($n = 29$), the 'availability and costs of organically produced inputs' ($n = 22$), the 'level of bureaucratic complexity and applicability of organic aquaculture rules' ($n = 22$), and the 'awareness and knowledge about organic aquaculture practices and product added value' ($n = 20$) (Figure 7). Other significant constraining factors (with more than 10 mentions) included 'availability of incentives' ($n = 17$), 'competition and/or confusion with other labels' ($n = 15$), 'risks associated with low-scale production' ($n = 13$), and 'consumer demand' ($n = 13$) (Figure 7).

3.2.3 | Result on Specific Factors to the Key Farmed Species in the EU

Focus was placed on various species of interest for EU aquaculture: Atlantic salmon ($n = 27$), rainbow trout ($n = 26$), common carp ($n = 43$), European sea bass/gilthead seabream ($n = 89$), and shellfish ($n = 21$). It is noteworthy that for Atlantic salmon, rainbow trout, and shellfish, the number of collected IFs was

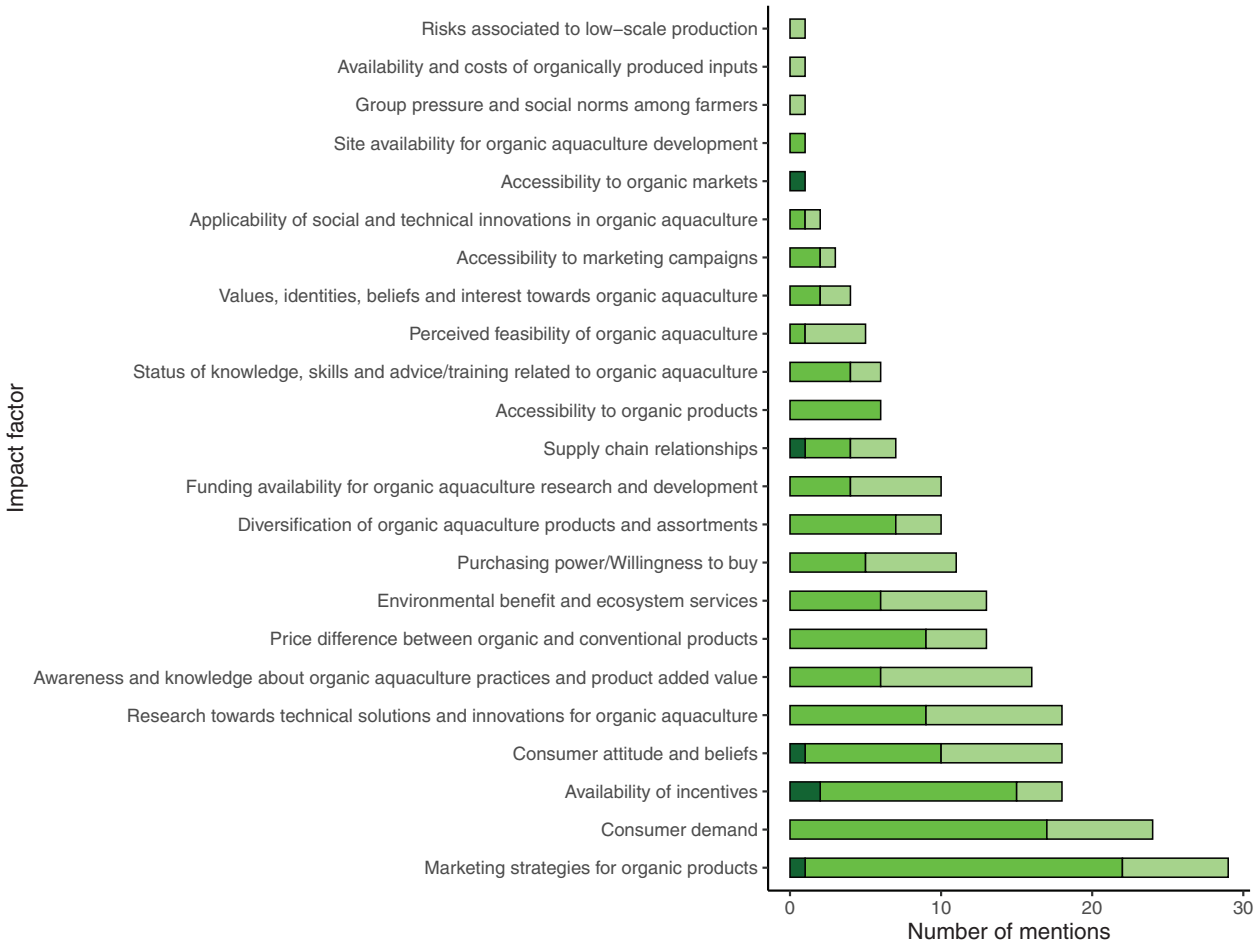

FIGURE 6 | Number of mentions of the different impact factors supporting the development of organic aquaculture in the EU. The level of impact factor was indicated using different colours ('supporting but insufficient' in light green, 'supporting' in green and 'very supporting' in dark green).

relatively low; hence, quantitative results should be interpreted with caution. Results for all species are presented in Figures 8 and 9.

Regarding salmon, the supporting factors most frequently mentioned in the reviewed documents for the development of organic aquaculture were 'consumer demand' ($n = 4$), the 'price difference between organic and conventional products' ($n = 3$), and the 'perceived feasibility of organic aquaculture' ($n = 2$) (Figure 8). Among the supporting factors cited only once, 'availability of incentives' emerged as the strongest supporting factor (Figures S2 and 8). Conversely, the factors most frequently cited as constraining to the development of organic farming of Atlantic salmon were the 'price difference between organic and conventional products' and the 'perceived feasibility of organic aquaculture' ($n = 3$ for both), along with the 'availability of incentives' ($n = 2$) (Figure 9). The 'availability of organically produced inputs' was identified as the most constraining factor among those cited only once (Figures S2 and 9).

Regarding rainbow trout, the supporting factors for the development of organic aquaculture included the 'price difference between organic and conventional products' ($n = 4$), 'consumer demand' ($n = 3$), 'awareness and knowledge about organic aquaculture practices and product added value' ($n = 3$), and the 'availability of incentives' ($n = 3$) (Figure 8). Additionally, 'marketing strategies for organic products' and 'research towards technical solutions and innovations for organic aquaculture' were also mentioned as important factors ($n = 2$ each) (Figure 8). 'Purchasing power/willingness to buy' and 'consumer attitude and beliefs' were each mentioned once as supporting factors (Figure S3). Conversely, the most frequently mentioned constraining factor in documents was the 'availability and costs of organically produced inputs' ($n = 2$) (Figure 9). 'Risks associated with low-scale production' and 'accessibility to organic markets' were each mentioned once as constraining factors (Figures S3 and 9).

