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Review

Use cases and future prospects of blockchain applications in global fishery and aquaculture value chains

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ABSTRACT

Fishery and aquaculture sectors use blockchains to enhance traceability and transparency in value chains and to fight illegal, unreported, and unregulated fishing. The aim of this paper is to provide the current status and future prospects of blockchain application in worldwide fisheries and aquaculture. A literature review was conducted using blockchain and global value chain frameworks. Results indicate that generally, the use of blockchain is vertically driven by the requirements of markets and business competitiveness. The majority of the blockchain use cases are for traceability and storytelling, and to a lesser extent for payments or incentives. Moreover, there has been limited use cases of blockchain at horizontal level, such as decentralized finance (de-fi), enabling fishers to gain capital access and entering global markets. Overall, enhancing the adoption of blockchain should address suitability, incentives, and trust factors in using blockchain. As future prospects, projects in fishery and aquaculture could better utilize the full potential of blockchains by (1) incorporating financing, capital, and insurance through de-fi solutions, (2) providing tangible incentives, and (3) using automation such as Internet-of-Things (IoT) in data collection to improve quality and trust in data.

1. Introduction

Managing global value chains (GVCs) is challenging due to the complex network of chain actors and the uncertainties posed by changing technologies, markets, and political environment. Sustainability and transparency of information in value chains have become standards in international trade and markets in the last decades (Busse et al., 2017; Gardner et al., 2019). Compliance with these standards requires coordination of value chain actors across multiple levels and regions using different governance mechanisms. The mechanisms that have been used in the last decades include public-private partnerships, certification schemes, and private labelling. By adapting such mechanisms, companies gain competitive advantages and reduce disruptions in the value chain.

Blockchain is a novel technology that is used in recent years to coordinate value chain actors (Ganne, 2018). A blockchain is a distributed ledger technology that records transactions such as value, information, or digital events, which can be accessed and validated by participants without requiring a central authority (Crosby et al., 2016). Blockchains are highly standardized, therefore facilitating interaction between many diverse actors. Any record added to the blockchain cannot be deleted which makes transactions immutable (Crosby et al., 2016; Nofer et al., 2017). In GVCs, the use of blockchain has been at the forefronts of facilitating cross-border trades by ensuring compliance of value chain actors to sustainability requirements, while enhancing traceability and transparency of goods. Furthermore, blockchains are a single source of truth that can be used for dispute resolutions and anchoring value chain data for business decision making (Ganne, 2018; Dujak and Sajter, 2019; Chang et al., 2020). The use of blockchain in GVCs encompasses many sectors that include logistics, health care, finance, agriculture and fisheries (Kamilaris et al., 2019; Chang et al., 2020).

Blockchains are increasingly used in fishery projects to improve the sustainability of fisheries, which is an access condition for markets such as the European Union (EU), the United States of America (USA), and Canada. In many fisheries, overfishing due to unsustainable fishing practices is a persisting problem (Tolentino-Zondervan, 2017). Unsustainable fishing practices include the use of unselective fishing gears that results to by-catch of non-target species, such as in the cases of tuna (Dagorn et al., 2013), pelagic trawl (Bonanomi et al., 2018), and swordfish fisheries (Gilman et al., 2007); and the Illegal Unreported and

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Unregulated (IUU) fishing. The IUU fishing exists in many fisheries worldwide and contributes to exceeding fishing quotas and to mislabelling of traded seafood and aquaculture products (Helyar et al., 2014), and contributes approximately US $10 billion to US $23 billion loses per year worldwide (Zabarenko, 2013). As such, blockchains have emerged as a suitable mechanism for addressing fishery issues. The cryptographic security and distributed nature of blockchain is ideally suited to create a trustless environment that will facilitate the management of fisheries. In principle, using cryptographic proof in blockchain can prove whether fishers and other chain actors comply with government rules and global market requirements in terms of sustainable practices and the quality of fish and seafood. In addition, a blockchain can also be used to facilitate transactions between actors in the value chain and to add value through price premium to existing products based on proof of quality and sustainability.

Despite promising examples of blockchain application in seafood value chains, a comprehensive analysis of all applications and the actual use of blockchain in the area around the world is still missing. Implementing blockchain includes financial, technological, and organizational barriers while various stakeholders in the chain have varying level of acceptance of this technology (Sander et al., 2018; Kouhizadeh et al., 2021). These barriers have led to continuous innovation. Many new technological developments in blockchain are recently made, which allow for better scaling, lower costs as well as better enabling of use cases of blockchain (Zeadally and Abdo, 2019). Blockchain applications in fishery and beyond are expected to keep growing in the coming years. Therefore, this paper analyzes the implementation of blockchain in seafood value chains in terms of its potentials and possible challenges.

This study answers the following questions: (1) What is the current status of blockchain in fishery and aquaculture value chains; and (2) What is the future prospect of blockchain in the fishery and aquaculture value chains? By answering these questions, this paper identifies opportunities to use blockchain in the GVCs and provides a roadmap for decision-making on how to use blockchain in fishery and aquaculture. Several studies have reviewed the use cases and application of blockchain in seafood value chains (e.g. Cook, 2018, Blaha and Katafono, 2020, Howson, 2020, Tsolakis et al., 2021). However, there is no comprehensive analysis of all the applications of blockchain in fishery and its future prospect. This paper aims to fill that gap. The next section explains blockchain and its properties and how blockchain is linked in the value chain. This is followed by a review of its application in fishery and aquaculture using value chain framework. Then the challenges and future prospect to enhance the implementation of blockchain in fishery and aquaculture are discussed. Finally, conclusions are made based on the learning from the use cases.

2. Blockchain in global value chains

Understanding the nature of blockchain is necessary for its proper implementation in any value chain. In this section we explain the elements of blockchain and how it is linked with value chains. Afterwards, the overall framework for blockchain application in GVCs is provided.

2.1. Blockchain

The increase in use of blockchains in GVCs can be attributed to blockchain's unique properties – (1) transparent transactions, (2) immutable data, (3) no central authority, (4) peer-to-peer value transfer, and (5) conditional transactions (Bano et al., 2019). To illustrate these properties, it is briefly explained how blockchains work, using a Proof of Work blockchain (like Bitcoin) as example. First, a transaction made by a participant in the network (called a node) is checked for validity before being added to a block. A block containing new transactions generates a hash value, which is a unique hexadecimal value of a fixed length that is generated from any type of data and is designated per block. For a block to be valid, the generated hash value must meet the difficulty of the requirements of the blockchain, which only can be done using many computations. By requiring a lot of computational power to generate a valid hash for a block, the blockchain secures its transactions. Once a block is added to a public ledger, it is visible to everyone in the network. Since each new block is linked to the previous block, they form a chain of blocks and therefore the name 'blockchain' was adopted (Yang et al., 2020). With each addition of a new block, previous transactions become more immutable since it is computationally costly and unrealistic to recalculate the hash value for every block. In recent years, alternative methods have been created to secure blockchains, such as Proof of Stake, Proof of Authority (in private blockchains), and Proof of Space. The degree of decentralization in blockchain also varies, depending on the type of blockchain and security that is used.

