SEA2SEE

INNOVATIVE BLOCKCHAIN TRACEABILITY TECHNOLOGY AND STAKEHOLDERS' ENGAGEMENT STRATEGY FOR BOOSTING SUSTAINABLE SEAFOOD VISIBILITY, SOCIAL ACCEPTANCE AND CONSUMPTION IN EUROPE

D1.3- REPORT ON THE MAIN IMPEDIMENTS AND POTENTIAL INCENTIVES FOR SEAFOOD BLOCKCHAIN DEPLOYMENT - UPDATE

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Document Approval

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Nature of the deliverable

R	**Document, report (excluding the periodic and final reports)**	☒
DEM	Demonstrator, pilot, prototype, plan designs	☐
DEC	Websites, patents filing, press & media actions, videos, etc.	☐
DATA	Data sets, microdata, etc.	☐
DMP	Data management plan	☐
Ethics	Deliverables related to ethics issues.	☐
SECURITY	Deliverables related to security issues	☐
Other	Software, technical diagram, algorithms, models, etc.	☐

Dissemination level

PU	Public — fully open (automatically posted online on the Project Results platforms)	☒
SEN	Sensitive — limited under the conditions of the Grant Agreement	☐

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Current seafood traceability tools and services have the potential to take advantage of novel blockchain technologies to obtain a wide range of data making sustainable seafood practices more visible to consumers. Sea2See project will fill in existing seafood traceability gaps through development and demonstration of an innovative end-to-end blockchain traceability model throughout the seafood value chain and professional and consumer applications to increase trust and social acceptance of sustainably fished and farmed seafood.

The project will provide technological solutions to answer the need of a valuable source of data collected throughout the whole seafood value chain, verified, and covering inputs from diverse stakeholders. For that purpose, a specific focus will be put on active commitment of stakeholders and real empowerment of consumers through the implementation of societal and sectoral strategies for co-creation, communication and awareness raising.

The project runs from July 2022 to June 2026. It involves 14 partners from 6 EU countries, and is coordinated by SMARTWATER PLANET SL, Spain.

More information about the project can be found at: http://www.sea2see.eu/

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EXECUTIVE SUMMARY

The current report presents the results of (i) a systematic review of the literature and (ii) interviews with key stakeholders in Europe to identify the challenges and incentives of implementing blockchain traceability in seafood value chains, both for the fisheries and aquaculture sectors.

Seafood traceability has become increasingly important in the globalized seafood market. Almost 60% of the seafood consumed in the European Union (EU) is imported and concerns about food safety, illegal unreported and unregulated (IUU) fishing, healthy fish stocks and sustainable fisheries have led to increasing seafood traceability regulations. In the EU, import documents and labelling information for consumers are mandatory for seafood products. Recently, in order to strengthen transparency, safety, accountability and safeguard consumers' interests, the European Parliament and the European Council Presidency agreed on new rules regarding seafood traceability, including digital traceability, which will certainly change seafood trade into the EU in the near future.

The use of blockchain technology - which allows for the creation of ledgers of transactions forming blocks of information that can be shared in real-time and cannot be tampered with, allowing data to be exchanged securely - in seafood value chains improves their transparency, promoting trust amongst seafood actors and consumers, and providing seafood actors with better access to reliable information regarding a products' origin, production method, processing and/or transformation method (if applied), at any point in the value chain.

For this report, a literature review was carried out by searching all databases in Scopus and ISI Web of Science (WoS). In total, 15 manuscripts were selected discussing opportunities and/or challenges related to blockchain traceability systems in fisheries and/or aquaculture.

A total of 17 incentives for using blockchain traceability systems in seafood value chains were identified, namely: improves efficiency (e.g., time of transactions); improves traceability; allows for the identification of origin/source of seafood products; increases value chain trust; increases public

acceptance and trust; allows to demonstrate compliance; allows for real-time access to information; allows to apply for certification/labelling; improves food safety (food quality); helps minimize IUU fishing; improves market opportunities; improves data security and decentralization; enhances reputation, accountability and ethics; leads to environmental sustainability; empowers communities and improves relationships; contributes to improve human rights and social sustainability; and reduces the cost of information exchange.

On the other hand, a total of 12 challenges related to the use of this technology in seafood were identified, such as the cost/price of implementation; the size of the supply chains; the complexity and amount of information needed; confidentiality/trust issues; the lack of interest by actors in the value chain/lack of buy-in; the complexity of use of this technology; the lack of interest by the public/consumers; the lack of interoperability of the information systems; the adulteration of seafood products during processing; the lack of access to technologies and lack of incentives (for the actors) to join the system.

The report also presents six examples, from around the world, of seafood supply chains where blockchain was implemented, describing in detail the opportunities and challenges of implementing this technology. Since different sectors face different challenges and incentives, we present two examples of blockchain in small-scale fisheries (Provenance, FLAGCHAIN), two in large-scale fisheries (Fiji Tuna Supply Chain Solution, Fishcoin), and two in aquaculture (Sustainable Shrimp Partnership, IBM Blockchain Transparent in Norway).

The literature review showed that most incentives and challenges to the implementation of blockchain are common to the fisheries and aquaculture sectors. However, some incentives are specific to the fisheries sector (reducing/stopping IUU fishing, enhancing reputation, improving accountability and ethics, enhancing community empowerment and relationships, and improving human rights and social sustainability), and some are specific to the aquaculture sector (improving market opportunities, and reducing costs of information exchange). The same was observed in terms of barriers, with some being specific to the fisheries sector, such as the size of the supply chain, the lack of access to technologies, and the lack of incentives for the actors to join blockchain traceability systems.

The expert consultation results align closely with the literature review on blockchain traceability in seafood value chain, highlighting key opportunities such as improved traceability, compliance, origin identification, and increased trust. Challenges identified include high implementation costs, lack of interest, complexity, and interoperability issues. Blockchain-specific opportunities (compared with seafood traceability in general) emphasize real-time information access and efficiency, while challenges maintain a similar hierarchy, with cost remaining prominent. Despite limited familiarity with blockchain, stakeholders across sectors and countries view it as a top

method for seafood traceability, indicating a uniform preference of methods across different seafood sectors (namely, blockchain, QR codes/RFID codes, mobile/web apps and certification schemes/labels) and a need for user-friendly tracking systems. The topic remains new, with experts still developing their understanding and knowledge.

Despite the general lack of distinction by consulted stakeholders between traceability methods, the literature review shows that the type of blockchain technology put in place should be adapted to the specific fishery or aquaculture value chain and the level of traceability aimed to be achieved so that a fair, trustful and transparent value chain can be efficiently implemented.

ACRONYMS AND ABBREVIATIONS

ACRONYM	DEFINITION
AI	Artificial Intelligence
ASC	Aquaculture Stewardship Council
CFP	Common Fisheries Policy
CMO	Common organization of the markets in fishery and aquaculture products
DApps	Decentralized Applications
EC	European Commission
EP	European Parliament
EU	European Union
FAO	Food and Agriculture Organization
FLAGs	Fisheries Local Action Groups
IBM	International Business Machine Corporation
IoT	Internet of Things
ISO	International Organization for Standardization
IUU	Illegal, Unreported and Unregulated

LCA	Life Cycle Analysis
NFC	Near Field Communication
NGO	Non-governmental Organization
P2P	Peer-to-peer
QR	Quick Response
RFID	Radio Frequency Identification
SDG	Sustainable Development Goals
SDKs	Software Development Kits
SSF	Small-scale fisheries
SSP	Sustainable Shrimp Partnership
TRL	Technology Readiness Levels
USA	United States of America
UN	United Nations
WoS	Web of Science
WWF	World Wide Fund for Nature

PROJECT PARTNERS

#	Partners full name	Short	Country	Website
1	SMARTWATER PLANET SL	SmartWater	ES	www.smartwaterplanet.com
2	TILKAL	Tilkal	FR	www.tilkal.com
3	PAGE UP	PAGE UP	FR	www.pageup.fr
4	SUBMON	SUBMON	ES	www.submon.org
5	CENTRO DE CIÊNCIAS DO MAR DO ALGARVE	CCMAR	PT	www.ccmar.ualg.pt
6	ASOCIACION NACIONAL DE FABRICANTES DE CONSERVAS DE PESCADOS Y MARISCOS-CENTRO TECNICO	ANFACO	ES	www.anfaco.es

	NACIONAL DE CONSERVACION DE PRODUCTOS DE LA PESCA			
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11	VITAGORA POLE	VITAGORA	FR	www.vitagora.com
12	ETHIC OCEAN	Ethic Ocean	FR	www.ethic-ocean.org
13	EVROPROJECT OOD	EP	BG	www.europroject.bg
14	ANP - ASSOCIACAO NATUREZA PORTUGAL	ANP	PT	www.natureza-portugal.org

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1. INTRODUCTION

1.1. TRADE IN SEAFOOD

International trade of aquatic products has grown significantly during recent decades. Seafood is currently the world's most traded food commodity, with 225 states and territories reporting trading activity of seafood products in 2020 (FAO, 2022). According to Gadhok and Avesani (2021), in 2019, 37% of seafood entered international trade. Recent data shows that, since the 1960s, seafood destined for human consumption more than doubled (standing now at 20.2 kg per capita) and is expected to continue increasing with population growth (FAO, 2022). The largest seafood markets in the world are the European Union (EU), the United States of America (USA), China and Japan, which together were recipients of 68% of all traded seafood in 2020 (FAO, 2022).

The EU has a big demand for seafood (importing 60% of the seafood it consumes) and traceability systems in place are crucial to ensure some accountability of practices along the supply chains (for the UE and its seafood supply countries) (Poulsen and Leroy, 2021). Traceability and catch documentation are considered essential to ensure compliance with food safety regulations and combat Illegal, Unreported and Unregulated (IUU) fishing. As such, information about a product's value chain and journey is expanding to be increasingly technological, ensuring transparency, data security and easy access to information (FAO, 2022).

There are currently increasing concerns about seafood's fair and safe trade, such originating from IUU fishing, ethical issues, human rights violations, and food security issues (both in terms of health and supply access), most of which would benefit from an increase in transparency and traceability in seafood supply chains (Du et al., 2020; Tsolakis et al., 2021; Zhang et al., 2021).

1.2. SEAFOOD TRACEABILITY

There are several available definitions of traceability, such as the one by the International Organization for Standardization (ISO) 9000:2005 which describes it as "*the ability to trace the history, application or location of that which is under consideration*", or the definition by the European Union's (EU) General Food Law that defines it as "*the ability to trace and follow food, feed, and ingredients through all stages of production, processing and distribution*". In simple words, traceability is the collection and verification of information on the product's origin and movements. However, there are global gaps (in terms of commitment, technology, implementation standards and awareness) on what information should be included in the breadth

of traceability and what its applicability should be. This can result in a lack of interoperability and, therefore, act as a barrier to the strategic cooperation between different entities, with possible loss of key data regarding a seafood product (Borit and Olsen, 2016). Therefore, traceability could benefit from political and strategic cooperation and unification of what it encompasses (Blaha and Katafono, 2020).

Seafood traceability has gained increasing prominence. Making seafood products traceable from the point-of-catch to the point-of-sale is a necessary precondition to prevent IUU products and illicit fish trade from reaching markets, improve safety and security of products, as well as improve sustainability and governance, reduce adverse human rights impacts and safeguard the livelihoods of fisheries-dependent communities (Borit and Olsen, 2016; Lewis and Boyle, 2017; Longo et al., 2021; Teh et al., 2019). Traceability is also key to monitoring and accounting for the environmental and social credentials of seafood products (Lewis and Boyle, 2017).

Traceability systems can either be paper- or computer-based. Considering the international seafood trade and the increasing digitalization of all kinds of industries, the use of technological data-sharing solutions is expected to enhance seafood traceability and to be increasingly used in the future. The use of digital tools such as the ones based on Blockchain, Internet of Things (IoT), Radio Frequency Identification (RFID), and other technologies, has the potential to facilitate tracking the movement and origin of seafood within its supply chain.

1.2.1. Traceability requirement for seafood products in the European Union

The EU imports almost 60% of its seafood (CFP, 2022) and these products originate mostly from developing countries. Concerns with food safety, IUU fishing, sustainable fisheries and healthy fish stocks have resulted in EU regulation to improve the traceability of seafood products sold in the EU market, and also improved consumer information.

The EU regulation to prevent, deter and eliminate IUU fishing (Council Regulation (EC) No 1005/2008 of 29 September 2008) has established a Catch Certificate Scheme, with the aim to ensure that products originating from IUU fishing activities were prevented from entering the EU market. Under this Scheme, all fisheries imports entering the EU need to be accompanied by import documents (i.e., catch certificates). The large volume of catch certificates received annually, most of which were paper-based or scanned copies of paper certificates, has resulted in the EU launching, in 2019, a EU-wide digital database of catch certificates (known as CATCH).

The EU seafood traceability requirements, for fisheries control purposes, are outlined in Council Regulation (EC) No 1224/2009 of 20 November 2009, establishing a community control system for ensuring compliance with the rules of the Common Fisheries Policy (CFP). This regulation dictates

the requirements needed for seafood trade (of both wild caught and aquaculture products), from catching or harvesting to the retail stage.

Regulation (EU) No. 1379/2013 of 11 December 2013, establishes the common organization of the markets in fishery and aquaculture products (CMO), and defines the needs in terms of labelling for consumer information.

Regulations (EC) No. 1224/2009 and (EU) No. 1379/2013 set the rules on the mandatory and voluntary information to be provided for prepackaged and non-prepacked fishery and aquaculture products. The mandatory information required on the label of all fisheries and aquaculture products includes:

- the commercial and scientific name of the species,
- the fishing gear used or the production method,
- the production method ("…caught…" or "…caught in freshwater…" or "…farmed…"),
- the area where the product was caught or farmed,
- the category of fishing gear used,
- whether the product has been defrosted (with limited exceptions),
- date of minimum durability ('best-before' date) – where appropriate.

The voluntary basis information recommended on the label of all fisheries and aquaculture products includes:

- date of catch of fishery products or date of harvest of aquaculture products,
- date of landing of fishery products or information on the port at which the products were landed,
- more detailed information on the type of fishing gear,
- in the case of fishery products caught at sea, details of the flag State of the vessel that caught those products,
- environmental information,
- information of an ethical or social nature,
- information on production techniques and practices,
- information on the nutritional content of the product.

In addition to the mandatory information set by Regulation (EU) No. 1379/2013, prepacked products must also display all the relevant information specified in Articles 9 and 10 of Regulation (EU) No. 1169/2011 of 25 October 2011 on the provision of food information to consumers.

Figure 1 provides a schematic representation of the information required in seafood labels by the European Union.

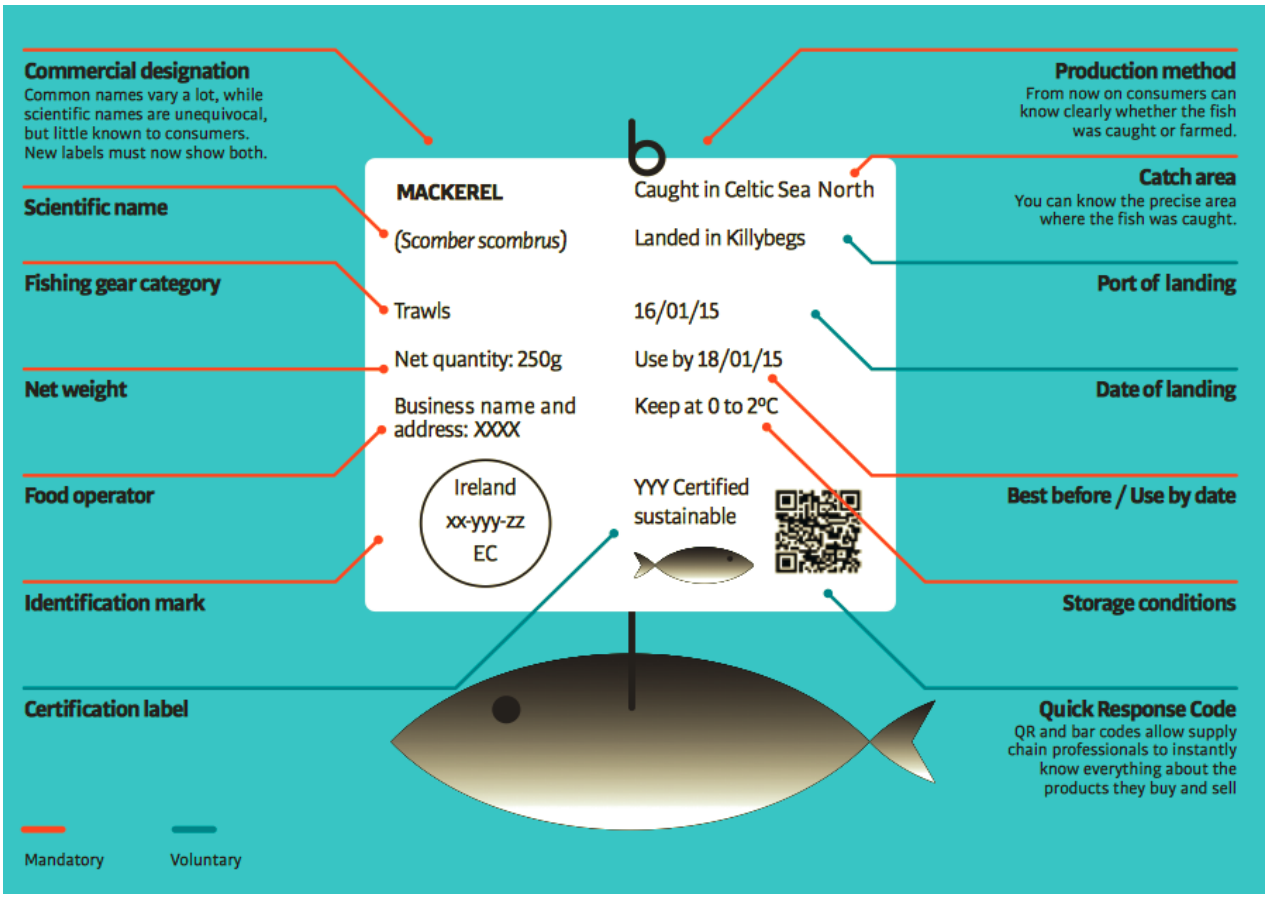

Figure 1. Information required in seafood labels by the European Union (Source: European Union, 2015).

The EU is in the process of reviewing its rules on seafood traceability as part of the revision of its fisheries control system. There are calls for an EU-mandated traceability system. Such a system would encourage transparency and accountability in the EU, but also beyond the EU in international seafood supply. In March 2021, the European Parliament (EP) voted for seafood products in the EU market to be digitally traceable from the point of catch to the point of retail. On the 30th of May 2023, an agreement was reached between the EP and the European Council Presidency on an update of CFP rules regarding, amongst other, the traceability of fish products. According to the agreed text, information on fresh and frozen fish will be fully accessible, including digitally, to safeguard food safety and consumer interests. This system of digitalized traceability will also be extended to cover processed fish in five years[1].