Concerning organic carp farming, the supporting factors for the development of organic aquaculture most frequently mentioned in the reviewed documents were the 'availability of incentives' ($n = 3$), the 'price difference between organic and conventional products' ($n = 2$), and the 'environmental benefit and ecosystem services' ($n = 2$) (Figure 8). Other impact factors were mentioned once as supporting factors, but among those, 'accessibility to organic markets' was highlighted as a highly supporting factor (Figure S4). Conversely, the factors most frequently mentioned in documents as constraining to the development of organic carp farming were 'consumer demand' ($n = 5$) and the 'perceived feasibility of organic aquaculture' ($n = 5$) (Figure 9). Additionally, other factors emerged as important constraining factors: the 'availability and costs

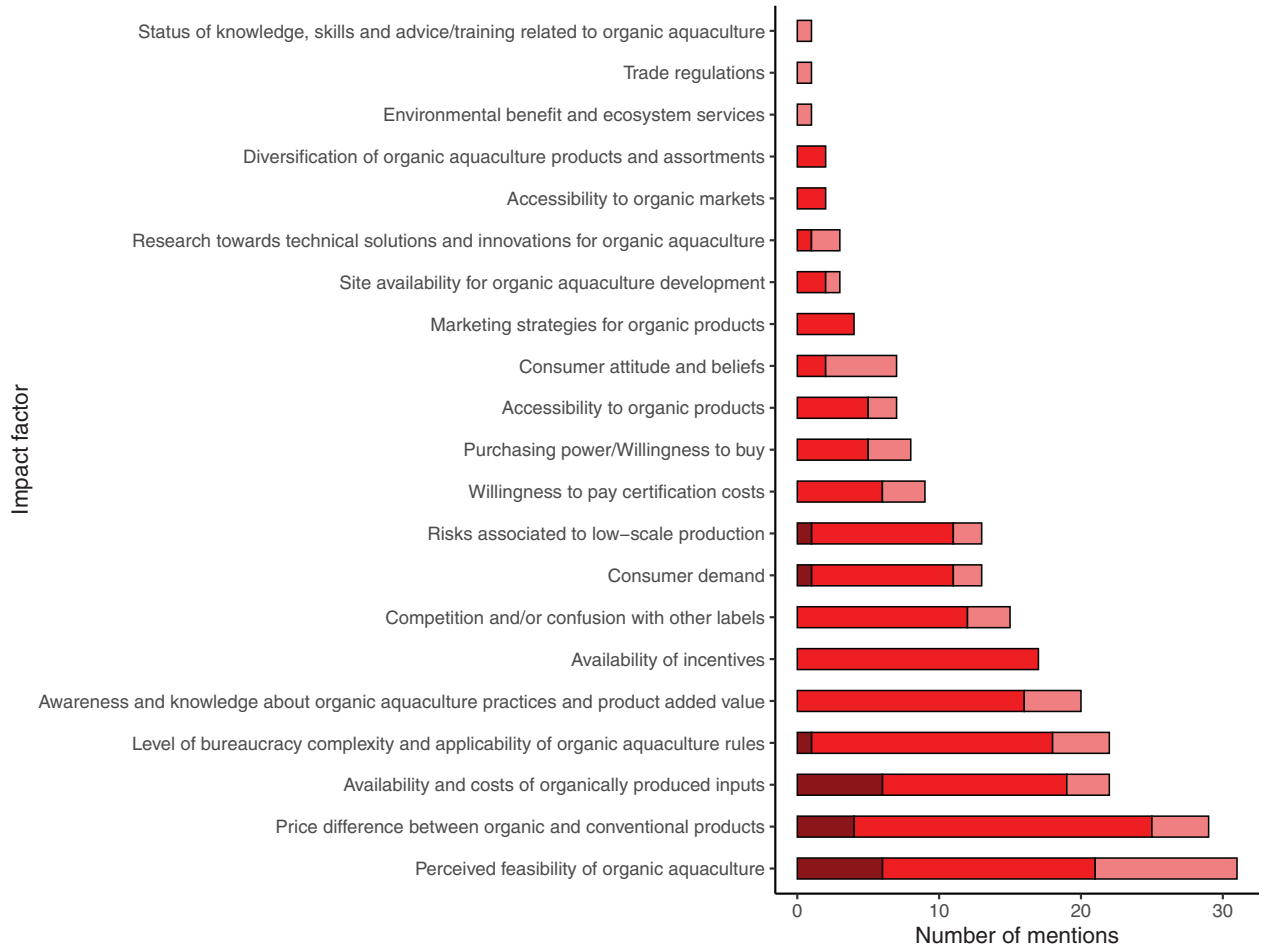

FIGURE 7 | Number of mentions of the different impact factors constraining the development of organic aquaculture in the EU. The level of impact factor was indicated using different colours ('constraining but insufficient' in light red, 'constraining' in red, 'very constraining' in dark red).

of organically produced inputs' ($n = 3$), the 'price difference between organic and conventional products' ($n = 3$), the 'level of bureaucratic complexity and applicability of organic aquaculture rules' ($n = 3$), and the 'availability of incentives' ($n = 3$) (Figures S4 and 9).

For European sea bass and gilthead seabream aquaculture farming practices are quite similar; therefore, data from the two species were merged in the analysis. The most frequently mentioned supporting factors for the development of organic aquaculture were 'marketing strategies for organic products' ($n = 9$), 'research towards technical solutions and innovations for organic aquaculture' ($n = 6$), 'consumer demand' ($n = 4$), and the 'availability of incentives' ($n = 4$) (Figures S5 and 8). Conversely, the most constraining factors were the 'price difference between organic and conventional products' ($n = 11$), followed by the 'perceived feasibility of organic aquaculture' ($n = 7$), and the 'availability of incentives' ($n = 6$). Other factors were also highlighted as important, such as 'consumer demand' ($n = 4$), 'purchasing power/willingness to buy' ($n = 4$), and 'risks associated with low-scale production' ($n = 4$) (Figures S5 and 9).

Regarding shellfish, the majority of data originated from organic mussel, in addition to oyster (one IF), organic shrimp (one IF) and eight IFs not targeting a specific species. The most frequently mentioned supporting factor in the documents was 'consumer demand' ($n = 2$; Figures S6 and 8). Among supporting factors mentioned only once, the most important factors appeared to be 'site availability for organic aquaculture development' and 'marketing strategies for organic products' (Figure S6). Regarding constraining factors, the most frequently mentioned ones were the 'perceived feasibility of organic aquaculture', the 'level of bureaucratic complexity and applicability of organic aquaculture rules', 'competition and confusion with other labels', 'awareness and knowledge about organic aquaculture practices and product added value', 'availability of incentives', and the 'availability and costs of organically produced inputs' ($n = 2$ for all; Figures S6 and 9). Among constraining factors mentioned only once, 'site availability for organic aquaculture development' was identified as the most important factor (Figure S6).

