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Supply network design to address United Nations Sustainable Development Goals: A case study of blockchain implementation in Thai fish industry

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ABSTRACT

Sustainable Development Goals present an opportunity for industries to (re)design their supply chains. It is understood that digital technologies like blockchain can be helpful in achieving certain Sustainable Development Goals linked to livelihoods, food security, and the environment, by identifying issues and implementing interventions in real-time. However, there is limited understanding over data structure requirements for blockchain technology implementation in digitally-enabled food supply chains. Therefore, this research studies the design of blockchain-centric food supply chains that promote Sustainable Development Goals, within the context of the Thai fish industry. Key findings suggest that data asymmetry exists in supply chains to achieve Sustainable Development Goals. This research presents four design principles and an integrated technology implementation framework, derived from empirical data, for blockchain-centric food supply chains. The research outcome contributes to the supply chain management field and could ultimately impact the resilience of fishery ecosystems and the achievement of Sustainable Development Goals.

1. Introduction

Digitalisation in the manufacturing sector unveils the potential to capture Big Data from an end-to-end manufacturing network perspective and drive operational improvements (Tiwari, Wee, & Daryanto, 2018). However, applications that entail the management of huge datasets encounter several challenges that mainly relate to the limited processing capability of incomplete, unstructured, and inaccurate data (Choi, Guo, & Luo, 2020). To that end, blockchain technology, a decentralised ledger which facilitates transactions of cryptographed data in blocks, has attracted increased academic and business interest as it enables authentication, auditability, and confidentiality of transmitted data and information (Lin, He, Huang, Choo, & Vasilakos, 2018). In a supply chain operations management context, blockchain has great implementation potential as it can facilitate complex interactions among network stakeholders and address the issue of data inconsistencies (Min, 2019). Business reports indicate that about 62% of supply chain executives have engaged with blockchain (Garner, 2018), while the expected business value added by this Industry 4.0 constituent technology is projected to exceed US$3.1 trillion by 2030 (Furlonger & Valdes, 2017).

A range of fraud vulnerabilities and counterfeiting issues are identified in food supply chains (van Ruth, Luning, Silvis, Yang, & Huisman, 2018), which motivate promising experimental applications of blockchain technology in the food and agriculture industries (Kshetri, 2018). In particular, the food industry highly appreciates the food safety and transparency benefits emanating from potential implementations of blockchain as the technology enables efficient data capture, management and control (Bumblauskas, Mann, Dugan, & Rittmer, 2020). However, the extant body of literature is fragmented as the majority of the related research studies myopically focuses on the transparency and traceability benefits of blockchain in supply networks rather than specific design interventions that deliver such benefits. The sustainability implications of blockchain pose an emerging topic in the supply chain management research agenda (Saberi, Kouhizadeh, Sarkis, & Shen, 2019), while the sparsity of relevant studies on food chains motivates research in the field (Feng, Wang, Duan, Zhang, & Zhang, 2020). To a greater extent, Hughes et al. (2019) declared the potential of blockchain to contribute to a range of the United Nations Sustainable Development Goals (SDGs) via articulating a number of research

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propositions; however, the authors' recommendations are not industry or use case specific. Notably, the authors did not investigate the role of blockchain towards promoting particular SDGs but rather claimed that the blockchain-targeted propositions can be valid in case specific SDGs are realised. Therefore, the lack of studies exploring the role of blockchain in promoting SDGs, especially with an emphasis on the food industry, constitutes an evident gap in the pertinent literature.

Notwithstanding the proclaimed traceability, transparency, and sustainability benefits of blockchain in global supply networks (Saberi et al., 2019), the technology has not yet been applied on real-world end-to-end network applications (Dallasega & Sarkis, 2018). The most significant challenge that hinders blockchain implementation for value creation relates to high-level collaboration requirements (Kittipanya-ngam & Tan, 2020), along with inconsistencies in data structures across the distributed data sources (Muzammal, Qu, & Nasrulin, 2019). However, unless data elements and their structure integrate across end-to-end networks, the value of information flows that could fuel performance improvements in supply chain operations is not realised (Gavirneni, Kapuscinski, & Tayur, 1999) while the supply chain maturity process stagnates (Trkman, Štemberger, Jaklič, & Groznik, 2007).

Blockchain along with Big Data can expedite Industry 4.0 advancements in food value chain management (Zhao et al., 2019). However, motivated by the evident paucity of studies exploring the usability of blockchain in real-world contexts (Zhao et al., 2019), this research argues that blockchain implementation is not understood from the perspective of supply chain (re)design. From an academic perspective, Treiblmaier (2018) provided a framework linking blockchain attributes to the characteristics of four supply chain management-centric theories, but the provided conceptual construct considered blockchain in a broader sense and did not identify data structure requirements as a distinctive blockchain attribute that can foster the technology's implementation. From a technical viewpoint, the sustainable food supply chain literature lacks application frameworks that can contribute to information visibility in data-driven environments (Kamble, Gunasekaran, & Gawankar, 2020), while the operability of typical assets and transaction data in blockchain applications (e.g., business documents, images) is disregarded (Kumar, Liu, & Shan, 2020). Considering that blockchain technology in sustainable food supply networks is a nascent, yet unexplored, research field with undetermined real-world challenges (Kamble, Gunasekaran, & Arha, 2019), this study bridges this gap by attempting to answer the following research question: How can blockchain-centric supply chains be designed and managed in the food industry in order to achieve SDGs?

It is essential to tackle the abovementioned research question to operationalise blockchain technology for delivering sustainable value networks (Capgemini Research Institute, 2018). More specifically, to address the research question, this study focused on empirically derived value chain effectuation by identifying necessary Key Data Elements and via proposing a framework for the implementation of blockchain in food supply network designs, particularly focusing on the Thai fish industry. The limited number of relevant research studies provides high-level discussions over the sustainability benefits of blockchain in fish supply chain management (Howson, 2020), while overlooking data-related implementation aspects of the technology at an operational level. Therefore, to tackle the research question, this study further developed four principles for blockchain-centric food supply chain designs to contribute to SDGs.

The research emphasis on the fish industry was stimulated by a range of reasons, including (Gopi, Mazumder, Sammut, & Saintilan, 2019): (i) global increasing demand on seafood; (ii) essential nutritional role of fish to human diets; (iii) significance of the seafood market to national economies and global trade; and (iv) increasing global concerns over fish provenance and authenticity, mainly in terms of food safety, quality, and fraud. In particular, sustainable fisheries management in Thailand is crucial owing to the significance of the seafood sector to the national economy. Based on the National Food Institute, Thailand is the leading global producer and exporter of canned tuna with a market share of about 40% (Kittipanya-ngam & Tan, 2020). However, the Thai fish industry encounters major sustainability challenges including illegal fishing activities amounting to financial losses of about US$5 billion (Wipatayotin, 2019), and unethical labour practices (Sasipornkarn, 2019). Therefore, Thailand's food supply chains need to continuously demonstrate efficiency and sustainability to maintain the leadership position in global exports.

This research employed a multiple case study approach, involving data and information collection from both interviews with stakeholders and field observations, to answer the enunciated research query. More specifically, three case studies were conducted within the context of the Thai fish industry via leveraging three data and information collection mechanisms – semi-structured interviews, field observations, official documentation of supply chain operations – to identify data sources, ensure data validity, and generate insights (McCutcheon & Meredith, 1993). The paradigm of the Thai fish industry aligns with the SDGs and helps link blockchain implementation requirements to supply chain design. To the best of our knowledge, no peer-reviewed research article on blockchain technology in end-to-end fish supply chains has combined literature analysis and empirical evidence.

Our research contributes to the Operations Management field by applying a multiple case study approach to develop a pragmatic view of traceability in blockchain enabled fish supply chains. In addition, this research studies the relationship between blockchain technology and supply chain design within the prospect of product traceability.

The remainder of this research is structured as follows. Section 2 summarises indicative studies examining blockchain in the food industry and provides the research background of blockchain implementation and supply chain design. Section 3 details the research methodology applied to gather and analyse evidence on the application of blockchain technology in the fish industry. Section 4 investigates the fishery ecosystem in Thailand. An integrated framework capturing supply chain (re)design implications stemming from the implementation of blockchain technology is proposed in Section 5. Critical evaluation of the research findings along with academic and management implications, limitations, and future research avenues, are explored in the final Section 6.

2. Research background

Key studies discussing blockchain in end-to-end food supply networks were reviewed followed by an investigation of pertinent extant works focusing on the fish industry and on sustainability implications. Additionally, major literature evidence on the design of technology-enabled supply networks was retrieved.

2.1. Blockchain in food supply networks

Blockchain technology's expected benefits are clearly documented for the food industry, mainly referring to advanced traceability capabilities and increased food safety leading to enhanced consumers' trust. In addition, blockchain could help mitigate the ripple effect that describes the propagation of any risks downstream a food supply chain, hence further impacting a network's structural design and planning parameters (Dolgui, Ivanov, & Sokolov, 2018).

Key studies investigating the potential application and implementation of blockchain within a food supply network context were recognised and taxonomised as part of this research; an exhaustive review of all research works in the field extends the current research scope. Most recently published review articles on the topic indicatively include the studies of Antonucci et al. (2019), Kamble et al. (2020), and Lezoche, Panetto, Kacprzyk, Hernandez, and Alemany Díaz (2020).

2.1.1. End-to-end food chains

Crew (2018a,b) discussed the role of blockchain in enhancing consumers' trust and food safety as the technology enables transparency, tracking, and traceability in transactions among end-to-end food supply network stakeholders. Notwithstanding the conceptual discussions in the domain, the need for feasible food traceability systems led Behnke and Janssen (2020) to investigate four dairy supply chain processes and identify five boundary conditions (recognised across the business, quality, and traceability categories) for the implementation of blockchain technology. In a similar vein, Chen, Liu, Yan, Hu, and Shi (2020) performed a thematic analysis of news articles and research studies jointly discussing blockchain and food networks, while the authors identified processes, benefits, and challenges prevalent in the adoption of the technology in food supply chains.

Furthermore, Kim and Laskowski (2018) developed a proof-of-concept ontology-based blockchain and investigated the feasibility of a traceability ontology for food supply chain provenance. Marfia and Degli Esposti (2017) considered blockchain for the case of organic farming to guarantee trust and increase product value. Similarly, Mondal et al. (2019) implemented a blockchain architecture enabled by a Radio-Frequency Identification (RFID) sensor to develop a tamper-proof digital database of food packages.

Sander, Semeijn, and Mahr (2018) surveyed the perceptions of meat supply chain stakeholders about blockchain, as a viable meat transparency and traceability system, and concluded that the technology could positively influence consumers' purchasing decisions in case trust towards blockchain is established. In cold food supply chains, blockchain is highly appreciated as the technology can promote transparency of temperature information about food products, particularly during storage and distribution, thus supporting waste mitigation (Ndraha, Hsiao, Vlajic, Yang, & Lin, 2018). Additionally, Tian (2017) conceptually investigated the architecture of a food supply chain traceability system enabled by HACCP (Hazard Analysis and Critical Control Points), blockchain, and Internet of Things, as a solution to support food safety and consumers' trust in the industry.

On a more pragmatic basis, Kamilaris, Fonts, and Prenafeta-Boldύ (2019) reviewed ongoing initiatives and projects on blockchain technology in agriculture and food supply networks, and further discussed related implications, benefits, and challenges. Indicatively, Walmart leads an initiative along with Nestlé SA, Unilever NV and other global companies to develop the Food Trust blockchain with the aim to trace and manage potential risks across end-to-end food supply chains (Nash, 2018). Likewise, Pendrous (2017) discussed trends and business initiatives (e.g., the joint initiative by Arc-net and PwC Netherlands) regarding the development of a blockchain-based platform across food supply networks to deliver product safety, quality and integrity.

2.1.2. Fish industry

From a fish supply chain operational perspective, Cook (2018) reported the benefits and challenges of a related pilot project on blockchain implementation, led by the World Wide Fund for Nature (WWF), particularly focusing on tuna caught in a Fijian longline fishery. Furthermore, Intel applied its proprietary open source blockchain platform, named Hyperledger Sawtooth, to enable seafood traceability and ensure compliance with storage conditions across fish supply chains (del Castillo, 2017). Fishcoin, a blockchain-based data ecosystem dedicated to the seafood industry, utilises tokens for incentivising data capture and transmission across fish supply chains in order to increase traceability (Fishcoin, 2018).

In addition, the social enterprise Project Provenance Ltd tested a prototype blockchain model to track and trace responsibly caught tuna fish in Indonesia by gathering diversified data across operations, from vessel tracking and registration to self-reporting of fish catch and fish tagging (Provenance, 2016). Moreover, WWF piloted the use of blockchain technology in the Pacific tuna industry to trace fish provenance, track illegal fishing instances, and eliminate abuses of human rights (WWF, 2018). Visser and Hanich (2018) discussed the transparency and traceability benefits of blockchain in aforementioned real-world pilot implementations, further highlighting the technology's contribution in tackling poor human working conditions in low-income countries. From a fish supply chain management perspective, Mathisen (2018) investigated the strategic compliance of blockchain technology to Norwegian aquaculture producers and discussed potential benefits with regard to the expected efficiency in terms of quality, cost, sustainability, and dependability.