2.2. Types of blockchain

The type of blockchain to be implemented depends on the needs of involved stakeholders in GVCs. General classifications are public and private blockchains. In this paper, this classification is extended to so called "hybrid" blockchain. Fig. 1 summarizes the types of blockchains including their advantages and disadvantages.

Public blockchains are synonymous to permissionless blockchains, where the platform is open to everyone, and no specific entity manages the platform. There are numerous advantages to this type of blockchain (see bottom triangle in Fig. 1). Public blockchains are characterized by a highly decentralized system wherein all stakeholders have access to the network, view public transactions, and participate in a consensus to verify transactions (Viriyasitavat and Hoonsopon, 2019). Public blockchains are seen as more credible as compared to private blockchains because of its transparency and decentralized nature. In addition, the number of 'blocks' of information built publicly are high and are therefore difficult to hack since they are highly secured. Despite these advantages, public blockchains face multiple limitations. Public blockchains have a limited transaction processing rate because of the consensus mechanisms, such as Proof-of-Work and Proof-of-Stake, requires the entire network to reach consensus. The computational power required for public blockchain is therefore high, making it costly to operate and making the process slow. Well-known examples of public blockchains are Bitcoins and Ethereum, two cryptocurrencies that demonstrate peer-to-peer approach via Proof-of-Work and Proof-of-Stake respectively, to validate transactions in the network.

Private blockchains are mostly used for corporate applications and its network can only be accessed by actors that have permissions (Strehle, 2020). Private blockchains are developed to tackle the shortcomings of public blockchains, such as data reversibility, data privacy, transaction volume scalability, and system responsiveness (Hamida et al., 2017). As shown in the upper triangle in Fig. 1, private blockchains are less costly than public blockchains since transactions maintained in such blockchains are coming from few participants (Viriyasitavat and Hoonsopon, 2019). The limited transactions made by participants also make private blockchain highly scalable and result to more control and privacy as compared to public blockchains. Private blockchains also include disadvantages. These blockchains are less secure because they are vulnerable to attacks due to limited transaction volume cause by limited number of nodes. The validation by few actors and the access to information by limited participants also raises credibility issues for the users of private blockchains. A well-known example of a private blockchain is Hyperledger, a technology used by IBM Food Trust for ensuring the sustainability in food supply chains. Companies such as Walmart, Nestle, and Carrefour participate in IBM Food Trust (IBM, 2021).

Since both public and private blockchains face limitations, innovations to combine advantages of types of blockchain are continuously being developed. Such innovations are hybrid blockchains and are often referred to as second layer technology. Hybrid blockchains offer many advantages such as better privacy, higher transaction throughput,

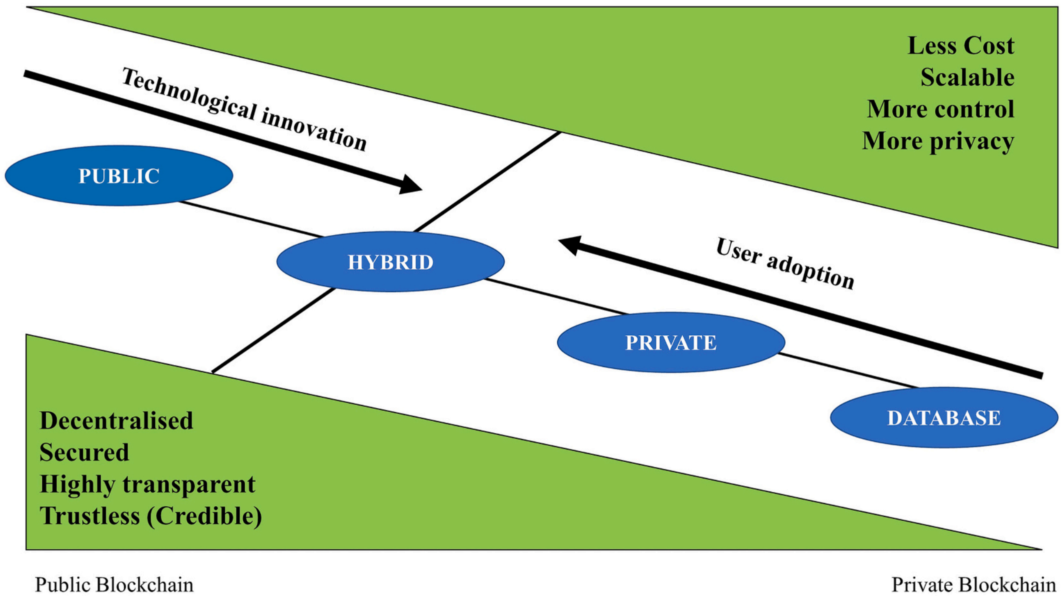

Fig. 1. The different types of blockchains including its advantages and disadvantages.

lower cost as well as allowing for use case specific rules and technologies such as zero-knowledge proofs. Using such technologies, information can be divided or even completely kept private unless revealed by the owner of that data, which is often a requirement for many business practices. Examples of hybrid blockchains include the use of technologies such as Lightning network, Side chains, and Sharding (Chauhan et al., 2018). These hybrid technologies are anchored on top of currently existing blockchains, such as Bitcoin and Ethereum. Through hybrid blockchains, the adoption of public blockchain technology becomes more accessible to various stakeholders, while keeping the costs lower and increasing scalability (advantages of private blockchain) and at the same time improving the security and credibility of the blockchain (advantages of public blockchain) (Geroni, 2021).

2.3. Blockchain in global value chains

Understanding the impact of blockchain in the globalization of trade requires an understanding of the implementation of blockchain in GVCs. Literature has emphasized the vertical and horizontal dimensions of the value chains (Gereffi et al., 2005; Riisgaard et al., 2010), while the study of Tolentino-Zondervan et al. (2016a, 2016b) extends these two dimensions into the intersection of both horizontal and vertical dimensions of value chain. Following the framework of Tolentino-Zondervan et al. (2016a, 2016b), the use cases of blockchain in GVCs are