3.3 | Supporting and Constraining Factors for the Development of Organic Aquaculture in the EU

Organic aquaculture is still in its infancy in the European Union and the larger global setting, in contrast to the well-established methods of organic agriculture farming. This is evidenced by the paucity of documentation available for review, with a total of 82 documents collected across various sources, including

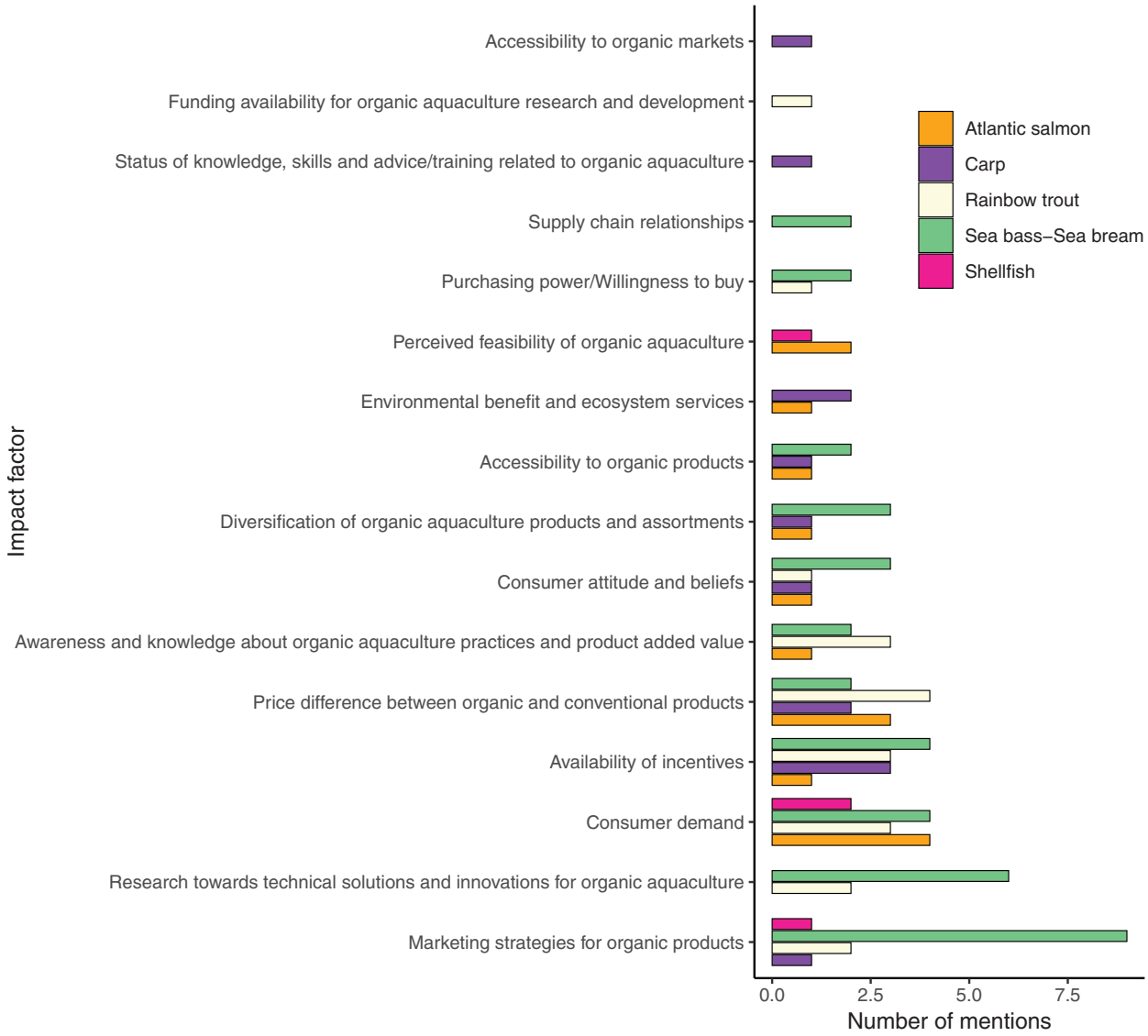

FIGURE 8 | Number of mentions of the different impact factors supporting the development of organic aquaculture in the EU for six species/species groups.

those from outside the European Union. The implementation of organic aquaculture practices is not without its challenges, and this study identified several significant constraints hindering the development of organic aquaculture in the EU, along with certain facilitating factors that could assist in surmounting these impediments.

The most common limitation identified in the literature review concerns farmers' perceived feasibility of organic aquaculture, including practicality and viability aspects, but also, concerns to put organic aquaculture principles into practice. Restrictions on stocking densities (which may require increased production capacity), restrictions on chemical and antimicrobial treatments (which could hinder for instance the treatment of sea lice in Atlantic salmon), restrictions on the use of recirculating aquaculture systems, and the requirement to keep conventional and organic cultures apart in space during all stages of production are some of the notable limitations that are commonly mentioned [8, 16, 21, 36]. These restrictions can have a negative impact on farmers' perceived feasibility of transitioning to organic aquaculture by implying additional costs, investments, equipment renewal, and new bottlenecks. Furthermore, farmers often express that the bureaucracy associated with organic aquaculture regulations is unduly extensive and complicated [8, 16, 37, 38], making the transition process complex. This transition is also characterised as costly, primarily due to the expenses associated with obtaining certification [8, 16, 21, 38, 39].

The reluctance of farmers to adopt organic practices is also associated with the fourth most constraining factor, namely, the availability and cost of organically produced inputs, including organic feeds, sanitary treatments, and organic certified eggs and juveniles [21, 36, 39]. For instance, several finfish species targeted for organic aquaculture (e.g., white amur and Chinese carp) cannot currently be reproduced without the use of pituitary hormones [8, 40], which are prohibited by organic production regulations. Furthermore, a number of factors have been identified that make it difficult to supply