2.1.3. Sustainability

In terms of sustainability, Ahmed and Broek (2017) summarised the potential food security benefits stemming from the adoption of blockchain technology in food supply networks, particularly stressing the emanating possibilities of distributing surplus food supplies to beneficiary bodies and enhancing the visibility over the environmental footprint of commodities/products. Chapron (2017) critically discussed governance and sustainability benefits stemming from the implementation of blockchain technology in manufacturing and food supply chain operations and particularly highlighted the associated potential of natural resources stewardship along with social sustainability implications. Moreover, Lin et al. (2017) discussed the evolutionary role of blockchain in agriculture to enable efficient water quality monitoring in farms.

In a humanitarian context, Juskalian (2018) presented the case of the "Building Blocks" initiative, set by the World Food Programme of the United Nations, which uses blockchain technology and iris scanning technology to allow refugees in Jordan to purchase daily grocery supplies. The author also discussed the efficiency gains deriving from the adoption of blockchain for humanitarian operations, including: (i) reduced bank fees applicable to transfers of humanitarian aid funds; (ii) digital proof of refugees' identity and educational/employment history that increases employment opportunities in hosting countries; and (iii) enhanced efficiency of humanitarian aid operations deployed by international organisations.

2.1.4. Critical taxonomy

A critical taxonomy of the reviewed literature on blockchain technology in food supply chains is presented in Table 1. The taxonomy reveals that most of the studies published in peer-reviewed scientific journals are limited on a discussion of potential benefits and challenges related to the adoption of blockchain technology in food supply networks. Few studies, mainly retrieved from grey literature, focus on real-world implementation cases while no articles highlight the role of data structures and supply chain (re)design opportunities. The general consensus is that blockchain technology can mainly ensure transparency and traceability in food systems with further positive effects regarding food safety and consumers' trust.

2.2. Technology-enabled supply network design

Blockchain is recognised as an ordered list of blocks which contain data and information regarding transactions, records, and events (Kamble, Gunasekaran, & Sharma, 2019). However, the structure of the gathered and transmitted data along with the need to (re)design prospective blockchain-enabled supply networks are often being neglected in the extant literature.

2.2.1. Data and supply chain design implications

Sener, Barut, Oztekin, Avcilar, and Yildirim (2019) found that information usage, rather than information sharing, among supply chain stakeholders could result in significantly better performance in terms of inventory, transportation, warehousing, and communication related costs. In tandem with the tamper proof records of blockchain that help cultivate a culture of trust, the commercially viable nature of end-to-end supply networks could be ensured (Nidumolu, Ellison, Whalen, & Billman, 2014). Within a digitalised business environment, we adopt the suggestion of Kohtamäki, Parida, Oghazi, Gebauer, and Baines (2019) who recognised that data alignment among firms within specific

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Table 1
Blockchain technology in food supply networks: An overview.

Scope	Author(s)	Blockchain Aim	Blockchain Implementation Benefits	Blockchain Implementation Challenges	Theoretical Foundation	Study Nature	Study Methodology
End-to-end Food Chains	Behnke and Janssen (2020)	Ensure food traceability	● Enables internal and chain traceability of food ingredients ● Ensures trust among supply chain partners ● Enables confidence over food safety and quality ● Enables effective management of recalls	● Low processing rate of transactions ● Expanding storage capacity requirements for blocks ● Intellectual property ownership and anonymity of users ● Security issues due to cyber attacks	Conceptual food traceability framework of Aung and Chang (2014)	Qualitative	Case study
	Chen et al. (2020)	Ensure food transparency	● Ensures reliability and transparency of information transactions ● Improves food quality management ● Provides perks to all stakeholders such as by eliminating the need for intermediaries ● Enhances the efficiency of supply chain operations ● Enables quick and accurate food traceability	● High complexity of data and systems integration ● Absence of regulations, legislation, and global standards over blockchain technology ● Confusion and immature application of blockchain technology ● Bounding blockchain technology characteristics ● High investment requirements on blockchain-based systems	Diffusion of Innovation theory; Technology, Organization, and Environment framework	Qualitative	Thematic analysis
	Crew (2018a)	Promote consumer trust	● Enables confidence over food provenance, integrity and safety ● Ensures provenance validation ● Allows end-to-end visibility ● Prevents food fraud and counterfeiting ● Ensures security, confidentiality and robustness of information transactions	● Intellectual property ownership and information confidentiality	N.A. – N.S.	Qualitative	Critical discussion
	Crew (2018b)	Promote food safety	● Assists in eliminating food fraud and counterfeiting risks ● Enhances food supply chain transparency, tracking and traceability ● Enables the identification of foodborne illnesses for the effective management of recalls ● Helps promote food security ● Fosters trust, accountability, and transparency across food supply networks ● Ensures security, confidentiality and robustness of information transactions ● Promotes reductions in food waste ● Ensures smoother and faster trade (i.e. import/export) transactions ● Ensures acknowledgement of suppliers/ producers ● Supports brand reputation	● Veracity of recorded data ● Safeguard of the physical integrity of legitimate goods ● Technology development time to ensure stakeholder inclusiveness ● System alignment and integrity ● Intellectual property ownership and information confidentiality	N.A. – N.S.	Qualitative	Critical discussion
	Kamilaris et al. (2019)	Ensure food supply chain transparency	● Facilitates financial transactions and promotes viability of small farmers ● Facilitates more informed consumer purchasing decisions ● Promotes sustainability along with emissions and waste reduction ● Eliminates the need for intermediaries ● Enables confidence over food safety and quality ● Enables food traceability	● Absence of regulations over blockchain technology ● Limited organisational education and skills, particularly in SMEs ● Intellectual property ownership and anonymity of users ● Bounding blockchain technology characteristics ● Considerable investment cost on required computing or Internet of Things equipment ● Veracity of recorded data	N.A. – N.S.	Qualitative	Review of initiatives and projects

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Table 1 (*continued*)

Scope	Author(s)	Blockchain Aim	Blockchain Implementation Benefits	Blockchain Implementation Challenges	Theoretical Foundation	Study Nature	Study Methodology
	Kim and Laskowski (2018)	Ensure supply chain provenance	● Enables provenance tracing ● Enforces traceability ● Ensures food safety	● High complexity of data and systems integration ● Distributed databases may not be consistent with a blockchain design ● Business practices and processes may not have adopted common data standards ● Common interpretation of data from different enterprises is lacking	Computational ontology	Programming – Code development	Proof-of-concept ontology
	Marfia and Degli Esposti (2017)	Promote consumer trust	● Helps maintain fidelity of the customer base ● Ensures quality attributes of products ● Inspires reshoring of business activities ● Supports food brand image ● Eliminates the issues of sybil attacks	● Veracity of recorded data	N.A. – N.S.	Qualitative	Conceptual case study
	Mondal et al. (2019)	Promote food safety & mitigate food waste	● Improves integrity of digital data ● Enables end-to-end food product visibility ● Enables real-time tracking and sensing of food products ● Discourages adulteration of food products ● Helps determine the shelf life of food products, thus leading to reduced waste ● Allows specific and targeted recalls	● Adding a single block in existing blockchain leads to extensive computational requirements and electricity consumption ● Increased operational cost ● Security issues due to cyber attacks	Proof-of-object-based authentication protocol	Programming – Code development	Proof-of-concept blockchain architecture
	Nash (2018)	Promote consumer trust	● Enables food tracking and tracing ● Helps ensure food safety ● Improves product recalls ● Limits the time period during which consumers are at risk due to food contamination ● Helps limit business financial losses from overly broad recalls ● Helps eliminate costly middle layers of operations due to the blockchain peer-to-peer structure	● Integration challenges of proprietary data management software tools currently used by supply chain actors	N.A. – N.S.	Qualitative	Critical discussion
	Ndraha et al. (2018)	Mitigate food waste	● Facilitates secure and transparent information transfers ● Enables the execution of pre-defined criteria (e.g., temperature level of a food product) beyond pre-defined thresholds	● Technical realisation challenges ● Infrastructural configuration requirements ● High computation power requirements ● Scalability issues ● Privacy and data leakage issues ● Inadequate legal framework in practice ● Lack of guidelines by relevant regulatory authorities	N.A. – N.S.	Qualitative	Critical discussion
	Pendrous (2017)	Ensure supply chain provenance	● Enables recording of transactions in a verifiable and permanent manner ● Assures provenance and authenticity of food products ● Enables confidence over food quality, integrity and safety ● Enhances food supply chain transparency and traceability ● Supports food fraud prevention	N.A. – N.S.	N.A. – N.S.	Qualitative	Critical discussion
	Sander et al. (2018)	Promote consumer trust	● Enhances food supply chain transparency and traceability	● Compatibility issues of systems across the supply chain	Stakeholder theory	Quantitative	

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Table 1 (*continued*)

Scope	Author(s)	Blockchain Aim	Blockchain Implementation Benefits	Blockchain Implementation Challenges	Theoretical Foundation	Study Nature	Study Methodology
			● Ensures independence, integrity, and credibility ● Enables confidence over food quality	● Resistance to change among supply chain actors ● Information overload ● Cost distribution of blockchain technology			Questionnaire-based survey; Semi-structured interviews
	Tian (2017)	Promote consumer trust	● Enhances food supply chain transparency and traceability ● Ensures food safety	● Scalability issues in terms of throughput, latency, and capacity ● Veracity of recorded data ● Security issues due to cyber attacks	HACCP process control system	Quantitative	Conceptual scenarios investigation
Fish Industry	Cook (2018)	Ensure responsible and ethical producers' reward & promote consumer trust	● Enhances seafood supply chain transparency and traceability ● Helps eliminate illegal or unethical seafood ● Supports regulatory authorities to identify and address potential risks ● Strengthens sustainability practices ● Allows specific and targeted recalls ● Enables confidence over seafood quality ● Assures provenance of seafood ● Allows the instantaneous execution of payments and other transactional arrangements	● Veracity of recorded data ● Digitalisation of supply chain processes is required ● Interoperability of information systems is necessary ● Platforms that capture Key Data Elements are required ● Supply, implementation, and maintenance of digital tools (e.g., RFID equipment, tags, sensors) can be challenging at a local level ● Long transaction times may limit blockchain feasibility ● Considerable investment cost	N.A. – N.S.	Qualitative	Case study
	del Castillo (2017)	Promote consumer trust	● Increases accuracy of data recordings ● Ensures compliant seafood storage conditions	N.A. – N.S.	N.A. – N.S.	Qualitative	Discussion
	Fishcoin (2018)	Ensure responsible and ethical producers' reward & deliver efficient business ecosystem	● Enhances seafood supply chain transparency and traceability ● Strengthens sustainability practices ● Helps verify seafood legality, safety and quality ● Improves integrity of data	● Seafood industry is fragmented – connection between harvest and consumption points is scarce ● Dominant role of middlemen creates information asymmetries	N.A. – N.S.	Qualitative	Case study
	Mathisen (2018)	Ensure supply chain operational efficiency	● Enhances fish supply chain traceability ● Improves seafood safety and quality assurance ● Supports seafood fraud prevention ● Improves product recalls ● Assures provenance of seafood products ● Supports regulatory audits ● Assures provenance of fish ● Improves information flows and minimises bureaucracy	● Interoperability of information systems is necessary ● Limited organisational education and skills ● Reluctance to the technology adoption till evident full-scale successful implementation paradigms	Innovation theory	Qualitative	Case study
	Provenance (2016)	Ensure responsible and ethical producers' reward & promote consumer trust	● Enhances fish supply chain transparency and traceability ● Helps in tracking responsibly-caught fish ● Helps in eliminating illegal, unreported and unregulated seafood ● Supports regulatory audits ● Fosters trust, accountability, and transparency across seafood supply networks	● Different data recording mechanisms among supply chain actors ● Interoperability of information systems is necessary	N.A. – N.S.	Qualitative	Case study
	Visser and Hanich (2018)	Tackle illegal and unsustainable fishing practices	● Helps in eliminating illegal, unreported, and unregulated seafood ● Helps in eliminating poor human working conditions ● Enhances seafood supply chain transparency and traceability	● Implementation is challenging to the range of food products deriving from a single fish ● Considerable investment cost on required computing or Internet of Things equipment	N.A. – N.S.	Qualitative	Case study

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Table 1 (*continued*)

Scope	Author(s)	Blockchain Aim	Blockchain Implementation Benefits	Blockchain Implementation Challenges	Theoretical Foundation	Study Nature	Study Methodology
	WWF (2018)	Deliver social impact	● Helps in eliminating illegal, unreported, and unregulated seafood ● Helps in eliminating poor human working conditions ● Strengthens sustainability practices	N.A. – N.S.	N.A. – N.S.	Qualitative	Case study
Sustainability	Ahmed and Broek (2017)	Determine ecological footprint	● Eliminates food fraud and counterfeiting risks ● Promotes food safety and security ● Promotes reductions in food waste ● Enables identification of foodborne illnesses ● Promotes appropriate distribution of surplus food supplies ● Increases food environmental impact visibility	N.A. – N.S.	N.A. – N.S.	Qualitative	Critical discussion
	Chapron (2017)	Inform management of natural resources	● Improves integrity of recorded data ● Ensures trust among supply chain partners ● Allows the instantaneous execution of payments and other transactional arrangements ● Limits the eviction of local populations ● Enhances traceability of sustainably caught fish ● Ensures tracking of water, energy, and raw materials' use ● Helps in promoting circular economy ● Promotes accountability of decision-makers	● Veracity of recorded data ● Low processing rate of transactions ● High energy consumption ● High computational power requirements ● Reluctance to the technology adoption ● Absence of regulations and legislation over blockchain technology	N.A. – N.S.	Qualitative	Critical discussion
	Juskalian (2018)	Improve humanitarian aid efficiency	● Eliminates bank transaction costs and fees ● Safeguards personal identify (especially in case of refugees) ● Reduces risk of sharing refugees' data ● Promotes transparency in organizations' operations	● Challenging collaboration with local or regional financial institutions ● Low processing rate of transactions ● Increased operational cost ● Ethical concerns over applications focusing on vulnerable populations	N.A. – N.S.	Qualitative	Case study
	Lin et al. (2017)	Remove opaqueness in agricultural environmental data management	● Enhances consumer trust ● Propels environmental sustainability ● Eliminates intermediary bodies ● Eliminates data manipulation risk ● Enhances engagement with the public ● Facilitates empowerment and capacity-building ● Increases public support to improve water resources use	● Scalability issues ● Low processing rate of transactions ● Security issues due to cyber attacks ● Veracity of recorded data ● Natural disasters compromising servers	Conceptual framework of Suichies (2015)	Qualitative	Conceptual system model and evaluation tool

Symbol: N.A. – N.S. refers to "Not Applicable – Not Specified".

ecosystems can propel value capture by all involved stakeholders. To that end, supply chain processes need to be (re)designed to accommodate blockchain-related data requirements and specifications.