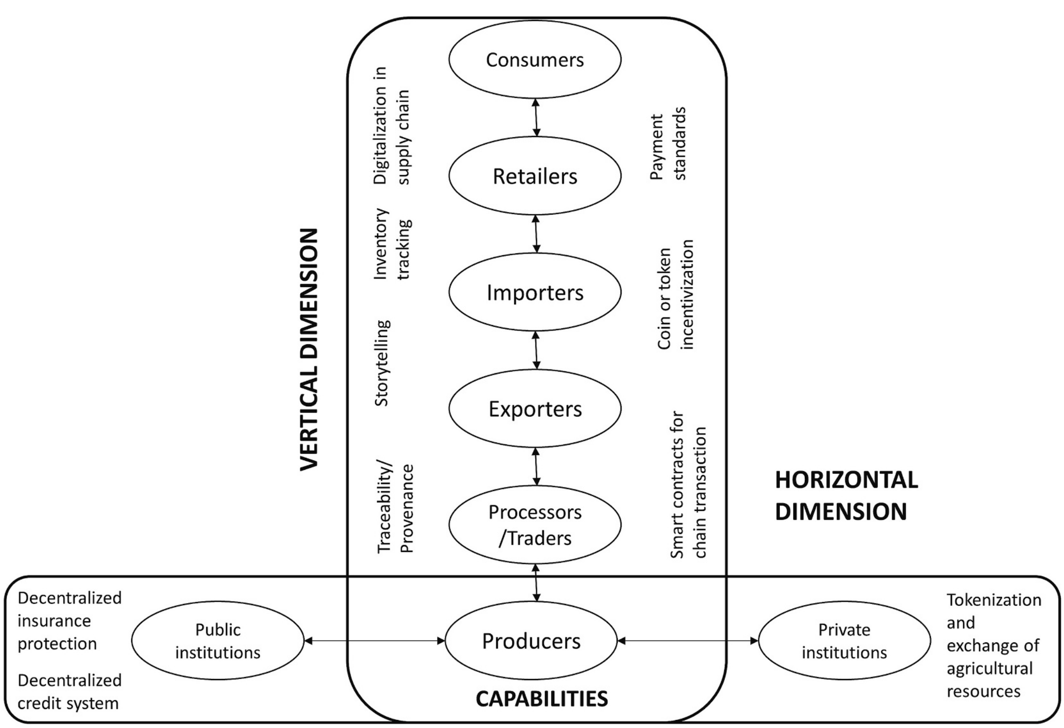

Fig. 2. Use cases of blockchain using the vertical and horizontal dimensions of GVC.
(Source: Adapted from Tolentino-Zondervan et al. (2016)).

summarized in Fig. 2 and the framework is utilized in analyzing the application of blockchain in fishery and aquaculture.

The vertical dimension focuses on the flow of products from suppliers to consumers and information from customers and retailers going to suppliers (Gereffi et al., 2001, 2005). The flow of products involves tracing seafood products from fishers, fish traders and processors, exporters, importers and brands or retailers. The flow of information includes the sustainability requirements in the market, such as compliance with quality and safety standards and use of sustainable fishing method. The vertical dimension answers questions related to (1) how brands and retailers coordinate production and set requirements for participation of value chain actors and (2) how incentives are distributed. Blockchain addresses these questions in vertical dimensions of GVCs through various use cases. These include traceability in the value chain, storytelling of products, distribution of incentives to chain actors for anchoring their data in the blockchain, use of smart contracts for coordinating transaction requirements in the value chain, peer-to-peer transactions that eliminate middlemen, and tracking inventory along the chain.

The horizontal dimension of the value chain relates to the set regulations and norms at producer level and the institutional support provided by both public and private actors outside the value chain, to build the capabilities that will enable producers to participate in the value chain (Tolentino-Zondervan et al., 2016a, 2016b). In the case of fishery, it includes the rules on fishing catch quota, licenses, and gears and the given supports to fishers such as training, education and funding provided by government and non-government organizations (NGOs). The issues that the horizontal dimension tries to address include the level of inequality and access to capital by local producers to improve their capability to participate in the GVC (Riisgaard et al., 2010). Blockchain addresses these issues through various use cases. These include blockchain for decentralized insurance protection for producers, decentralized financing and micro-credit for banks and producers, and tokenization and exchange of agricultural resources. The blockchain implementation at the horizontal level can help producers to comply with requirements of the vertical dimension of the value chain such as sustainability standards.

3. Methodology

3.1. PRISMA

This study presents a systematic literature review using Preferred Reporting Items for Systematic Reviews and Meta Analyses, called PRISMA (Moher et al., 2009). The flowchart showing the four stages of PRISMA such as (1) identification, (2) screening, (3) eligibility, and (4) inclusion of articles, is presented in Fig. 3. The search is divided into two parts: (1) identification of studies via databases and registers and (2) via other methods. For the identification stage using databases and registers, a keyword search has been made in Google Scholar and Science Direct. The keywords search is "Blockchain" AND "fisheries" as well as "Blockchain" AND "aquaculture". Since blockchain in fishery is a relatively new topic, the years of the published records are also recent dating from years 2018–2021. A total of 31 records are identified in Google Scholar and additional 2 records in Science Direct. The identified works include peer-reviewed articles (15), conference papers (7), theses (5), reports (2) and discussion papers (2). After records have been identified, non-English and non-accessible works were eliminated on the lists before screening the content of the records. A total of 4 records have been removed. Afterwards, all articles were assessed for eligibility based on the objective of this paper. Five articles were excluded because they do not fit the objective of this study, e.g. partial or indirect focus on fishery/aquaculture. In total, 24 works were included in the analysis. For identification via other methods, records were also identified through Google ($n = 12$) and searching organizational websites ($n = 6$). One report is not retrievable, while the materials from websites are available online. For further eligibility assessments, four reports were duplicates from the previous databases and were therefore eliminated. A total of 13 reports were included in the analysis. Together with the 24 works identified in databases and registers, a total of 37 works was included in the analysis.