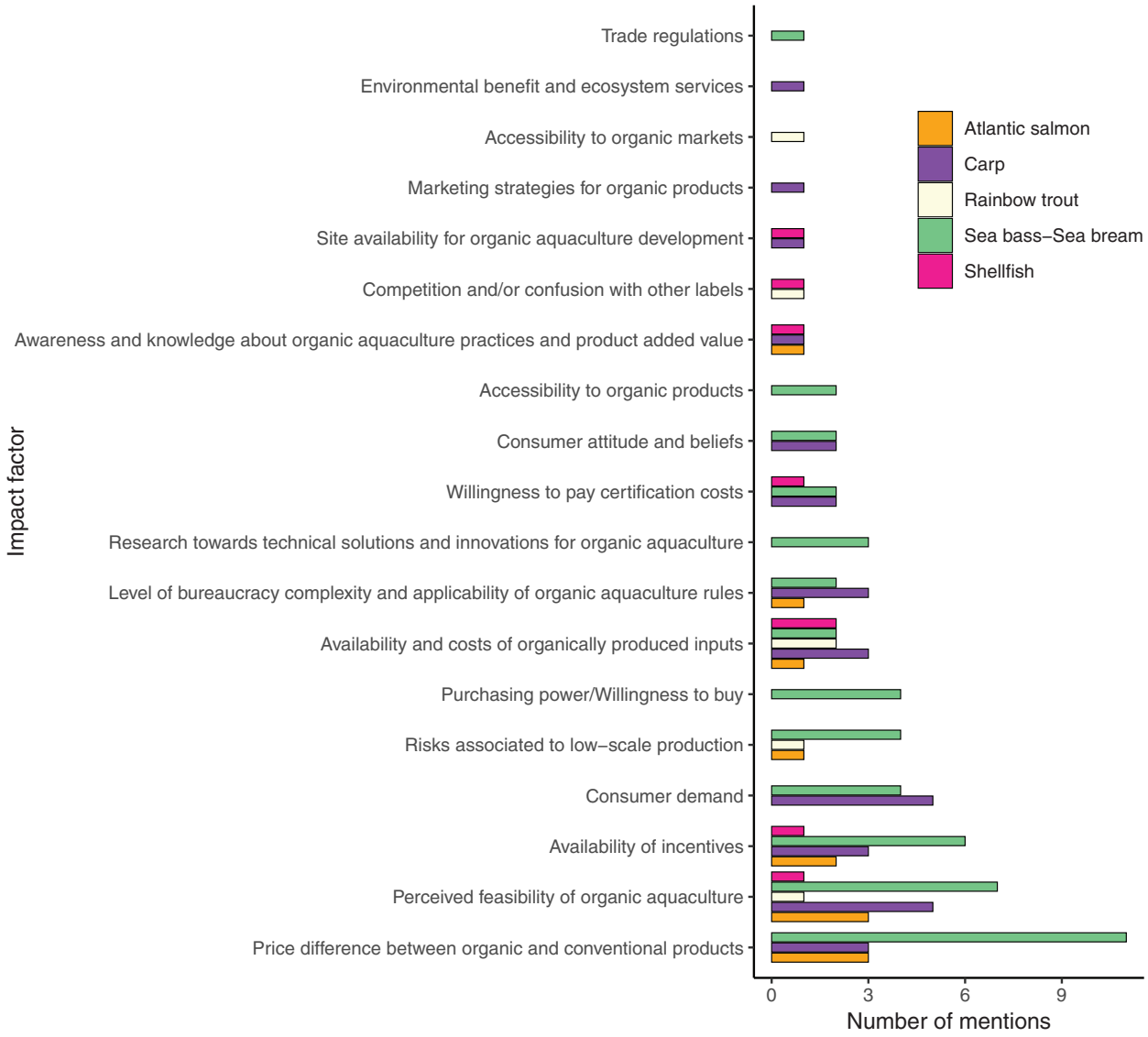

FIGURE 9 | Number of mentions of the different impact factors constraining the development of organic aquaculture in the EU for six species/species groups.

organic juveniles. The restrictions on the movement of live animals (Council Directive on the movement of living animals, EC No 88/2006) are of particular concern. In addition, the risks associated with a small number of suppliers for eggs and juveniles, as well as the costs and environmental effects of lengthy transportation, must be given due consideration. Finally, the introduction of new individuals into operating farms may be met with reluctance because of concerns regarding the potential pathogen load or the suitability for the local environment (e.g., genetic status, disease resistance, behaviour). Conversely, local phenotypes may not be suitable for production at a given site. Research addressing these impediments was identified as pivotal to facilitate the provision of organic eggs and juveniles (e.g., [41]). However, given the present circumstances, the provision of organic eggs/juveniles for on-growing in certified organic farms appears to be an unrealistic and overly ambitious undertaking. Moreover, the development of organic aquaculture appears to be impeded by limitations on the composition of organic feeds, including prohibitions on the use of genetically modified organism material and amino acid supplementation (e.g., unavailability of vitamin B2 [riboflavin] to be incorporated into the feed formulation for carnivorous species [42, 43]). The feed industry is encountering challenges in adhering to the stipulated criteria of organic regulation [43]. These challenges primarily stem from the restricted range of ingredients that can match the profiles of amino acids and fatty acids, therefore satisfying the dietary needs of species. Additionally, the restricted production volumes and higher costs of authorised raw ingredients pose significant obstacles for farmers [8, 16, 21], as the cost of organic feeds represents a substantial part of the farm budget [39]. As a result, modern feed industry actors and aquaculture farmers have significant challenges in meeting the mandated organic feed requirements.

A significant constraint identified in the literature review, with the potential to influence the propensity of farmers to transition to organic aquaculture, pertains to the absence or inadequacy of incentives (e.g., price premiums at the farm level) that hinder farm profitability [8, 20, 39]. While premiums have been

documented to underpin the expansion of organic aquaculture (e.g., organic trout in Denmark, France, and Italy), it has been predominantly reported that premiums and the ensuing price disparity between organic and conventional products remain inadequate for the majority of commercially reared species [16]. Higher production costs are attributable to the higher costs of organic fish feed and seeds, potential additional labour, the loss of gains induced by lower stocking densities (i.e., smaller production scales), and the certification costs, which translate into a negative profitability/margin at the farm level [39]. Economies of scale emerge as a prominent strategy for reducing costs, manifesting not only at the production level but also in logistics and distribution [16]. Operating at a reduced scale in organic aquaculture engenders diminished revenue for farmers, impeding the capacity to offset elevated production costs, particularly in scenarios where incentives are lacking or inadequate. The limited size of the organic farming sector engenders instability and uncertainty, as small changes in the number of organic aquaculture farms can lead to significant market fluctuations [21]. This instability is particularly evident in countries with a paucity of organic aquaculture farms, where the local feed industry may be hesitant to produce new organic feeds due to low demand and changes needing to be implemented to avoid contamination from non-organic feed production [44]. Organic aquaculture production's small size also renders it more vulnerable to financial and geopolitical crises.

Overall, the transition to organic aquaculture is widely perceived by farmers as a lengthy, costly, risky, and intricate process with no guaranteed success. Nevertheless, lowering organic aquaculture standards, as previously suggested in literature, is not deemed a suitable solution due to the association of high-quality standards with consumer trust in organic products. Simplification and clarification of organic regulation are regarded as supportive measures alongside innovation in organic farming practices. The promotion of such innovations can be facilitated through substantial research efforts and funding from European and national research programmes, as well as transdisciplinary projects [43–45]. Innovations in organic farming may include improvements in fish feed formulation, the use of alternative protein sources, enhanced nutrient utilisation, and waste reduction [43, 46, 47].

The increased expenses of producing organic products should be included in their higher prices [20, 39]. However, the justified higher price should also not exceed what consumers are willing to pay for a particular product, which varies across countries and species [20]. Indeed, the price difference between organic and conventional products was identified as the second most significant constraining factor from consumers' perspective [39]. One strategy to address this issue is the provision of incentives, which was identified as the third most important supporting factor. One strategy that has been proposed is the introduction of eco-premiums for farmers (e.g., rewarding initiatives), which would serve to offset the financial expenses associated with organic production. Additionally, the implementation of subsidised prices for consumers has been suggested as a means of offsetting costs [8, 37, 48]. However, the current insufficiency of incentives does not favour the expansion of organic aquaculture practices and the consumption of organic products (e.g., [20, 39]).

