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Review

Improving Maritime Transport Sustainability Using Blockchain-Based Information Exchange

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Abstract: In this paper, the authors perform a comprehensive literature review of the positive impacts of blockchain-based information exchange in the maritime transport sector, as well as the challenges and barriers for successful blockchain-based information exchange, considering all three aspects of the sustainability (economic, environmental, and social). The papers from relevant databases (Web of Science and Scopus) and selected studies have been used. The literature coverage was expanded by using backward snowball sampling. In total, 20 positive impacts and 20 challenges/barriers were singled out. Despite the identified barriers and challenges (such as the slow acceptance of blockchain technology in the maritime transport sector or the high implementation cost), blockchain technology possesses a definite potential to improve the information exchange between all involved stakeholders (for example, by improving the visibility across transport routes and by reducing the paper-based processes), positively affecting all three aspects of sustainability. The authors contribute to the existing research of the economic aspect of maritime transport sustainability by blockchain-based information exchange by expanding it and by researching the environmental and social aspects of sustainability.

Keywords: blockchain; information exchange; maritime transport; sustainability; positive impacts; challenges; barriers

1. Introduction

The shipping industry is still a traditionally oriented industry, despite numerous technological revolutions [1]. The companies in the maritime transport sector are facing notable challenges resulting from the emergence of disruptive technologies, for example, the lack of regulation and the issues of security and privacy. Nevertheless, the disruptive innovations definitely possess a potential to improve transport business [2]. The blockchain, as a disruptive technology and a driver of digital transformation, is projected to be the latest transformative innovation and is increasingly gaining attention from academics, practitioners, and regulators across various industries [3,4]. The blockchain research frequently lacks theoretical foundations, and it is unclear which organizational theories (and to what extent) are being used to research the blockchain technology in the logistics and transport fields [4].

The movement of goods and related information through a supply chain can be a complex process, involving numerous and various stakeholders such as the importers, exporters, and logistics firms [5] that should closely cooperate in order to achieve smoother information exchange. The inability to effectively manage documents may represent a burden for port management, since standard vessel shipping includes numerous stakeholders (shipping companies, terminal operators, etc.) as well as numerous iterations of confirmations and various regulations [6]. A part of the problem arises due to the lack of mindfulness about the upcoming transport, and this refers to informing the parties about the arrival, the type of cargo, checking of documents, etc., along the supply chain [6].

The environmental regulations and rules are one of the key drivers of developing sustainable practices in organizations. Organizations invest and strive to meet minimum sustainability criteria, and that can at the same time prevent their creativity and innovation in applying sustainable methods [7]. The blockchain may transform the maritime industry and could provide various benefits to the exporters, importers, shipowners, and governments [8]. However, the stakeholders and enterprises in the maritime transport sector, as many enterprises in other industries, struggle with the lack of awareness, collaboration, and commitment for a successful blockchain implementation. The majority of contemporary research is focused on the blockchain impact in the supply chain. A lack of research and scientific papers offering a comprehensive overview of the blockchain-based information exchange (in terms of sustainability) in the maritime transport sector is particularly pronounced [6]. To overcome this research gap and to provide a better understanding of the blockchain-based information exchange in the maritime transport sector, the authors have conducted a comprehensive literature review focusing on the period from 2015 to 2020 in order to capture the recent research in the field of blockchain. Moreover, the aim of the research endeavor was to identify the positive impacts of blockchain on information exchange among the stakeholders as well as the challenges and barriers to successful blockchain-based information exchange in the maritime transport sector, considering all the aspects of sustainability. To achieve this aim, the following research questions were addressed in this study:

- What are the positive impacts of the blockchain-based information exchange in the maritime transport sector (considering all three aspects of the sustainability)?
- What are the challenges and barriers to successful blockchain-based information exchange in the maritime transport sector?

After analyzing the connection between the maritime transport and sustainability as well as the theoretical part of blockchain technology, the authors analyzed the positive impacts of blockchain-based information exchange in the maritime transport sector and have identified the challenges and barriers of the blockchain technology in the maritime transport sector, considering all three aspects of sustainability.