2.2.2. Blockchain implementation elements

Astill et al. (2019) identified key technological enablers required to advance transparency in food supply chains, namely: (i) data acquisition technologies; (ii) Internet of Things; (iii) data management platforms; and (iv) Big Data analytics solutions. Furthermore, dos Santos, Torrisi, Yamada, and Pantoni (2019) described the implementation of smart contracts and blockchain tokens, based on the ISO 22005:2007 standard, to certify the origin of food ingredients via a mobile phone application. Also, Borrero (2019) provided an overview of blockchain implementation in the supply chain of berries in southern Spain and highlighted basic technical requirements.

Kumar, Liu, and Shan (2019) examined blockchain design and implementation phases in a food supply chain context with the aim to provide a pragmatic view about the associated key challenges of storage, networking, and processing costs. Moreover, Kamble, Gunasekaran, and Sharma (2019) identified thirteen enablers of blockchain technology in agriculture supply chains and further investigated the underpinning causal relationships. Table 2 summarises blockchain implementation elements in supply networks and further depicts the particular lack of focus in the structure of the data needed to be collected across different echelons of operations.

3. Materials and methods

Considering that the outcome of this research shall contribute to SDGs through developing principles for blockchain-centric supply chain design, along with a technology implementation framework, the object of scrutiny has to be a critical analysis of the relevant literature (Tranfield, Denyer, & Smart, 2003), whilst further supported by real-world case studies (Gibbert, Ruigrok, & Wicki, 2008). Therefore, following the provided literature overview in the field, the theoretical lens and the research design underpinning this study are detailed in the subsections that follow.

3.1. Theoretical lens

The realisation of food traceability is not underpinned by any generally approved conceptual framework or theory (Karlsen, Dreyer, Olsen, & Elvevoll, 2013). To that end, motivated by the need to support real-world blockchain implementation in fish supply network operations, this study followed a pragmatist research philosophy to allow the collection of both objective and subjective data (Saunders, Lewis, & Thornhill, 2009).

From a theoretical standpoint, the enabling role of blockchain technology in fulfilling supply chain management objectives (e.g., cost, quality, flexibility) is recognised (Ksherti, 2018). However, to systematically investigate blockchain in the supply chain management arena, we complementarily adopted the “Principal-Agent Theory” and the “Transaction Cost Analysis” Theory for blockchain-centric supply chain (re)design, along with the “Resource-Based View” and the “Network Theory” for blockchain-centric supply chain management (Halldórsson, Kotzab, Mikkola, & Skjøtt-Larsen, 2007). A combination of these theories has been applied to motivate middle-range theory development for interpreting structural and management changes in supply chains imposed by disruptive technologies (Treiblmaier, 2018).

Following the theoretical framework of Halldórsson et al. (2007), and considering that data structure was not distinctly contemplated by Treiblmaier (2018), this research selected blockchain data as the primary focus of analysis. In particular:

- “Principal-Agent Theory” – Information asymmetry between supply and demand echelons is a common issue in supply chain management that can negatively impact stakeholders’ relationship (Whipple & Roh, 2010). Therefore it can be argued that consistent data structures enable blockchain technology implementation and are a requisite to align priorities and inter-firm contracting perspectives (Jensen & Meckling, 1976).
- “Transaction Cost Analysis” Theory – Data visibility and reliability are key in governing production and transaction costs in a supply chain owing to the higher level of information sharing that helps assess performance of contractual agreements and reduce opportunistic behaviour (Wacker, Yang, & Sheu, 2016). Therefore, based on the “Transaction Cost Analysis” Theory, asset specificity from the angle of data capture is a key attribute of supply chain transactions enabled by blockchain technology (Rindfleisch & Heide, 1997).
- “Resource-Based View” Theory – Accurate data is recognised as a primary resource for supply chain operational performance and competitive advantage (Chae, Yang, Olson, & Sheu, 2014). However, data can be available in various types within a supply chain that serve data usability purposes only within specific analytical systems or software. In particular, understanding the stratification and identification of existing data types could help tackle triple bottom-line sustainability concerns (Raut et al., 2019), like food losses and waste generation (Irani et al., 2018). To that effect, following the “Resource-Based View” Theory, data interoperability even at the level of insignificant processes can assist in tackling the heterogeneity of supply chain data sources and capabilities, and to the configuration of operational competency (Halldórsson & Skjøtt-Larsen, 2004).
- “Network Theory” – Except for transactions in supply chains, data is a driver of interorganisational relationships and can be used to establish interfaces among the different types of resources at the involved operational echelons (Rinehart, Eckert, Handfield, Page, & Atkin, 2004). Consequently, according to the “Network Theory”, streamlining data archetypes among the various dispersed data sets is essential for assuring two types of stakeholder interactions (Johanson & Mattsson, 1987): (i) exchange processes (e.g., information, products); and (ii) adaptation processes (e.g., legal, administrative elements).

Therefore, this research investigated the unexplored linkages between the unit of analysis per considered complementary theory to understand supply chain (re)design and management opportunities enabled by blockchain technology (Fig. 1). Specifically, we argue that supply chain (re)design should include the elements of data consistency and data capture to eliminate any transaction errors that can impact operational and sustainability performance assessment, along with the pertinent decision-making process. Ensuring data unit consistency across end-to-end supply chain operations and utilising digital technologies to capture data can help eliminate human errors. Furthermore, to manage blockchain and the available multiple types of data in sustainable supply networks, SDG-centric data interoperability and data

Table 2
Blockchain implementation elements in supply networks.

Research Study	Blockchain Implementation Elements								
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Astill et al. (2019)	•	•	•	•					
Borrero (2019)	•	•	•						•
dos Santos et al. (2019)	•	•	•		•	•	•	•	•
Kamble, Gunasekaran, and Sharma (2019)		•	•	•	•				
Kumar et al. (2019)	•	•	•		•				•

Symbol: [1] Data acquisition technologies; [2] Internet of Things; [3] Data management platforms; [4] Big Data analytics solutions; [5] Traceability plans; [6] Responsibilities and Training plans; [7] Monitoring mechanisms; [8] Key performance indicators; [9] Critical tracking events and Key Data Elements.

archetypes are required. Traditional data interoperability and data archetypes typically have a financial focus and may not capture sustainable development perspectives.

3.2. Research design

Considering that the aim of this research is to derive theoretical findings with practical implementation potential, a multiple case study research strategy was adopted (Yin, 2003). The case study approach allowed to combine a range of data and information gathering methods, like interviews and field observations, thus fostering the understanding of the real-world context of blockchain-enabled food supply chains (Eisenhardt, 1989). This research is inductive as it employed a bottom-up approach to collect data and information, map fish supply chain operations, and generate insights.

3.2.1. Case identification

Aquaculture constitutes an important source of national incomes, specifically for developing countries; hence, blockchain could catalyse seafood trade and logistics by establishing direct links between producers and consumers (Bush, Belton, Little, & Islam, 2019). Indicatively, Thailand is a major global seafood trader with exports valued at US$5.8 billion in 2017, contributing about 20% to the national food exports (USDA, 2018). However, the limited application of efficient and reliable traceability systems across end-to-end fish supply chains often results in significant overexploitation of the marine fishery resources, product recalls, foodborne illnesses, and financial losses (Xiong et al., 2016). For example, overfishing phenomena exert significant pressure on the marine fisheries' stock in the Andaman Sea and the Gulf of Thailand. Notably, the European Commission asserted pressure on Thailand to proceed to timely improvements on the governance of illegal, unreported and unregulated fishing activities by issuing the country with a yellow card (European Commission, 2015). In this regard, implementing a reliable full-chain traceability system in the Thai fishery ecosystem could improve the export outlook of the sector.

The main SDG challenges related to the Thai fish industry are inserted in Table 3. To develop a more robust construct about blockchain in the Thai fishery ecosystem, we conducted three case studies to collect essential data, namely: (i) Case study #1 – Local fishing operations; (ii) Case study #2 – Commercial fishing operations and trade; and (iii) Case study #3 – Canned tuna manufacturing. The different scale of operations that were investigated through these case studies allowed the identification of particularities along with the examination of blockchain implementation challenges and potential in the Thai fishery ecosystem. This multi-scale perspective assisted in generating robust and valid results.

3.2.2. Data collection

The approached Thai fish supply chain stakeholders were initially involved in semi-structured interviews and field research; the interview participants represent the main stakeholders in the Thai fishery ecosystem hence allowing the collection of data and information from different perspectives and over a range of processes, technical aspects, social angles, and legal related issues. In particular, seven key categories of actors were recognised involving a total of fifteen informants, namely: (i) fishermen; (ii) traders; (iii) processors; (iv) wholesalers; (v) technology providers; (vi) certification organisations; and (vii) governmental bodies.

Especially, data and information were collected via three case studies involving: (i) thirteen semi-structured interviews with stakeholders in the Thai fish industry; (ii) three physical walkthroughs; and (iii) official documentation that is used during the operations. Table 4 enlists the interviews' informants along with the selection criteria and the utilised data collection methodology. Table A1 in the Appendix summarises the salient points of the interviews. The triangulation of data captured via direct field observations and documentation of operations helped in mitigating the bias from the semi-structured interviews and in ensuring validity and quality of the findings (Yin, 2009).

3.2.3. Data analysis

The data and information collected were analysed based on the principles adopted from the Best Practice Guidelines on Traceability (FAO, 2014), as summarised in Fig. 2. Initially, TraceFish (i.e. a series of voluntary standards relating to information recorded at every fish supply chain echelon) was used to evaluate the completeness of data collection by different supply chain stakeholders as being the acceptable standard in the industry (Konovalenko & Ludwig, 2019). The data collected from the case studies was compared to the list of Key Data Elements recommended by TraceFish to determine the completeness of stakeholders' data sets. Secondly, the "Unique Identification" (i.e. any unit or actor that modifies the product should be recognisable) was assessed by using a process mapping framework for seafood firms' traceability systems developed by Mai, Margeirsson, Stefansson, and Arason (2010). Thirdly, data sharing was evaluated by analysing the communication method between various stakeholders and vertical integration. Finally, the capabilities of the technology were analysed against a set of criteria gathered from literature and the case studies.

4. Fish supply network ecosystem in Thailand

The fishery ecosystem in Thailand consists of thirteen distinct actors, as these are mapped on three clusters (Fig. 3), namely: (i) national bodies; (ii) key stakeholders; and (iii) certification bodies. Notably, every national entity utilises its proprietary database despite any overlaps of the gathered data. Therefore, an increased probability of maintaining duplicate and/or incomplete databases exists.

From a legislative perspective, fishing is only allowed to registered vessels. Officially, two types of vessels are recognised in Thailand (Table 5): (i) local fishing vessels; and (ii) commercial vessels. Local fishing vessels are neither required to install a Global Positioning System tracker nor to have a logbook. On the other end, commercial vessels are required to both have an installed Global Positioning System tracker, called Vessel Monitoring System, to inform about the real-time location of the vessel and to record all required information onto an issued logbook. Currently, a total of 27,261 registered local vessels and 10,615 registered commercial vessels operate in Thailand.

4.1. Case study #1 – local fishing operations

In order to map local fishing operations, the activities of "Fishermen 1", who own a 9 Gt vessel in Prachuap Kiri Khan, were observed. The laws applicable to local fishermen are loose and this reflects upon the management style of "Fishermen 1".

4.1.1. Fishing processes

At the predeparture stage, "Fishermen 1" load ice and insulation storage boxes on the vessels while the fishing equipment (e.g., sonar) is prepared the previous day (see Image S1 in the Supplementary Material). Regarding the fishing method, "Fishermen 1" use the 'purse seining' approach which allows the capturing of targeted fish species with a low probability of unintentional by-catches. The captured fish are sorted by size and stored inside boxes/buckets of ice (see Image S2 in the Supplementary Material). After the fishing is completed, "Fishermen 1" return to the port to unload the catch and trade with fishmongers.