[1]https://www.europarl.europa.eu/news/en/press-room/20230526IPR92701/fisheries-deal-reached-on-new-rules-to-improve-compliance-and-traceability

More recently, Regulation (EU) No 2023/2842 was adopted by co-legislators (on 22 November 2023, and formally implemented on the 9th of January 2024), amending the EU legislative framework to shorten the gap between the Common Fisheries Policy (CFP) and other EU policies, improving fisheries control systems (such as tracking of fishing vessels) and, among others, enhancing traceability of fishery products in supply chains (Article 58). This regulation states that:

- Lots from fisheries and aquaculture available on the market must be marked appropriately to ensure traceability,
- In order to improve effectiveness, information on products falling under Chapter 3 of the Combined Nomenclature[2] has to be made available in a digital way to the operator to whom the fishery or aquaculture product is supplied, and, upon request, to the competent authorities,
- The European Commission will conduct a study on minimum traceability information and feasible existing digital solutions or methods to enable effective traceability of fisheries and aquaculture products, considering the impact on small operators,
- There are exceptions to traceability rules for small quantities sold directly from fishing vessels to consumers (maximum of 10 kg per consumer per day) provided that the products are only used for private consumption. This small threshold will be established to minimize the lack of traceability and illegal trade.

The application of this regulation will be gradual. For the first time full digital traceability will be mandatory along the supply chain, and needs to be fully in place by January of 2029.

1.3. OBJECTIVES AND STRUCTURE OF THE DELIVERABLE

Technology is expected to bring more transparency, trust, efficiency, market opportunities and other benefits to seafood industries. However, several challenges encompass traceability implementation and its digitalization.

The present document aims at identifying the main incentives and barriers to the implementation of seafood blockchain, based on (i) a review of the literature, and (ii) a survey of key stakeholders. The report is organized into 5 sections:

- Section 1 presents an introduction to traceability and the purpose of this deliverable;

[2] This refers to fish and crustaceans, molluscs and other aquatic invertebrates established by Council Regulation (EEC) No 2658/87

- Section 2 describes blockchain, its history, and the use of blockchain as a seafood traceability tool;
- Section 3 describes the incentives and barriers to seafood blockchain in fisheries and aquaculture, based on a review of the literature;
- Section 4 provides examples of several initiatives using blockchain technology to trace seafood from catch to consumer;
- Section 5 describes the incentives and barriers to the implementation of blockchain traceability in seafood value chains (in both the fisheries and aquaculture sectors), based on information collected during interviews with key stakeholders in the seafood value chain;
- Section 6 presents the conclusions of this report.

2. BLOCKCHAIN

In this section we describe what is blockchain, how it first came to be, its utility, and briefly discuss the different types of existing blockchains (section 2.1), we also discuss the reasons why blockchain should be used as a form of traceability in the seafood sector (section 2.2).

2.1. WHAT IS BLOCKCHAIN

According to Ruoti et al. (2019), blockchain's core concepts emerged in the late 1980's, early 1990's. One of the most recognized descriptions of blockchain is in the work of researchers Haber and Stornetta (1991), where they discuss timestamps that could not be tampered with. In 2008, an anonymous person or group of people (under the name "Satoshi Nakamoto") conceptualized the decentralized blockchain in a paper entitled "Bitcoin: A Peer-to-Peer Electronic Cash System" (Nakamoto, 2008). The following year, Nakamoto used this technology to design the bitcoin cryptocurrency, which today is one of the most well-known forms of application of the blockchain technology.

Blockchain technology builds a digital ledger of transactions. As the name implies, this ledger is formed by a chain of blocks of information (Figure 2). Each block contains a digital impression that identifies the particular block (the current transaction), called hash or label. The first block of information (the genesis block) only has one hash. Every other block in the chain has the hash from the previous block (data) containing transaction details and timestamps (Di Pierro, 2017; Lin et al., 2021).

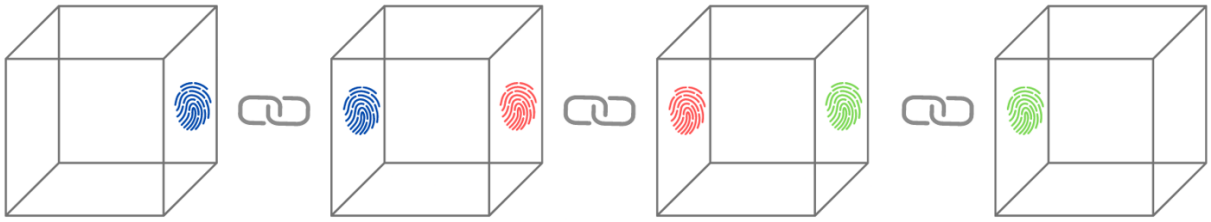

Figure 2. Schematic representation of how blockchain traceability connects blocks of information, each with specific hashes. Adapted from Seafood Alliance Legality and Traceability (SALT, 2021).

This is a decentralized ledger, which means there is no authority managing the whole database (Blaha and Katafono, 2020). Instead, the data is distributed peer-to-peer (P2P), between all the different participants of the blockchain ledger. This way, data is verified when there is a consensus of its validity between all participants, meaning a synchronization of the transaction ledger is in place (powered by consensus algorithms) (Lin et al., 2021). When new information is added to the blockchain, it is sent to everyone on the network and each node verifies it.

These characteristics make it a secure and tamper proofing technology, because:

1. If a block is changed, for example, if it is tampered with, its hash changes, which means the hash in the next block changes too and an error is detected, making the chain invalid and not allowing transactions,
2. When a transaction happens, there is no way to delete that information. The data becomes immutable, unless the majority of the participants in the blockchain agree to change some information within it.

Blockchains can be public, private or a consortium. Public blockchains are open, so anyone can join to either view information or help verify it. This makes the database free to access and completely transparent, but, in some cases, there can be issues regarding the energy requirements to validate the transactions and, with this, concerns arise regarding blockchain sustainability. On the other hand, private blockchains are restricted to only include certain participants and restrict who can see the transactions. This way, the public is only allowed to see selected information which is disclosed. Finally, consortium blockchains are a hybrid between private and public, since the network is managed by a group of entities and not just by a single entity (which is what happens in private blockchains). Consortium blockchains allow information sharing that can enhance transparency across several businesses, including the seafood sector.

There are multiple blockchain platforms (as can be seen in Section 4 regarding "Examples of Seafood Blockchain Initiatives"), each with different characteristics. According to Blaha and Katafono (2020), the two most common blockchain platforms applied in seafood value chains are:

- Ethereum: decentralized applications (DApps) can be built from it, with a big community of active developers surrounding it and a native cryptocurrency associated,
- Hyperledger: mostly used in the International Business Machine Corporation's (IBM) blockchain solutions, hosted by the Linux Foundation; it is a solution made possible by the collaborative effort of cross-industry blockchain technologies.

Besides these, there are other solutions and tools that can be found in Section 4, such as:

- Quadrans: open source, public and decentralized blockchain, this platform seems to be particularly environmentally oriented, as it is being developed to ensure there is minimal energy consumption in creating new blocks of information and sharing data (Quadrans Blockchain, 2023),
- Viant: a tool to improve Ethereum's efficiency in supply chain traceability systems. It uses the Proof of Authority consensus mechanism, a type of algorithm to achieve consensus within the blockchain system that achieves greater performance and energy efficiency (Cook, 2018).

Potential blockchain applications include digital payments and cryptocurrencies, smart contracts (self-executing contracts), asset trading, database management and market transactions (Ruoti et al., 2019). Blockchain can be used for recording and allowing transactions within value chains of different products, including seafood.

2.2. BLOCKCHAIN IN FISHERIES AND AQUACULTURE

As described before, blockchain is a decentralized system that allows for tamper-proof data to be exchanged between stakeholders in a transparent way. The use of this technology in seafood value chains can enhance traceability and transparency regarding products and their transactions.

Blockchain can be used to connect different stakeholders along the value chain, from producers to final consumers (Figure 3). This technology allows data to be exchanged securely, with each stakeholder having access to selected information. For instance, when choosing to buy a seafood product, the blockchain solution may be programmed so that consumers are allowed to access information about who, when and where produced, processed and/or transported the product. This allows actors to make conscious decisions regarding what they consume and might add value to products that are produced in a more transparent way.

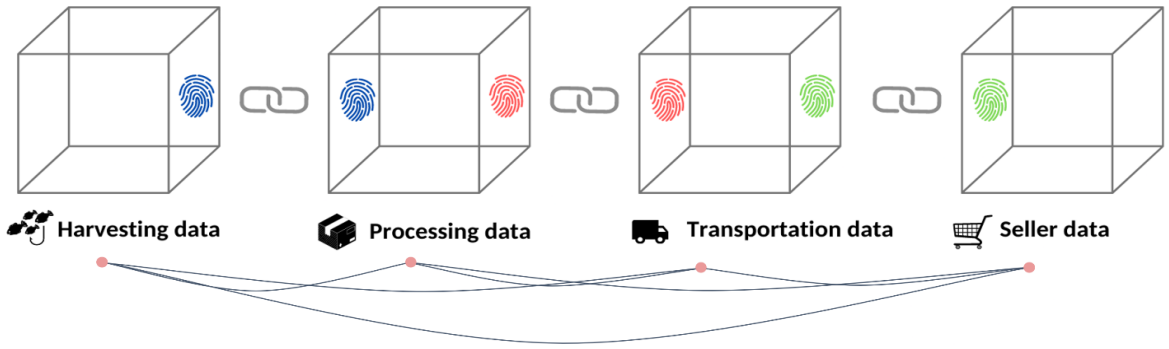

Figure 3. Schematic example of a seafood blockchain with possible connections between value chain actors. Adapted from Seafood Alliance Legality and Traceability (SALT, 2021).

Transparent interactions between value chain actors lead to increased trust-based relationships and to a fairer and sustainable seafood trading system (Lin et al., 2021; Zhang et al., 2021). Avoiding seafood fraud also avoids quality and health concerns for consumers and helps combat IUU fishing (Senguptaet al., 2021; Tsolakis et al., 2021; Zhang et al., 2021).

There are several technological solutions for seafood traceability such as RFID, Near Field Communication (NFC) and Quick Response (QR) codes but, according to Patro et al. (2022), these do not work as well as blockchain since they are not tamper-proof nor decentralized, leaving space for more vulnerabilities. Additionally, these tools do not work as well for fragmented data, which is common in seafood value chains. Some RFID tags, for example, are very prone to damage during transportation; meanwhile, by using blockchain it is possible to create a digital profile and add a QR-code to the product. DNA barcoding methods, the identification of geographic origin and other morphological identification are also used for enhancing seafood traceability, but they are susceptible to data tampering since they involve manual activities.

2.2.1. Sea2See blockchain

Sea2See blockchain innovative platform will be built upon the existing prototype of blockchain model (Tilkal blockchain tool, currently live or in deployment (Technology Readiness Levels (TRL) 6 to 9) in food, cosmetics and textile sectors). Additionally, a prototype has been developed as a result of one small-scale project for a blockchain platform with TRL 7 in the seafood industry on a short value chain, which will serve as a basis for Sea2See.

The Tilkal platform is based on a permissioned blockchain that uses the Multichain technology. A permissioned blockchain is a decentralized ledger that requires permission to access and use. Only a specific group of participants who have been granted access by the network administrators can

join and use the network. Tilkal's permissioned blockchain uses a PBFT algorithm (Practical Bizantine Fault Tolerant), a "round robin" type, where there is a random validation of each block. It does not require a significant amount of energy.

In contrast, public blockchain is a decentralized ledger that is open to anyone who wants to participate, typically used for cryptocurrencies, such as Bitcoin. They use a proof-of-work (PoW) consensus algorithm, which requires nodes to solve complex mathematical problems to validate transactions and add new blocks to the blockchain. This process is computationally intensive and requires a significant amount of energy, as nodes compete to be the first to solve the problem and earn a reward.

The Sea2See blockchain network creates a distributed database based on a protocol which ensures that no one can modify the data posteriori. The system includes encryption and complete auditability for each member. The system allows sharing data through a specific format with predefined content to extract entities from the notarized message.

Main advancements of the Sea2See blockchain: Adding new predefined content such as Life Cycle Analysis (LCA) analysis of the value chain, and more advanced industry-specific data. Add data quality assessment to verify coherence and completeness. Existing small-scale platforms will be extended with new industry-specific algorithms powered by AI and additional platforms to be fully functional for the European seafood industry. Sea2See blockchain technology consolidates and analyses data from these value chains, in a system that is flexible enough to adapt to the changes of the value chain. At the end of the value chain, it provides transparency to end consumers. On the one hand, data collection has to adapt to the physical reality of each working conditions in the field as well as to what is measured: from automated measures through the Internet of Things (IoT), to manual entries through a mobile app, to passive or active tags, etc., from bulk measures to individual tracking, from volume measures to practice evaluation. On the other hand, all of the above-stated data shall be collected and aggregated to build a “360° traceability view”. As some data collected on the field might be wrong (mistake, broken sensor, fraud, etc.) the collection of data from field sources shall be fully traced and immutable, with multiple verifications after the data notarization to track any data incoherence. The system will be opened enough to be enriched by new measures over time, to be enriched by new actors in the supply chain, and to provide its traceability data in more or less “open data” for various usage (marketing, optimization, product control or even recall, regulation and customs, etc.).

3. METHODS

Blockchain traceability can be used for both fisheries and aquaculture products, and it is to be expected that the challenges and opportunities faced by each industry may be different. In this section we describe the incentives and barriers to seafood blockchain in fisheries and aquaculture. The identification of incentives and barriers to seafood blockchain is based on a systematic review of the literature and, in section 3.1, we describe the methodology used for the review. Section 3.2 describes and discusses incentives to seafood blockchain for fisheries and aquaculture, and section 3.3 describes and discusses barriers to seafood blockchain for fisheries and aquaculture.

3.1. SYSTEMATIC REVIEW OF THE LITERATURE

A systematic review of the literature was undertaken to identify challenges and opportunities for the implementation of blockchain traceability systems in the seafood sector.

3.1.1. Search strategy and inclusion criteria

The literature search was carried out by searching all databases in Scopus and ISI Web of Science (WoS). A sensitive systematic search strategy combining the terms 'blockchain', with 'seafood', 'fisheries', 'fishery', 'aquaculture', 'aquatic food', 'aquatic supply chain', 'aquatic value chain', 'aquaculture value chain', 'seafood value chain', 'seafood supply chain', 'aquaculture supply chain' or 'aquatic supply chain', and 'barrier', 'problem', 'challenge', 'difficulty', 'impediment', 'obstacle', 'struggle', adversity', 'hindrance', opportunity', 'incentive', 'benefits', 'motivation' or 'advantage' and their synonyms, and using the truncation features of the databases. Titles and abstracts were scanned by all authors to identify studies potentially eligible for inclusion. No major disagreements arose regarding the studies selected for inclusion. The full text of the initially selected studies was then retrieved, and a further selection process undertaken. References in all relevant papers were screened for additional papers.

Criteria for inclusion in the rapid review were restricted to the following:
(1) the study focused on blockchain in seafood,
(2) the studies identified challenges or opportunities regarding the use of blockchain,
(3) the study was published in a peer-reviewed journal indexed in the databases up to December 2022.

The review question was intentionally left broad with the aim of identifying all articles. To the best of our knowledge, no previous attempt has been made to systematically review any of the work published in this topic. Also, and although systematic reviews often benefit from spatial restrictions

as country and cultural context may severely impact outcomes (Egan et al., 2009), no geographic, sectoral (we included both the fisheries and aquaculture sectors) or language restrictions were included in the search in order to collect all available data (i.e., although the search terms were in English, due to all the databases searched being indexed and having titles and abstracts available in English, no studies were excluded on the basis of being published in another language). Overall, a total of 65 papers were identified through Scopus (n=36) and WoS (n=29). Of those, 50 were excluded due to being a duplicate or not fulfilling the inclusion criteria. In total, 15 full text documents were selected and included in the review (Figure 4).

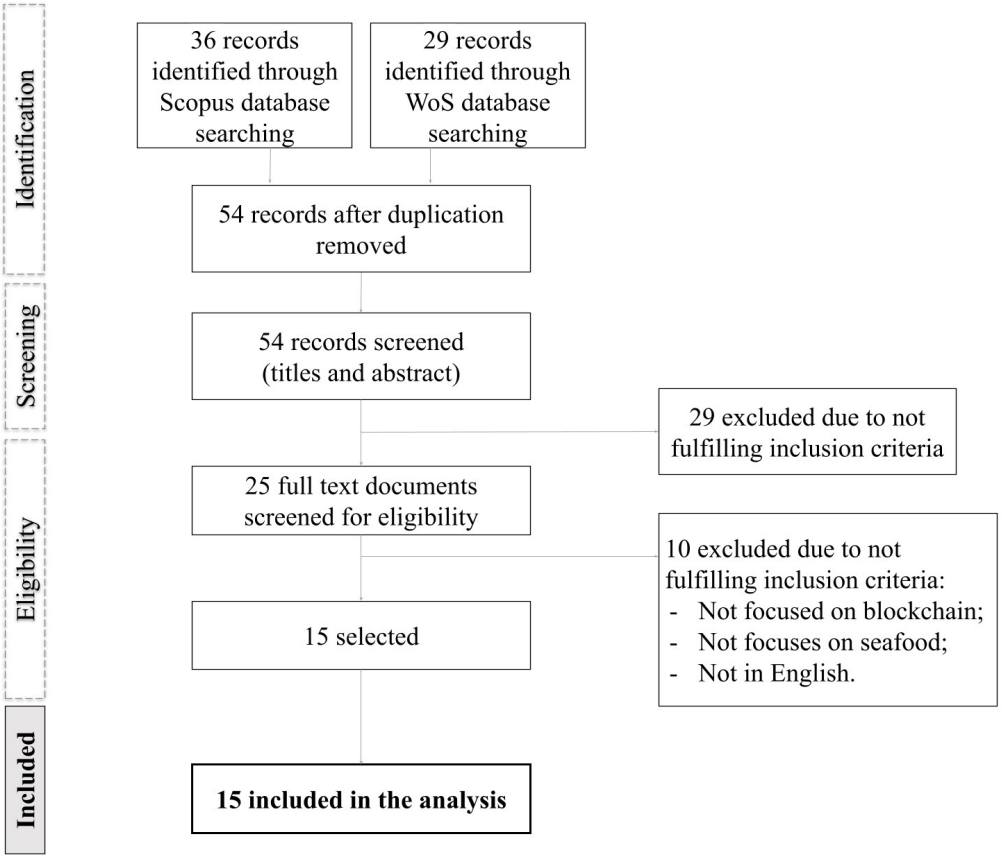

Figure 4. Flowchart showing the stages of identification of the studies in the systematic review.

3.1.2 Data extraction and analysis

A database was created with the essential information extracted from the papers, this included:

- Topics covered,
- Sector (fisheries, aquaculture or both),
- Governance aspects,

- Supply chain identified,
- Challenges to using blockchain,
- Incentives to using blockchain.

The articles were analysed descriptively. The literature review provided an overview of the use of blockchain in different seafood value chains worldwide, mapping motivations and/or barriers to its implementation in fisheries and aquaculture, and providing important insights into the potential use of blockchain by different segments of the seafood value chain.