The selected 37 records were used for answering the first research

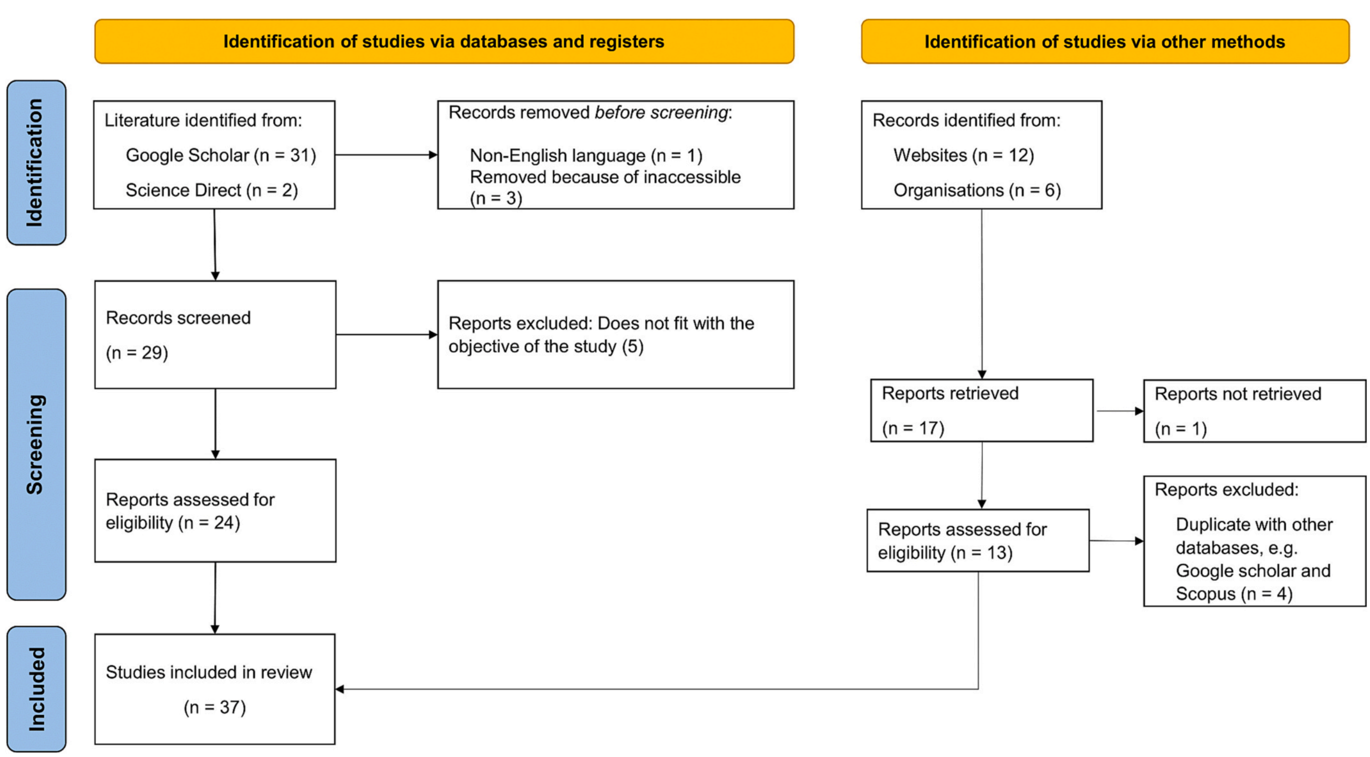

Fig. 3. The PRISMA flow diagram using databases, registers, and other methods.

question related to the current use cases of blockchain in fishery and aquaculture value chains. Information such as actual blockchain projects, collaborators, purposes, species, and locations, were manually obtained from the identified records. The information was summarized and presented via tables and figures in the Results section.

3.2. Text mining

The manual analysis of literature review is further supplemented by conducting text mining, a data science field used for extracting high quality information from the text to generate insights. Text mining uses visualizations, statistics, text, and information analyses to present insights (Kaushik and Naithani, 2016). In recent years, text mining has been used for conducting and supplementing manual literature review in fisheries (e.g. Wei et al., 2021, Takacs and O'Brien, 2022, Tolentino-Zondervan and Zondervan, 2022). In this study, text mining is used to achieve the second research objective, which is to identify the gaps and to recommend future prospect for the application of blockchain in fishery in a quantitative manner.

Text mining involves several steps. First the pdf articles were converted to text corpus using the pdftools R package version 3.0.1. The text corpus was loaded and cleaned by removing stop words, numbers and punctuation and further analysis were performed using the tm R library version 0.7–8. Keywords were selected based on three categories: Traceability, Payments, and De-fi. Time-based analysis is performed by filtering the articles per year and by building the term-document matrix. The relative frequency of these keywords was then plotted as a bubble plot using ggplot2, to show the development and the gap of blockchain use cases in fishery and aquaculture overtime. Frequently occurring terms in the application of blockchain in fishery and aquaculture were also identified and were presented in Supplementary Material 1.

4. Results

The results are presented in three sections. First, we present information about the blockchain projects in the fishery and aquaculture sector worldwide. Then, we zoom-in at the use cases of blockchain at the vertical and horizontal dimensions of the value chain. This is followed by identifying the potential use cases of blockchain in the fishery and aquaculture value chains using text mining.

4.1. Overall implementation of blockchain in fishery and aquaculture sector

Fig. 4 shows the worldwide implementation of blockchain in fishery and aquaculture. The blockchain projects are mainly implemented in developing countries such as Indonesia (Provenance, Bumble Bee Fair Trade Yellowfin Tuna, This Fish, Jumbo Tilapia Blockchain), Pacific Island nations (Pacifical-Atato, TraSeable), Philippines (Tracey), Ecuador (Sustainable Shrimp Partnership), and Thailand (eMin). Most of the participating fisheries in developing countries are small-scale fisheries, except for the cases of Pacifical-Atato and TraSeable. The developed countries that implement blockchain in their fisheries and aquaculture include Australia (Open SC Patagonian toothfish & Spencer Gulf King Prawn Fishery), Norway (IBM Blockchain Transparent), and USA (New England Fishery Blockchain Seafood and Fishcoin in Alaska). Developed country fisheries are implementing blockchain on large-scale level, often, at industry level.

The specific purpose of each blockchain project shown in Fig. 4 is further elaborated in Table 1. Most of the projects are in captured fisheries such as tuna, Patagonian toothfish, wild salmon, scallops, while a few are focused on aquaculture such as farmed shrimps, salmon and tilapia. These species are mostly considered as high value products. The presence of various entities that require transparency, sharing, and auditing of data, such as NGOs, governments, private companies, and the specific fisheries makes the use of blockchain suitable in the given use cases. For instance, the Pacifical-Atato case helps different groups, such as the PNA government, retailers (Thai Union), consumers, and certification bodies (e.g., MSC), to track and to verify that the MSC Pacifical canned tunas were sustainably caught, processed, and canned. Similarly, blockchain facilitates trust in many projects such as the Norwegian salmon fishery, Jumbo Tilapia, Bumble Bee Foods, and Provenance by ensuring compliance of different supply chain actors on the sustainability and transparency of information. Public blockchains are used in fisheries especially those that are aided by NGOs and governments (e.g. Pacifical case, Fishcoin), while private blockchains are