2. Theoretical Background

2.1. Maritime Transport and Sustainability

Over the last century, maritime transport has been the predominant mode of transport for global trade, involving a large number of stakeholders [9]. According to [10], due to economic globalization and the rapid growth of international trade, maritime transportation has become the main conveyor belt of cargo flow between countries. Maritime transport sustainability means the ability to provide accessible, affordable, reliable, safe, socially inclusive, economical, and environmentally friendly transport infrastructure and services [11]. The shipping should be efficient and sustainable in order to enable the growth of the global economy, but it should also focus on protecting the environment, cost-effectiveness, and providing safe and energy-efficient global transport of goods [8].

While researching the three pillars of sustainability, Oh, Lee, and Seo [12] identified the key management criteria for sustainable seaport business: an environmental management criterion includes environmental policy, environmental risks reduction, and stakeholder collaboration [12]. Economic management criteria include cost-saving by using cleaner technologies. Criteria in social management include welfare and working conditions improvement, education and training, and supporting economic and social activities [12]. With regard to the economic sustainability aspect, economic parameters may (among others) include connectivity, market access, trade competitiveness, infrastructure capacity, and transport costs [11], which represent a significant portion of total logistics costs for many organizations [13,14]. Currently, the attention is being paid not only to the economic but also to the ecological issues of transportation, with the aim to lower the damaging impact on the environment [15]. In maritime transport, an increasing focus is placed on the environmental aspect of sustainability because of tightening emission regulations and stakeholder demands. Non-compliance or inactivity related to environmental sustainability can ultimately lead to unexpected costs for companies [16]. With regard to the social aspect of sustainability, safety and security, health, employment, employee engagement, and working conditions should be considered [11,17].

Seaports represent the important logistics and transport chains' nodes and are at the core of national and regional economies [18]. In order to achieve seaport sustainability, it is necessary to integrate environmentally friendly methods of seaport activities, operations, and management. As loading and unloading are among the main activities in seaports, unnecessary waiting for cargo due to ineffective, obsolete document exchange causes the increase of CO_2 emissions [13]. The paper documents that are exchanged between the seaport stakeholders and the necessity of physical presence during the so-called "coordination meetings" slow down the business processes and produce higher costs. Furthermore, the bottlenecks and truck congestion inside and outside the container terminal can lead to serious local environmental problems such as noise and harmful emissions, but also to major inefficiencies in various operations [19]. The importance of the environmental aspect of seaport sustainability is increasingly recognized by the port authorities, port users, policy makers, and local communities. Despite the numerous environmental benefits that innovations can provide, resistance to change is often present [20].

2.2. Blockchain

The blockchain is a decentralized ledger that uses peer-to-peer consensus to verify and authenticate all information recorded within the ledger [21]. The blockchain may be defined as a record-keeping system that stores transaction record information that is shared peer-to-peer, including all computers within the network [22]. In blockchain technology, transactions are stored in a distributed ledger; the copies are available with each node, enabling transparency [23]. This node network will be secured against inaccurate or malicious alterations caused by a defective data source (either one of the nodes or an external attacker) [24]. The blockchain is a "chain of blocks" containing details of a transaction for a specific time period that cannot be edited easily. The "block" is related to transactions and represents the basic blockchain unit, while the "chain" connects the transactions into one chain. In other words, each block includes a list of transactions and links to the previous block within the chain. The blockchain technology principle is achieved through a decentralized peer-to-peer network, i.e., through a network through which the data is shared between many working units [25]. The blockchain can be divided into two types according to openness and access to data: public and private [26]. According to [27], the public and private networks differ in terms of access to the ledger. In the public network, each user has a copy of the ledger and participates independently in the conforming transactions, while in the case of a private network, participants need permission to keep a copy of the general ledger and participate in the confirmation of transactions [27].

The blockchain also supports more advanced concepts, such as smart contracts and the smart property, also known as tokenized assets [3]. Smart contracts may be characterized as distributed transactions that are stored on the blockchain, allowing highly automated workflows that do not require human interaction [28]. A smart contract is a self-executing pre-evaluated contract that aims to digitally facilitate, verify, or enforce the negotiation or the contract execution [29,30]. The smart contracting may be defined as the usage of a blockchain technology-based computer program in order to support and automate the execution of contractual agreements [31]. The smart contracts may perform numerous functions, such as the automatic change of ownership of goods, execution of payments, and even compensation or insurance payments for late deliveries to the compensate the relevant parties [5].