3.2. STAKEHOLDER CONSULTATION

3.2.1 Survey

To further identify the main barriers and potential incentives for the implementation of blockchain traceability on seafood value chains a survey with key stakeholders was conducted in the countries where Sea2See solutions are being developed (Portugal, Spain, France and Greece). These surveys were designed to collect information about the challenges and opportunities of implementing seafood traceability based on findings from the literature review. The interviews were carried out in the official language of the interviewee and subsequently, all answers were translated to English.

3.2.2 Stakeholders consulted

Stakeholders identified in Deliverable 1.1 were contacted, including seafood value chain actors (producers/processors/distributors/etc.) related to each Sea2See project case study, seafood administration/policy professionals, researchers and consultants. A total of 36 key stakeholders were consulted: 16 from Portugal, 8 from Greece, 7 from France and 6 from Spain. Figure 5 shows a characterization of the consulted stakeholders.

Many interviewed stakeholders claimed to work in different seafood sectors at the same time, but the most mentioned sectors, in general, were research (24%) and aquaculture production (24%), followed by, fisheries (11%), seafood supplier (11%), certification (6%) and export/wholesale (4%). Around 15% work on “other” categories including NGOs, catering services, consumer protection organizations, interprofessional seafood associations, business analysis, information and scientific consultancy.

Spanish, Portuguese and Greek stakeholders interviewed are quite experienced in the seafood industry, having worked for more than 20 years in the sector. French stakeholders interviewed have worked for an average of 10 years in the sector (Figure 5). Considering all the stakeholders interviewed, the mean amount of professional experience in the seafood sector is 23 years.

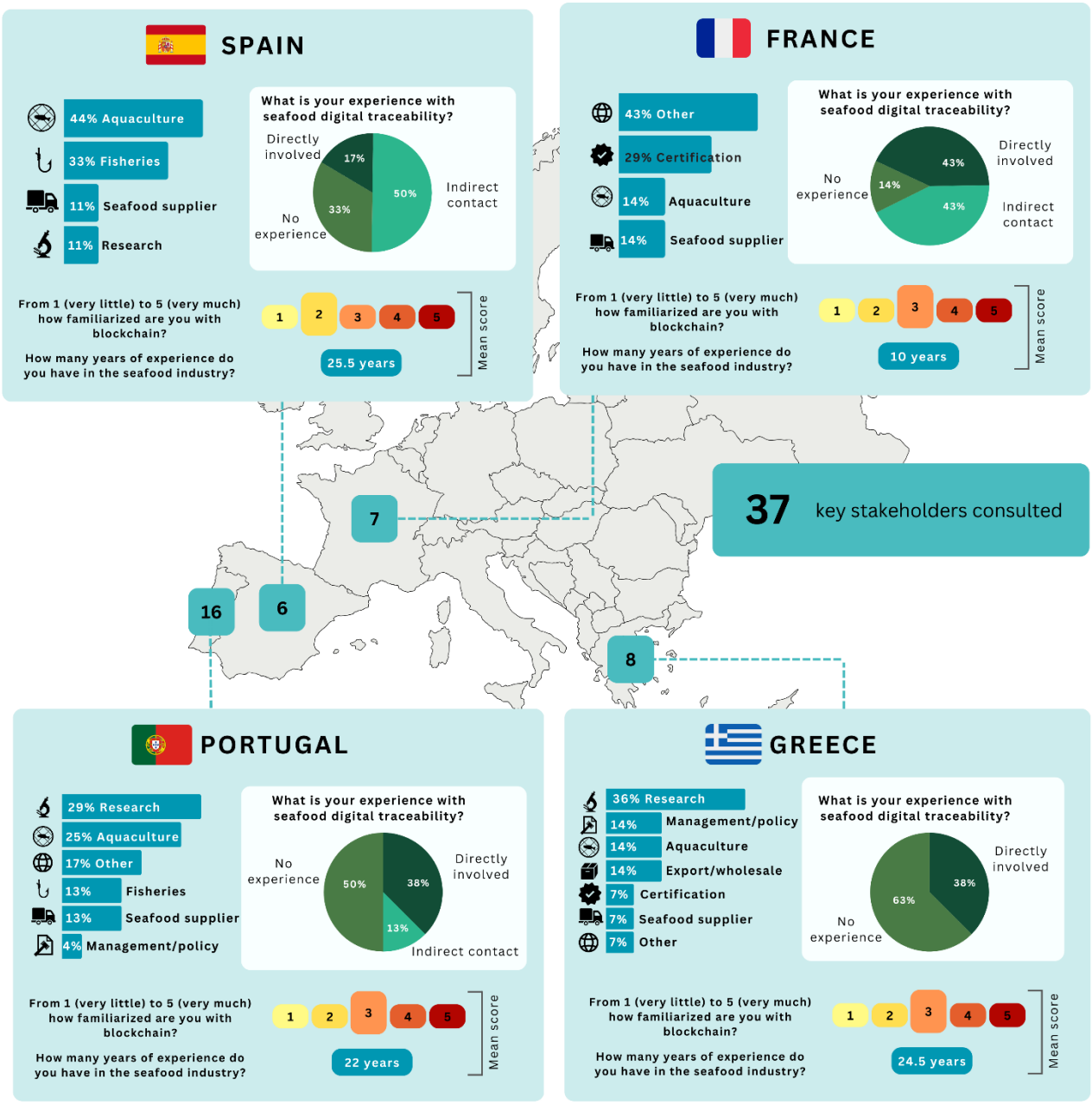

Figure 5. Characterization of the key stakeholders consulted from each country.

Regarding stakeholders' experience with seafood digital traceability, most stakeholders interviewed in Spain and France reported to have indirect experience with traceability, while in Portugal and Greece, most stakeholders reported to not have experience with traceability.

In general, stakeholders reported to be somewhat familiar (scale “3”) with blockchain (Spain being the country where the mean answers were “2”).

4. LITERATURE REVIEW ON INCENTIVES AND BARRIERS TO BLOCKCHAIN

4.1. INCENTIVES TO BLOCKCHAIN IN SEAFOOD SUPPLY CHAINS

Table 1 shows the incentives to using blockchain in fisheries and aquaculture as identified in the literature. A total of 17 incentives to the implementation of blockchain were identified in the literature.

Table 1. Result from the systematic review of the literature on incentives to the implementation of blockchain in fisheries and aquaculture value chains.

Incentives to blockchain in fisheries and aquaculture			
	Fisheries	**Aquaculture**	**Reference**
Improve efficiency (e.g., time, transactions)	✓	✓	Afrianto et al. (2020); Du et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Hang et al. (2020); Jaya et al. (2021); Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Rahman et al. (2021); Tsolakis et al. (2021); Zhang et al. (2021).
Improve traceability	✓	✓	Afrianto et al. (2020); Du et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Hang et al. (2020); Jaya et al. (2021); Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Rahman et al. (2021); Sengupta et al. (2021); Tsolakis et al. (2021); Zhang et al. (2021).
Identification of origin/source	✓	✓	Afrianto et al. (2020); Du et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Hang et al. (2020); Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Tsolakis et al. (2021); Zhang et al. (2021).
Increase value chain trust	✓	✓	Afrianto et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Hang et al. (2020); Jiang and Ræder (2022); Lin et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Rahman et al. (2021); Sengupta et al. (2021); Tsolakis et al. (2021); Zhang et al. (2021).
Increase public acceptance and trust	✓	✓	Afrianto et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Hang et al. (2020); Jiang and Ræder (2022); Lin et al. (2021); Patro et al. (2022); Rahman et

			al. (2021); Sengupta et al. (2021); Tsolakis et al. (2021); Zhang et al. (2021).
Demonstration of compliance (with rules and regulations, with certification schemes)	✓	✓	Gopi et al. (2019); Hang et al. (2020); Jaya et al. (2021); Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Rahman et al. (2021); Tsolakis et al. (2021); Zhang et al. (2021).
Real-time access to information	✓	✓	Garrard and Fielke (2020); Gopi et al. (2019); Jiang and Ræder (2022); Lin et al. (2021); Mondragon et al (2020); Patro et al. (2022); Tsolakis et al. (2021); Zhang et al. (2021).
Ability to apply for certification/labeling	✓	✓	Garrard and Fielke (2020); Korneyko and Podvolotskaya (2019); Zhang et al. (2021).
Food safety (food quality)	✓	✓	Patro et al. (2022); Tsolakis et al. (2021); Zhang et al. (2021).
Stop IUU fishing	✓	✗	Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Patro et al. (2022); Tsolakis et al. (2021).
Improve market opportunities	✗	✓	Afrianto et al. (2020); Du et al. (2020); Garrard and Fielke (2020); Zhang et al. (2021).
Data security and decentralization	✓	✓	Afrianto et al. (2020); Patro et al. (2022); Zhang et al. (2021).
Enhance reputation, accountability and ethics	✓	✗	Lin et al. (2021); Tsolakis et al. (2021)
Environmental sustainability	✓	✓	Hang et al. (2020); Tsolakis et al. (2021).
Community empowerment and relationship improvement	✓	✗	Lin et al. (2021).
Human rights and social sustainability	✓	✗	Tsolakis et al. (2021).
Reduce costs of information exchange	✗	✓	Zhang et al. (2021).

From the total of 17 incentives to the implementation of blockchain identified in the literature, the most popular were enhancing traceability and improving efficiency, followed by identifying the origin/source of the products, increasing value chain actors and consumers trust, amongst others (Figure 6).

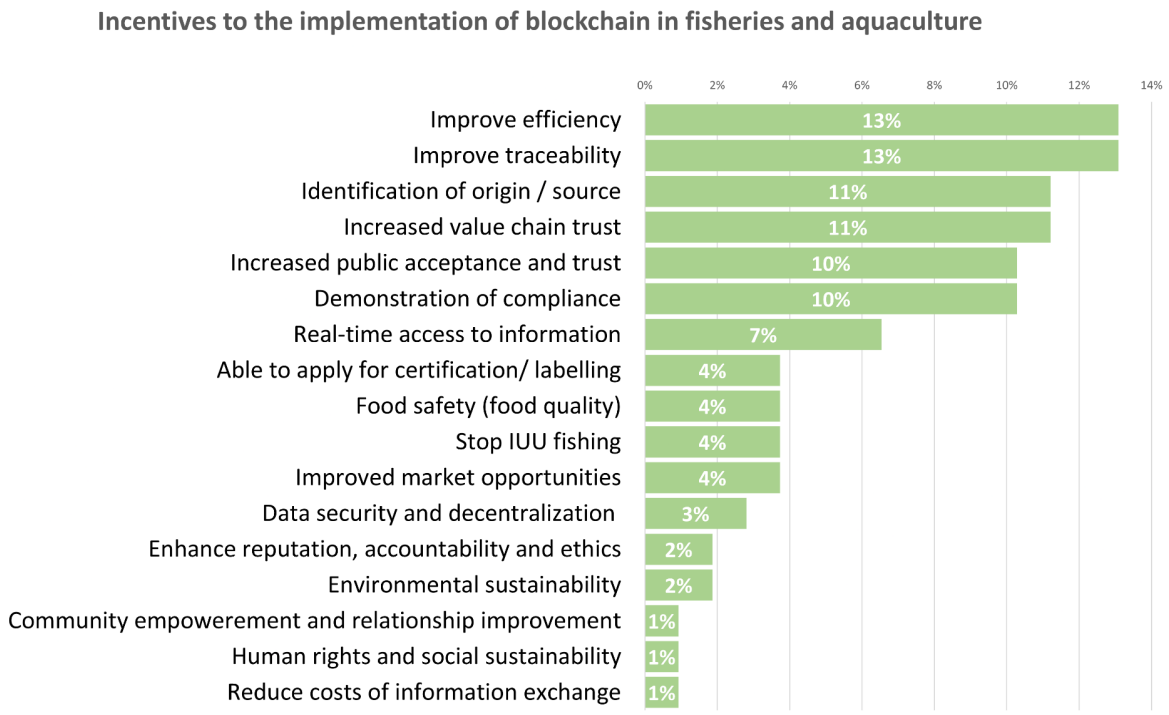

Figure 6. Incentives to the implementation of blockchain in seafood value chains (fisheries and aquaculture) as identified in the systematic review of the literature.

Most incentives, but not all, were common to the aquaculture and fisheries sectors. In this section, we discuss in detail the incentives identified in the literature and, in case of differences between sectors, we provide information on how they apply to the aquaculture and fisheries sectors (Figure 7).

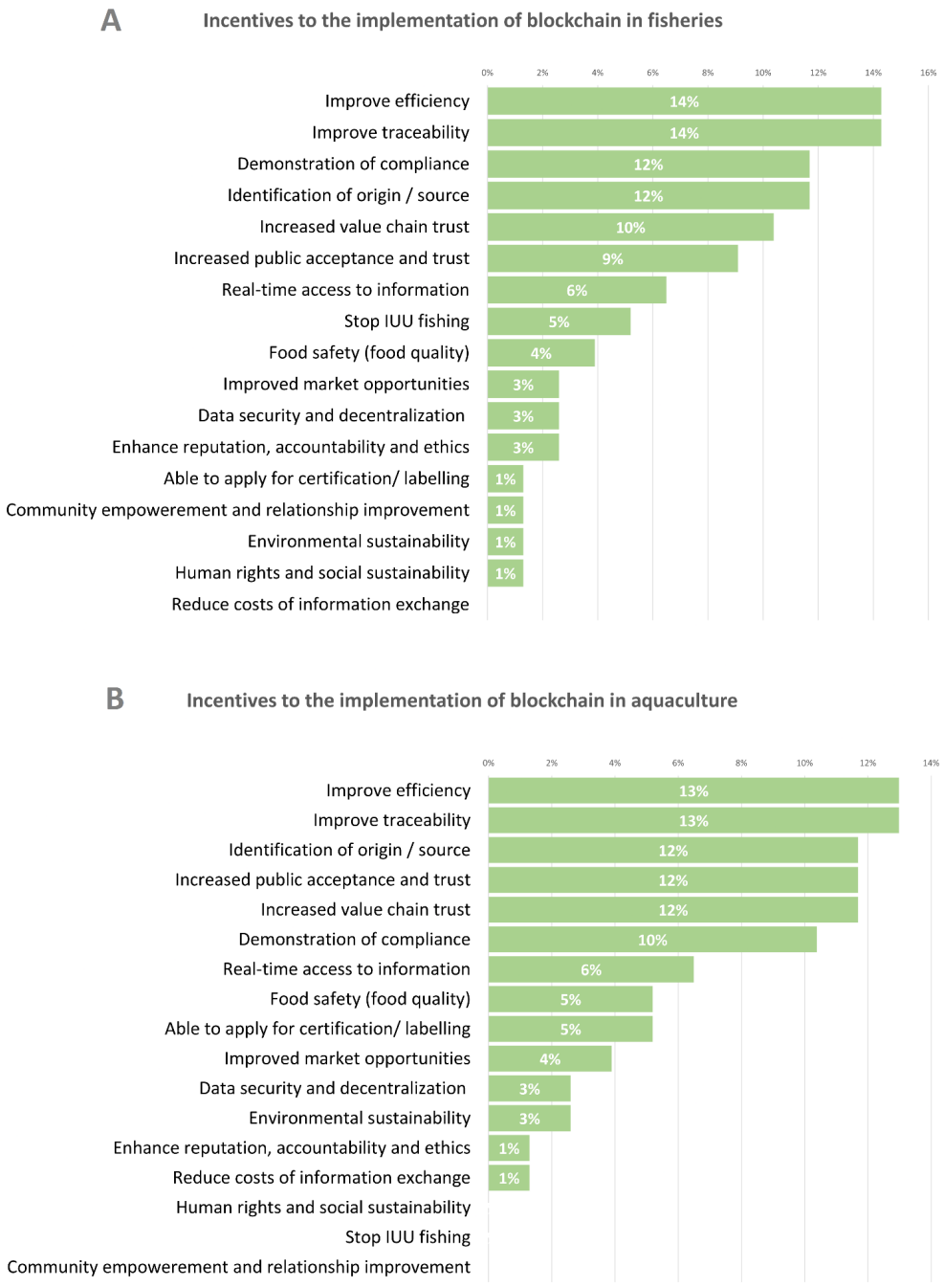

Figure 7. Incentives to the implementation of blockchain in (a) fisheries and (b) aquaculture value chains as identified in the systematic review of the literature.

Improve efficiency

Seafood value chains can be complex systems that deal with a significant amount of information and actors. Blockchain technologies can improve efficiency by connecting information and actors

in an easy real-time accessible network that has a good response time of operation and prevents data manipulation (Jaya et al., 2021; Zhang et al., 2021). There are reports that show that real-time data availability and transparency improve the efficiency of transactions, in particular, within aquaculture value-chains (Jiang and Ræder, 2022). To add to this, according to Korneyko and Podvolotskaya (2019), the use of digital tools substitutes a large number of papers/physical documents, decreasing the time taken to ensure traceability.

Improve traceability

All the blockchain characteristics (already described), including the fact that it cannot be tampered with and the amount of information it can store and transmit in real-time, enhance traceability in seafood in general. Lin et al. (2021) refer that blockchain enhances efficient traceability of seafood and, in the case of the fisheries sector, blockchain could trace seafood to the individual fisher who caught it. In the case of aquaculture, Sengupta et al. (2021) refer that blockchain might also address issues related with food-fraud, food waste and food safety.

Allow for the identification of origin/source

With blockchain, it is possible to easily trace the source of a seafood product, which can be very helpful for consumers to be more aware of their choices, to prevent a food safety outbreak, to identify the origin of the product, and to guarantee a product's authenticity (Lin et al., 2021). Information on the origin of the seafood (as well as identifying the several steps from catch/production to sale, such as processing and transportation) improves the product's reliability not only for consumers, but also for producers, retailers, and all other value chain actors. According to Jiang and Ræder (2022) this proof of authenticity might add value to seafood products.

Increase value chain trust

Blockchain tools contribute to increasing trust in and acceptance of seafood and also of traceability itself amongst all actors in the value chain (including consumers). The increase in data sharing, security and accountability, improves mutual trust amongst value chain actors (Zhang et al., 2021), including producers, processors, retailers and governments/regulator entities. Lin et al. (2021) refers that the blockchain decentralized system (which means there is not a particular entity that owns the data) and immutable data allows to build trust among value chain actors, since the database is secure and the data cannot be tampered with. Besides these characteristics, smart contracts also enhance compliance with value chain processes and, therefore, increase the confidence of actors (Mondragon et al., 2020). The automatization and digitalization of the value chain processes makes it easier to avoid data mistakes or non-compliances within the seafood

sectors, improving trust in the technology used and in the seafood produced, and improving transparency between the actors that operate it (Lin et al., 2021).

Increase public acceptance and trust

The use of blockchain technology in seafood traceability has been reportedly increasing consumers' trust in seafood products. Consumers are increasingly interested in knowing where their seafood comes from, if it is environmentally friendly and if it involves ethical working conditions (Tsolakis et al., 2021), therefore, these digital tools resonate in general with consumers. With blockchain technology, consumers are able to access information that allows them to make more conscious purchase decisions and, as such, it increases their trust in the product (Gopi et al., 2019; Lin et al., 2021).