From a consumer perspective, the lack of awareness and knowledge about organic aquaculture practices and product added value was identified as a significant constraint to the development of organic aquaculture in Europe. Between 1961 and 2021, the consumption of aquatic products expanded significantly worldwide, growing at an average annual rate of 1.4% [49]. This increase is also evident in organic aquaculture, where a 20% surge in the consumption of organic aquaculture products was witnessed between 2015 and 2019 in Europe [17], with a subsequent 15% rise observed between 2019 and 2020 [16]. However, while consumer demand is a significant contributing factor, it remains comparatively low on a global scale. This is primarily attributed to the limited awareness regarding organic products and their associated values, as well as the general public's inability to differentiate between conventional and organic products and practices [8, 16, 39, 50–52]. Furthermore, recent studies have demonstrated that consumers generally exhibit a preference for wild-caught fish over farmed fish (i.e., linked to consumer attitude and beliefs), primarily due to a lack of knowledge concerning aquaculture systems and practices ([17] and references within). This preference also extends to organic aquaculture and partly explains consumers' inability to recognise the added value of organic aquaculture products [17].

A minority of consumers have expressed scepticism regarding the superiority of organic products over conventional ones, as well as the credibility of the certification process [8, 50, 53]. This scepticism has a deleterious effect on consumer attitudes toward organic aquaculture products, leading to a decrease in their propensity to purchase these products. The competition with other labels, such as Friend of the Sea, Aquaculture Stewardship Council, and Best Aquaculture Practices Certified, and the potential confusion of organic labels with these other labels have been identified as constraining factors during the literature review. The proliferation of labels and sustainability schemes, often referred to as the ‘labelling jungle’, can result in consumer confusion rather than facilitating informed choices, contrary to its initial intent [17, 39]. This phenomenon has been highlighted in various studies investigating consumers' preferences (e.g., German, Italian, and Spanish) [16, 54]. The diversity of labels with varying concepts (e.g., sustainable, ecological, fair trade, and environmentally friendly) can create competition with the European organic label [16]. However, recent surveys indicate that an increasing number of consumers are able to recognise the EU organic logo (61% in 2022; Special Eurobarometer 520) and that consumers are generally more willing to pay for organic products than for other eco-labels [55–57].

Notwithstanding the aforementioned barriers, consumers have generally favourable opinions about organic aquaculture products [10, 20, 21, 58, 59]. A growing inclination towards a healthier diet has been fuelled by consumer concerns regarding health, environmental issues, and the potential environmental advantages of specific rearing techniques (i.e., ecosystem services) [60, 61]. The market for organic aquaculture products, along with other sustainable products, is anticipated to rise as a result of this trend [62]. The social acceptability of aquaculture products is significantly influenced by public perceptions of the environmental impact of aquaculture methods [63, 64]. Consumer choices are also

influenced by ethical considerations, particularly those pertaining to animal welfare [64–66]. Furthermore, the purchasing power/willingness to buy organic products has been cited as a supporting element in several papers; however, in some instances, it was either not fully acknowledged or was specific to particular markets (e.g., nation, species, consumer profile) [16, 39, 50]. Despite the higher cost of organic aquaculture goods, increased awareness among consumers regarding the added value of these products may encourage a shift towards their selection.

A proposed solution to the issue of consumers' lack of awareness regarding organic aquaculture practices and the added value of organic products is the enhancement of marketing campaigns designed to inform consumers about these practices and the added value of organic products. Marketing strategies have been identified as the most crucial supporting factor for the development of organic aquaculture [16, 21, 53, 67]. To this end, the organic aquaculture sector must prioritise the cultivation of consumer confidence and attitudes favouring food safety, animal welfare, and sustainability. This can be achieved by the provision of information substantiated by scientific evidence, which serves to differentiate the sector's products from their conventional counterparts [68]. Such an approach is poised to enhance consumer acceptance, thereby fostering increased willingness to purchase organic products. The effective communication of the characteristics and benefits of organic food, including organic aquaculture products, will depend on utilizing appropriate channels to reach the target audience. Data collected in the FutureEUaqua project has shown that the internet is the preferred medium for the public compared to more traditional media channels. Therefore, future marketing campaigns should prioritise online platforms to effectively communicate with consumers.

Furthermore, enhancing willingness to buy and improving returns for farmers could be achieved through both the diversification of organic products and assortments, as well as better availability of organic products for consumers in various market structures, closer to their homes. Firstly, further diversification of fish species in certified organic aquaculture is crucial, along with diversification of products offered through processing, such as filleting or smoking, which could enhance returns [8, 51, 57, 69]. This diversification strategy has been identified as essential for strengthening the competitiveness of the producers' sector, particularly through exports, and expanding the organic aquaculture market. Secondly, it is crucial to make organic aquaculture products available in local stores, including specialised fishmonger. Ensuring accessibility to local markets for small producers is a critical prerequisite for the long-term establishment of organic aquaculture in Europe. This approach has been emphasised in various studies as a means to enhance market reach and consumer access to organic products [8, 68, 70].

Finally, the availability of suitable sites for organic aquaculture development was identified as a minor constraining factor. However, according to the most recent EUMOFA report [16], there is potential for organic aquaculture farming expansion in many EU countries (e.g., Bulgaria, Lithuania, and Romania). Stakeholders should carefully examine this potential to inform the development of EU spatial planning for organic aquaculture farming. Indeed, competition for spatial sites has been previously reported as one of the main drivers of social perception and attitudes towards aquaculture development and products from local communities ([64] and references within). To mitigate these conflicts, various regulations and guidelines have been instituted, including the Maritime Spatial Planning Directive 2014/89/EU, Reg.1380/2013, the FAO AZAs Guidelines, and the FAO General Fisheries Commission for the Mediterranean and the Black Sea Resolution 36/2012/1. The latter, for instance, aims to facilitate the implementation of designated zones for aquaculture development [64]. The collective effect of these regulations and guidelines is anticipated to be a reduction in the occurrence of conflicts among maritime area users.

3.4 | Specific Supporting and Constraining Factors to the Organic Production of Key Farmed Species in the EU

3.4.1 | Atlantic Salmon in Europe

Major producers of organic Atlantic salmon in Europe include Norway, the United Kingdom, Iceland, and Ireland. The perceived feasibility of organic aquaculture from farmers' perspective, the price difference between organic and conventional products, and the insufficient availability of incentives were the most cited constraining factors.