"Fishermen 1" return to the departed port, without having to comply to a particular schedule or inform any authority, and then unload and weight the fish catch. The empirical study revealed that approximately 3% of the catch would be characterised by minor damages such as bruises; however, these fish are not discarded as such defects are considered insignificant. Thereafter, fishmongers would sell the fish to the local market. The market usually consists of local restaurants and

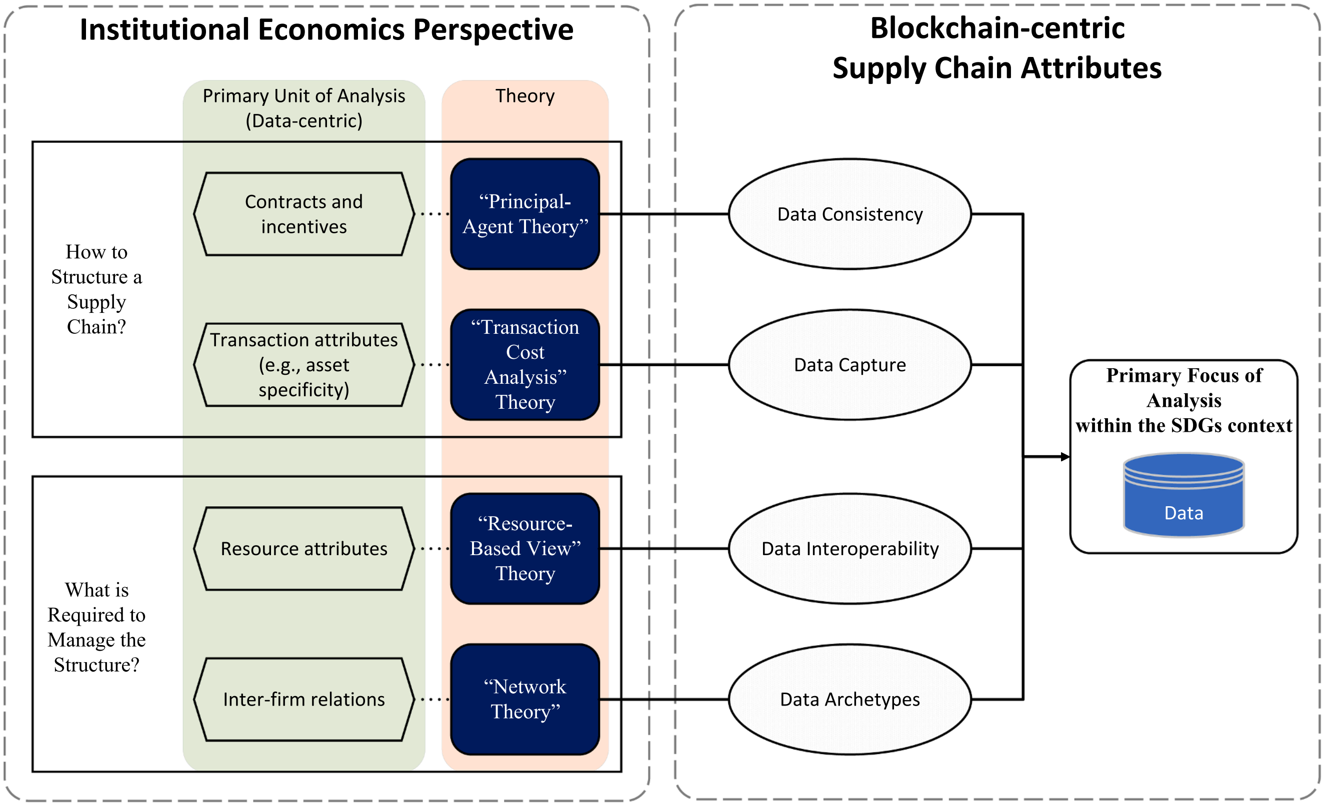

Fig. 1. Data-centric research model for supply chain design and management enabled by blockchain technology.

Table 3
Blockchain in the Thai fish industry and relevant United Nations Sustainable Development Goals challenges.

Sustainable Development Goal (SDG)	Description	Selected Supporting Study(ies)
▪ SDG #1 – No Poverty	Due to the low compensation generated from traditional monocrop plantations, viability in the fish industry can enhance household income. In addition, the Asian crisis during the 1990s followed by the recent global economic crisis affected Thailand in terms of food price shocks and inflationary pressures. Thus, fish exports could support the local and national economy. However, blockchain technology could ensure exports' potential and help transform the traditional fishery ecosystem to high-value business chains via building trust in the international markets.	Klasen, Lechtenfeld, and Povel (2015), Tanielian (2018), Viswanathan (2008)
▪ SDG #3 – Good Health and Wellbeing	Blockchain in the fish industry could eliminate illegal, unreported, and unregulated fishing in Thai waters and limit the provision of products with uncertain quality, hence allowing the national fishery ecosystem to sustain its contribution to food security.	Nong (2019)
▪ SDG #5 – Gender Equality	In Thai rural provinces, about 21% of households are female-headed. Also, female-headed households in Thailand lose significant more assets due to food price shocks compared to male-headed households. Blockchain implementations can help record labour statistics and motivate gender equality in the industry.	Klasen et al. (2015)
▪ SDG #8 – Decent Work and Economic Growth	In Thailand, illegal labour practices in the fish industry are prevalent. Thai fishing fleets are mainly staffed by poor migrant workers (mainly from Myanmar, Laos, and Cambodia) who often encounter rights abuses and receive very small salaries. Blockchain implementations can help assure visibility over labour working conditions and motivate fair trade agreements.	Lindley and Techera (2017)
▪ SDG #12 – Responsible Consumption and Production	The Thai fish industry is characterised by major sustainability challenges related to responsible production, including: (i) illegal, unreported and unregulated fishing activities resulting to 11–26 million tons of illegal caught fish per annum; and (ii) forced labour along with human and labour rights abuses. Blockchain ensures transparency, traceability and visibility over the sustainable performance across the supply chain.	Poseidon (2019), Sasipornkarn (2019), Wipatayotin (2019)
▪ SDG #14 – Life Below Water	Illegal, unreported and unregulated fishing activities in Thailand have resulted in declining fish species populations like seahorses and tuna. Blockchain could help monitor overexploitation fishing activities and inform targeted policies for the conservation of the marine ecosystem.	Foster, Kuo, Wan, and Vincent (2019), Kuo, Laksanawimol, Aylesworth, Foster, and Vincent (2018), Loh, Tewfik, Aylesworth, and Phoonsawat (2016), Perry, Lunn, and Vincent (2010), Poseidon (2019)

Table 4
Interviews' informants, selection criteria, and data collection mechanism.

Category of Informant	Number of Informants	Selection Criteria	Data Collection Mechanism
▪ Fishermen	1	• Fishermen 1 uses a 9-ton gross fishing vessel.	• *1 Physical Walkthrough/Field Observation Visit* Observation of the process after the vessel, which is full of wild caught seafood, arrives at the port, up until the process of selling the seafood.
▪ Fishermen	2	• Fishermen 2 uses a 67-ton gross fishing vessel.	• *1 Physical Walkthrough/Field Observation Visit* Observation of the process after the vessel, which is full of wild caught seafood, arrives at the port, up until the process of selling the seafood. • *1 Interview* Interview with the vessel owner.
▪ Traders	1	• Seafood trader is based in Phuket.	• *1 Interview* Interview with trader.
▪ Processors	1	• Processor purchases frozen tunas worldwide according to customers' specifications and produces canned tuna products to export.	• *1 Physical Walkthrough/Field Observation Visit* Factory visit. • *1 Interview* Interview with the purchasing, quality and production manager.
▪ Wholesalers	1	• An original equipment manufacturing company which supplies customers' labels. • The wholesaler imports processed fish products (mainly canned fish) and exports them worldwide. • The wholesaler does not own any manufacturing sites. The operations only include importing, storage, delivering, and exporting. • All the suppliers of the wholesaler are certified by the British Retail Consortium Global Standard for Food Safety.	• *1 Interview* Interview with the purchasing and responsible sourcing manager.
▪ Tech Providers	6	• A combination of non-blockchain and blockchain technology providers to compare the capabilities of different technologies.	• *6 Interviews* Interview with information technology managers and developers.
▪ Marine Stewardship Council	1	• Organisation which conducts audits and provides certification for sustainable fishing.	• *1 Interview* Interview with the information technology manager and auditor.
▪ Government	2	• Department of Fisheries. • 'Port-In-Port-Out'.	• *2 Interviews* Interviews with officers.

Total Engagements: Thee (3) Physical Walkthroughs/Field Observation Visits; Thirteen (13) Interviews.

consumers. The process flow diagram of "Fishermen 1", resulting from observations and interview insights, is illustrated in Fig. 4.

4.1.2. Data captured

Considering the legislative requirements for vessels with size less than 10 Gt, "Fishermen 1" are not obliged to gather any data related to fishing operations and to the fish catch per se. The only recorded information refers to the invoices of fishmongers which state the weight, species, and price of the traded fish.

4.2. Case study #2 – commercial fishing operations and trade

Commercial fishing operations are performed by "Fishermen 2" who are located in Phuket. The entire process is more complicated compared to local fishing operations owing to the dominant interdependency among storage duration, fish freshness, and profit, which could affect the scheduling of the operations and the quality of the traded seafood.

4.2.1. Fishing processes

"Fishermen 2" empirically prepare sufficient volumes of ice for storing and preserving the catch during fishing to achieve maximum profit under the constraints of seafood freshness and the vessel's fuel. Fishing vessels cannot be sailing for more than thirty consecutive days; nevertheless, "Fishermen 2" return to port within about fifteen days of departure to maintain the freshness of the caught fish. Every vessel is equipped with a Vessel Monitoring System that tracks and monitors the fishing operations while the data are centrally stored and managed by the Department of Fisheries to inspect for any illegal, unreported and unregulated activities. "Fishermen 2" use the 'fishing trawler' method which is considered unsustainable as it associates to high killing rates of by-catches. In this regard, any endangered fish species caught are required to be recorded on the vessel's logbook (see Image S3 in the Supplementary Material). The trawling process is performed three to four times during a day. Thereafter, the catch is released onto the vessel and the sorting process begins while the trapping is repeated (see Image S4 in the Supplementary Material).

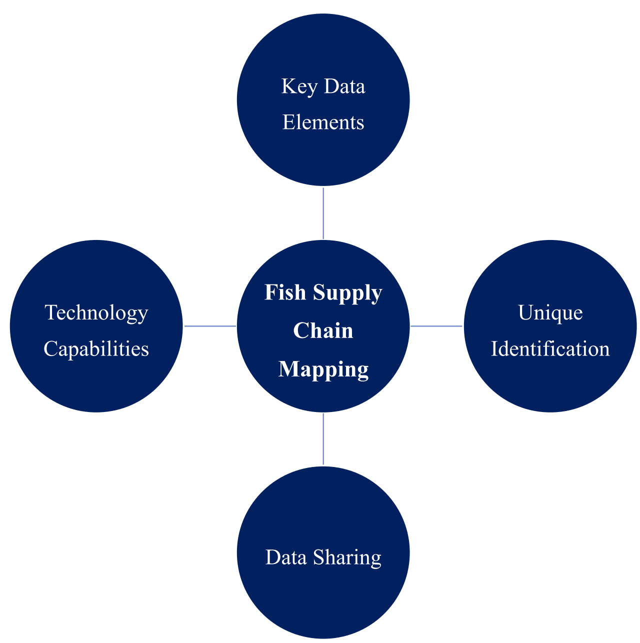

Fig. 2. Fish supply chain analysis framework, based on the Best Practice Guidelines on Traceability (FAO, 2014).

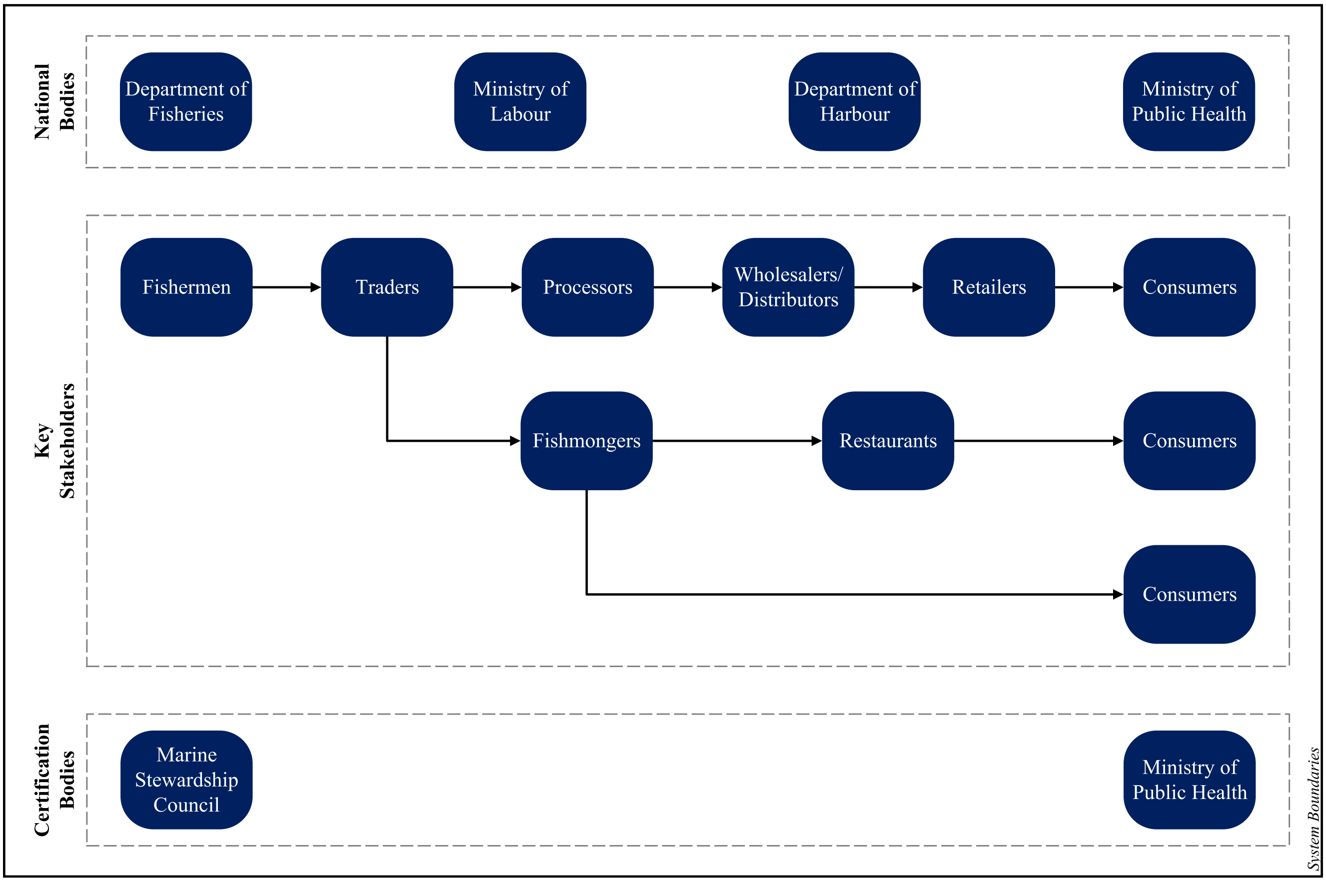

Fig. 3. Key actors in the fish supply network ecosystem in Thailand.