The blockchain provides numerous benefits and can be used in various areas such as logistics and supply chain management, Industry 4.0, etc., to provide more security and to successfully process large quantities of data [32]. The blockchain is an innovative technology that promises to disrupt the applications and use-cases across most industry sectors, including the maritime industry [1]. The blockchain technology has already been introduced into the maritime industry in the form of a bill of lading, regulatory compliance, etc., and should bring cost-saving to the industry [33].

3. Methodology

In total, 99 sources have been identified as relevant for this research. Table 1 shows the journals, books, and conference papers categorized based on topics. 62 papers were selected from 43 journals, and 10 papers were selected from 10 conferences. Two books relevant to this topic were also included.

Table 1. Categorized journals, conferences, and books (related to sustainability and blockchain-based information exchange) based on topics from 2012 to 2020.

Categorization Based on Topics	2012–2018	2019	2020	TOTAL
Sustainable development and management	2	5	6	13
Supply chain	0	2	0	2
Logistics and transport	2	6	3	11
Maritime industry	4	4	3	11
Economy	0	5	0	5
Engineering	1	0	1	2
Security and privacy	1	0	0	1
Management, strategy, and policy	0	3	3	6
Technologies and systems (general)	6	10	7	23

To provide a better understanding of the blockchain as a tool for improving information exchange in the maritime transport sector, a comprehensive literature review has been conducted. The research methodology has been adapted from [34]. Figure 1 shows the methodological steps of the research.

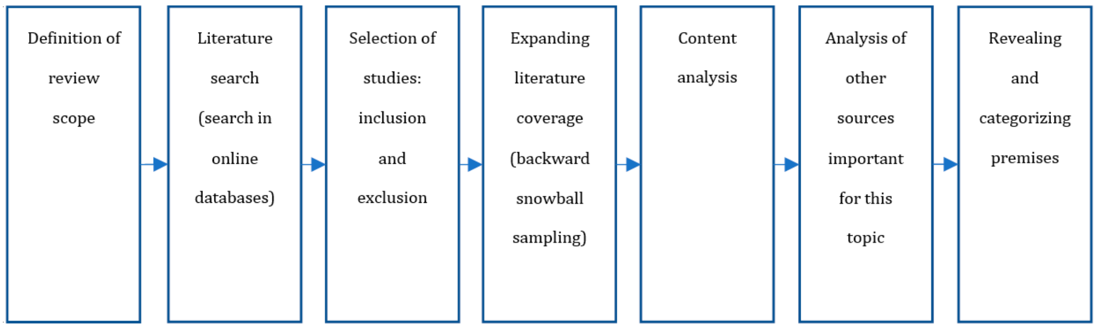

Figure 1. Methodological steps for the research.

The search was carried out using two databases: Web of Science and Scopus.

In this research, we have focused on the following keywords:

- Blockchain AND Sustainability
- Blockchain AND Document exchange
- Blockchain AND Information exchange
- Blockchain AND Transport
- Blockchain AND Sustainability AND Transport
- Blockchain AND Maritime transport
- Blockchain AND Maritime industry
- Blockchain AND Shipping
- Blockchain AND Seaport
- Blockchain AND Port

A search was performed in order to determine whether the publications contained at least one of the search terms in the title, abstract, or the entire manuscript (formal criteria). As shown in Figure 2, the highest number of hits was obtained by searching for the keyword "Blockchain AND Information exchange". The lowest number of hits was obtained by searching for the keyword "Blockchain AND Seaport", because seaports are in themselves a narrow topic.