The limitations imposed by the specified organic standards, which include restrictions on stocking density (resulting in higher fixed and general costs), feed requirements and certification costs, act as significant constraining factors to farmers seeking to transition to organic Atlantic salmon production [39, 48]. This is primarily attributable to elevated production costs, which are approximately 30% higher than conventional methods [71], and end-product prices for consumers, resulting in challenges for farmers to compete within the organic market segment [16]. A significant challenge in organic salmon production is the requirement to adhere to the full life cycle under organic standards [56]. Another important limit is linked to the restrictions on the use of chemical treatments/medicine, which represent a challenge in Atlantic salmon aquaculture, particularly in the context of sea lice treatment. While alternative methods, such as the utilisation of cleaner fish, have been devised [72], these solutions are not yet optimal due to their association with additional environmental concerns, including heightened risks of viral infections and overfishing of wild wrasse populations ([71] and references within). A key facilitating factor in the transition from conventional to organic salmon farms is the use of price premiums to offset higher production costs (about 20%–30% higher in average compared to conventional salmon production [73]), contingent on consumer willingness to pay a premium for organic salmon and its benefits to all stakeholders across the value chain [55, 56, 73]. The literature has documented price premiums ranging from 13% to 50% for organic salmon, contingent on factors such as the country and the type of product marketed [20, 56]. A profitable activity, characterised by margins that exceed those of conventional products, has been documented in several countries, including the United Kingdom, Norway, and Romania [16, 71]. Interestingly, a recent study showed that a company which had diversified its

production to include organic salmon achieved higher returns on sales, despite higher production expenses. This was due to a lower mortality rate among the salmon when they were farmed in accordance with organic principles [73].

Consumer demand for organic Atlantic salmon has been identified as the primary catalyst for the development of organic production. This demand can be further strengthened by enhancing consumer awareness regarding organic practices and the added value of the product. Research into consumer perceptions has revealed a limited understanding of the organic concept, which has led to concerns about the long-term stability and potential growth of demand [48]. This concern remains valid today, as Budhathoki et al. [68] recently posited that the organic Atlantic salmon sector should prioritise the promotion of consumer beliefs and attitudes regarding food safety, animal welfare, and sustainability by providing reliable information grounded in scientific evidence. This approach is expected to facilitate the differentiation of organic products from conventional and wild-caught salmon, thereby enhancing the likelihood of consumers opting for organic options. Indeed, research in Norway has demonstrated that consumers are willing to pay a price premium for organically farmed salmon, particularly when they believe that it can help to reduce environmental impact compared to conventional farming [71, 74]. Another effective strategy to distinguish organic salmon products from other production methods or fisheries is the proper utilisation of labels [68, 74]. Finally, it has been suggested that making organic Atlantic salmon products available in local stores could guide consumer purchasing habits towards their consumption [68]. Consequently, the expansion of organic aquaculture salmon production has augmented the available product range, thereby stimulating consumer demand and leading to enhanced prices [69]. The diversification of products has also been instrumental in accessing specific market segments, as evidenced by the predilection of French and German consumers for frozen products [16].

3.4.2 | Rainbow Trout in Europe

The EU top producers of organic rainbow trout are France, Spain, Denmark, Italy, and Germany [16]. The most significant constraint identified in the literature was the availability and cost of organically produced inputs [16, 75]. As Lund et al. [42] noted, the absence of amino acid supplementation in organic feed formulations for carnivorous species like rainbow trout poses a significant challenge in fully replacing fish meal protein with organic plant protein concentrates in organic feeds. According to the French producers' organization CIPA ('*Comité Interprofessionnel des Produits de l'Aquaculture*'), the most significant current obstacles for organic trout aquaculture development in France are the limited number of raw materials that can be incorporated into the feed, as well as the uncertainty concerning the provisioning of juveniles following organic requirements [75]. In other countries, such as Poland, there is an absence of suppliers of certified feed for rainbow trout, which may impede the transition of aquaculture farmers towards organic farming practices [16]. Over the past decade, research has been conducted to identify alternative feeds using innovative formulations to promote rainbow trout organic farming (e.g., [42, 76–78]). However, further research efforts are necessary to address this issue.

The price difference between conventional and organic products has been demonstrated to be sufficiently significant to motivate consumers to purchase organic rainbow trout products [16, 79]. Price premiums have been observed to vary globally between 20% and 46% for organic rainbow trout products [20]. Consumer demand and awareness regarding organic practices and the added value of products have also been identified as supporting factors for rainbow trout organic farming. For instance, an increasing demand for organic trout has been observed in France [16], and German consumers have expressed positive preferences for organic-labelled fish, indicating an average willingness to pay 1.2 euros/kg more than for non-organic farmed rainbow trout [54, 80]. Furthermore, it has been demonstrated that providing consumers with specific information regarding rainbow trout welfare, a critical driver for social perception of aquaculture development and products [64], and the consequences associated with the organic label significantly increases the likelihood of choosing the organic trout product [54]. In Denmark, France, and Italy, farmers can sell organic trout at a price premium that is approximately double the additional cost they incur. This enables them to generate an additional margin of 0.36–0.57 euros/kg [16]. The OrAqua project demonstrated that rainbow trout conventional farming is unprofitable in Denmark, despite subsidies, and only marginally profitable in France (small margins). Conversely, organic farming has been demonstrated to yield positive and more substantial margins [16].

3.4.3 | Common Carp in Europe

A substantial portion of the available literature on the subject was reviewed by Adámek et al. [8] and the EUMOFA report [16]. Pond farming remains the dominant aquaculture method for common carp production in Europe, with carp organic farming primarily conducted in Eastern Europe (e.g., Hungary, Romania, Lithuania, Poland, Austria [81]).

The perceived feasibility of organic production by farmers was identified as a significant constraint for trout organic farming. Specifically, the prohibition on the use of hormones and hormone derivatives, in addition to limitations on supplemental feeds, which play a determinative cost factor in carp aquaculture profitability, are considered limiting factors [8]. Furthermore, price premiums of 30%–50% have been reported in Europe for organic carp products [8, 20]. However, the OrAqua project has shown that the price premium often does not fully cover the increased costs of switching to organic carp farming. Furthermore, losses during the production stage, typically resulting from disease or predation, are not adequately compensated by higher prices [16]. The financial burden of organic carp farming, which is estimated to be approximately 30% higher in Poland, relative to conventional farming, hinders its adoption [16]. This, in turn, necessitates the provision of substantial political and financial support to promote the development of organic carp aquaculture, particularly among small-scale producers [8].

Another significant impediment to the adoption of organic carp farming appears to be the substantial bureaucracy and the modest consumer demand [8, 16]. It is noteworthy that pond cultivation methods currently employed for carp farming are

already quasi-organic, and the transition to certified organic farming does not appear to be as demanding as for other species. However, the process may be time-consuming, and there is an absence of public support for organic production that could facilitate the conversion process [8]. Moreover, consumer demand for conventional carp products remains modest, frequently attributable to a lack of awareness and understanding of organic carp farming principles and practices [16]. However, recent studies suggest a potential increase in consumer interest in organic carp products [8]. Carp is regarded as a potentially environmentally sustainable farming solution for provisioning fish in Europe in the future [82]. However, the successful integration of organic carp into the European market is predicated on the resolution of issues pertaining to consumer preference and the fish's unfavourable reputation. A concerted effort is necessary to promote the merits of organic carp farming to the public [8, 16]. The aforementioned constraining factors are likely the reason why some carp farmers have reverted to non-organic production methods [16].