Table 5
Major Thai fishery legislative requirements by vessel type (Source: Department of Fishery, 2018).

Requirements by Thai Fishery Legislation	Vessel Type	
	Local Fishing Vessel	Commercial Vessel
Vessel size	Less than 10 Gt	Greater than or equal to 10 Gt
Vessel registration	Yes	Yes
Fishing logbook	No	Yes
Fishing area	Within 3 miles from the coastline	Beyond 3 miles from the coastline, but within the Thai borders
Tracking devices	No	Yes
Fishing quota	No	Yes

In Thailand there are thirty ports that can accept commercial vessels for unloading seafood to prevent unreported catch. In this regard, fishermen are required to book a date and request a specific time-window from the destination port to land vessels and unload the catch. In addition, a ‘Port-In-Port-Out’ form must be administered to the Department of Fisheries while a photographic copy of the logbook data recorded during the trip must be submitted via a public messaging application to obtain approval prior to unloading the catch at a specified port (see Image S5 in the Supplementary Material). “Fishermen 2” then unload and deliver the catch to the trader. Notably, the fish storage containers include a varying amount of ice due to lack of storage conditions’ monitoring or differences in the dates of the catch (see Image S6 in the Supplementary Material). The process flow diagram of “Fishermen 2” is depicted in Fig. 5.

4.2.2. *Trading processes*

Traders are responsible for supplying the consumers’ market with seafood delivered by the fishermen, with the risk of unsold units. A trader proceeds to a more accurate seafood sorting process performed on an aluminium platform (see Image S7 in the Supplementary Material). The seafood is segregated into different containers according to species, size, freshness, and appearance; the fish are not preserved in ice until the end of the auction. Each sorting container is labelled by the fishermen with a paper-based printed vessel code (see Image S8 in the Supplementary Material) to account for traceability (see Image S9 in the Supplementary Material). Following the seafood weighting and provision to the market (see Image S10 and Image S11 in the Supplementary Material), the gathered data (already recorded onto the vessels’ logbook) is reported to the ‘Port-In-Port-Out’ form by the traders to prevent overfishing and illegal trade. The process flow diagram of the “Trader” is shown in Fig. 6.

4.2.3. *Data captured*

Every stakeholder involved in commercial fishing activities needs to record data. “Fishermen 2” are required to record all their data onto the fishing logbook while, prior to unloading the catch, a ‘Port-In-Port-Out’ form must be completed. Traders need to record less data compared to fishermen. Data required for international customers, where international standards apply, would be different. The detailed list of Key Data Elements recorded in commercial fishing operations is inserted in Table A2 in the Appendix.

4.3. *Case study #3 – canned tuna manufacturing*

The approached canned tuna processor is located in the Hat-Yai city and produces personalised fish product labels according to customer

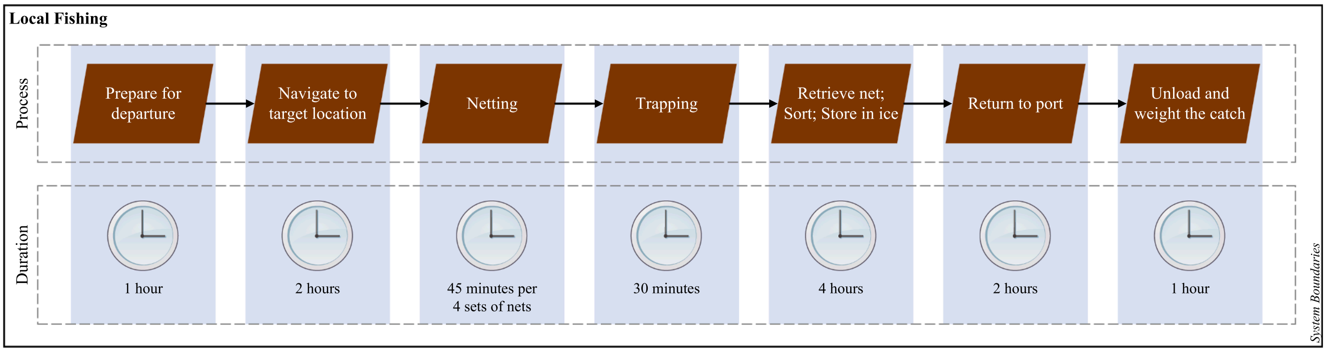

Fig. 4. Local fishing operations process flow diagram.

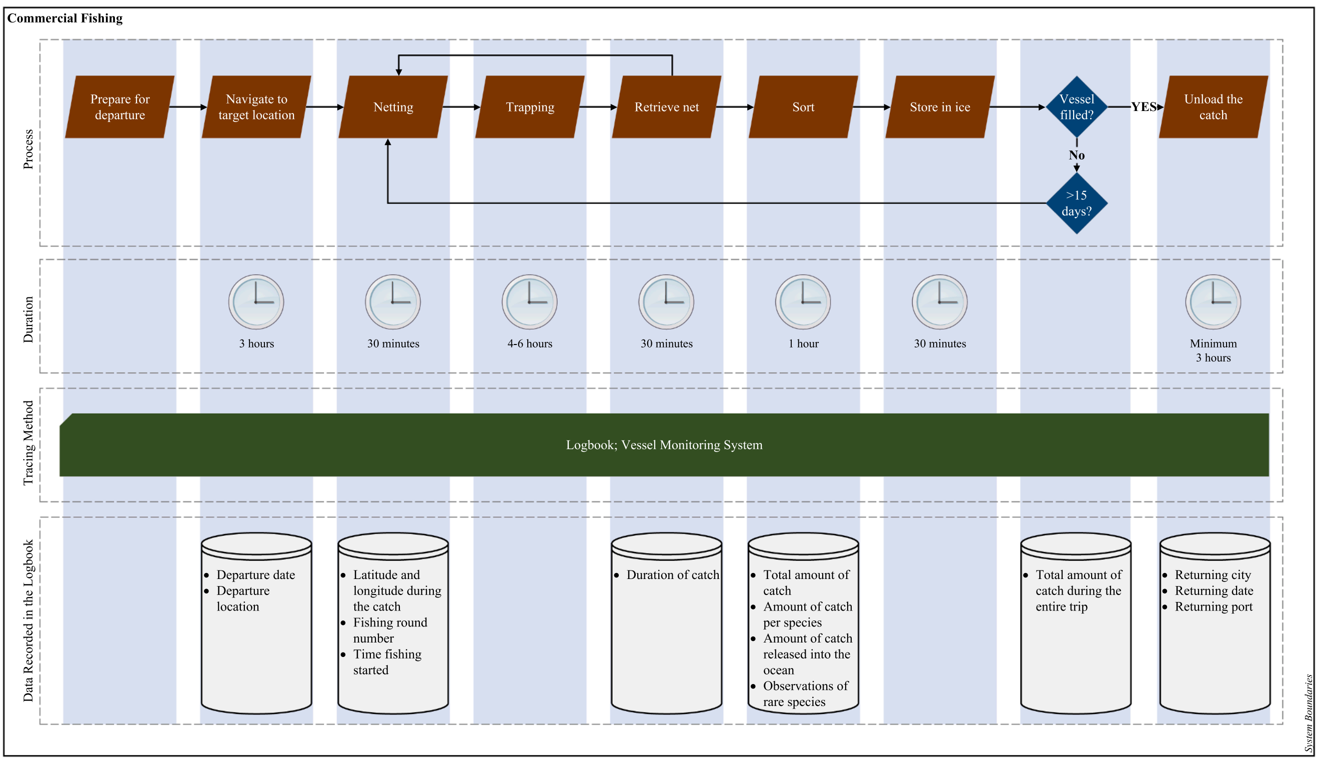

Fig. 5. Commercial fishing operations process flow diagram.

specifications. In 2017, the manufacturer received 45 million kg of tuna, 80% of which was imported.

4.3.1. Canned tuna processes

In terms of inbound logistics, tuna is delivered in containers which would then be loaded onto a conveyor so that fish are manually sorted by weight. To conduct quality control tests, a random sample is taken from the batch. Following the inspection and sorting process, the batch is registered to the inventory system and transferred to the cold storage warehouse with a maximum storage duration of three months.

Regarding the manufacturing process, tuna would be taken out for the thawing process and would be traced with the use of a production card as a tool for tracing material flows (see Image S12 in the Supplementary Material). After the cleaning, tunas are placed on trolleys where relevant information would be recorded on the production card. Herein, all data are recorded by RFID tags (see Image S13 in the Supplementary Material) which accompany the tuna until the end of the filleting process. The fillets are then automatically canned. The ingredients and packaging identification number would be linked to the product identification number for traceability purposes.

Production output is affected by three main factors, namely: (i) tuna size; (ii) tuna species; and (iii) skills of operators. The process flow diagram of the canned tuna manufacturing activities is illustrated in Fig. 7.

4.3.2. Data captured

Data required to be captured by the canned tuna manufacturer depends on the specifications of the customers. After the tunas are being weighted and sorted, the traceability information provided by the supplier for the production batch would be linked to each batch's identification number. A final sealing report for each batch would be created and approved by the quality control department. The comprehensive list of Key Data Elements for the canned tuna manufacturing supply chain is provided in Table A3 in the Appendix.

5. Discussion

Evidence derived from the literature and empirical observations reveal that notwithstanding the proliferation of industrial discussions and academic studies on blockchain, limited understanding is

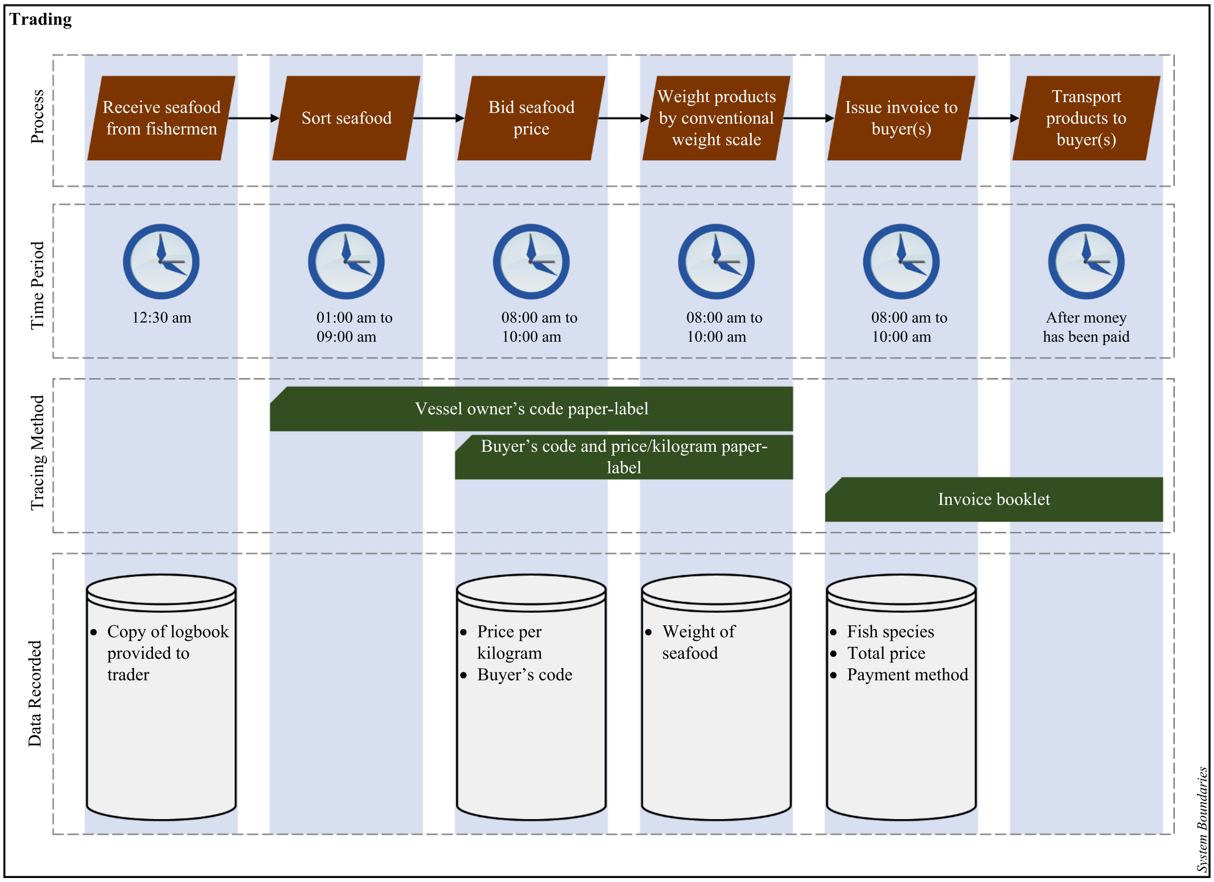

Fig. 6. Seafood trading process flow diagram.