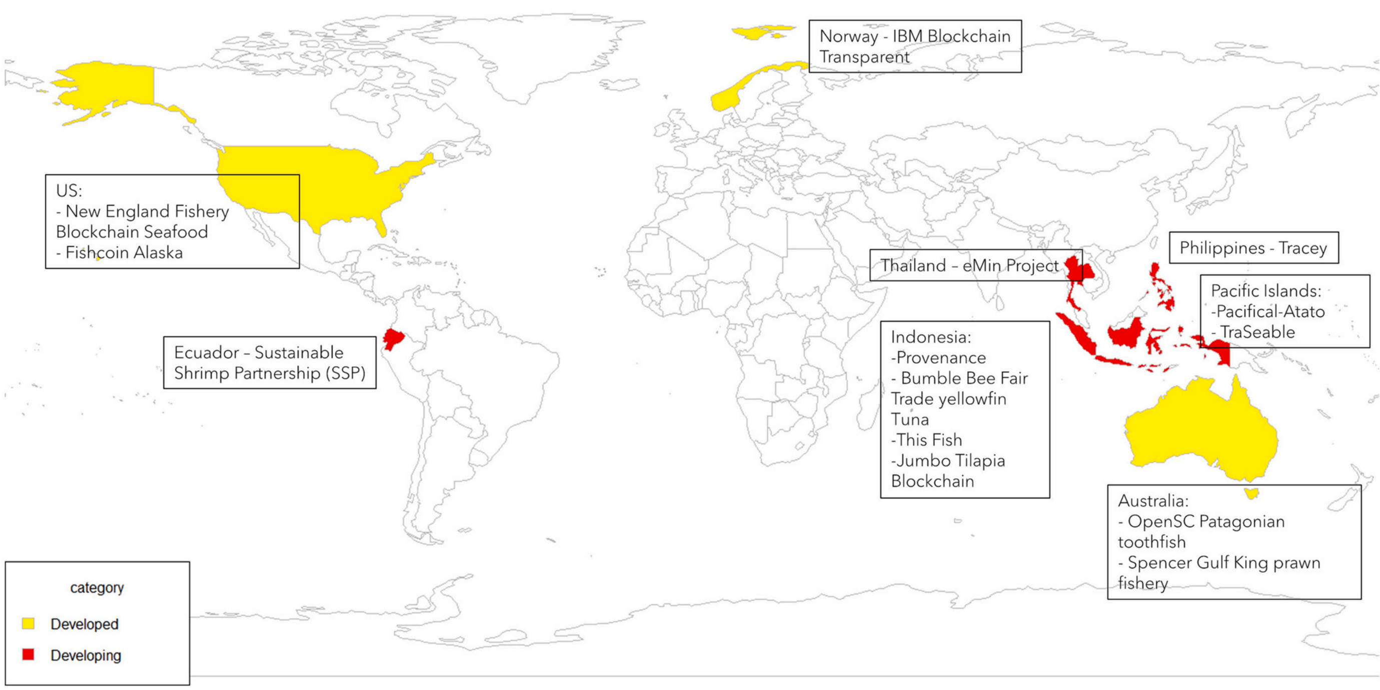

Fig. 4. The implementation of blockchain in fishery and aquaculture worldwide.

Table 1
Summary of use cases of blockchain in fisheries and aquaculture worldwide.

Cases	Specific purpose	Type of blockchain	Species	Lead Actors	Sources
Pacifical-Atato	Support documentation for MSC chain of Custody, track purse seine-caught skipjack tuna	Public (Ethereum)	Skipjack tuna	Gustav Gerig, Pacifical, Atato Notary	(Pacifical, 2018; Cohem, 2020)
Provenance project	Track and record caught fish, prevent double expenditure on certificates, and serve as basis for open system traceability.	Public (Ethereum)	Yellowfin and skipjack tunas	Provenance, International Pole & Line Foundation (IPNLF), World Wide Fund for Nature (WWF)	(Provenance.org, 2015; Blaha and Katafono, 2020; Howson, 2020)
TraSeable	Have transparent and traceable supply chain to fight IUU and human rights abuses	Private (Treum-Ethereum)	Tuna	WWF, ConsenSys, Sea Quest (Fiji) Ltd., TraSeable Solutions	(Visser and Hanich, 2018; Cook, 2018; Blaha and Katafono, 2020)
OpenSC Patagonian toothfish	Record data of tagged toothfish with RFID tags from capture to end supply chain, to prove that fish are caught in an MSC certified fishery	Public (Ethereum)	Patagonian toothfish	OpenSC, WWF-Australia, BCG Digital Ventures, Australia fisheries	(AFR.com, 2019; Blaha and Katafono, 2020; Howson, 2020)
Bumble Bee Foods "Fair Trade" yellowfin tuna	Provide transparency to consumers and customers	Private (SAP)	Yellowfin tuna	Bumble Bee Foods, Indonesian yellowfin tuna fishery, SAP HANA	(SE, 2019; Blaha and Katafono, 2020)
Fishcoin	Incentivize collection and input of data by supply chain actors through token ecosystem	Public (Eachmile)	Fish and seafood products (Alaskan wild salmon, shrimp, tuna, etc.)	Fishcoin, Eachmile technologies	(Fishcoin, 2018)
Sustainable Shrimp Partnership	Provide transparency and traceability information, through consumer app, fight fish fraud and poor-quality products	Consortium /Private (IBM)	Farmed shrimps	Sustainable Shrimp Partnership (SSP), IBM Food Trust, Ecuadorian shrimp farms	(Insights, 2020; Blaha and Katafono, 2020)
Tracey	Document and verify catch and traceability data, financial institutions use provided data as basis for providing microloans to fisherfolk based on credit request assessment	Private (Streamr)	Handline tuna fishery	WWF Philippines, UnionBank, TX Streamr	(Marttila et al., 2019)
ThisFish	Improve business efficiency and increase trust and accuracy in supply chain data.	Private (Tally)	Tuna, farmed shrimp and fish sectors	ThisFish, Ecotrust Canada, Canadian fishing industry Slowfood, MDPI	(ThisFish, 2020)
New England Fishery Blockchain Seafood	Promote food traceability, safety, and sustainability among scallop supply chain members.	Private (IBM Hyperledger)	Scallop	IBM Food Trust, New England scallopers, Raw Seafoods	(Dan McQuade, 2019; Océane Elia Boulais, 2020)
Jumbo Tilapia Blockchain	Make chain more transparent through use of QR code	Private (SIM Powerchain)	Farmed fish tilapia	Jumbo Supermarket, Regal Springs, Seafood Connection Mayonna	(SIM, 2020)
IBM Blockchain Transparent (Norwegian seafood)	Provide insights on the origin, quality of seafood and feed the fish consume to ensure safer, better seafood to consumers worldwide	Private (IBM Hyperledger)	Farmed fish and seafoods, such as salmon	Norwegian Seafood Association, IBM, Atea	(Mathisen, 2018; Førsvoll and Åndal, 2019; Altoukhov, 2020)
eMin Project (Thailand)	Use blockchain as existing farm monitoring tool	Public (Eachmile)	Shrimp aquaculture	Diginex, Mekong Club	(Océane Elia Boulais, 2020)
Spencer Gulf King Prawn fishery	Fishcoin tokens	Public (Eachmile)	Spencer Gulf along the coast of South Australia to Singapore	Eachmile & Fishcoin, Kolega Fisheries, Singapore-based hotels	(Océane Elia Boulais, 2020)

used by industry associations, brands, and retailers coming from both large- and small-scale fisheries.