Reports of improvement in consumer trust usually come together with reports of increases in the accuracy of data reporting and aquatic food quality information - such as in Tsolakis et al. (2021) or Zhang et al. (2021) - which, consequently, improves transparency, safety and reliability within the seafood sector. In particular, this has allowed consumers to gain confidence in blockchain and aquaculture (Hang et al., 2020).

Demonstration of compliance

Since aquaculture industries have to comply with specific chemical and physical parameters in their production, those that use blockchain traceability technologies have an easier way to prove their legal status and responsibility with regards to the quality of their seafood. In aquaculture, this demonstration of compliance is related with seafood safety and animal welfare and can contribute to increasing consumer trustworthiness in the sector (Zhang et al., 2021).

In the fishery sector, blockchain traceability is seen as a way to ensure regulatory compliance with legal and ethical sourcing and allows for efficient regulatory audits (Lin et al., 2021). Tsolakis et al. (2021) further describe blockchain traceability as a way to ensure seafood quality and safety and, at the same time, ensure that fisheries are performing in a responsible way and not misleading consumers about the origin of the product.

Real-time access to information

Blockchain technologies allow for the real-time access to information at any point in the seafood value chain, which reinforces its transparency and efficiency (Jiang and Ræder, 2022; Zhang et al., 2021). Real-time access to information and historical data about seafood products is a motivation to use blockchain technologies in seafood traceability. With value chains having complex

transactions, real-time information is a relevant feature for different parties to be able to check all records being made (Zhang et al., 2021).

Ability to apply for certification/labelling

Most literature points to the fact that with blockchain technologies in place (to ensure a transparent data-sharing system and information tracking) mislabelling is reduced and chances of getting a certification/label can be improved. For instance, Lin et al. (2021), presented the case of a traceable solution for a tuna value chain called TraceTales, which allowed for the automated print of labels, giving actors more trust in the product and the accuracy of information.

Food safety (food quality)

Food safety is an important topic in seafood, and in particular for aquaculture products. The transparency promoted by blockchain traceability tools ensures that the production, storage and transportation of seafood is done in accordance with quality parameters and ensures food safety, which potentiates consumers trust to acquire these products (Du et al., 2020; Tsolakis et al., 2021; Zhang et al., 2021). According to Tsolakis et al. (2021), seafood quality can also be ensured in fisheries by using blockchain technologies. This relates to the elimination of IUU fishing and with the possibility of having a mechanism that easily verifies food quality and traces seafood back to its origin if any concerns arise.

Stop IUU fishing (specific to the fisheries sector)

Studies indicate that blockchain traceability helps eliminate IUU fishing by improving the visibility of exploitation practices and supporting regulatory entities to identify responsible actors (Tsolakis et al., 2021).

Improve market opportunities (specific to the aquaculture sector)

The aquaculture sector has reportedly had market advantages with the implementation of blockchain traceability. Zhang et al. (2021) refer that the increase in consumers' trust in aquaculture products makes the use of these tools a competitive advantage and might lead to improved market opportunities. There are no studies about the real costs of implementing and maintaining this technology in seafood value chains, so it is difficult to evaluate the costs and economic return. The fact that this opportunity was not reported for fisheries might relate to the lack of knowledge about it, but can also be due to smaller businesses, such as SSF value chains, lacking economic capital to risk the investment in blockchain (Lin et al., 2021).

Data security and decentralization

The blockchain decentralized system and database management is by itself considered to be an opportunity to record business transactions in a secure way for both the fisheries and aquaculture sectors. These characteristics have been mentioned by Patro et al. (2022) and Zhang et al. (2021) as motivations for implementing blockchain. The cryptography used in this tool improves the security of transactions, and the reliability and decentralization of this technology allows for a solid distributed system that is access-free and fair.

Enhanced reputation, accountability and ethics (specific to the fisheries sector)

The transparency promoted by blockchain technology allows all involved parties to confirm ethical work conditions and seafood production and holds everyone accountable (Lin et al. 2021). These incentives of blockchain have only been referred to in fishery studies, but it is to be expected that blockchain has the potential to enhance any entity's reputation for ethics and sustainability.

Environmental sustainability

Blockchain traceability contributes to preventing food waste, the equal distribution of surplus food, and allows seafood industries and consumers to be aware of their ecological footprint (Hang et al., 2020; Tsolakis et al., 2021).

Tsolakis et al. (2021) also refer to the United Nations (UN) Sustainable Development Goal (SDG) 14 "Life Below Water", stating that blockchain technologies can monitor and inform consumers about fisheries activities and how their exploitation is affecting ocean life. This study highlights several blockchain advantages from a sustainability perspective, such as increasing the visibility of the environmental impact of food, enabling the identification of foodborne illnesses, and helping promote a circular economy. This way, it potentially helps to conserve marine ecosystems and create adequate regulations.

Community empowerment and relationship improvement (specific to the fisheries sector)

According to Lin et al. (2021), blockchain can enhance the fishing communities' empowerment by giving them access to information and promoting more transparent, responsible and efficient practices. It can also promote accountability of decision-making (Tsolakis et al., 2021).

Human rights and social sustainability (specific to the fisheries sector)

Enhancing the transparency of seafood value chains means it is easier to understand if workers and communities are engaged in an equitable system. Tsolakis et al. (2021) pointed out different UN SDGs, which can be addressed when using traceability tools like blockchain. Even though these are

addressed in regard to the fisheries sector, blockchain can also potentially enhance social aspects in aquaculture industries. Tsolakis et al. (2021) mention in their study that blockchain can address SDG 1 "No Poverty" (it allows for an increase in the visibility of fish captured by traditional fishers and, with this, allows for more exports and enhancement of household incomes), SDG 5 "Gender Equality" (it can help increase the visibility of women's role in the seafood industry and enhance gender equity), SDG 8 "Decent Work and Economic Growth" (migrant workers living in poor conditions are increasingly employed in the fishing industry, where illegal labour conditions are prevalent, blockchain can help increase their visibility and promote the fight for human rights). It also can contribute to limiting the eviction of local populations and safeguarding personal identity (especially in the case of refugees) (Tsolakis et al., 2021).

Reduce costs of information exchange (specific to the aquaculture sector)

Blockchain traceability is seen as providing an opportunity to reduce the costs of information exchange in the aquaculture sector. Zhang et al. (2021) refer that blockchain is a way to cut costs related to data storage and exchange and, at the same time, ensure high safety and quality of large amounts of information content. This contributes to cutting the costs of aquaculture food production.

4.2. BARRIERS TO BLOCKCHAIN IN SEAFOOD SUPPLY CHAINS

A total of 12 barriers to the implementation of blockchain in fisheries and/or aquaculture were identified in the 15 papers reviewed. Table 2 shows the barriers to the implementation of blockchain as identified by the literature and to which sector (fisheries and/or aquaculture) these barriers apply.

Table 2. Result from the systematic review of the literature on barriers to the implementation of blockchain in fisheries and aquaculture value chains.

Barriers to blockchain in fisheries and aquaculture			
	Fisheries	**Aquaculture**	**Reference**
Cost/price	✓	✓	Du et al. (2020); Hang, et al. (2020); Jaya et al. (2021); Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Rahman et al., 2021; Sengupta et al. (2022); Tsolakiset al. (2021).

Size of supply chain	✓	✗	Du et al. (2020); Gopi et al. (2019); Jaya et al. (2021); Jiang and Ræder (2022); Rahman et al. (2021); Tsolakis et al. (2021).
Complexity of information needed	✓	✓	Gopi et al. (2019); Jiang and Ræder (2022); Patro et al. (2022); Rahman et al. (2021); Sengupta et al. (2021); Tsolakis et al. (2021).
Confidentiality/trust issues	✓	✓	Du et al. (2020); Garrard and Fielke (2020); Jaya et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Tsolakis et al. (2021).
Amount of information needed	✓	✓	Du et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Jiang and Ræder (2022); Rahman et al. (2021).
Lack of interest by actors in the value chain/lack of buy-in	✓	✓	Hang et al. (2020); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Rahman et al. (2021); Tsolakis et al. (2021).
Complexity of use	✓	✓	Lin et al. (2021); Patro et al. (2022); Rahman et al. (2021); Tsolakis et al. (2021).
Lack of interest by the public/consumers	✓	✓	Lin et al. (2021); Rahman et al. (2021).
Lack of interoperability of information systems	✓	✓	Patro et al. (2022), Tsolakis et al. (2021).
Adulteration of seafood products during processing	✓	✓	Patro et al. (2022).
Lack of access to technologies	✓	✗	Lin et al. (2021).
Lack of incentives for the actors to join	✓	✗	Lin et al. (2021).

From the 12 barriers identified, the one most commonly mentioned in the literature, for both the fisheries and aquaculture sectors, was the cost/price of implementation of this kind of traceability technology (Figure 8).

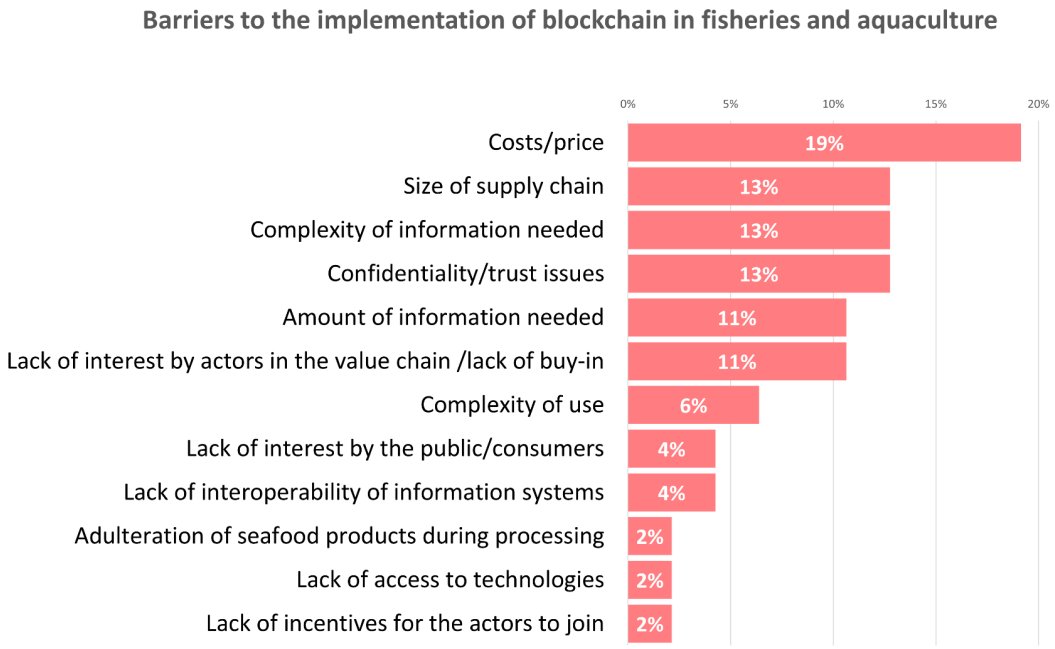

Figure 8. Barriers to the implementation of blockchain in seafood value chains (fisheries and aquaculture) as identified in the systematic review of the literature.

Most barriers to the implementation of blockchain in seafood identified in the literature were common to the fisheries and aquaculture sectors, except for three: the size of the supply chain, the lack of incentives for the actors to join blockchain, and the lack of access to technologies. These were only mentioned as a problem for the fisheries sector. Also, in the case of the fisheries sector, besides costs, the size of the supply chain was commonly identified as an important barrier to the implementation of blockchain. In the case of the aquaculture sector, the complexity of information needed seems to be the second most mentioned barrier, after costs, that makes the implementation of this technology difficult (Figure 9).

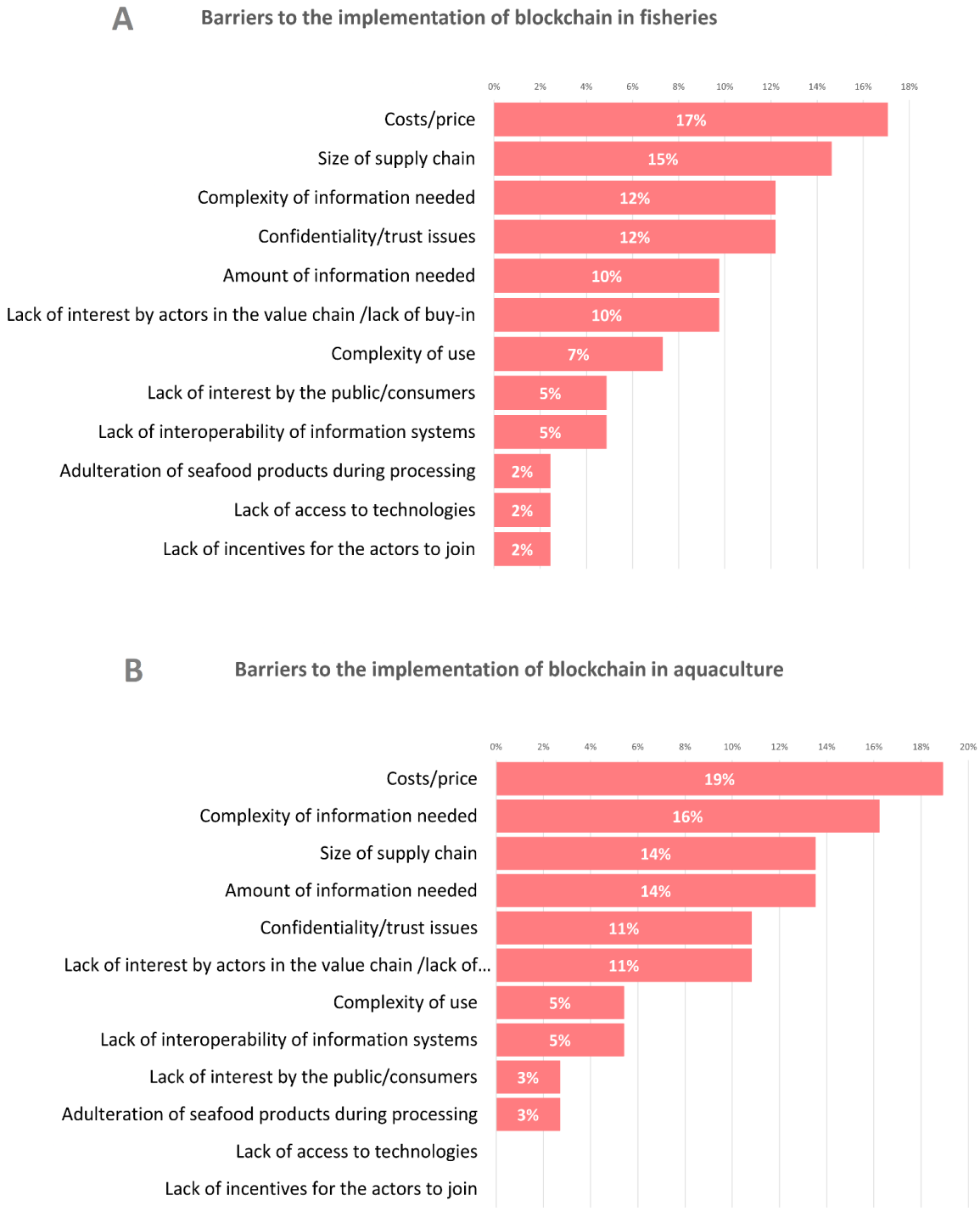

Figure 9. Barriers to the implementation of blockchain in (a) fisheries and (b) aquaculture value chains as identified in the systematic review of the literature.

Cost/price of implementation

Although it is hard to estimate the costs of implementing blockchain technology (Lin et al., 2021), the initial costs of implementing IoT equipment are large and cannot be ignored (Korneyko and Podvolotskaya, 2019; Tsolakis et al., 2021). It is important to notice that to implement blockchain well any enterprise/value chain needs to invest in infrastructure, skills and training (Jiang and Ræder, 2022). The application of blockchain in both fisheries and aquaculture is similar to a major software development project that will store large amounts of data. This requires everything from a software backbone to a hardware sensor, processing power, etc. (Jaya et al., 2021; Sengupta et al., 2021). Hang et al. (2020) refer that small and medium-sized businesses might not even have the means to invest in blockchain platforms by themselves.

Size of the supply chain (specific to the fisheries sector)

Fisheries supply chains are usually very long and complex, involving a great number of actors and covering a wide geographical area (Rahman et al., 2021). According to Jaya et al. (2021), a long value chain means more users and, consequently, fewer "*throughput*" (a measure of how many actions are completed within a given time frame). This represents a challenge for maintaining food quality and performing an efficient food recall when necessary. Therefore, the ideal condition is to keep the value chain length as short as possible. Perhaps the fact that, in general, the aquaculture sector has shorter value chains, with fewer actors, could justify this being less of a challenge for the sector.

Complexity of information needed

Blockchain technology is used mainly to combat fraud, document long and complex production cycles and track critical chains of custody (Sengupta et al., 2021). Value chains can be long and complex, and the initial product can be processed multiple times before reaching consumers, therefore it can be difficult to manage and trace its multiple components and the probability of losing some information is high (Gopi et al., 2019; Rahman et al., 2021). For instance, a processing company might get the same species of fish from multiple sources, a box of filets might get filled with fish from different sources and that information might not be stored in the blockchain platform since the filets are indistinguishable (Gopi et al., 2019). All actors need to collaborate to ensure an unbroken traceability chain despite the asymmetries in information caused by the domination of middlemen in the value chains (Jiang and Ræder, 2022; Tsolakis et al, 2021). The required digitalisation of the supply chain and the implementation and maintenance of digital tools used in a blockchain platform (e.g., RFID equipment, tags and sensors) can be challenging and complex (Tsolakis, et al., 2021).

This point seems to be a bigger problem for the fisheries sector than for the aquaculture sector (the only paper reviewed focusing on this problem in aquaculture is Sengupta et al. (2019)), and this might be linked to the fact that value chains tend to be smaller in the aquaculture sector and, therefore, there is less data to collect.

Confidentiality/trust issues

Although confidentiality and trust issues are mentioned by some authors, this seems to be more of a barrier in public value chains, since these are open to everyone (Jaya et al., 2021). To combat this barrier, the data being collected must itself be trustworthy (Garrard and Fielke, 2020; Tsolakis et al., 2021). For Jaya et al. (2021), these issues are minimized by only accepting organizations approved by the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia. In private blockchain systems, actors share transaction and contract records, therefore trust no longer needs to be verified. This also lowers expenses since there is no need for auditors or third-party intermediaries to verify the information (Du et al., 2020; Mondragon et al., 2020).

Amount of information needed

The amount of information needed in a blockchain traceability system depends on the size of the value chain and the type of blockchain used (Garrard and Fielke, 2020; Rahman et al., 2021). Public blockchains are fully decentralized, immutable and vulnerable to a variety of failures, meanwhile, private blockchains are easy to query and can have large amounts of data being inserted quickly (Garrard and Fielke, 2020). Jiang and Ræder (2022) suggest that not all data should be stored on the blockchain system, rather only essential data and their hash should be stored on-chain, while detailed information for traceability should be stored on an off-chain database. Although this might cause entropy when collecting data (Jiang and Ræder, 2022).