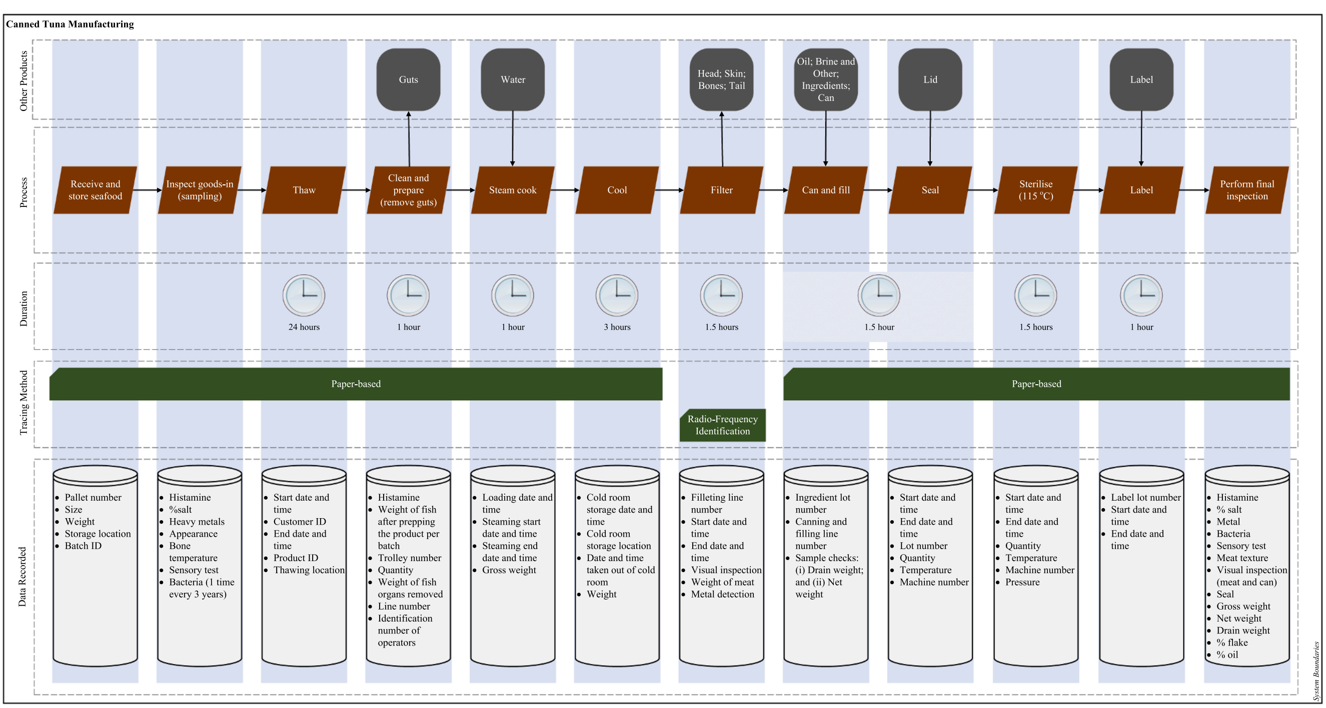

Fig. 7. Canned tuna manufacturing process flow diagram.

demonstrated over the data structure requirements for supporting the technology implementation and the respective supply chain (re)design. The results of the case studies suggest that data consistency, capture, interoperability and archetypes-related issues exist in the Thai fish

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pply chain that could ultimately impact the resilience of the fishery system and the achievement of SDGs. To that end, this research articulates four principles for blockchain implementation, namely:

- Principle #1 "Data Archetypes" – Linking data sets available in multiple echelons of supply chains is essential.

- Principle #2 “Data Capture” – Data on technology limitations needs to be captured.
- Principle #3 “Data Consistency” – Data archetypes should not only be developed for compliance purposes, but they have to extend beyond regulatory requirements.
- Principle #4 “Data Interoperability” – Insignificant supply chain processes and operations have to be accounted.

5.1. Data archetypes (Principle #1)

The observations of fishermen, traders and the manufacturer’s activities emphasise the lack of interface between operations and information flow, in terms of workflows and data triggers, meaning that the granularity of data is lost at the transition points from upstream to downstream supply chain operations thus limiting transparency and traceability. Key observations with regard to the limited possibility of linking data across fish supply chains include:

- Legislative voids – Fish supply network stakeholders might leverage legislation to avoid recording data that could reassure traceability and food safety. For example, local fishermen are not obliged to record any data. However, considering the local fishing capacity (~72% of total vessels) and the short cycle-times of the respective operations, fishmongers have access to fish supplies that are only accounted for their weight and species. The absence of any records also allows the possibility for overfishing and by-catches of endangered species. In addition, commercial fishermen and traders are not required to record any data with regard to fish unloading, sorting, and storage conditions.
- Not standardised data structure and recording format – The lack of standardisation in data structures and means of data recording establishes decoupling points across supply chain transactions. Firstly, local fishermen do not need to record any data and fishmongers have visibility only about the species and the weight of the traded fish supplies. Secondly, commercial vessels use a manually updated logbook to record data with regard to the fishing activities while the Vessel Monitoring System is only used for verifying the location of vessels and not to record or transmit fish catch reports. Furthermore, the arrival ports require only a pictorial copy of the logbook, a format that does not allow the automatic extraction and analysis of the data gathered during fishing activities. Thereafter, traders sort the fish into containers and the only traceability element refers to a hand-written note with each vessel’s code. Thirdly, the canned tuna manufacturer receives fish containers without having access to data about the geographical origin of the fish. Quality inspections on the production line are based on random samplings without providing the capability to track the vessel of origin or even the trapping process.

Therefore, linking the data sets that are available across the different supply chain echelons of operations is essential to ensure sustainable performance. Adopting common data archetypes can assist towards this direction.

5.2. Data capture (Principle #2)

Data capture mechanisms and technologies have inherent technical limitations and functional challenges that raise data reliability concerns. On the one end, paper-based data recording on logbooks entails bias, lacks accuracy, enables duplicated data recordings, and renders the data not reliable or even not accessible in case the physical logbook is damaged. On the other end, functional disruption of the data recording mechanisms could result in data inconsistencies or gaps. Indicatively, during commercial fishing operations the intentional or unintentional malfunction of the Vessel Monitoring System could result in the manipulation of the fishing location data thus raising visibility concerns over illegal fishing operations.

Another technical aspect refers to the calibration of any used equipment. For example, the mere common metric used to assess the traded seafood is the fish weight; however, the weighting process is typically executed by using a probably decalibrated or malfunctioning equipment. In addition, quality controls, if any applied in practice, are based on visual inspection that entails the subjective judgement of the involved operators. Therefore, capturing data with regard to technology limitations is essential to allow for data accountability and trust.

5.3. Data consistency (Principle #3)

Empirical evidence led to the conclusion that data regarding the flow of food products throughout the observed fish supply network is only recorded for merely regulatory compliance purposes. However, the magnitude of the gathered data is not leveraged to essentially support fish traceability or to inform downstream operations.

In a future state, to realise the potential of advanced traceability systems, data collection accountability would require stakeholders to demonstrate relevant responsibility. For example, local fishermen account for about 70% of the total fishing vessels and are not required to install a Vessel Monitoring System. Therefore, adulteration, commercial frauds, and dangerous substitutions are possible, whereas in case of quality and safety incidents food recalls of particular fish batches will not be feasible. Moreover, the reporting of by-catches of endangered species is manual, thus the monitoring of any environmentally or wildlife biodiversity damaging actions is not ascertained. To that end, data consistency is needed as data archetypes should not only be developed for compliance purposes, but they have to extend beyond regulatory requirements.

5.4. Data interoperability (Principle #4)

The scope of traceability needs to guide the design of data collection and sharing. For the case of the Thai fish industry, the primary aim of data recording is to avoid illegal, unregulated and unreported fishing operations. However, this is contradictory to the fact that around 70% of the fishing vessels are not required to be equipped with an electronic positioning system. In addition, certain critical operations are overlooked in terms of data monitoring, including:

- Ice preparation – The volume and condition of the ice prepared prior to fishing activities is not monitored. The temperature of the ice is not recorded while the ice might not ensure the appropriate preservation conditions for the stored fish after the catch. Similar reasoning applies for the ice used to store fish in containers for trading.
- Fish unloading – The unloading of the fish occurs on the vessel’s deck or on aluminium platforms at the port. The cleaning process of these surfaces, if any exists, is not documented.
- Fish sorting – The sorting of fish, occurring either on a vessel’s deck or at the port, is prone to subjectivity errors particularly in terms of species and skin quality.

In this regard, data interoperability is important as multiple insignificant supply chain operations are often being overlooked; however, the aggregate effect of such neglected processes could severely impact the sustainability of fish supply network operations.

5.5. Blockchain-centric supply networks design and implementation framework

Main concerns relating to fish supply chain operations include: (i) lack of connectivity between different departmental databases; (ii) no logbook requirement for local fishing vessels; (iii) lack of requirement for Vessel Monitoring System installation on local fishing vessels; (iv) inability to share logbook information in real-time; (v) 20% tolerance allowance on the accuracy of the amount of fish catch; and (vi) unregistered vessels. To that end, blockchain could be a feasible technology intervention for the viability and sustainability of the fishery ecosystem in Thailand but requires a set of supply chain design and technology implementation decisions.

5.5.1. Research findings

Lack of databases' integrity in the Thai government system instigates data inaccuracy issues in the fish industry, like incorrect number of registered vessels, thus overlooking illegal activities and impeding traceability. As local fishing vessels are triple in number compared to commercial vessels, about 11–26 million tons of fish caught annually are not recorded and are not considered in the sustainability assessment of the national aquaculture ecosystem. In addition, due to the technical inability for real-time sharing of the vessels' logbook information, a tolerance level of 20% is allowed on the accuracy of the amount of the fish catch. Considering the nature of the challenges in the Thai fish industry, Table 6 summarises relevant blockchain-centric supply chain design recommendations.

5.5.2. Blockchain implementation framework

Blockchain applications in the food sector provide added value in areas like trust, security, and decentralisation (Galvez, Mejuto, & Simal-Gandara, 2018). However, extant studies focus on the business benefits or information technology elements of traceability systems without discussing the data structures and their importance to supply chain management. Our claim is that the design of blockchain-centric supply chains should first consider the existing data structures and technology specifications in place. To that effect, the adoption process of an effective blockchain platform includes decisions at both supply chain design and technology implementation levels, as depicted in the proposed framework in Fig. 8.

5.5.2.1. Design decisions. Transitioning towards value networks enabled by blockchain technology requires that fundamental traceability systems are implemented to achieve tangible (e.g., market growth) and intangible (e.g., corporate reputation) benefits (Mai, Bogason, Arason, Árnason, & Matthíasson, 2010). In this regard, an effective production identification system has to already link resources to other Key Data Elements and to the finished product. Following that, on the condition that Key Data Elements are complete, the data gathering method is important for ensuring data accuracy. A blockchain database is a trusted database in an untrusted environment. In this sense, blockchain could be complemented by Internet of Things technologies to increase productivity and food traceability (Tian, 2017). Automation (e.g., RFID e-tagging and scanning of fish) ensures data accuracy as it eliminates human errors and intentional fraud that typically result in incorrect information (Girard & Du Payrat, 2017). The use of sensors and automation allows the integration of total quality management in the blockchain. Basic digital technologies that need to underpin blockchain include:

- RFID tags to trace fish from origin and collect data transmitted directly from sensors (e.g., date, time, temperature).
- Smart weighting system that takes into consideration a vessel's movement while weighting the fish catch during fishing operations. Weight logging could be automated to help forecast the landing date to the selected port.
- On-board survey cameras and electronic monitoring systems to help identify interactions with by-catches and protected fish species.

The benefits of blockchain in end-to-end supply networks can be operationalised through the establishment of a trustworthy traceability system that enables sharing of critical data among all collaborating actors. For instance, upstream suppliers would benefit from improved relationships with corporate customers to generate more business opportunities while downstream customers gain access to trusted data that prevent fraud and ensure food safety. Collaboration is recommended both among companies to improve the audit process and between governmental authorities of neighbouring countries to improve accuracy in aquaculture monitoring and fishing operations.