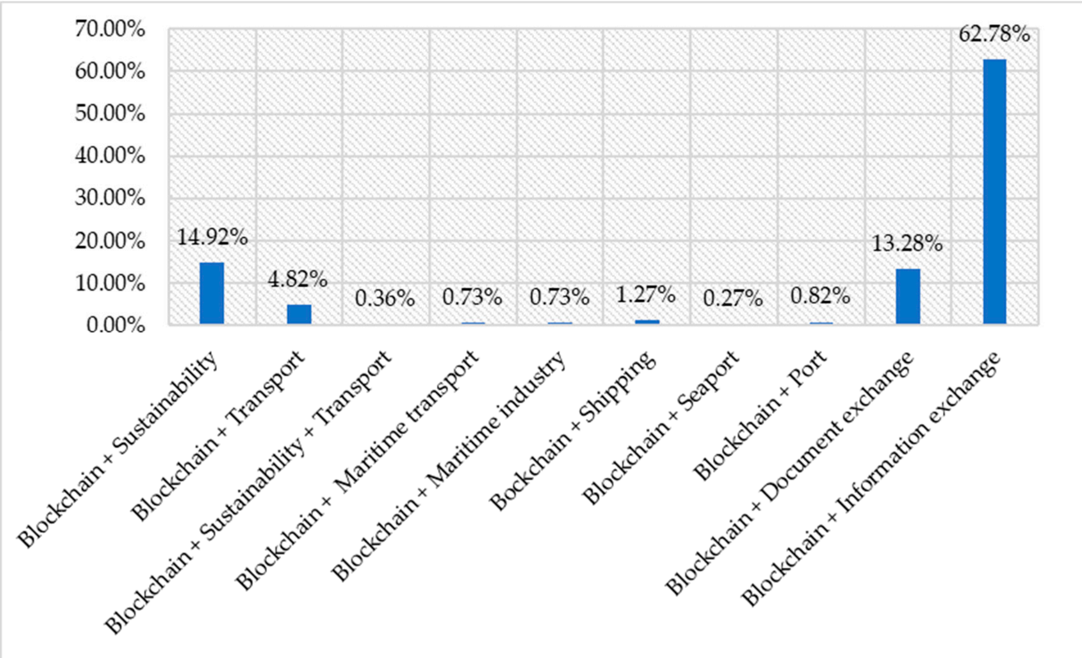

Figure 2. Keyword search distribution in %

In the Web of Science database, the following limitations were used: 2015–2020, TOPIC or TITLE. In the SCOPUS database, the limitations used were: Article title, Abstract, Keywords, 2015–2020, Document type: all. Furthermore, backward snowball sampling was utilized to extend the set of relevant primary studies [35]. According to [36], relevant papers should be defined as those that can contribute to new insights into the similarities, differences, or types of relationships between the concepts studied. If a new paper is included in the sample, its references should also be examined for new data, and these repetitions should continue until a new and/or significant insight relevant to the research is found. Eight papers have been identified though backward snowball sampling. After identifying the positive impacts of blockchain-based information exchange and challenges and barriers to successful blockchain-based information exchange, the importance of blockchain-based information exchange in the maritime transport and seaports is demonstrated through the analysis of several cases such as Port of Koper, CMA CGM, Maersk and IBM, Port of Rotterdam, Port of Veracruz, Mexico, and The Nautical Institute in partnership with Navozyme.

4. Results and Analysis

4.1. Positive Impacts of Blockchain-based Information Exchange

In this chapter, the positive impacts of blockchain-based information exchange in the maritime transport sector, divided by all three aspects of sustainability, have been analyzed and presented in Table 2. In total, 78 sources have been used in this process.

Table 2. The positive impacts of blockchain-based information exchange in the maritime transport sector.