3.4.4 | European Sea Bass / Gilthead Seabream in Europe

In contrast to other fish species, a greater volume of data could be retrieved concerning the supporting/constraining factors for the development of organic Mediterranean fish species farming. This reflects the growth in the organic share of these species, as is also seen in total EU aquaculture for these two species, with a global rising trend in carnivorous fish production [83]. The primary producers of organic sea bass/sea bream in the EU are Greece, Italy, and Spain, with smaller proportions produced by France and Croatia [84, 85].

The price differential between conventional and organic products represents the most significant impediment to the expansion of sea bass and seabream organic aquaculture. Indeed, retail prices of organic products are notably higher than those of conventional products [16, 57, 86]. This price disparity has been observed to have a discouraging effect on both farmers and consumers, thereby leading to a decline in market demand [16, 86, 87]. The elevated costs of end products can be attributed to the augmented expenses associated with organic rearing in comparison to conventional aquaculture [16, 86]. The discrepancy in costs ranges from 29% to 42% [20, 39]. The elevated costs are attributed to the lengthier growing period, the greater water volumes necessitated for a specific production level, the costs of organic inputs, particularly organic feeds, and the expenses associated with certification [57]. The onerous bureaucracy has also been identified as a hindrance to the advancement of organic sea bass and seabream aquaculture [57]. This, in turn, has a deleterious effect on the perceived feasibility of organic production from the perspective of farmers, who consider it the second most constraining factor. Research aimed at developing technical solutions and innovations has been identified as a crucial supporting factor. Specifically, the improvement of organic feed formulation and the quality of feed ingredients have been identified as significant issues to be addressed to optimise the nutritional quality of organic sea bass and sea bream. The enhancement of organic feed formulation continues to be a pivotal research priority in the context of organic sea bass and seabream production [86, 88–91]. The provision of organic juveniles is another constraining factor which poses significant challenges due to various factors (e.g., limitations on the movement of live animals, risks associated with relying on a limited number of suppliers for eggs and juveniles, expenses and environmental impact of long and costly transport, hesitancy of introducing new individuals into farms due to potential pathogen load or unsuitability for the local environment, as well as other factors such as genetic profile).

The availability of incentives was identified as the third most significant constraining factor, with price premiums reaching up to 50% being reported [20, 92]. However, this appears to be inadequate, as in several instances (e.g., Spain and Italy), the additional production costs exceed the farm gate prices, resulting in negative margins. This aspect is particularly salient for small and medium enterprises, which are unable to shoulder mounting costs. It is noteworthy, however, that consumer demand for these products is rapidly escalating, while the market's capacity to meet this demand remains inadequate [57, 69]. To this end, the development of effective marketing strategies is paramount to enhance consumer awareness regarding organic products and practices, as sea bass and seabream are currently regarded as ultra-niche products [57, 69, 86]. In Greece, a diverse array of promotional materials, including discount coupons, labels, recipes, brochures, and photographs, has been utilised. These products are disseminated through all recognised distribution channels, such as wholesalers, importers, and distributors, as well as supermarkets [69]. The implementation of effective marketing campaigns has the potential to modify consumer attitudes and augment demand for organic sea bass and seabream products.

3.4.5 | Shellfish in Europe

While shellfish organic farming has been demonstrated to contribute meaningfully to organic sales in the EU, a review of relevant documents revealed limited mention of the factors that enable or constrain this practice. The majority of the documents focused on mussel organic farming, with the Netherlands, Italy, and Germany being the primary organic producers [16]. The constraining factors observed for fish species are analogous to those experienced by shellfish farmers, primarily concerning the perceived feasibility of organic production, the availability and costs of organically produced inputs, and the complexity of bureaucracy. Conventional and organic shellfish production practices are largely similar, which supports the transition to organic farming. However, several factors can impede this transition [16]. Specifically, Regulation (EU) 2018/848, which took effect on January 1, 2022, has emerged as a significant concern for shellfish farmers. This regulation stipulates that growing areas utilised for organic mollusc farming must be deemed suitable from a health perspective. Such areas are required to either be of good environmental status, as defined by Directive 2008/56/EC, or of high ecological status, as delineated by Directive 2000/60/EC, or of equivalent quality to areas classified as A in accordance with article 18(8) of Regulation (EC) 2017/625 since December 2019 [16]. This presents a considerable challenge, as it introduces instability into the long-term farm strategy due to the potential variability in water quality resulting

from external factors. The interpretation of 'equivalent quality to zone A' necessitates further clarification. Furthermore, the use of non-organic juveniles for on-growing reasons is restricted. This presents a significant challenge for species such as oysters and mussels, for which there is an absence of developed organic hatcheries and a reliance on wild seed collection [93]. Furthermore, there is a necessity for streamlined regulations, as the licensing procedures for mollusc production sites are regarded as overly complex. This issue is shared with conventional production methods. This cumulative effect is detrimental to the feasibility perceptions of farmers seeking to transition to organic farming. It has been observed that the initiation or conversion to organic farming has been hindered, and in some cases, has come to a halt [16].

The literature review also reveals several other constraining factors that impede the development of the organic shellfish sector. These include the limited market size, attributable to consumer awareness issues regarding organic practices and product added value, inadequate incentives, and competition with other sustainability schemes. Consumers often lack awareness or comprehension of the added value of organic shellfish aquaculture products, which complicates differentiation between these products and conventional options. This is further compounded by the fact that the quality of growing waters differentiates conventional shellfish from organic farming. Another constraining factor, which was previously identified for fish species, is competition with other sustainability labels, such as MSC labelled products [16]. Finally, the limited market incentives and the absence of a price premium hinder further development of the shellfish organic sector [16]. However, consumer demand constitutes a significant catalyst for the advancement of European shellfish organic farming. For instance, organic mussel farming, which emerged more recently, is experiencing robust retail demand for organic shellfish products in certain countries (e.g., France), although demand remains constrained in others (e.g., the Netherlands) [79]. Furthermore, the organic shellfish farming sector benefits from a favourable image associated with environmental benefits and ecosystem services [9, 16], indicating a promising trajectory for its future expansion.

3.5 | Limitations of the Review

The present review is subject to several limitations that merit attention. Primarily, the paucity of extant documents pertaining to European organic aquaculture creates a lack of evidence, particularly with regard to quantitative analyses conducted at the species/species group level (e.g., Atlantic salmon, rainbow trout, and shellfish). This is, in essence, an inevitable consequence of the recent emergence and nascent state of organic aquaculture. A further limitation is the funding bias, which is evident in the documents retrieved and analyzed in the present study. Funding opportunities influence the selection of studies, with some being more readily financed than others. Additionally, the topic of study affects the feasibility of execution, with micro-level studies or those encompassing the entire supply chain being more manageable than others. Finally, given its recent occurrence, the impact of reduced purchasing power of consumers (due to the overall increased prices related to both the COVID-19 pandemic and the Ukrainian war) on the demand and willingness to buy organic aquaculture products has yet to be evaluated. This is a crucial factor that should be taken into account when assessing the future development of organic aquaculture in the EU. Significant constraints on purchasing power can cause consumers to prioritize essential purchases, potentially having a negative impact on the niche market of organic aquaculture. While the study's analysis of supporting and constraining factors for organic aquaculture development in the EU is relevant to the existing literature, it is crucial to acknowledge the influence of other factors that were not addressed due to the aforementioned reasons. These include, but are not limited to, decreasing purchasing power and challenges in supply chain relationships. These additional factors also serve as significant drivers, warranting further investigation and consideration for a comprehensive understanding of the dynamics influencing the growth and sustainability of organic aquaculture in the EU.