Furthermore, a major design decision is to select the on-chain or off-chain attributes to be shared on a blockchain. Companies need to balance among performance, privacy, and risk as the blockchain will be growing continuously due to data agglomerations.

5.5.2.2. Implementation decisions. Integrated off-the-self blockchain solutions for supply chains are being developed and tested. However, depending on the blockchain implementation purpose, type of data, and participants in the blockchain, enterprises can select the type of permission, consensus, smart contracts, and storage location, accordingly. In particular, for enterprises some data would be confidential, therefore a permissioned or hybrid blockchain would be more suitable to maintain firm proprietary competitive edge.

6. Conclusions

This research extends the "Principal Agent Theory" and the "Transaction Cost Analysis" Theory into the digital supply chain design domain, while contemporarily broadening the "Resource-Based View" Theory and the "Network Theory" view into the digital supply chain management field, specifically within the context of SDGs. In response to the research question considered in this study, blockchain-centric food supply chain designs that foster SDGs need to ensure data consistency for extending the focus on regulatory compliance purposes towards sustainability impact. To this end, the pivotal role of data capture is recognised to alleviate any data consistency challenges. In addition, blockchain-centric food supply chain management for SDGs needs to consider data interoperability among the dispersed systems and services to enable the efficient sharing of the content and context of the captured data. To that effect, the management of data archetypes is essential to link the different data sets that are available across multiple supply chain echelons.

From a technical viewpoint, key primary and secondary research evidence suggests that data asymmetry exists in the Thai fish supply chain that hinders the achievement of SDGs. Especially, the requirements of a blockchain implementation should derive from: (i) the expected scope of the technology application; (ii) the nature and specificities of the targeted operations; (iii) the type of data to be gathered and shared; and (iv) the participants in the blockchain. Thereafter, organisations can consider the type of permission, consensus, smart contracts, and storage locations, accordingly. Furthermore, the study findings confirm that the application opportunities of blockchain in fish supply networks clearly indicate that a single technological solution to tackle supply chain transparency and traceability challenges is not feasible. The design of a respective supply network depends on the fundamentals of traceability systems, namely Key Data Elements and collection mechanisms thereof. These elements need to be designed and managed properly for enabling the benefits of blockchain. From an implementation perspective, in human-dependent data entry points, errors or even fraud incidents could occur; hence, Internet of Things applications can help address data inaccuracy issues. Except for the non-exclusive traceability, immutability and trust related benefits, blockchain enables sustainability performance and helps promote SDGs.

6.1. Academic contributions

Within the particular context of SDGs, this research extends the "Principal Agent Theory" and the "Transaction Cost Analysis" Theory into the digital supply chain design domain. Cotemporally, the study

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Table 6
Blockchain-centric supply chain design recommendations for the fish industry.

Case	Observations and Issues	Consequences	Blockchain-centric Supply Chain Design Recommendations
■ Governmental Challenge	• Different databases for different fisheries-related departments.	• Different data in different databases.	• Create a decentralised database using blockchain to gain access to data in near real-time.
■ Governmental Challenge	• 20% tolerance on weight of catch allowed to fishermen.	• Over-fishing. • Data inaccuracy.	• Implement an on-board smart weighting system to increase weighting accuracy during fishing; automatically record the weight and transmit this information to the blockchain.
■ Governmental Challenge	• Unregistered vessels are untraceable.	• Illegal, unreported and unregulated fishing.	• Detect unregistered/illegal vessels with coastal radars and satellites.
■ Case Study #1 & Case Study #2	• Paper-based logbook delays data transmission into the government's traceability system.	• Fraud opportunities. • Low efficiency.	• Implement Electronic Catch Documentation Traceability or Electronic Recording and Reporting System or E-logbook where catch data can be immediately recorded and become accessible to the government in near real-time. Information on the location from the Vessel Monitoring System can also be automatically linked to the catch data. These data can be immutably stored on a blockchain.
■ Case Study #2	• With the current Vessel Monitoring System fishermen can decide to switch it off at any point in time but would risk getting caught and fined.	• Illegal, unreported and unregulated fishing.	• Install a motion sensor at ports to monitor incompliance of vessel entry at 'Port-In' case of illegal unloading of catch. • Use alternative technological solutions, such as the Pelagic Data System which is a solar-powered Global Positioning System that can operate 24 h per day.
■ Case Study #2	• Unmonitored storage temperature of fish on vessels. • Inconsistency in the amount of ice mixed with seafood in each basket.	• Inappropriate storage temperature has a high probability in impacting seafood freshness, thus resulting in food safety issues.	• Install a temperature sensor to continuously monitor storage temperature. An approval process can be self-executed by creating a protocol to verify the seafood storage temperature with a smart contract. This can improve the safety and quality of the seafood and can accelerate the verification process using a trusted mechanism.
■ Case Study #2	• Lack of batch identification number and tracking mechanism.	• Lack of traceability.	• Implement Radio-Frequency Identification to trace the product. Radio-Frequency Identification can be linked to different sensors and data can be automatically stored to a blockchain.
■ Case Study #2	• Inaccuracy in identifying the weight of catch as it is technically difficult to measure weight on a moving vessel.	• Inaccurate data collection.	• Implement smart weighting system at sea to increase accuracy of measurement while data can be automatically transmitted on a blockchain.
■ Case Study #2	• Limitation in monitoring off-shore activities such as actual fishing equipment used and illegal by-catches caught.	• Illegal, unreported and unregulated fishing.	• Use digital documentation, through for example photos or videos, as proof of equipment used and desired information recorded and time-stamped off-chain (because the file sizes are big).
■ Case Study #3	• Duplication can occur with Catch Certificates in terms that a single 'Catch_Certificate.pdf' file is sent to multiple buyers. Currently, there is no platform for cross-checking Catch Certificates.	• Product delivered may be mixed or replaced by illegal, unreported and unregulated fish but stated in the documents as 'certified'. • Sales exceed the amount of certified provisioned fish.	• Transmit the available information in a public blockchain, as being a responsibility of the government. A consensus can be created to validate the transactions in case a particular Catch Certificate reference number has not already been taken by someone else, i.e. a different buyer. Blockchain can make this possible to prevent sending duplicate certificates to multiple buyers.
■ Case Study #3	• Data interoperability is limited with the use of paper-based systems.	• Interoperability issues.	• Implement, depending on the business model, a hybrid/permissioned blockchain as the most desirable type for fishery industries where a selection of data would be shared to the public (such as origin of catch, storage temperature, etc.) and confidential information would be shared with permissioned stakeholders across the value chain.

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Table 6 (*continued*)

Case	Observations and Issues	Consequences	Blockchain-centric Supply Chain Design Recommendations
▪ Wholesaler	• Audits and certification are usually only conducted once per year. • Lack of full-chain real-time transparency and auditability.	• Does not provide full prevention from fraud on days where suppliers were not audited but products can still be sold as 'certified'.	• Implement blockchain and Internet of Things to potentially solve this issue. Data can be collected in real-time onto a blockchain with the use of Internet of Things technologies. Certification organisations and customers can then audit the data at any point.
▪ All Stakeholders	• Problems with not having access to real-time data.	• Less efficiency and safety of data.	• Use blockchain so that every organisation in the value chain would be able to access the same copy of data simultaneously.

findings extend the "Resource-Based View" Theory and the "Network Theory" view into the digital supply chain management field.

In the financial market, cautions about the prevalence of blockchain technology relate to the lack of governance as capital market regulators continue to raise disclosure requirements (Tappsocott & Tapscott, 2017). However, in the case of food supply networks, operational and governance requirements are not significant thus fuelling the rapid and disruptive role of the technology, particularly in case blockchain is standardised and matures to accommodate considerable transaction volumes (Knezevic, 2018).

Notably, uncertainties around data structure and blockchain implementation result in only generic understanding over the issue and create confusion. On the contrary, this study contributes to the Operations Management field by applying a multiple case study approach, combining both primary and secondary data and information, to develop an integrated and pragmatic view over data structure and transparency in end-to-end fish supply networks enabled by blockchain technology.

In addition, the findings of this research recognise the potential of blockchain to promote sustainability across a range of SDGs, depending on the particular operational context. In principal, blockchain promotes collaboration among stakeholders, hence allowing resources to be directed to priority areas. For the case of fish supply networks, blockchain could help remove from the food market environmentally damaging, illegal or unethical products of uncertain geographical origin and quality, whilst enhancing consumers' trust. Contemporarily, the increased transparency and accountability could stimulate business growth in local fish industries, subsequently contributing to the well-being of vulnerable populations. More specifically, this research articulates four principles for blockchain-centric supply chain design,

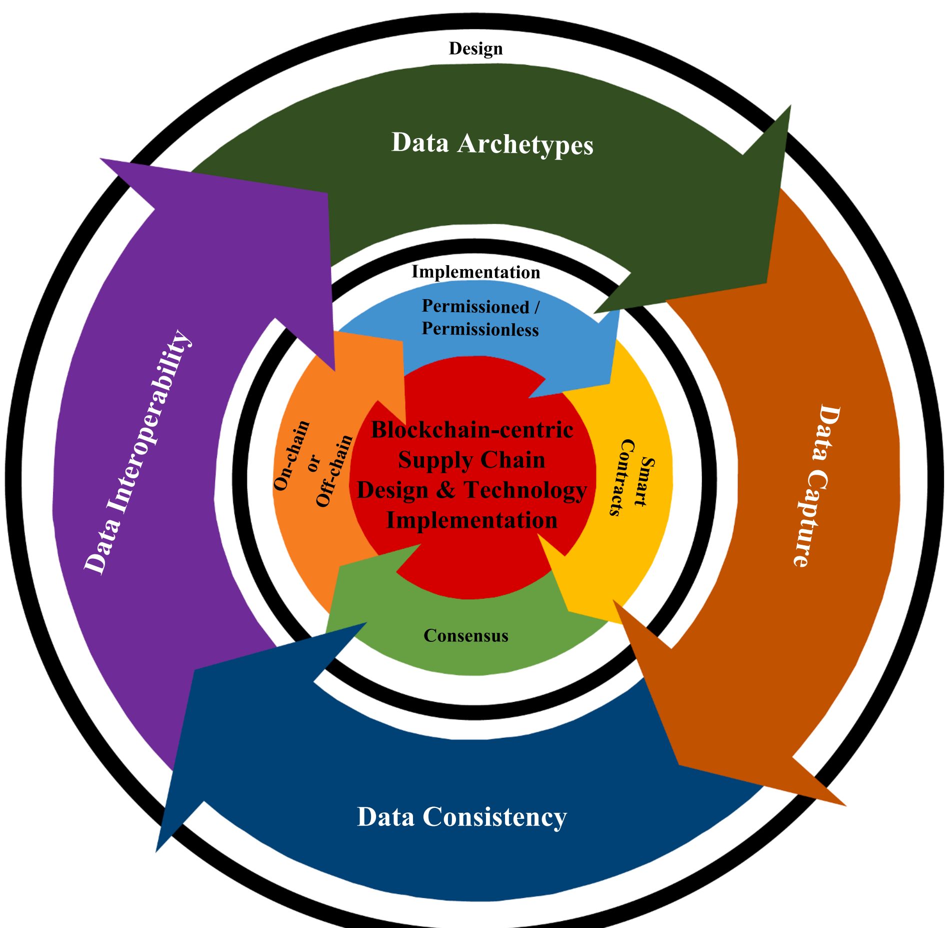

Fig. 8. Integrated framework of blockchain-centric supply chain design and technology implementation.

along with a technology implementation framework, that could ultimately impact the resilience of the fishery system and the achievement of SDGs, namely:

- Principle #1 "Data Archetypes" – Linking data sets available in multiple echelons of supply chains is essential.
- Principle #2 "Data Capture" – Data on technology limitations needs to be captured.
- Principle #3 "Data Consistency" – Data archetypes should not only be developed for compliance purposes, but they have to extend beyond regulatory requirements.
- Principle #4 "Data Interoperability" – Insignificant supply chain processes and operations have to be accounted.

In line with the research concerns identified by Kouhizadeh and Sarkis (2018), this research contributes to the blockchain body of research by investigating the real-world potential of blockchain implementation to support the competitiveness and export dynamics of the Thai fish industry. At a greater extent, blockchain could enable the holistic consideration of a supply chain to integrate all involved stakeholders, data and technologies thereof, in a collaborative style and promote environmental sustainability in a consistent manner (Koh et al., 2013).

6.2. Management implications

The extant literature on blockchain technology is proliferated by conceptual expositions while real-word empirical cases in the non-finance sector are scarce (Ying, Jia, & Du, 2018). On the contrary, the findings of this research assist in addressing real-world practical issues by investigating fish supply chains in Thailand. The outcome of this research contributes to the management field by developing four principles for blockchain-centric supply chain design (i.e., "Data Archetypes" – "Data Capture" – "Data Consistency" –"Data Interoperability"), along with proposing a blockchain implementation framework structured around these principles. The proposed framework could assist the decision-making process of managers towards the achievement of SDGs.

Blockchain in the fish industry can enable the development of the necessary real-time supply network capabilities (e.g., visibility and data-enabled product quality reporting) to catapult network performance and competitiveness (de Oliveira & Handfield, 2019). Our study reveals that the use of more sensors and automation inspires total quality management to include devices' certification and calibration into the blockchain. Moreover, contrary to established blockchain applications for cryptocurrency purposes, food supply networks entail physical commodities/products. Therefore, cryptographical proofs of the provenance and handling condition of fish could possibly disrupt the food certification industry as the cost of audits and certifications can be reduced.