4.2. Use cases of blockchain in fishery and aquaculture value chains

This section further analyzed the use cases of blockchain in the value chain based on the specific purpose of each project (see Table 1). Table 2 shows an overview of the classification of use cases of blockchain projects in fishery and aquaculture using the horizontal and vertical dimensions of the value chains.

4.2.1. Blockchain application in the vertical dimension

Two main use cases of blockchain in the vertical dimensions were identified. These include the use of blockchain (1) for traceability and storytelling and (2) for payments/delivering incentives to fishers and other chain actors. These two classifications are both market and business driven.

In terms of traceability and storytelling, the aim is to address the market requirements for fish and seafood products related to food safety, mislabeling, seafood quality, and proof of sustainable origin. Most of the fishery and aquaculture projects use blockchain for this purpose. They often use QR-codes in the can or in the packaging to trace the journey of fish and seafood products from bait-to-plate. Examples are Bumble Bee Foods Fair Trade Yellowfin Tuna, Sustainable Shrimp Partnership, Provenance, This Fish, and Jumbo Tilapia. All caught fish and aquaculture species in these projects are from developing countries and go to high-end markets such as the EU, the USA, and Canada. Other projects, such as Pacifical Atato and TraSeable, use traceability to not only track the journey of tunas caught in the Pacific Islands, but also to deter IUU fishing and human rights abuses in the tuna industry. The Norwegian salmon fisheries use blockchain to communicate to consumers the provenance and the story behind the water quality and feeds of the farmed salmon. The New England scallop fishery uses traceability to bring consumers in close contact to producers, such as by informing the captain on the quality of caught scallops. Trust, which is measured in terms of validity, reliability, and governance of data, is important factor in traceability. The use of automation and IoT facilitates trust by reducing human error in the traceability of information. For example, ThisFish project integrates in the hardware like the weighing scales, printers, and RFID scanners and readers the Tally software so that the data can be anchored automatically to the blockchain. In terms of governance, the IBM Blockchain platform enables Norwegian seafood

Table 2
Classification of use cases of blockchain projects in fishery and aquaculture using the vertical and horizontal dimensions of the value chains.

Use cases	Traceability & Storytelling					(De)centralized Finance	Transfer incentives
	Quality	Food safety	Mislabelling or Fraud	IUU fishing*	Work conditions**		
Pacifical-Atato				X	X		
Provenance project				X	X		
TraSeable			X	X	X		
OpenSC Patagonian toothfish				X			
Bumble Bee Foods – “Fair Trade” yellowfin tuna			X				
Fishcoin	X			X			X
Sustainable Shrimp Partnership	X		X				
Tracey				X		X	X
New England Fishery Blockchain Seafood		X		X			X
Jumbo Tilapia Blockchain	X				X		
IBM Blockchain Norwegian seafoods	X	X	X				
eMin Project					X		
Spencer Gulf King Prawn Fishery	X	X	X				X

* IUU fishing includes the use of sustainable fishing methods and providing catch data, as support for certification such as MSC.
** Fight slavery and human rights abuses.

companies to manage their own membership and share traceability data in a secured manner, thus enhancing trust among supply chain actors.

The second use case of blockchain, related to payments and direct delivery of incentives to fishers, has so far only limited applications. First is the case of Fishcoin, which uses and transfers tokens or coins to fishers as an incentive for providing data in the blockchain. Fishers can then use the Fishcoins to pay their bills or to buy minutes for their phones (Fishcoin, 2018). Another example is the Tracey project, which provides income to fishers by monetizing their catch and trade data to Streamr Marketplace. This marketplace sells data to third parties that include retailers, end consumers, and micro-financing institutes. In the case of new England fishery, consumers can directly transfer tips to boat captains or fishers for their catch.

4.2.2. Blockchain application in the horizontal dimension

So far, only one classification has been identified in terms of the use of blockchain in the horizontal dimension. This is the use of blockchain for Centralized- and Decentralized- Finance (CeFi and DeFi), which is done in the project Tracey in Philippines. Here, fishers are encouraged to anchor their catch data in the blockchain to improve the transparency in the first mile of the chain. In exchange, information related to fishers' catches are used by bank in assessing credit request of fishers (Marttila et al., 2019; Howson, 2020).

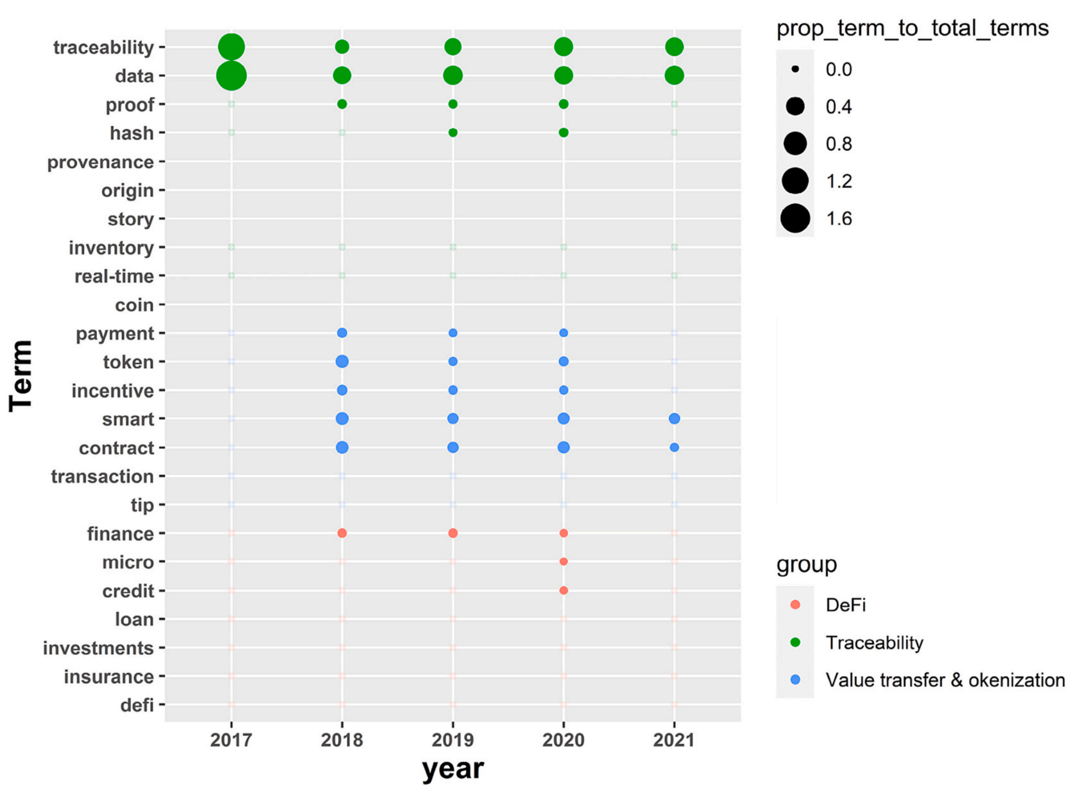

Fig. 5. Time-based analysis of use cases of blockchain in fishery and aquaculture based on traceability, payment, and De-fi categories.