Aspects of Sustainability	Positive Impacts	Sources
Economic	**Cost reduction** = Reduced global shipping costs, improved supply chain visibility, and eliminated inefficiencies resulting from paper-based processes; Reduced transaction and administrative costs; Reduced governance cost and the optimization of governance structure; Reduced cost of maintaining records and transportation costs; Lower costs due to the elimination of intermediaries, lower transaction costs, less paperwork, etc.; Reduced costs of trade information (the costs of coordinating trusted information on the characteristics of goods for consumers, producers, and governments); Reduced cost for clearance and movement of the cargo; Reduced issuance costs	[1,3–5,7,8,22,26,33,37–52]
Economic	**Improving transparency and visibility and real time information** = Real time data provided from the blockchain network; More efficient cooperation within the transport sector	[1,3,6,7,22,26,27,37–39,41,42,44–47,49,51–60]
Economic	**High data availability on the network** = High data availability even after the node crash or quitting, transactions can be performed at any time	[1,44,47,49,51]
Environmental	**Reduced need for paper documentation** = Automated paperwork (bill of lading, customs declaration, etc.) and secure sending and signing of contracts	[1,6,8,37–39,42,44,47,51,52,54,55,57]
Social and Environmental	**Smoother information exchange, a peer-to-peer network** = Improved transparency and data sharing; Resilient and truly distributed peer-to-peer systems, trustful and auditable peer interaction; Reduced need of transmitting electricity over long distances, creating significant savings	[1,3,7,37,44,49,51,52,55,58,61–63]
Social	**Data and Information Immutability** = Immutability—records cannot be modified without network members' consensus; record history is unchanged and reliable	[1,6,22,26,51,57,58,60,63]
Social	**Establishing trust** = Assessing logistics company's performance based on previous performance, timely pickups and deliveries; Affective trust for authentication, access to resources, delegation, provision, and infrastructure	[1,3,6–8,22,27,37–39,42–46,49,53,54,56–59,61,64,65]
Social	**Improving the security and privacy in distributed networks** = Improved security of privacy-sensitive data; Secure data processing and storage; Theft prevention—pick up only after the digital approval from other parties and the system; Blocking of counterfeit certificates, enabling the management of certificates in a secure and transparent manner	[1,6–8,24,26,33,37–39,42–44,46–49,51,54–59,63–67]
Economic, social and Environmental	**Enhancing collaboration and cooperation** = Reduced overall costs and improved profitability; Reduced energy consumption and carbon emissions	[6,8,16,22,27,37–39,42,45–47,49,51,53,58]
Social	**Facilitated determination and setting of rules and governance norms at the transport, logistics, and supply chain levels** = Improved visibility—facilitates government oversight of the transport and logistics industry	[39,42,53,61]
Economic, Social and Environmental	**Ability to trace and track goods or transactions** = Improved temporal and spatial visibility of the flow of goods; Improved cargo tracking and recording vessel information, smart contract and maritime insurance policies usage, etc.; Reliable and consistent information regarding the logistics process of the goods; Recording each step during transactions	[1,3,5,6,16,22,26,38,39,41–44,46,47,49,51–55,57,58,60,61,63–66]
Economic	**Possibility of integration with the disruptive technologies (Internet of Things, Big Data)** = Improving the sustainable operations of logistics	[5–7,22,26,38,39,43,44,47,48,52,53,55,62,64–66]
Economic, Social and Environmental	**Reducing human errors and eliminating the possibility of providing inaccurate or incomplete information; reducing the rework and recall, the possibility of losing documents; enhanced job performance** = Reduced resource consumption and GHG emissions; Reduced task completion time, simplification, enhanced job performance; Reduced transport costs by error elimination	[3,7,8,38,42,44,49,51,52,54]

Table 2. *Cont.*

Economic	**Possibility of increasing the trade contract efficiency and harmonizing conflicting objectives** = Efficient monitoring and execution and increased effectiveness of a trade contract; Harmonization of conflicting stakeholder interests	[4,51,68]
Economic, Environmental and Social	**Reduced transaction delays** = Reduced delays and improved transparency by reducing errors and malpractice; Saved time because of the elimination of sending physical documents; Accelerated pick-up process of the freight forwarder due to reliable and secure flow of information between the consigner bank and the seaport network; Reduced execution time (smart contracts can enforce a set of rules that everyone involved in the process agrees with)	[1,3,6,7,33,42,44,47,50–52, 54,55]
Social	**Automated compliance to freight and trade regulations and standards** = The development of high-quality policy settings by crypto-friendly countries in order to encourage policy learning, the emulation of similar policies by other legislatives in the region, spread of relatively consistent blockchain policy responses; The development of upper-level policy forums or governance bodies in order to create open standards	[3,5]
Economic and Environmental	**Improved decision making** = Equal access for all involved parties to the transaction-related information; Possibility to choose more efficient modes of transport, affecting the environmental aspect of sustainability	[45,51,54]
Social	**Ensuring human rights and fair working practices** = The capability of smart contracts to independently monitor and control sustainable conditions and regulatory policies; Implementation or management of appropriate corrective activities	[7]
Environmental	**The basis for supply chain mapping and the application of low carbon transportation** = Reduced carbon emissions in the product transport chain by providing the basis for supply chain mapping and the application of low-carbon transportation	[7]
Environmental	**Reduction of energy and fuel consumption, pollution, and environmental degradation** = Energy saving due to faster tracking and less paperwork; Improved monitoring and storage of activities related to data responsible for environmental pollution and degradation; Real time collection and analysis of low-carbon data for quicker decision-making; Considerable reduction of fossil fuel usage and emissions	[1,44,45,49,50]

According to [53], trust can be improved by increasing traceability and transparency, for example by increasing operational efficiency, improving sustainability performance, meeting stakeholder needs, reducing illicit practices, and enhancing the information flow and stakeholder collaboration.