6.3. Limitations

Few limitations that characterise this study occur that could motivate further research. Firstly, during the fieldwork few fishermen seemed to be reluctant in providing direct answers about the fishing methods and records. As the Thailand's Fishery Foundation informed, such an attitude could be attributed to the abrupt changes in the legislation that did not allow enough time for the fishermen to adapt. Secondly, our research focused on the diversified data structures and recording practises while the provided blockchain-centric supply chain design and technology implementation framework does not capture technical details.

6.4. Future research

In the future, we aim to perform a similar detailed study on the agricultural sector to support the dual objective of efficiency and sustainability, particularly with refer to natural and business resources' appropriation in sensitive regions (Leng, Bi, Jing, Fu, & Van Nieuwenhuyse, 2018). Regarding data privacy concerns, further research should also explore ownership and analytics functions that balance privacy preservation to information loss (Wieringa et al., 2019).

Finally, we aspire to conduct pertinent studies on multiple food products and industrial sectors such as automotive, aerospace, and pharmaceuticals. Additionally, the proposed blockchain implementation framework requires multiple testing through action research in order to observe key patterns on how principles on blockchain-centric supply chain design and management vary in different sectors and how does product-process-location characteristics impact data consistency, data capture, data interoperability, and data archetypes.

Acknowledgements

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Appendix A

See Tables A1–A3.

Table A1
Interviews' salient points.

Informant	Key Points of Interview
Wholesaler	• The Wholesaler, as a private-labelled supplier, is prone to the fish and seafood sourcing standards dictated by the customers. • All the Wholesaler's suppliers are certified by the British Retail Consortium, and therefore the Wholesaler has Good Manufacturing Practise, Hazard Analysis Critical Control Point, and Threat Assessment Critical Control Point systems in place. In addition, the Wholesaler has a Marine Stewardship Council Chain of Custody certification and uses a corresponding ecolabel on the packaging. • The Wholesaler conducts on-site due diligence audits and routine traceability checks which cover a range of quality areas depending on the specific customers. • The Wholesaler's suppliers are required to have sufficient information to complete a full supply chain map back to source, a full vessel list, and ethical and sustainability risk assessment. • Prior to signing a contract for supply, the Wholesaler seeks independent verification (by a consultant) that systems, documentation and evidence is in place for: (i) legal conformity; (ii) adherence to the Wholesaler's policies (e.g., tuna sourcing protocol); and (iii) compliance to any specific customer requirements. The effectiveness of the system and processes is then checked at regular intervals by audits conducted by the Wholesaler. • Wholesaler's internal traceability is achieved through a commercial Enterprise Resource Planning system. Several of the Wholesaler's suppliers who also use the same system would be able to share 'few' documents using Electronic Data Interchange. According to the Wholesaler, the

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Table A1 (*continued*)

Informant	Key Points of Interview
	Electronic Data Interchange has limitations and can only allow the sharing of few documents. Therefore, communication and data sharing with suppliers and customers is mainly performed via e-mails and telephone calls. ● Shared database would reduce administrative burden and time spent on individual requests on sustainability information. ● Intentional or unintentional substitution of fish species can occur in the supply chain. An incentive for fraud or intentional substitution is cost reduction. When two species of fish look very similar, it is easy to mix them up. When the fishes are processed, it is even harder to differentiate them. For instance, Yellow Fin and Big Eye Tuna look and taste very similar; however, there is a difference in price. In case intentional substitution does occur, it is possible that the supplier could have also modified the paperwork to hide this fraudulent information. ● The Wholesaler does not raise any concerns regarding fraud, mislabelling or substitution with suppliers. ● The Wholesaler encounters minor losses sometimes where pallets or containers are accidentally damaged or poorly packed. The Wholesaler monitors these incidents to prevent them; however, major challenges include: 1. Fish unavailability leading to shifting sources and processing sites at a challenging pace. 2. Visibility that inevitably 'blinds' the Wholesaler regarding the current end-to-end supply chain operations. ● To gain visibility downstream the supply chain, the Wholesaler must engage with direct suppliers (Tier 1) who may be able to provide the information or can communicate with their suppliers (Tier 2) to gather this information.
Marine Stewardship Council	● In the auditing process, the auditors would verify the absence of illegal, unreported and unregulated fishing activities according to the fisheries and chain of custody standards. For fisheries, the assessment reports need to clearly state that there is no illegal fishing. Auditors would prepare an assessment report and send it to the Marine Stewardship Council that assesses the report. In case the report is approved, it is uploaded to the Council's website for allowing public access. For Chain of Custody audits, there is a checklist for auditors. All data from Chain of Custody audits is however confidential due to agreements that the Marine Stewardship Council sets-up with clients. ● The Marine Stewardship Council is moving towards digital traceability systems for certifying supply chains and verifying the absence of illegal, unreported and unregulated fishing. Such a digital system would be able to integrate into any client's current Information Technology system and facilitate data sharing. Data can be then digitally tracked and verified against the data collected by the client and against other sources of information such as a new vessel's registry by the Food and Agriculture Organization. Information such as provenance can be captured in near real-time. Such a digital system is in the late design stage and is planned to be launched within the forthcoming two years. ● The Marine Stewardship Council is aware of the blockchain potential and has considered integrating blockchain into its digital system under development; however, the Council decided to delay this implementation due to high cost, high technology risk, and the long development time. ● Blockchain offers a unique opportunity to secure shared information. The information is neutral, distributed and cannot be orchestrated by one company. The Marine Stewardship Council is of the opinion that blockchain can amplify trust on fishermen and the certification per se. Although the Council had never come across concerns with regards to security, blockchain could be a disruptive technology for the certification organisation as the technology gains more trust over the organisation. ● The major weakness of blockchain is the cost of scalability. The cost would be too high for the fisheries' industry since a fee/payment would be required for such a service. ● A key challenge of blockchain technology is consolidation of data and stakeholders' collaboration. The Council revealed that there have been examples in other organisations where similar projects were unsuccessful because stakeholders did not collaborate.
Tech Provider #1	● Tech Provider #1 has developed a pilot Electronic Catch Documentation Traceability system that has been implemented by some fishermen in Thailand. ● The developed Electronic Catch Documentation Traceability system can automatically record the date, time, location and speed of each vessel at any time. The system allows robust communication beyond 10 miles from the coastline (mobile telecommunication networks are not accessible beyond this point). The developed Electronic Catch Documentation Traceability system can also be used to record the amount of catch and automatically link this information to the catch location. ● The developed Electronic Catch Documentation Traceability system associates to significant investment cost. The installation cost is approximately THB 100,000 and the subscription cost, dependent on airtime, is approximately THB 4,000–5,000.
Tech Provider #2	● Tech Provider #2 provides a cloud-based Enterprise Resource Planning solution through subscription by offering a full range of services for the entire value chain, including: Hazard Analysis and Critical Control Points quality control; fishery quota; manufacturing management; financial management; business analytics; retail management; internal and external traceability etc. Data backup, updates, Structured Query Language database and security are also included. The installation can be done remotely and incurs minimal installation cost because software licenses and a centralised computer system are not required. Data can be entered using peripherals and scales. The information can be accessed anywhere in the world. The system can be customised according to customers' requirements.
Tech Provider #3	● Tech Provider #3 is a blockchain start-up company which offers solutions for pharmaceutical supply chains to comply to regulations, such as tracking temperatures and keeping a safe record. ● Tech Provider #3 has integrated Internet of Things with blockchain for automated and tamper-proof data collection by using temperature sensors during the transportation of pharmaceutical products with the information stored in the blockchain. ● Tech Provider #3 developed a web application and a dashboard control panel that analyses and presents data and information in real-time. ● Tech Provider #3 has included a module to monitor weather and uses Big Data and machine learning to create predictive models for better informed supply chain management. ● The blockchain implementation is only limited to transportation operations of medications and has not yet been integrated to other echelons of the pharmaceutical supply chain.
Tech Provider #4	● Tech Provider #4 is an Information Technology consulting firm which has advised and assisted in the implementation of blockchain into supply chains. ● Tech Provider #4 recognises the beneficial role of blockchain for mutual stakeholders' access to the same data without having to send data 'back-and-forth', especially in complex ecosystems. ● According to Tech Provider #4, benefits of blockchain include: auditability; tamper-proof data; decentralisation; proof-of-origin. Tampering can only be achieved in case the entire ecosystem fraudsters the digital platform at exactly the same time.

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Table A2
Key Data Elements recorded during commercial fishing operations.

Key Data Element	Data Recording Responsibility			Data source
	"Fishermen 2"	'Port-In-Port-Out' form	"Trader"	
● Vessel name	•	•	•	Department of Fishery; Vessel owner
● Vessel identification number	•	•		Department of Fishery
● Vessel registration code	•	•		Department of Fishery
● Date of departure	•	•		Department of Fishery; Vessel owner/Vessel Monitoring System
● Departure port name	•	•		Vessel Monitoring System; Vessel owner/ Vessel Monitoring System
● Return port city	•			Vessel Monitoring System
● Date of return	•	•		Vessel Monitoring System; Vessel owner/ Vessel Monitoring System
● Return port name	•	•		Vessel Monitoring System; Vessel owner/ Vessel Monitoring System
● Departure time		•		Vessel owner/Vessel Monitoring System
● Return time		•		Vessel owner/Vessel Monitoring System
● Latitude and longitude of the catch	•	•		Vessel Monitoring System; Vessel owner/ captain
● Fishing round number	•			Logbook
● Time fishing started	•			Fishermen's clock
● Duration of catch	•			Fishermen's clock
● Total amount of catch during the entire duration of the harvest (in kilograms)	•			Fishermen's approximation
● Amount of catch per species (in kilograms)	•			Fishermen's approximation
● Total amount of catch per fishing day (in kilograms)	•			Fishermen's approximation
● Amount of aquaculture released back to the sea (in kilograms)	•			Fishermen
● Observations of caught rare species	•			Fishermen
● Number of days at sea entitled		•		Department of Fishery
● Number of days departed		•		Automatically calculated by the system
● Number of days already at sea				Department of Fishery
● Fishery identification number		•		Department of Fishery
● Fishery equipment		•		Department of Fishery
● Vessel Monitoring System's brand, model and identification number		•		Department of Fishery
● Radio (VHF/FM, HF/CB, HF/SSB)		•		Department of Fishery
● List of seafood species with the top three catches (in kilograms)		•		Logbook
● Objective of departure (i.e. fishing, maintenance, other)		•		Vessel owner
● Objective of arrival (i.e. unloading catches of certain weight, refilling supplies, maintenance, other)		•		Vessel owner
● Telephone number		•		Vessel owner
● Vessel captain's name, certificate identification number, citizenship identification number, address, telephone number		•		Vessel owner
● Vessel owner's name, citizenship identification number, address, telephone number		•		Vessel owner
● List of vessel workers' names, age, gender, nationality, citizenship identification number, responsibilities in the vessel, working contract		•		Vessel owner
● Date of trade			•	Calendar
● Weight of traded seafood			•	Conventional weight scale
● Seafood species traded			•	Visual inspection
● Price per kilogram of traded seafood			•	Trader/auction
● Total price of traded seafood			•	Weight of traded seafood × Price per kilogram of traded seafood
● Buyer's code			•	Auction
● Payment method for traded seafood (bank transaction/cash)			•	Decision by buyer

Table A3
Key Data Elements recorded by the canned tuna manufacturer at the different supply chain echelons.

Suppliers	Packaging	Batch (by Supplier)	Quality Control	Final Batch Report
1. Invoice	1. Product identification number	1. Pallet number	1. Histamine levels	1. Product number
2. Supplier name	2. Batch number	2. Fish species	2. % salt	2. Customer identification number
3. Packing list	3. Receival number	3. Size	3. Heavy metals (e.g., mercury, cadmium)	3. Lot/vessel
4. Bill of landing	4. Quantity	4. Date received	4. Appearance before and after steam cooked	4. Receive date
5. Dolphin safe certificate	5. Total weight	5. Delivery truck license number	5. Bone temperature	5. Size
6. Captain statement	6. Supplier name	6. Lot number	6. Sensory of fish before and after steam cooked	6. Time taken out of storage
7. Fisheries certificate of origin NOAA form 370	7. Marine Stewardship Council (if required)	7. Supplier code		7. Steaming duration
8. Certificate of origin	8. Origin of catch	8. Marine Stewardship Council (if required by the customer)		8. Duration in cooling room
9. Beneficiary's letter of guarantee	9. Vessel number	9. Origin of catch		9. Fish weight
10. Health certificate	10. Catch method	10. Year		10. Ingredient lot number
11. Catch certificate (unique reference number; date of catch; amount of catch)	11. Non-illegal, unreported and unregulated certificate	11. Catch method		11. % salt in brine
12. Aggregate catch certificate for traceability – Harvest and landing/receipt	12. Catch certificate (for the European Union market)	12. Non-illegal, unreported and unregulated certificate		12. Quantity
13. Catch certificate for traceability – Harvest and landing/receipt		13. Sequence number		13. % cooked fish
14. Reprocess certificate for traceability – Primary or secondary processing				14. Start seam
15. Detail loading container				15. Stop seam
16. International P&L Foundation member or participate letter				16. Time pressure
17. Marine Stewardship Council (if required)				17. Filleting line number
18. Date and time received				18. Seamer number
19. Delivery truck license number				19. Batch number
20. Receival number				20. Steamer number

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbusres.2020.08.003.

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