Lack of interest by the actors in the value chain/lack of buy-in

There is a lack of literature aiming at identifying digital solutions to combat counterfeit goods in specific markets, especially seafood products, limited by the lack of existing databases and the disinterest of fishery companies and the government of some countries in such studies for commercial and political reasons (Korneyko and Podvolotskaya, 2019). The reluctance shown towards this technology by consumers, distributors and sellers is also caused by the lack of full-scale successful implementation (Rahman, 2021; Tsolakis et al., 2021). Hang et al. (2020) point out that one of the most common arguments against blockchain technologies is the fact that there is no significant adoption of this methodology outside of cryptocurrencies.

Complexity of use

Working with a blockchain platform can be complex and its implementation can be challenging. Not only because of the range of products that can derive from a single seafood product, but also because of the limited organizational level of education and skills (Tsolakis et al., 2021), the maintenance of the system itself, and the architecture of the network and data management (Rahman et al., 2021). The complexity of the platform is usually linked to the length of the value chain and collected data.

Lack of interest by the public/consumers

The lack of interest by the public/consumers is mentioned only by Lin et al. (2021) and Rahman et al. (2021). The former authors mention mainly the fact that consumers are very "price sensitive" and question if the price change aggravated by the implementation of blockchain technology would be worth it, as it would probably result in a lack of interest by consumers. Rahman et al. (2021) approach the problem from a different perspective and mention the lack of interest by consumers and other actors in the value chain in using the technology available to know more information about seafood products.

Lack of interoperability of information systems

The use of different data recording mechanisms among supply chain actors and, consequently, a lack of interoperability (the ability of different systems, devices or applications used by different actors to connect and communicate in a coordinated way) of information systems represents a barrier to the implementation of an efficient blockchain system. The lack of a standard data-collecting system will lead to longer transaction times that will limit blockchain feasibility (Du et al., 2020), for this reason, all actors must use compatible systems.

Adulteration of seafood products during processing

As mentioned previously value chains tend to be long and complex and, normally, have a processing step. It is often difficult for seafood consumers to identify the species they consume, and this becomes even harder if the product they consume has been through a processing step. Processing companies might get seafood products from various sources or even get two different species in which one is cheaper than the other, and process it the same way, if this is the case it is difficult to differentiate the products (Gopi et al., 2019). Furthermore, mislabelling, species substitution, and IUU fishing have become major barriers that undermine consumers' trust and represent a big challenge for traceability systems (Patro et al., 2022).

Lack of and/or difficulties in access to technologies (specific to the fisheries sector)

The lack of access to technologies and/or the lack of know-how to work with said technologies is a problem, especially when talking about small-scale fisheries, where fishers tend to be older with low levels of formal education. Lin et al. (2021), for example, focused on a fishery on a remote island in Indonesia and pointed to the fact that although children had access to tablets and knew how to work with them, adults seemed to have a lot of problems having access and working with any type of technology, and opted to collect data manually.

Lack of incentives for the actors in the value chain (specific to the fisheries sector)

The lack of incentives for actors in the value chain to join blockchain is mentioned by Lin et al. (2021) when trying to engage fishers to join the blockchain platform and use it effectively. The authors defend that, in remote communities, where there is a lack of knowledge regarding this kind of technology, incentives are one way to convince actors to collect data and share it with the value chain.

5. EXAMPLES OF SEAFOOD BLOCKCHAIN INITIATIVES

In this section, we provide examples of several initiatives using blockchain technology to trace seafood from catch to consumer around the globe (Figure 10). We divided the initiatives into three categories, according to the sector: small-scale fisheries (4.1), large-scale fisheries (4.2) and aquaculture (4.3), and analysed two initiatives from each sector.

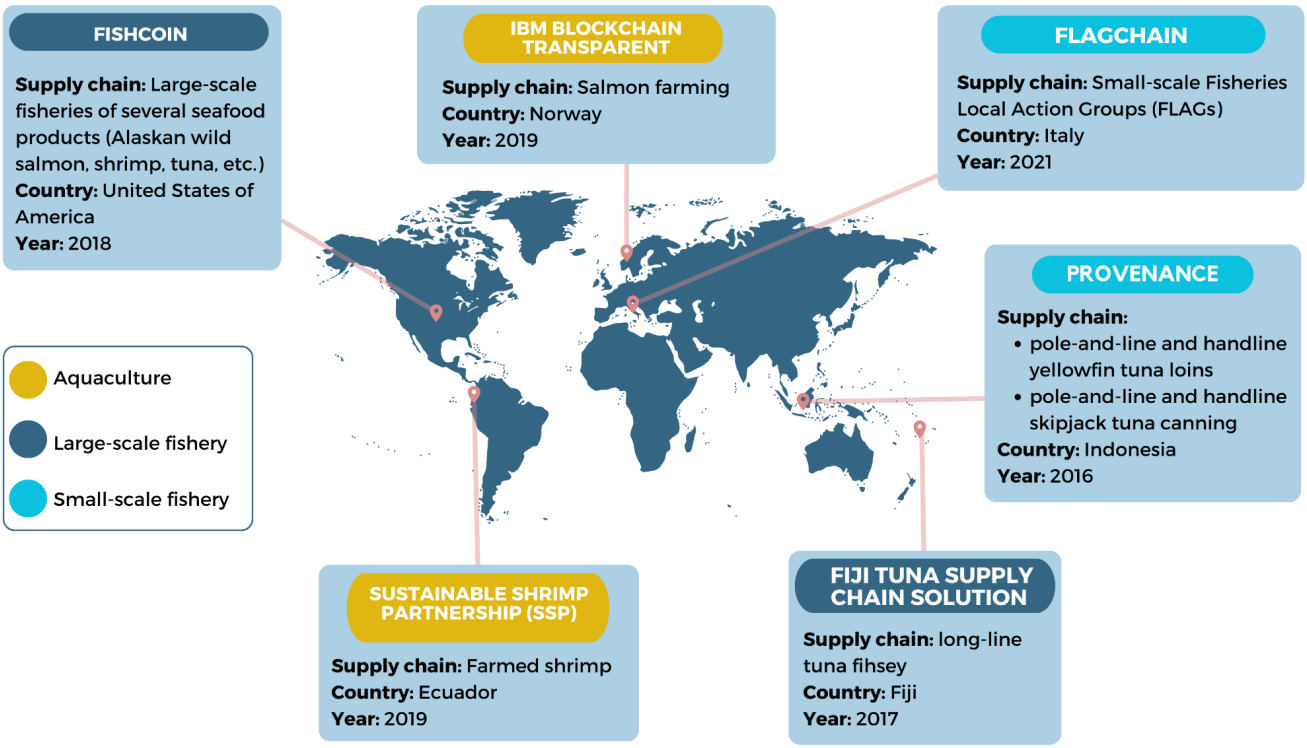

Figure 10. Blockchain initiatives applied to the large- and small-scale fisheries and aquaculture sectors around the globe.

5.1 SMALL-SCALE FISHERIES

In this section, we identify and analyse the implementation of blockchain in two small-scale fisheries initiatives: provenance pilot blockchain, in Indonesia (5.1.1), and FLAGCHAIN, in Italy (5.1.2).

5.1.1. Provenance

In 2016, Provenance used the peer-to-peer (P2P) payment system technology used by bitcoin to track tuna from landing to the factory and beyond, in Maluku, Indonesia. To the best of our knowledge, this was the first blockchain documented initiative applied to the fisheries sector. Table 3 sums up the Provenance pilot, the way of operating and the technicalities of their platform.

Table 3. Summary of the Provenance pilot project.

Provenance pilot blockchain
Type of fishery: Small-scale
Supply chain: pole-and-line and handline yellowfin tuna loins, pole-and-line and handline skipjack tuna canning
Country/region: Indonesia
Year started: 2016 (6 months pilot)
Way of operating
Actors involved: local Non-governmental Organizations (NGO), fishers, suppliers.
How it works: mobile phone and smart tags.
Challenges: connecting the physical asset (tuna) to the digital asset; amount of time spent.
Technicalities
Blockchain platform: Ethereum
Blockchain type: NA

Sources of information: Blaha and Katafono (2020), Provenance (2016).

The Provenance project was a six-month pilot study to demonstrate how blockchain technology could be used to track fish from sea to consumer, ensuring transparent, traceable and sustainable fishing practices. This pilot focused on the pole-and-line and handline tuna fishery, tracking the supply chains of yellowfin tuna loins and skipjack tuna for canning. The primary objectives included assisting local fishers in recording their catches, tracing the catch data to the suppliers, and evaluating how the technology could be used to: (i) aid robust proof of compliance with standards; (ii) prevent the "double-spend" of certificates; and (iii) explore how the technology could form the basis for an open system for traceability (Blaha and Katafono, 2020).

The pilot tracked tuna from catch to landing on to the factory and into retail using the Ethereum blockchain, mobile phones, and smart tags. According to the pilot report, a significant challenge encountered was establishing a connection between the physical asset (tuna) and the digital asset. Various methods such as two-dimensional QR codes, RFID and NFC were implemented for identification purposes. Nevertheless, the process of digitizing each stage consumed considerable time. To ensure interoperability, fairness, and consensus, the report recommended the utilization of public blockchains (Provenance, 2016).

Certain aspects of the process remained unclear. It was uncertain whether each tuna was individually tagged and recorded on the blockchain, or if the entire catch was tagged and recorded

as a collective unit. Additionally, the tracking of the catch from the supplier to the factory, as well as within the factory itself, lacked clarity in terms of how the catch was monitored and differentiated in various products (Provenance, 2016).

5.1.2. FLAGCHAIN

The FLAGCHAIN project was started by three Fisheries Local Action Groups (FLAGs) from Campania, southern Italy. The project uses blockchain to deliver the "history" of the product (origin, capture techniques, processes undergone, transport, and conservation) to consumers. It aims to provide complete transparency and traceability of the catches from small-scale fisheries (SSF) boats in their areas of operation. In table 4 we present, in a very concise way, the FLAGCHAIN project, the way of operating and the technicalities of their platform.

Table 4. Summary of the FLAGCHAIN project.

Flagchain
Type of fishery: Small-scale
Supply chain: Small-scale boats operating in the areas of operation of the Pesca Flegrea, Litorale Miglio D'Oro and Sviluppo Mare Isole di Ischia e Procida.
Country/region: Campania, Italy
Year started: 2021
Way of operating
Actors involved: Fishers, Port authorities, Cooperatives.
How it works: mobile app.
Challenges: poor digitalization, onerous bureaucracy required to comply with marketing regulations, lack of traceability of the SSF catches, low public awareness of local catches and their season, loss of traditional habits of eating local fish.
Technicalities
Blockchain platform: Quadrans
Blockchain type: Private

Sources of information: FARNET (2021), FEAMP (2020).

The main goal of the three FLAGs was to have a common platform where all the information needed to ensure the traceability of fish originating from the local SSF sector was recorded. The FLAGCHAIN app was built using the blockchain platform Quadrans, which has low running costs

and energy requirements. This platform can be customized to meet the needs of other FLAG areas, and the more fishers use the app, the more detailed the traceability will be. Using this technology modernizes the SSF value chain and moves the sector towards a digitalization process. It allows small-scale fishers to get ahead of their competitors, satisfy the pressing consumer demand for transparency, and emphasize the strengths of the sector, the quality of their product and the processes they use.

The project trained fishers who, due to their age, lacked digital skills. The fishers who entered their data into the system via their phones were involved from the start of the project to ensure the app was user-friendly. An awareness-raising campaign was carried out to stress the benefits of traceability to small-scale fishers, and thus promote the use of the app.

All three FLAGs identified weaknesses in the implementation of blockchain, mainly related to poor digitalization, the bureaucracy required to comply with marketing regulations, the lack of traceability of the SSF catches, the reduced public awareness regarding local catches and their seasons, and the loss of traditional habits of eating local fish.

This project shows that the involvement of all stakeholders (small-scale fishers, port authorities, cooperatives) from the start of the blockchain implementation process is vital to ensure transparency and traceability in the value chain of SSF products. It also shows that blockchain systems can be applied successfully in the SSF sector, even given the old age of fishers and low level of digitalization.

5.2 LARGE-SCALE FISHERIES

In section 5.2 we identify and analyse two large-scale fisheries initiatives: the Fiji Tuna supply chain solution (5.2.1) and Fishcoin, adopted in Alaska (5.2.2).

5.2.1. Fiji Tuna Supply Chain Solution

To the best of our knowledge, the first documented application of blockchain technology in a tuna longline fishery was implemented in 2017 when the World Wild Fund for Nature (WWF), ConsenSys, Sea Quest (Fiji) Ltd and TraSeable Solutions partnered to implement the project in Fiji. The goal was to create a completely transparent and traceable supply chain in this fishery, using an innovative blockchain technology, for the fresh and frozen tuna supply chain. In table 5 we present, in a very concise way, the Fiji Tuna Supply Chain Solution project, the way of operating and the technicalities of their platform.

Table 5. Summary of the Fiji Tuna Supply Chain Solution.

Fiji Tuna Supply Chain Solution
Type of Fishery: Large-scale **Supply chain:** longline tuna fishery **Country/region:** Fiji **Year started:** 2017
Way of operating
Actors involved: Fishers, regulators, processors, distributors/retailers and consumers. **How it works:** QR codes and RFID technology. **Challenges:** reliance on paper-based processes, availability of local suppliers and technicians, mapping the supply chain past the importer, cooperation of downstream supply chain actors, authenticity of data, transaction time limitations, basic costs.
Technicalities
Blockchain platform: Ethereum (Viant) **Blockchain type:** NA

Sources of information: TraSeable Solutions (2023), Blaha and Katafono (2020), Cook (2018).

The first step of the process consisted of mapping the supply chain into *Viant* and setting the needed roles and permissions. Onboard the vessels, each tuna was tagged with unique identifiers initially using RFID tags, and later with QR code tags. Key data about the capture event (e.g., catch zone, vessel, crew details) and tuna (e.g., weight, RFID number, species) were recorded into the app. Individual landed fish were given a tag, so it was possible to trace it through the value chain, from the moment it was caught to the final consumer. The QR code or RFID tags associated with each product could be scanned by any individual at any given time, and the entire journey of that asset (tuna) would pop up on their phone - no application download or sign was needed.

Various challenges related to the application of this blockchain solution were identified, such as:

- The reliance on paper-based processes,
- Lack of local suppliers and technicians,
- Difficulties mapping the supply chain past the importer,
- Lack of cooperation of downstream supply chain actors,
- Authenticity of data,
- Transaction time limitation,
- Basic costs.

Nevertheless, project participants also identified several advantages (such as the increase of detail of the fishing activities, increase in value chain trust, decrease of theft of catch onboard fishing vessels, and the reduction of paperwork and payment processing time (Cook, 2018)) to this approach and expect that this will become the standard way to use the blockchain-based platform Viant for complex supply chains where digital traceability platforms already exist.

5.2.2. Fishcoin

Fishcoin was created in 2018 as a way to provide an affordable, accessible, transparent, secure and trusted interoperable traceability tool for seafood supply chains. It was designed to be a blockchain peer-to-peer traceability system, a decentralized tool, with the engagement of the seafood industry to develop the tool. In table 6 we present, in a very concise way, the Fishcoin project, the way of operating and the technicalities of their platform.

Table 6. Summary of the Fishcoin project.

Fishcoin
Type of fishery: Large-scale **Supply chain:** Different seafood products (Alaskan wild salmon, shrimp, tuna, etc.) **Country/region:** USA **Year started:** 2018
Way of operating
Actors involved: Eachmile Technologies, Fishcoin. **How it works:** the system uses a public blockchain system that rewards value chain stakeholders for providing information regarding seafood transactions. **Challenges:** understanding the company's values and mission.
Technicalities
Blockchain platform: Ethereum **Blockchain type:** Public

Sources of information: Douglas (2021), Fishcoin (2018), Fishcoin (n.d.).

This blockchain involves a token ecosystem mechanism, meaning that seafood producers and intermediaries are rewarded (with tokens, or digital vouchers) for providing data onto the platform. The Fishcoin team believes this will allow for more information to be available for consumers,

improving the safety and quality of seafood, while shifting the economic burden of it to downstream actors such as hotels, restaurants and retailers. Its network works through a series of open-source tools and software development kits (SDKs) that can be used by stakeholders to integrate decentralized applications (DApps) to the Fishcoin Ecosystem (Fishcoin, 2018; Fishcoin, n.d).

Not many challenges were identified regarding this initiative. However, the Fishcoin Manifesto was not easy to achieve. The team described that there were some difficulties trying to appeal to investors, employees and society, all at once, and that brought difficulties when trying to write a truthful mission, vision and values regarding Fishcoin. Nevertheless, after this reflection, a Manifesto came to life to explain Fishcoin's beliefs, including the importance of working in partnerships, how the positive changes for achieving ocean sustainability should be industry-driven, and the need to ensure that fishers and farmers are not the ones to carry the costs of traceability (Douglas, 2021).

5.3 AQUACULTURE

Finally, we describe and analyse two examples from aquaculture, the Sustainable Shrimp Partnership case study in Ecuador (5.3.1) and IBM Blockchain Transparent in Norway (5.3.2).

5.3.1. Sustainable Shrimp Partnership (SSP)

The Ecuador-based SSP joined the IBM Food Trust blockchain platform in May 2019. This was the first shrimp organization to join the IBM Food Trust network and included three Ecuador-based producers using the platform: Omarsa, Songa, and Promarisco-Grupo Nueva Pescanova (Ledger Insights, 2020). In table 7 we present, in a very concise way, the Sustainable Shrimp Partnership project, the way of operating and the technicalities of their platform.

Table 7. Summary of the Sustainable Shrimp Partnership project.

Sustainable Shrimp Partnership (SSP)
Sector: Aquaculture
Supply chain: Ecuadorian farmed shrimp
Country/region: Ecuador
Year started: 2019

Way of operating
Actors involved: Sustainable Shrimp, Partnership (SSP), IBM Food, Trust, Ecuadorian shrimp farm processors, retailers.
How it works: a Consortium/Private (IBM) blockchain and consumers have access to a traceability web-application.
Challenges: price competitive market and the communication with stakeholders
Technicalities
Blockchain platform: HyperLedger
Blockchain type: Consortium/Private

Sources of information: Tolentino-Zondervan et al. (2023), Sustainable Shrimp Partnership (2022), Blaha and Katafono (2020), Ledger Insights (2020).

The blockchain platform is used to provide transparency and traceability, which is something lacking in the farmed shrimp sector with the rise of food fraud (FishFocus, 2019). This platform helps retailers to remain informed about production and processing methods. Consumers are also able to access data about the value chain processes through an app. Additionally, IBM Food Trust also enhances food safety by making sure the shrimp is antibiotic-free, Aquaculture Stewardship Council (ASC) certified, and has a neutral impact on the environment (Blaha and Katafono, 2020; Ledger Insights, 2020).

Given the price competition in the industry (which often leads to seafood fraud), SSP's level of transparency appeared to be a challenge. However, SSP's traceability solution seemed to have changed the sector, since other companies started to embrace these practices and push for improvement in the Ecuador shrimp industry. Another challenge involved sharing information with consumers and customers in a meaningful way. This allowed them to make informed purchasing decisions by simply scanning a QR code (Sustainable Shrimp Partnership, 2022).