4.3. *Text mining analysis to identify prospects of blockchain in fishery and aquaculture chains*

The results of the text mining analysis further enrich the findings related to the use cases of blockchain in the value chain discussed in Section 4.2. Fig. 5 illustrates the applications of blockchain in fishery and aquaculture under traceability, payment/incentive, and De-fi categories. The results show that overtime (2017–2021), most of the blockchain projects in fishery and aquaculture chains are heavily focused on traceability. The traceability part includes storytelling via data, proof of species, and traceability of products within the chain. Other uses of traceability such as real-time tracking and inventory show less applications through time. The payment/incentive part of the blockchain is generally present but less prominent than the traceability aspect. The applications of incentive include tokens, smart contract, and payments. Incentive keyword such as tip is underrepresented for all years in literature. Finally, the De-fi use cases in fishery are rarely used and keywords associated to financing only appear in 2020. De-fi related use cases, such as loan, investments, insurance, micro-credits are also rarely mentioned in literature.

5. Discussion

In this section, the learning from the use cases in the vertical and horizontal dimensions of the value chain are discussed in more detail.

5.1. *Blockchain use cases in the vertical dimension of the value chain*

Consistent to the findings of many studies that analyze the use of different sustainability instruments in the value chains such as certifications, labels, and voluntary (Nadvi, 2008, Mol, 2015; Mol and Oosterveer, 2015), this study illustrates that blockchain in the vertical dimension of the fishery and aquaculture value chains are mostly used to provide traceability and transparency of information to claim sustainable production. As can be seen in the results presented in Sections 4.2.1 and 4.3, almost all use cases of blockchain in fishery and aquaculture apply traceability and storytelling to address the quality, food safety, fraud, IUU fishing, and working condition issues. The use of blockchain for transparency and traceability is needed as market requirements and for business competitiveness (Rejeb, 2018, Gopi et al., 2019, Cruz and da Cruz, 2020, Probst, 2020, Oliveira et al., 2021). The use of blockchain for traceability could further grow based on the developments in the macro-environment. For example, it is becoming a requirement at regional and international level that products being imported cross border should be traceable and is anchored on a database, as part of consumer protection and fight against IUU fishing. In the USA, several fish products that are imported need to be traceable as part of the customs requirement (NOAA, 2018). In the EU, seafood traceability at all stages of production (including catching or harvesting, processing, distribution, and retail) is a requirement (Tsolakis et al., 2021). Current systems used in EU vary per country while in some cases lack digitalization. The EU recently called for a mandatory and more standardize digital system for the traceability of fish and seafood products (Securingindustry.com, 2021). Blockchain fits very well to these needs. In addition, blockchains are often applied on species, fishing gears, specific country, or institution levels (Ricardo et al., 2015). With the current need of standardization on the international level, standardization of data will most likely push industries to move to blockchain. On market aspect, many companies are gaining competitive advantage with the implementation of blockchain (Carson et al., 2018). As a future consequence, blockchain could become a potential standard for digitization in supply chain and for managing the traceability of products.

Our study also shows that so far, only few use cases of blockchain have moved beyond the traceability in the vertical dimension, by focusing as well on payments and direct delivery of incentives to fishers. The case of Fishcoin, New England fishery, and Tracey projects have shown a clear model of incentivizing fishers for anchoring their data in blockchain, such as direct payment for the data they deliver. Literature shows that incentives mainly drive participation of actors in adopting blockchain in fishery value chain (Cook, 2018; Jardim et al., 2021). Focusing on tangible incentives could be a future direction of blockchain projects especially those being implemented in developing countries. For example, consumers can directly give a tip to the producers to see clear transfer of incentives to fishers for anchoring their data.

5.2. *Blockchain use cases in the horizontal dimension of the value chain*

The results of this study also indicate that there has been limited focus on the use cases of blockchain at the horizontal dimension of the value chain. Looking at the specific projects and the result of text mining, De-Fi blockchain projects for improving capabilities of producers in fisheries and aquaculture are rare. As such, there are opportunities to move in this direction. As argued by Tolentino-Zondervan et al. (2016a, 2016b), supporting the capabilities of producers will enable them to improve the sustainability in their practices and therefore comply with the requirements in the GVC. Since most fish and seafoods come from developing countries, the access to resources and financing are important for fishers and aquaculture farmers to adopt blockchain technology. This is well-aligned with the United Nations Sustainable Development goal that aims to improve livelihoods and food security of marginalized people (Tsolakis et al., 2021). For fisheries in developed countries, the small-scale fisheries could be the relevant focus in terms of aiding their compliance with market and government regulations via blockchain. To improve blockchain application at horizontal level, fisheries can learn from existing use cases of blockchain that focus on producer level such as Decentralized Finance (DeFi) in agriculture, decentralized insurance protections such as Etherisc, and micro-financing and loans for small businesses or producers in developing countries (Chinaka, 2016; Kamilaris et al., 2019).

5.3. *Challenges and prospect of blockchain in fishery and aquaculture*

Despite the use cases found in literature, overall, there is still limited application of blockchain in fisheries and aquaculture. The fish production worldwide reached approximately 179 million tons in 2018 (FAO, 2020), and only a handful of these fisheries use blockchain based on the number of use cases. There are challenges that need to be overcome and opportunities that need to be developed, as identified in the results of this study. In terms of challenges, firstly, there needs to be greater awareness on how blockchain can be applied in seafood and fishery. As identified in literature (e.g. FAO, 2020; Ghode et al., 2020), the limited adoption of blockchain could be attributed to three factors: (1) suitability of blockchain to solve a given problem, (2) incentive(s) to motivate fishers and other chain actors to adopt blockchain, and (3) trust in blockchain technology use.