4 | Concluding Remarks

While there is an increasing demand for organic aquaculture products in the EU, the market remains niche. Following an initial phase of development, most of the countries have shown signs of stagnation (if not regression), with a few exceptions, also reflecting the current state of the global European aquaculture sector [83]. The implementation of the regulation on organic aquaculture appears to have preceded the widespread adoption and consolidation of production, and more crucially, the resolution of significant technical challenges, resulting in a lack of the anticipated growth in the sector.

From a policy standpoint, the CFP 2021–2027 demonstrates an increased commitment to sustainable practices, including organic aquaculture, compared to the 2014–2020 period, as evidenced notably by the strategic guidelines for the sustainable development of EU aquaculture. These guidelines offer concrete recommendations to the Commission, Member States, aquaculture producers, and other relevant actors. The aforementioned recommendations encompass the promotion of organic aquaculture and other aquaculture systems that exhibit a reduced environmental impact, the promotion of organic aquaculture certification and labeling, the promotion of organic production, which stipulates more specific requirements on animal welfare, and the implementation of spatial planning measures that ensure the availability of designated areas for organic aquaculture. At the national level, the organic aquaculture policies are incorporated into the Multi-Annual Strategic Plans for Aquaculture. However, we show a relative paucity of attention on the promotion of organic aquaculture compared to global sustainable conventional aquaculture, despite the fact that measures are more oriented towards organic aquaculture for the 2021–2027 period compared to 2014–2020. The development of organic aquaculture is supported by European and national funds, which have been and are currently used in the implementation of strategic guidelines. However, a commitment difference can be seen across member states. Moreover, in contrast to the identification of critical actions for the development of a sustainable conventional aquaculture, the goals and initiatives intended to support the growth of organic aquaculture in the national operational programs of the EMFF 2014–2020 and the EMFAF 2021–2027 are generally not very detailed. A comprehensive evaluation of

the utilization of these financial resources for organic aquaculture was hindered by the absence of consolidated data. The current financial cycle (2021–2027) has seen yet an augmentation in funding compared to the previous one (2014–2020), which suggests the potential for enhanced support for organic aquaculture. However, no specific funding was identified to be allocated exclusively to organic aquaculture, and the level of funding will be contingent on the submissions of projects by organic companies. Overall, our findings underscore the significant room for enhancement in the configuration and execution of organic support. This enhancement is imperative to align with the aspirations of the EU Commission and Member States while concurrently safeguarding the attainment of environmental, food security, and public health objectives.

Numerous constraining and supporting factors for the development of organic aquaculture in EU nations were identified by the literature analysis. Because these issues are frequently interconnected, officials in the EU and Member States must take a comprehensive approach and put up strong efforts. The analysis identified significant constraints that currently impede the development of organic aquaculture, including the applicability of regulations. This is in line with the call for a review of certain aspects of the prevailing regulation on organic aquaculture in the multi-annual national plans of Denmark and Ireland. In addition, efforts should be concentrated on two key areas: (i) enhancing the feasibility of transitioning to organic farming for farmers by addressing issues such as the cost and availability of organic inputs, optimizing administrative processes, and providing enhanced premiums (e.g., eco-premiums) to encourage organic production; and (ii) fostering greater consumer awareness of organic farming methods and product value through targeted marketing campaigns and offering sufficient incentives to consumers (e.g., subsidised prices) to influence their choice towards organic products. In order to address these issues and achieve the objectives set out in the EU's farm-to-fork strategy for organic aquaculture, collaboration between policymakers, farmers, academics, and other relevant stakeholders is essential. In addition, it is interesting to note that the challenges can vary depending on the species produced, making country and species-specific approaches needed in addition to global European analyses. Finally, it is interesting to note that the global patterns observed in organic aquaculture also reflect those seen in EU aquaculture as a whole and that analyses of the growth of both conventional and organic aquaculture should be considered in parallel.

Author Contributions

Conceptualization: G.L., P.C., E.M., I.J., N.L. and S.A. Methodology: G.L., P.C., I.J., N.L. and S.A. Investigation: L.T., S.A. and G.L. Formal analysis and Visualization: L.T. and S.A. Resources: all authors. Writing – Original Draft: L.T., S.A. and G.L. Writing – Review and Editing: all authors. Project administration: G.L., I.J., E.M., N.L. and P.C. Funding acquisition: E.M., P.C., I.J., N.L. and G.L.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All the data that support the findings are available in the Appendix S1.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** (A) List of all articles gathered and whether they were kept of not for the review. (B) List of impact factors collected from selected articles and the associated factor type (at two different scales), level (i.e., micro, meso, and macro), system element, subsystem element and the connection with other system elements. For each impact factor are also reported associated articles/reports, year, geographic region, country and production information (marine or freshwater, family, and species). (C) Dataset for the European analysis. **Figure S1:** Species targeted by the different impact factors. **Figure S2:**. Number of mentions of the impact factors supporting or constraining the development of organic aquaculture in the EU in Atlantic salmon ($n = 27$). The level of impact factor is indicated using different colours ('supporting but insufficient' in light green, 'supporting' in green, 'very supporting' in dark green, 'constraining but insufficient' in light red, 'constraining' in red, and 'very constraining' in dark red). **Figure S3:**. Number of mentions of the impact factors supporting or constraining the development of organic aquaculture in the EU in rainbow trout ($n = 26$ mentions). The level of impact factor is indicated using different colours ('supporting but insufficient' in light green, 'supporting' in green, 'constraining but insufficient' in light red, 'constraining' in red, and 'very constraining' in dark red). **Figure S4:** Number of mentions of the supporting or constraining impact factors for common carp organic European aquaculture development. The level of impact factor is indicated using different colours ('supporting but insufficient' in light green, 'supporting' in green, 'very supporting' in dark green, 'constraining but insufficient' in light red, 'constraining' in red, and 'very constraining' in dark red). **Figure S5:** Number of mentions of the supporting or constraining impact factors for seabass/sea bream organic European aquaculture development. The level of impact factor is indicated using different colours ('supporting but insufficient' in light green, 'supporting' in green, 'constraining but insufficient' in light red, 'constraining' in red, and 'very constraining' in dark red). **Figure S6:** Number of mentions of the supporting or constraining impact factors for shellfish European organic aquaculture development. The level of impact factor is indicated using different colours ('supporting but insufficient' in light green, 'supporting' in green, 'constraining but insufficient' in light red, and 'constraining' in red).