5.3.2. IBM Blockchain Transparent (Norwegian seafood)

In 2019, the IBM Food Trust, in collaboration with Atea (a technological partner), launched a blockchain tracking tool aimed at seafood traceability. Later, the Norwegian Seafood Association (or Sjømatbedriftene) joined the collaboration to develop this tool in the Norwegian seafood industry. In table 8 we present, in a very concise way, the IBM Blockchain Transparent (Norwegian Seafood) project, the way of operating and the technicalities of their platform.

Table 8. Summary of the IBM Blockchain Transparent (Norwegian Seafood) project.

IBM Blockchain Transparent (Norwegian seafood)
Aquaculture
Supply chain: Salmon farming **Country/region:** Norway **Year started:** 2019
Way of operating
Actors involved: Norwegian Seafood Association, IBM, Atea. **How it works:** the private (IBM Hyperledger) blockchain systems provide data to consumers about the salmon origin, processing processes and nutritional content. **Challenges:** employees initial mistrust of the traceability system and user difficulties to operate it.
Technicalities
Blockchain platform: Hyperledger **Blockchain type:** Private

Sources of information: Tolentino-Zondervan et al. (2023), IBM (2021), Norwegian Seafood Trust. (n.d.).

With this blockchain technology, the consumer can have information about the origin of the salmon, what it has been fed and how sustainable the production has been. The initiative defends that this enhances consumer trust in the product, by making it safer and more traceable. It appeared as a way to push the Norwegian seafood industry to be more sustainable while also giving it a competitive market advantage (IBM, 2021; Norwegian Seafood Trust, n.d.).

It is noticed that the older generation of farmers is a bit more sceptical about using this technology because there is a lack of user experience and worries about data security and privacy. Nevertheless, trust is being built with producers by explaining the system's technicalities.

Additional features projected for the future are related to transportation details (which will be helpful for wholesalers and enhance further the traceability of salmon), calculation of carbon footprints and the use of AI (Artificial Intelligence) to increase production efficiency (IBM, 2021; Norwegian Seafood Trust, n.d.).

6. EXPERT OPINIONS ON INCENTIVES AND BARRIERS TO THE IMPLEMENTATION OF SEAFOOD TRACEABILITY AND BLOCKCHAIN

6.1. INCENTIVES FOR THE IMPLEMENTATION OF TRACEABILITY AND BLOCKCHAIN

A summary of the 5 incentives most frequently mentioned by the stakeholders of each country is provided in Figure 11. Stakeholders from all countries were quite similar in their opinions, mentioning that stopping IUU fishing, and enhancing tracking and tracing of seafood as the most important incentives for the implementation of traceability.

Answers regarding the incentives for the implementation of blockchain technology traceability (Figure 12) do not differ much from the incentives that stakeholders perceived for the implementation of traceability, but new topics are introduced, such as real-time access to information, improvement of efficiency, increased value chain trust and increased public trust. Identification of origin/source, enhanced tracking and tracing and demonstration of compliance were incentives mentioned in all countries.

By analysing all traceability opportunities identified (without separating by country) it is clear that key stakeholders perceive enhancing tracking and tracing, stopping IUU fishing and identifying the origin/source of the products as the biggest opportunities coming from the implementation of traceability (Figure 13). Doing the same exercise for blockchain technology, enhancing tracking and tracing is again the most mentioned opportunity, followed by demonstration of compliance and identification of origin/source (Figure 14).

Figure 11. Top-five opportunities of the implementation of traceability in seafood value chains according to the stakeholders interviewed, by country (from most mentioned (top) to least mentioned (bottom).

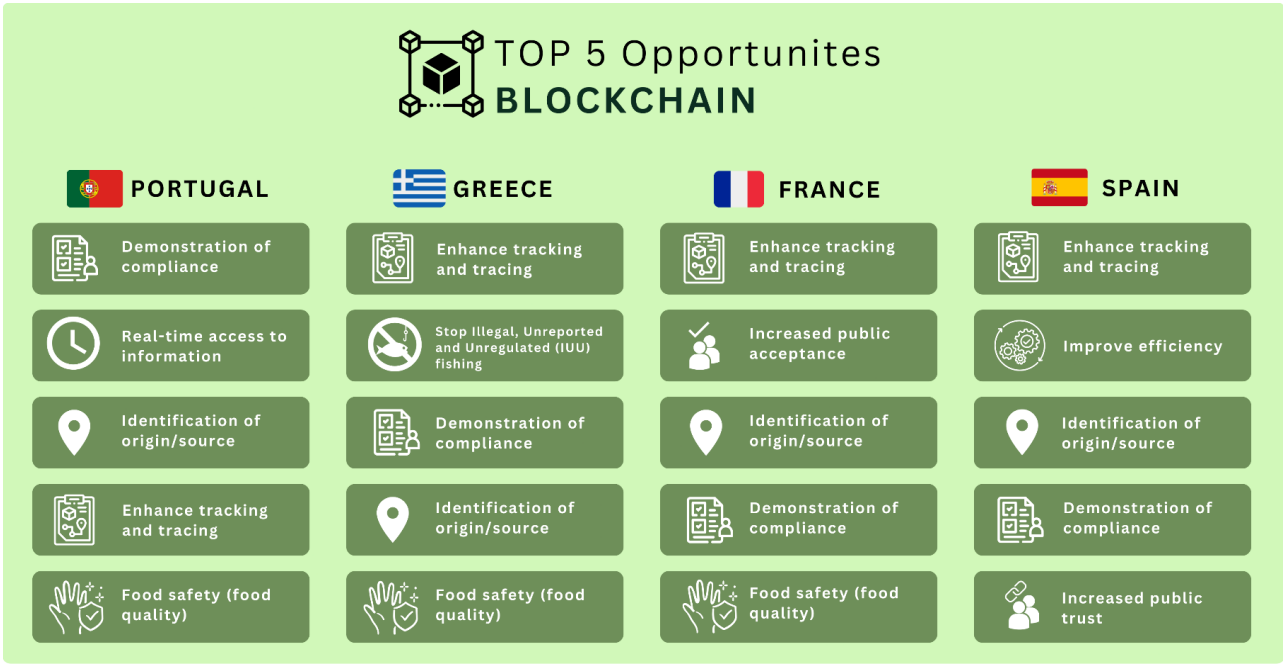

Figure 12. Top-five opportunities of the implementation of blockchain technology in seafood value chains according to the stakeholders interviewed, by country, from most mentioned (top) to least mentioned (bottom).

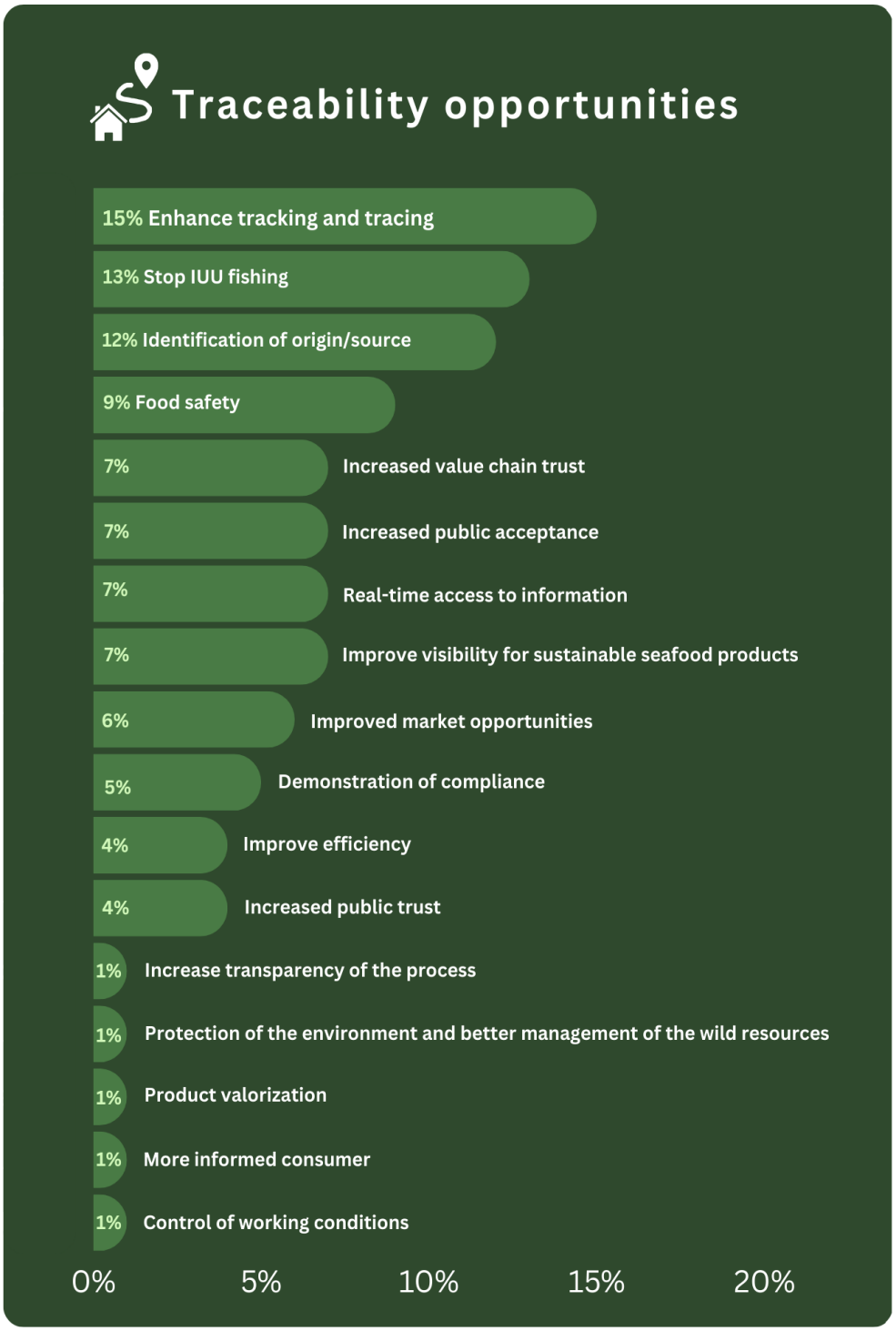

Figure 13. Overview of the opportunities of implementing traceability to seafood value chains identified by the stakeholders interviewed.

Figure 14. Overview of the opportunities of implementing blockchain to seafood value chains identified by the stakeholders interviewed.

6.2. CHALLENGES TO THE IMPLEMENTATION OF TRACEABILITY AND BLOCKCHAIN

Stakeholders from different countries presented diversified perceptions of the top-five most important challenges of implementing traceability to seafood value chains. The only common challenges mentioned by stakeholders from the different countries were the cost/price of implementation (mentioned by stakeholders from France, Spain and Portugal) and the lack of access to technology and lack of familiarity with traceability (mentioned by stakeholders from Portugal, Greece and Spain) (Figure 15).

Comparatively perceptions about the top-5 challenges of implementing blockchain (Figure 16), were different. In Portugal, most stakeholders admitted to not knowing what challenges implementing blockchain could bring. Cost/price of implementation appeared again as one of the most important challenges across countries, but the lack of interest by producers was mentioned as well.

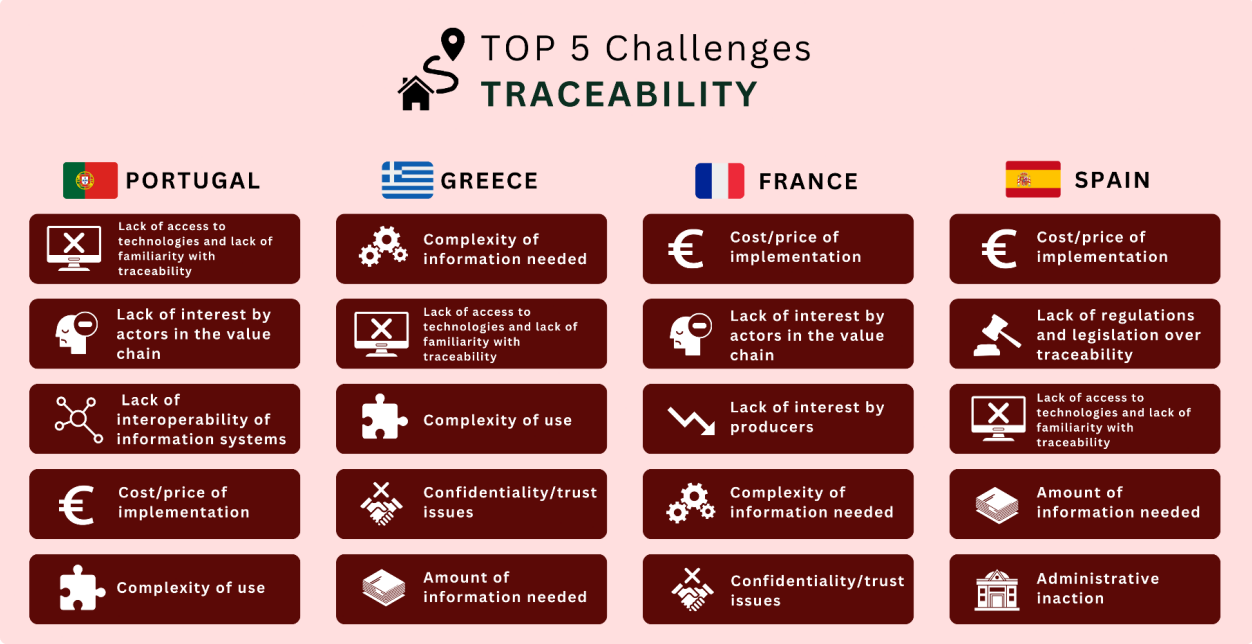

Figure 15. Top-five challenges to the implementation of traceability in seafood value chains identified by the stakeholders interviewed, by country, from most mentioned (top) to least mentioned (bottom).

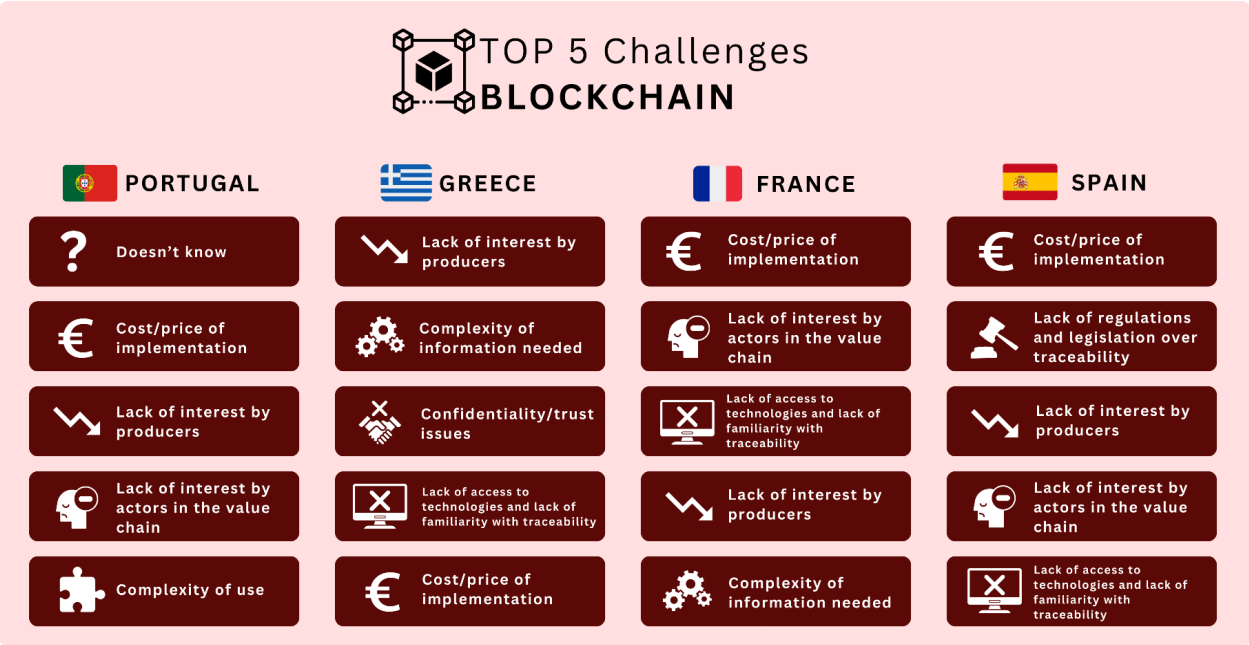

Figure 16. Top-five challenges to the implementation of traceability in seafood value chains identified by the stakeholders interviewed, by country, from most mentioned (top) to least mentioned (bottom).

Analysing all the challenges to the implementation of traceability in seafood value chains identified by the stakeholders interviewed (without separating by country) we see that key stakeholders perceive the lack of access to technologies and lack of familiarity with traceability as the biggest challenges, followed by the cost/price of implementation and lack of interest by actors in the value chain (Figure 17). Regarding the challenges related to the implementation of blockchain, stakeholders perceived the cost/price of implementation, followed by producers' lack of interest and the lack of access to technologies and familiarity with traceability as the biggest challenges (Figure 18).