In terms of suitability, the first step is to understand whether blockchain is needed in fishery or not based on a decision tree presented in Fig. 6. The need for a ledger technology is determined by factors such as the need for data storage of multiple entities, tamperproof and need for auditing, more than one entity contributes to data and shared visibility. If all these elements are present in the given fishery case, it is more likely that blockchain could be a solution to address fishery problems. The various use cases presented in this study show that the multiple parties ranging from government, NGOs, retailers and producers in fishery and aquaculture, require sharing and validating of data in the blockchain. If there is a need for blockchain adoption, the next step is to identify configurations such as the type of blockchain and the platform to be used. Next is to conduct a Costs-Benefit Analysis of the designed blockchain solution to determine the long-term gain or loss, and if implementing blockchain is beneficial or not as compared to other alternatives. The final step is to identify who makes the decision in the blockchain. Somebody must design the blockchain, often the

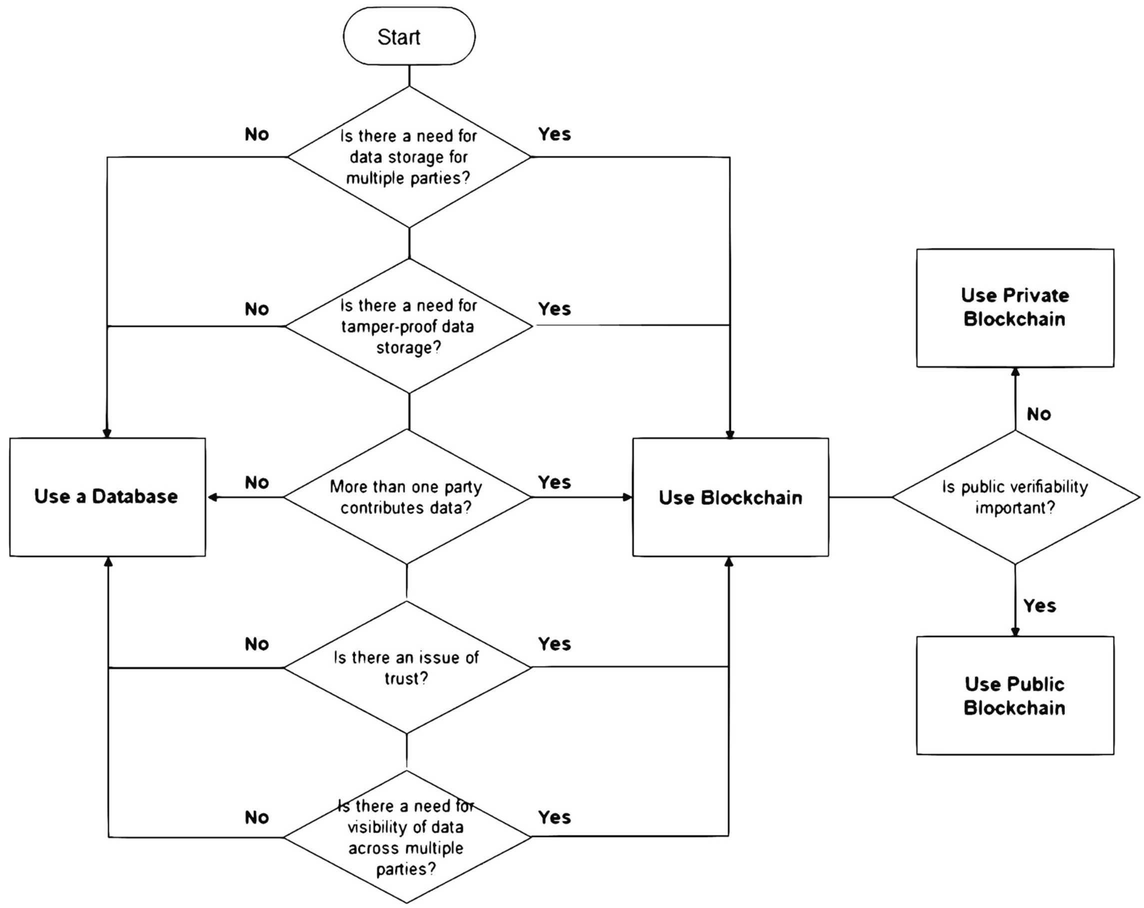

Fig. 6. Decision tree related to the adoption of blockchain and its type (based on Gartner and Chowdhury et al., 2018).

independent parties outside the value chain. Depending on the type of blockchain, the participants can give a vote in validating the transactions that happen in the blockchain.

In terms of incentives, it is both a challenge and at the same an opportunity for future adoption of blockchain. Many use cases of blockchain in various industries failed and only reached pilot phase, because of the lack of tangible incentives for the chain actors, especially the producers (Collart and Canales, 2022, Nodehi et al., 2022). The adoption rate of blockchain for improving the sustainability of fishery and aquaculture will more likely become higher if the incentives for participating in blockchain is tangible.

Finally, improving trust in the use of blockchain can improve its adoption in fishery and aquaculture. As seen in various studies on the implementation of blockchain in fishery (Cook, 2018; Blaha and Katafono, 2020; FAO, 2020; Tsolakis et al., 2021), the authenticity and accuracy of data that enters the blockchain has been a challenge. Most fisheries are reliant on human input and lots of paperwork, making the data that enter the blockchain prone to error. In addition, different technologies, which vary from data format and required data, are used by actors at different stages of the value chain. This makes it difficult to harmonize blockchain use among chain actors. To address the challenge of data authenticity and accuracy, the use of automated data entry through IoT devices in fishery could be anchored on a blockchain. The case of ThisFish addresses this issue well. Other methods include the use of fishing boxes with sensors, identifiers that generate the DNA and chemical properties of product or species, Automatic Identification System, and blockchain that can reconciliate real-time data and check for fraudulent information.

6. Conclusions

This paper provides a review of use cases and future prospects of blockchain in fishery and aquaculture. The main findings can be summarized in three parts. First, blockchain in fishery and aquaculture value chains are mostly applied in the vertical dimension, in the form of traceability and payment/incentive to a lesser extent. Second, the application of blockchain in the horizontal dimension of the value chain is still limited. More attention could be given to De-fi blockchain projects since majority of the fishery and aquaculture producers are from developing countries. Access to financing can motivate developing country producers to adopt blockchain, and as such, enable them to improve their production practices. And third, challenges such as the suitability, incentives, and trust in the adoption of blockchain technology pose opportunities for future implementation of blockchain in fishery and aquaculture. Being able to identify whether a blockchain is needed or not, designing blockchain that focus on tangible incentives, and anchoring blockchain on automated technologies can improve adoption of blockchain in the future.

The analysis of this study is limited to the application of blockchain in fishery and aquaculture value chains. Nevertheless, this framework could also be applied in investigating the use of blockchains in other sectors, such as agri-food and healthcare logistics. Future research may also investigate the anchoring of the physical assets and data in fishery and aquaculture value chain using automation, robotics and IoT among others. Finally, on applied level, future research can look at the actual perceptions of fishers, aquaculture farmers and other chain actors related to the adoption of blockchain technologies in their practices.

Author statement

Details of each author with their contribution in this paper:

Frazen Tolentino-Zondervan: Conceptualization, Methodology, Acquisition of Literature, Formal Analysis, Visualization, Writing – original draft, Writing – review & editing.

Pham Thi Anh Ngoc: Conceptualization (initial to end), Writing – review & editing, Finalizing of the manuscript.

Jamal Luka Roskam: Conceptualization (initial to end), Writing – review & editing, Finalizing of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is publicly available literature and reports. For the used sources, refer to Table 1 of the article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aquaculture.2022.739158.

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