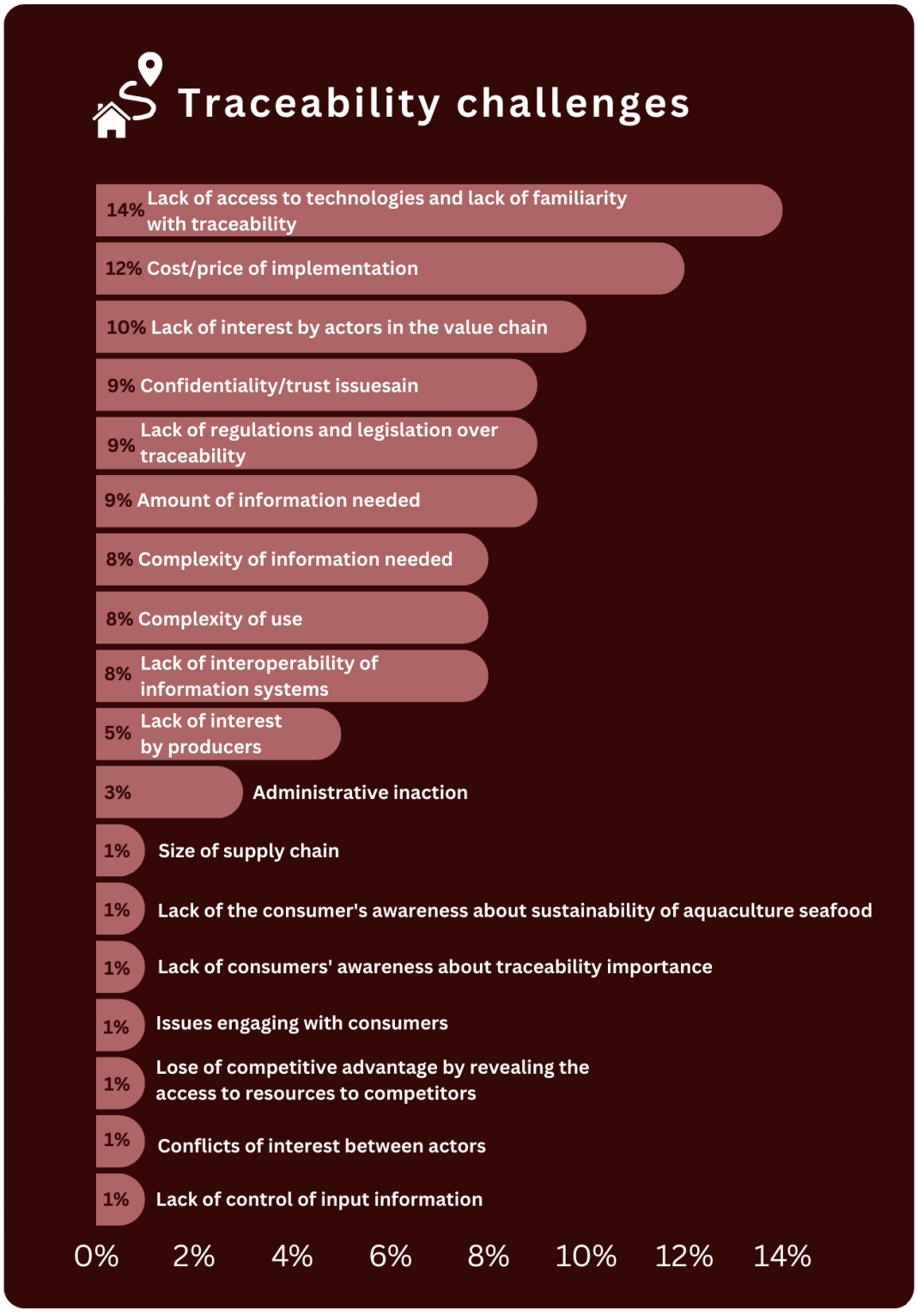

Figure 17. Overview of the challenges of implementing traceability in seafood value chains identified by the stakeholders interviewed.

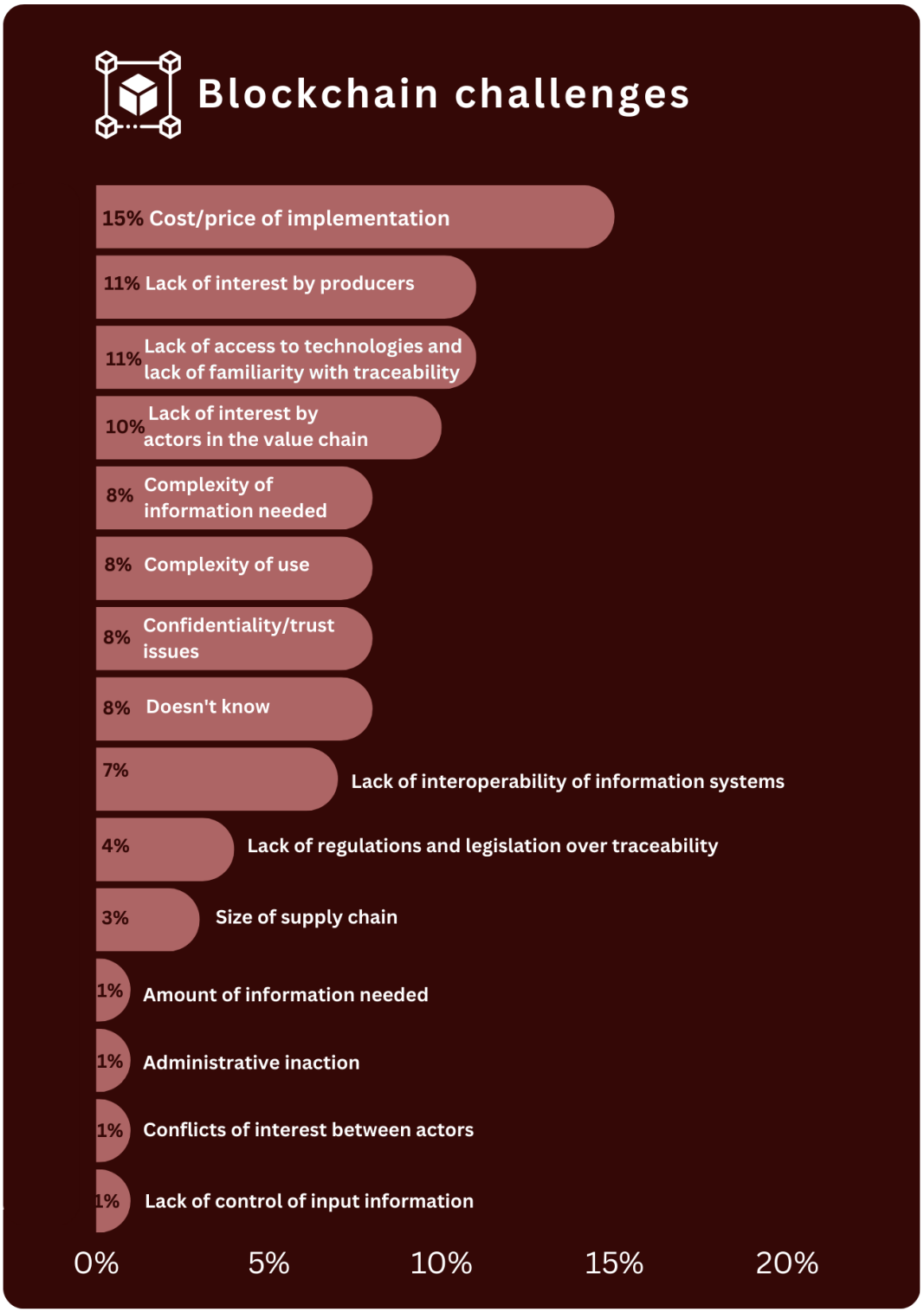

Figure 18. Overview of the challenges of implementing blockchain in seafood value chains identified by the stakeholders interviewed.

6.3. OTHER PERCEPTIONS ABOUT TRACEABILITY

Additional information about traceability was also collected, such as the kind of information that should be integrated into a seafood traceability system. Catch zone/place of origin, followed by fishery information, species information, aquaculture-related information, environmental sustainability information, information on supply chain, certification/ecolabel and freshness/date of catch/harvest were the types of information stakeholders perceived should be included in any traceability system (Figure 19). Other information mentioned included nutritional information, only information required by regulations (i.e., only the data that is legally mandatory for seafood commercialization), fishing bait information, information on socio-economic aspects of the production/harvest, information on carbon footprint, photo of the product, price, workforce income and subsidies for fisheries and feed used.

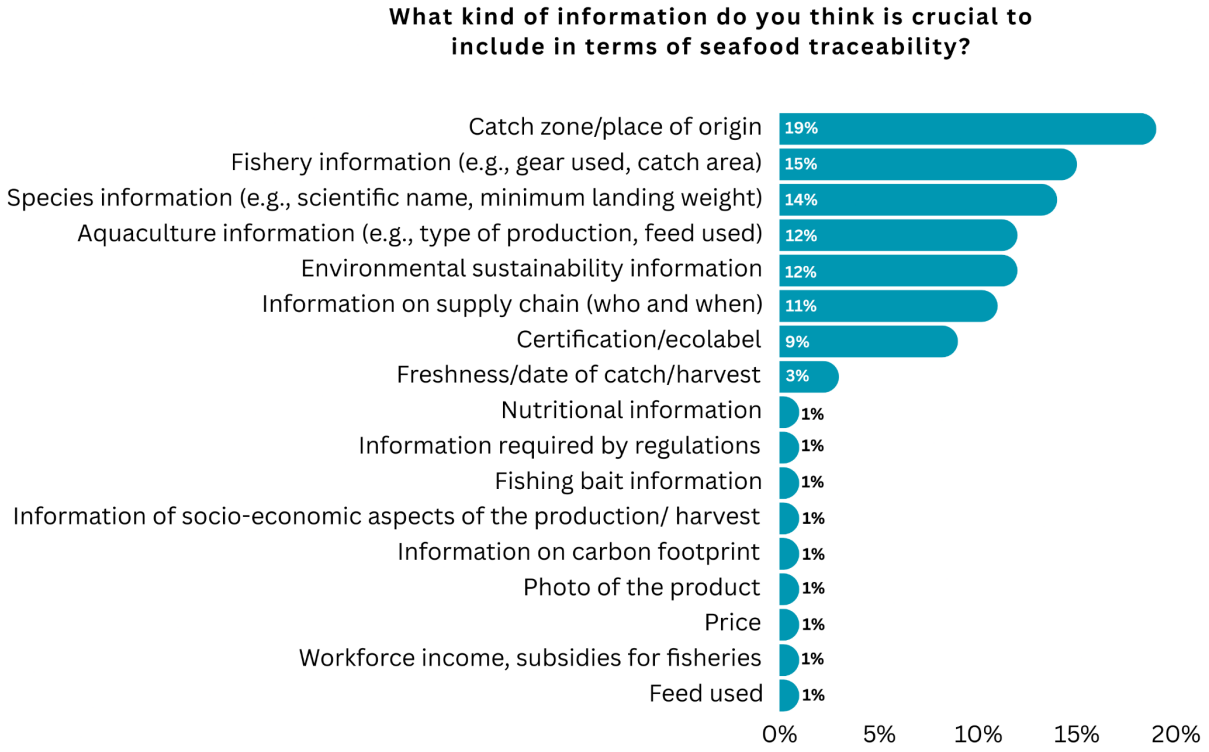

Figure 19. Information considered to be crucial in a seafood traceability system, as identified by the stakeholders interviewed.

Despite most stakeholders interviewed being involved in the aquaculture production sector (24% of those interviewed), fishery information is considered to be more important to be included in a traceability system when compared with aquaculture information. This could be a reflection of the

fact that traceability is usually associated with identifying the origin of products in fisheries, and also that EU aquaculture already carries out traceability of the process both for normative compliance and for business/process efficiency (total traceability of process from egg to plate). So, the current status of traceability is very different between the fisheries and aquaculture sectors, both in terms of compliance, extension and technology, with the latter being more used to traceability because it is part of the needs for the business efficiency of any production process. An expression of this is the fact that, for more than two decades, there have been many commercial Production Management softwares for aquaculture, which include "traceability" tools.

Food safety and quality demands are considered the main drivers for traceability and the transformation in the seafood sector, which contrasts with food safety not being perceived as the biggest opportunity for seafood traceability and blockchain. This driver is followed by environmental reasons and certification demands, then by origin assurance and consumer interest/demands, and other possibilities are mentioned in a smaller number (Figure 20).

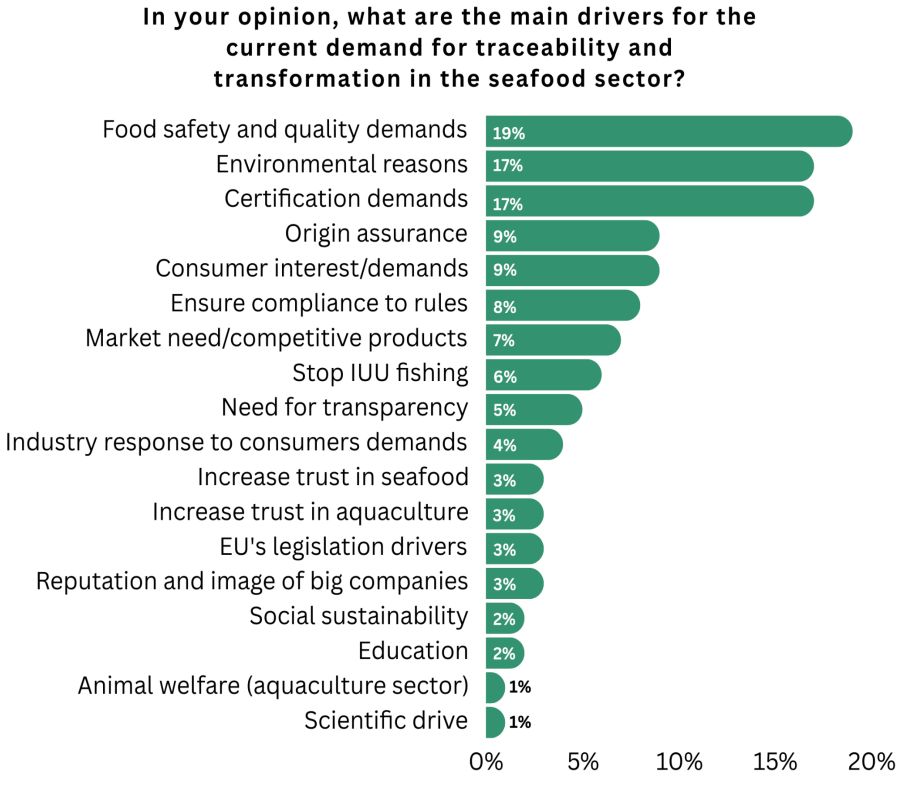

Figure 20. Main drivers for seafood traceability, as identified by the stakeholders interviewed.

Stakeholders were asked to classify on a scale of 1 (very little importance) to 5 (very high importance) how important it is to implement digital traceability in seafood at a global scale, at the EU scale, at a national scale and a local scale. Stakeholders from all countries perceived that is it very important to implement digital traceability in seafood (the mean numbers are very close to 5) at all geographical scales (global, EU, national and regional), with the EU scale and national scale scoring slightly higher overall (Table 9).

Table 9. Importance of implementing seafood digital traceability. Data was measured on a scale of 1 (very little importance) to 5 (very high importance) and mean values are shown here.

How important is it to implement digital traceability in seafood:	Portugal	Spain	France	Greece	All
At a global scale	4.6	4.2	5.0	4.9	4.7
At the EU scale	4.6	4.7	5.0	4.9	4.8
At a national scale	4.5	4.5	5.0	5.0	4.8
A a local scale	4.6	4.5	4.6	5.0	4.7

It was asked what methods were preferable to enhance/promote seafood traceability in different sectors value chains: small-scale fisheries, industrial fisheries, fish farming and shellfish farming. The four preferable methods were the same for all sectors, and included blockchain, QR codes/RFID codes, mobile/web apps and certification schemes/labels (Figure 21-24).

Stakeholders' justification for their choices was that these methods were easy to use or efficient. Some considered the simplest methods to be "the best option". The motives behind the choices provided are presented in Annex 1. Some stakeholders acknowledge that blockchain might be harder to implement since it might be perceived as harder to use or require more technological and economic means. Certifications were also mentioned by some as not being accessible to everyone and being expensive.

The traceability and blockchain opportunities most frequently mentioned by experts (such as stopping IUU fishing, demonstration of compliance or identification of origin) were not considered to be the most important reasons for the selection of these methods, with reasons focusing more on the ease of use, efficiency, price and data security.

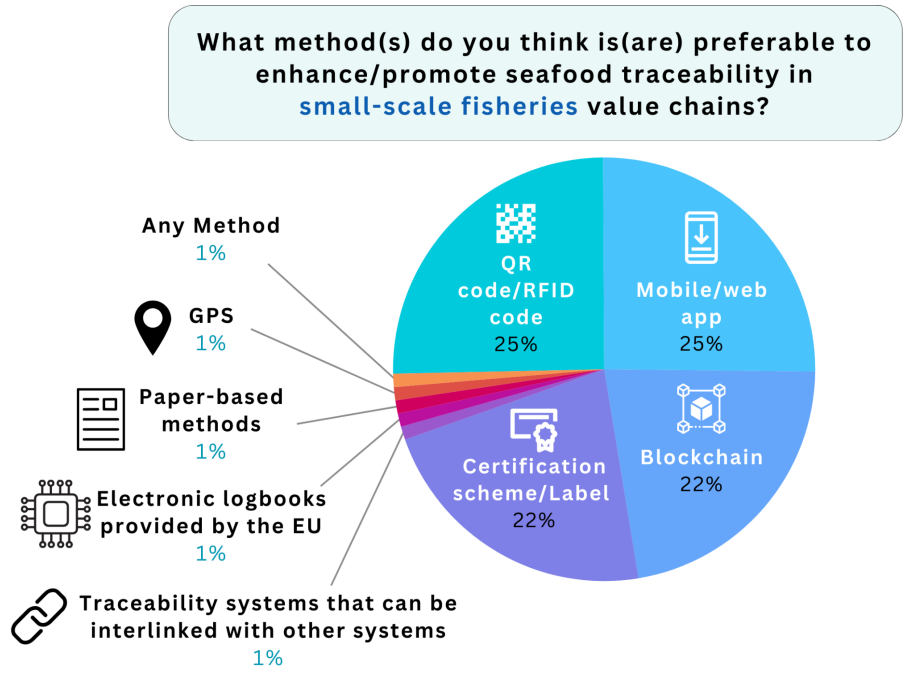

Figure 21. Preferable methods to promote seafood traceability in small-scale fisheries, as identified by the stakeholders interviewed.

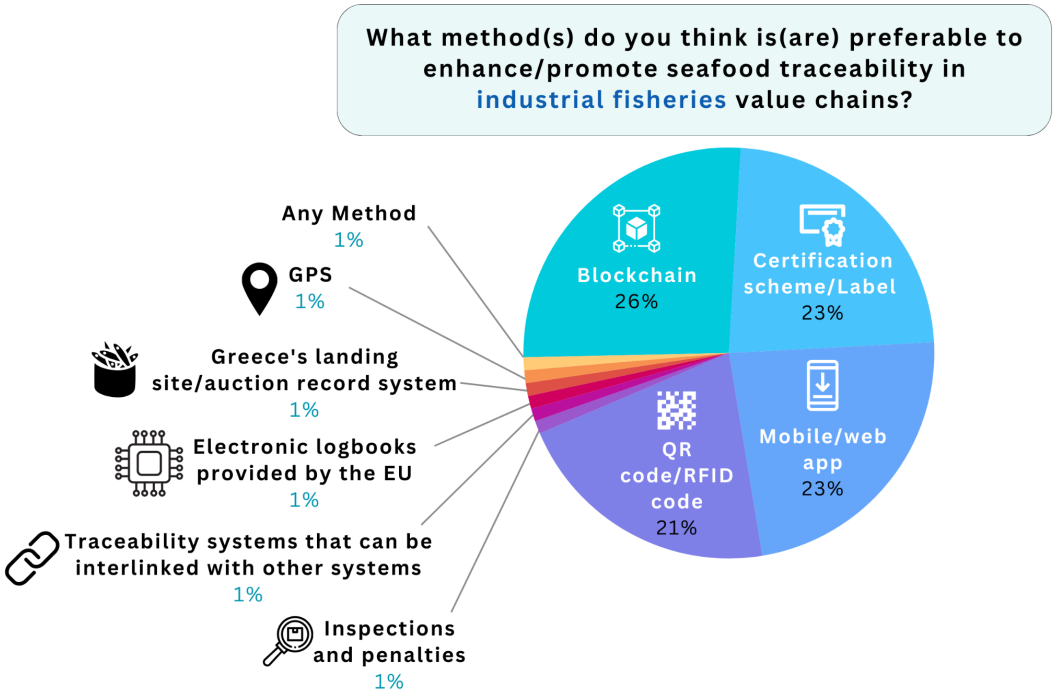

Figure 22. Preferable methods to promote seafood traceability in industrial fisheries, as identified by the stakeholders interviewed.

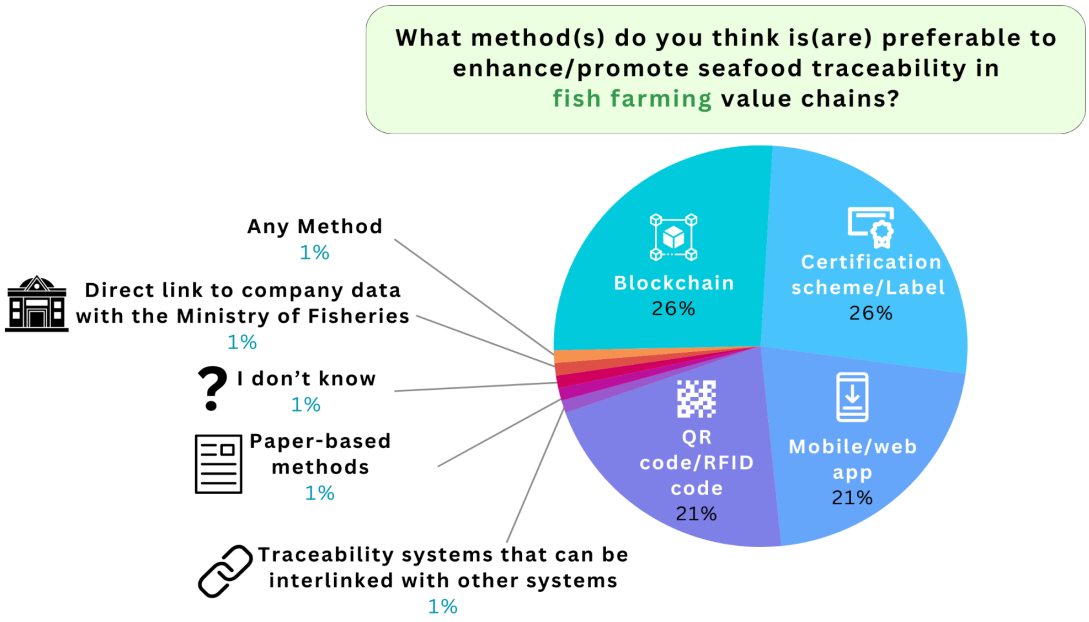

Figure 23. Preferable methods to promote seafood traceability in fish farming, as identified by the stakeholders interviewed.

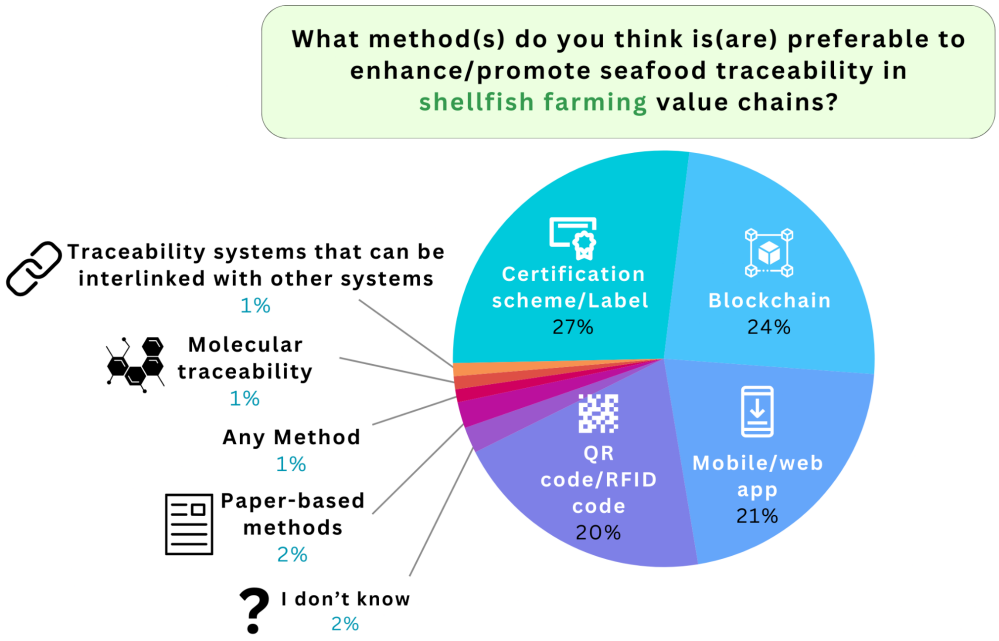

Figure 24. Preferable methods to promote seafood traceability in shellfish farming, as identified by the stakeholders interviewed.

7. CONCLUSIONS

Seafood products are the most traded food commodity globally and the EU is one of its largest markets, importing 60% of all the seafood consumed. The current increasing concerns about IUU fishing, fair trade, ethical issues, human rights violations and food security has resulted in the need to improve transparency and traceability in seafood supply chains.

The use of blockchain in seafood value chains ensures better traceability from sea to plate in a secure and tamper-proof way and has been gathering a lot of interest recently. The development and implementation of blockchain technologies are inevitable and may bring many advantages to markets and actors of the seafood value chain, but there are also many challenges to its implementation.

From the literature review, it can be seen that the major barriers to implementing blockchain in fisheries and aquaculture include the cost of implementation, the difficulty of implementing this technology in large supply chains, the concerns regarding the complexity and amount of information needed, issues around confidentiality and trust by actors in the value chain, and even the lack of interest and buy-in by some actors of the seafood value chain and by the public/consumers.

Although there are many challenges to the implementation of blockchain traceability, there are also many incentives for the implementation of this technology in fisheries and aquaculture. From the review of the literature it was possible to identify that the incentives include enhancing traceability and improving efficiency, being able to identify the origin/source of seafood products, increasing value chain actors and consumers' trust, acceptance and confidence in products, providing the ability to demonstrate compliance with certification and labelling schemes, rules and regulations and sustainable fishing, allowing for real-time access to information, putting the fishery/aquaculture production in a better position to apply for certification and labelling, improving food safety, combating IUU fishing and improving marketing opportunities. The experts consulted mostly agreed with the incentives and challenges of blockchain seafood traceability found in the review of the literature.

Some examples of implementation and using blockchain technology demonstrate that it can be implemented both in the fisheries (small- and large-scale) and aquaculture sectors, but also attest to the complexity of implementing such traceability technology in these sectors. Examples also demonstrate that there is not a one-model-fits-all blockchain technology and different types of technologies should be chosen and adapted, using different platforms and forms of data collection adjusted to the level of traceability aimed to achieve in different fisheries and aquaculture value chains.

It is interesting to notice that, although most stakeholders do not consider themselves to be very familiarised with blockchain, this was still perceived as one of the preferable methods for seafood traceability across countries and for both the fisheries and aquaculture sectors, and many times referred as the best new available method.

Although stakeholders did not differentiate much between traceability methods, the literature suggests that the chosen blockchain technology should be tailored to the specific fishery or aquaculture value chain and the desired level of traceability. This customization is essential for establishing an efficient, fair, and transparent value chain.

Traceability is a relatively new topic of discussion in the seafood sector and experts are still creating knowledge and understanding around this topic. Most stakeholders mention the importance and opportunities that come with traceability and believe that easy-to-use systems are needed to track and trace seafood along supply chains.

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ANNEXES

Annex 1. Justification for the choices regarding the preferable methods for traceability in different seafood sectors.

Small-scale fisheries		
Traceability methods	**Motive**	**Percentage (%)**
QR code / RFID code	Easy to use	40%
	Most efficient	16%
	Cheap option	8%
	Best option	8%
	Free from internet connection	4%
	Good as accessory method	4%
	Creates added value	4%
	Can be easily adapted to the sector	4%
	In comparison, blockchain is hard to use	4%
	In comparison, blockchain requires bigger means to implement	4%
	In comparison, certifications are not accessible to everyone and are expensive	4%
Mobile/web app	Easy to use	35%
	Most efficient	12%

	Best option	12%
	Can be easily adapted to the sector	6%
	In comparison, certifications are not accessible to everyone and are expensive	6%
	Cheap option	6%
	In comparison, blockchain is hard to use	3%
	In comparison, blockchain requires bigger means to implement	3%
	Serves as a pre-made traceability system	3%
	Allows real-time access to information	3%
	Good as accessory method	3%
	Speed up procedures and improve the quality of products	3%
	Improves digital security	3%
	Accessible method	3%
Blockchain	Best option	23%
	Most efficient	18%
	Improves digital security	18%
	Easy to use	14%
	Real-time access to information	5%

	Creates added value	5%
	Facilitates the other methods and traceability	5%
	Good as accessory method	5%
	Speed up procedures and improve the quality of products	5%
	Increase the reliability of traceability	5%
Certification scheme/Label	Easy to use	19%
	In comparison, blockchain is hard to use	10%
	Best option	10%
	Control by independent third party	5%
	Creates added value	5%
	Facilitates the other methods and traceability	5%
	Good as accessory method	5%
	Good for informing the consumer	5%
	Generally good tool (might not be the best for SSF)	5%
	Improve the quality of products	5%
	Speed up procedures and improve the quality of products	5%
	Incentive to promote traceability	5%

	It is a way to value the product	5%
	Most appropriate to the sector	5%
	Most efficient	5%
	Not time-consuming	5%
	To establish good practices	5%
Any Method	Can be easily adapted to the sector	100%
Electronic logbooks provided by the EU	If a logbook could be accessed through an ID number on an official website provided by the EU, it would be much easier to control the information	100%
GPS	Easy to implement	100%
Paper-based methods	Most fishermen in Greece have low educational level	100%
Traceability systems that can be interlinked with other systems	May help in the digitalization of traceability	100%
Industrial fisheries		
Traceability methods	**Motive**	**Percentage (%)**
Blockchain	Best option	28%
	Improves digital security	16%
	Most efficient	9%
	Most appropriate to the sector	9%

	Can be easily adapted to the sector	6%
	Easy to use	6%
	Increase the reliability of traceability	6%
	This sector has the appropriate means for this technology	3%
	Real-time access to information	3%
	In comparison, certifications are not accessible to everyone and are expensive	3%
	Facilitates the other methods and traceability	3%
	Speed up procedures and improve the quality of products	3%
	Good as accessory method	3%
Certification scheme/Label	Best option	19%
	Easy to use	12%
	To establish good practices	8%
	Incentive to promote traceability	8%
	Can be easily adapted to the sector	8%
	Most appropriate to the sector	8%
	Most efficient	8%
	Contains solid framework and standards	4%
	This sector has the appropriate means for this method	4%
	It is a way to have control in fisheries	4%

	Good as accessory method	4%
	Good for informing the consumer	4%
	Facilitates the other methods and traceability	4%
	Speed up procedures and improve the quality of products	4%
	Gives a commercial advantage	4%
Mobile/web app	Best option	25%
	Easy to use	25%
	Most efficient	11%
	Cheap option	6%
	In comparison, certifications are not accessible to everyone and are expensive	6%
	Most appropriate to the sector	6%
	Can be easily adapted to the sector	3%
	Good as accessory method	3%
	Speed up procedures and improve the quality of products	3%
	Real-time access to information	3%
	Serves as a pre-made traceability system	3%
	This sector has the appropriate means for this technology	3%
	Already widely used	3%

	Improves digital security	3%
QR code / RFID code	Easy to use	28%
	Best option	20%
	Cheap option	8%
	Most efficient	8%
	Most appropriate to the sector	8%
	Can be easily adapted to the sector	4%
	In comparison, certifications are not accessible to everyone and are expensive	4%
	Improves digital security	4%
	Free from internet connection	4%
	Good as accessory method	4%
	Increase the reliability of traceability	4%
	This sector has the appropriate means for this technology	4%
Any Method	Can be easily adapted to the sector	100%
Electronic logbooks provided by the EU	If a logbook could be accessed through an ID number on an official website provided by the EU, it would be much easier to control the information	100%
GPS	Easy to implement	100%
Greece's landing site/auction record system	Under Greece's national obligation law, there is already a programme for the collection, management and use of fisheries catch data found and cross-checked with the fish auction/landing site of Keratsini database. Keratsini fishing auction/landing site is the largest fishing auction in Greece	100%

Inspections and penalties	Industrial fisheries have more resources and create most of the impact. There is a need to control their activity, inspect and implement penalties and fines to bad practices	100%
Traceability systems that can be interlinked with other systems	May help in the digitalization of traceability	100%
Fish farming		
Traceability methods	**Motive**	**Percentage (%)**
Blockchain	Best option	22%
	Improves digital security	14%
	Most appropriate to the sector	11%
	Most efficient	11%
	Good for informing the consumer	6%
	Easy to use	6%
	This sector has the appropriate means for this technology	3%
	Secure the quality and safety of the product	3%
	Contribute to environmental sustainability	3%
	Eliminate unfair competition with non-EU-countries	3%
	Give visibility to good practices in aquaculture and good quality	3%
	Good as accessory method	3%
	Increase the reliability of traceability	3%

	Mobile/web app is not used in aquaculture, since other more advanced technological solutions are on place	3%
	Promotes eco-labeling	3%
	Promotes ethical standards	3%
	Real-time access to information	3%
Certification scheme/Label	Best option	16%
	Good for informing the consumer	10%
	Easy to use	10%
	Most appropriate to the sector	6%
	Assure environmental and social sustainability	3%
	Can be easily adapted to the sector	3%
	Contribute to environmental sustainability	3%
	Contribute to the increase of industry's credibility and improve product's traceability	3%
	Control by independent third party	3%
	Eliminate unfair competition with non-EU-countries	3%
	Facilitates the other methods and traceability	3%
	Give visibility to good practices in aquaculture and good quality	3%
	Good as accessory method	3%
	Incentive to promote traceability	3%

	Promotes eco-labeling	3%
	Promotes ethical standards	3%
	Secure the quality and safety of the product	3%
	Contains solid framework and standards	3%
	This sector has the appropriate means for this technology	3%
	To establish good practices	3%
	A control is required for certification	3%
	Focused on national origin	3%
Mobile/web app	Easy to use	23%
	Best option	20%
	Most efficient	6%
	Good for informing the consumer	6%
	Cheap option	6%
	Contribute to environmental sustainability	3%
	In comparison, certifications are not accessible to everyone and are expensive	3%
	Can be easily adapted to the sector	3%
	Eliminate unfair competition with non-EU-countries	3%
	Good as accessory method	3%
	Most appropriate to the sector	3%

	Promotes eco-labeling	3%
	Real-time access to information	3%
	Secure the quality and safety of the product	3%
	Serves as a pre-made traceability system	3%
	This sector has the appropriate means for this technology	3%
	Already widely used	3%
	Improves digital security	3%
	Accessible method	3%
QR code / RFID code	Easy to use	18%
	Best option	18%
	Most efficient	9%
	Most appropriate to the sector	6%
	Good for informing the consumer	6%
	Cheap option	6%
	In comparison, certifications are not accessible to everyone and are expensive	3%
	Contribute to environmental sustainability	3%
	Improves digital security	3%
	Eliminate unfair competition with non-EU-countries	3%
	Free from internet connection	3%

	Give visibility to good practices in aquaculture and good quality	3%
	Good as accessory method	3%
	Mobile/web app is not used in aquaculture, since other more advanced technological solutions are on place	3%
	Promotes eco-labeling	3%
	Promotes ethical standards	3%
	Secure the quality and safety of the product	3%
	This sector has the appropriate means for this technology	3%
Any Method	Can be easily adapted to the sector	100%
Direct link to company data with the Ministry of Fisheries	Easy to implement	100%
I don't know	—	—
Paper-based methods	Most appropriate to the sector	50%
	Allows control of information	50%
Traceability systems that can be interlinked with other systems	A system that is interlinked with other systems may help in the digitalization of traceability	100%
Shellfish farming		
Traceability methods	**Motive**	**Percentage (%)**
Blockchain	Best option	22%

	Improves digital security	14%
	Most appropriate to the sector	11%
	Most efficient	11%
	Good for informing the consumer	6%
	Easy to use	6%
	This sector has the appropriate means for this technology	3%
	Secure the quality and safety of the product	3%
	Contribute to environmental sustainability	3%
	Eliminate unfair competition with non-EU-countries	3%
	Give visibility to good practices in aquaculture and good quality	3%
	Good as accessory method	3%
	Increase the reliability of traceability	3%
	Mobile/web app is not used in aquaculture, since other more advanced technological solutions are on place	3%
	Promotes eco-labeling	3%
	Promotes ethical standards	3%
	Real-time access to information	3%
Certification scheme/Label	Best option	16%
	Good for informing the consumer	10%

	Easy to use	10%
	Most appropriate to the sector	6%
	Assure environmental and social sustainability	3%
	Can be easily adapted to the sector	3%
	Contribute to environmental sustainability	3%
	Contribute to the increase of industry's credibility and improve product's traceability	3%
	Control by independent third party	3%
	Eliminate unfair competition with non-EU-countries	3%
	Facilitates the other methods and traceability	3%
	Give visibility to good practices in aquaculture and good quality	3%
	Good as accessory method	3%
	Incentive to promote traceability	3%
	Promotes eco-labeling	3%
	Promotes ethical standards	3%
	Secure the quality and safety of the product	3%
	Contains solid framework and standards	3%
	This sector has the appropriate means for this technology	3%
	To establish good practices	3%
	A control is required for certification	3%

	Focused on national origin	3%
Mobile/web app	Easy to use	23%
	Best option	20%
	Most efficient	6%
	Good for informing the consumer	6%
	Cheap option	6%
	Contribute to environmental sustainability	3%
	In comparison, certifications are not accessible to everyone and are expensive	3%
	Can be easily adapted to the sector	3%
	Eliminate unfair competition with non-EU-countries	3%
	Good as accessory method	3%
	Most appropriate to the sector	3%
	Promotes eco-labeling	3%
	Real-time access to information	3%
	Secure the quality and safety of the product	3%
	Serves as a pre-made traceability system	3%
	This sector has the appropriate means for this technology	3%
	Already widely used	3%
	Improves digital security	3%

	Accessible method	3%
QR code / RFID code	Easy to use	18%
	Best option	18%
	Most efficient	9%
	Most appropriate to the sector	6%
	Good for informing the consumer	6%
	Cheap option	6%
	In comparison, certifications are not accessible to everyone and are expensive	3%
	Contribute to environmental sustainability	3%
	Improves digital security	3%
	Eliminate unfair competition with non-EU-countries	3%
	Free from internet connection	3%
	Give visibility to good practices in aquaculture and good quality	3%
	Good as accessory method	3%
	Mobile/web app is not used in aquaculture, since other more advanced technological solutions are on place	3%
	Promotes eco-labeling	3%
	Promotes ethical standards	3%
	Secure the quality and safety of the product	3%

	This sector has the appropriate means for this technology	3%
Any Method	Can be easily adapted to the sector	100%
Direct link to company data with the Ministry of Fisheries	Easy to implement	100%
I don't know	—	—
Paper-based methods	Most appropriate to the sector	50%
	Allows control of information	50%
Traceability systems that can be interlinked with other systems	A system that is interlinked with other systems may help in the digitalization of traceability	100%