One of the benefits of the blockchain is the reduced need for documentation. According to [42], "for international shipments, companies and customs officers are compelled to fill out over 20 different kinds of paper documents to have the goods transported from the exporter to the importer and vice versa. Most of these documents do not provide visibility in real time and data quality, which often leads to obstacles in financial reconciliation". Paperless trade presents a number of potential benefits, including reduced shipping and communication costs, lower paper handling costs, reduced errors and faster receipts, reduced trade financing costs, and reduced inventory [5].

The blockchain technology can potentially solve the following problems: interruptions in cargo monitoring (as the maritime transport involves numerous stakeholders) and the lack of data transparency (due to poor data handling) [37]. Apart from the economic benefits, according to [39], real-time optimization of the vehicle routes is also possible, which positively affects both the congestion and the carbon emissions, improving the ecological aspect of sustainability. Furthermore, all shipment requirements and specifications are recorded in the blockchain, and users can retrieve them and set optimization targets [39], affecting the economic and ecological aspects of sustainability.

According to [54], all shipments can be tracked in real time, from the origin to the delivery. The paper documents are being replaced by smart contracts and unnecessary parties are being removed from the transport process, making the global logistics sector less centralized [54]. According to [42], by tracking the cargo (shipment) in real time using blockchain technology, the shipping companies and ports can plan ahead for the land manipulation, thus expediting the terminal operation and reducing the costs.

According to [47], enabled by the automation of smart contracts in the online market, shipowners can transparently present their services and availability periods to charterers. The charterers can similarly indicate their service demand. All this can be achieved without the necessity of an interposed shipbroker.

Du et al. [10] have researched the berth allocation problem by modelling the impacts of tides on the entrance/exit of vessels into/from ports and by borrowing the so-called virtual arrival policy. The blockchain can solve a part of the problem by consequently affecting the reduction of bunker fuel consumption and vessel emissions. Nguyen et al. [67] have investigated the potential operational risks of the blockchain-integrated container shipping systems, but have also identified a potential of the blockchain technology adoption in strengthening security and improving efficiency in container shipping operations. The focus of the Venturini et al. [69] has been the optimization of assigning the berthing times and positions to the vessels in container terminals. By implementing the blockchain, the collaboration between port terminals and the shipping liners can be improved (leading to the reduced costs, affecting the economic aspect of sustainability), and operations and sailing times can be optimized (leading to reduced bunker consumption, fuel cost, and air emissions, affecting the environmental aspect of sustainability). Zhang et al. [70] have researched the cold chain shipping mode choice problem. The blockchain could simplify the maritime cold chain mode choice, the shipment scheduling, and the ship deployment problem by utilizing speed optimization for time sensitive products.

The maritime transport sector and the seaports involve numerous stakeholders and documents. One of these documents is the bill of lading. The bill of lading is one of the most significant and valuable documents in the shipping industry, acknowledging that the cargo has been shipped and can contain details such as the quantity, descriptions, weight, loading, and discharge port of the cargo and shipping marks [1]. According to the information by DHL, up to 10 percent of bills of lading contain incorrect data that could lead to disputes and litigation [71,72]. The blockchain technology may have an important role in mitigating the mentioned issues. Regardless of that, the blockchain could largely affect the port digitalization [37]. This will be particularly evident in the development of smart contracts with the further implementation of the blockchain [38].

According to [55], integrating the blockchain into maritime transport can increase sustainability, reduce fraudulent activities, reduce delays and waste caused by paperwork, and identify problems more quickly. Furthermore, this might increase global GDP by almost 5% and global trade volumes by 15%. According to the IDC Group report on digital transformation for 2021, blockchain-enabled in-industry value chains will have extended their digital platforms to their entire ecosystems, therefore reducing transaction costs by 35% [73]. It is hard to predict the container freight rates, but it is possible to expect that a company that starts using the digital bill of lading will reduce their costs by up to USD 30, and compared to other companies will achieve larger market share and will earn more profits [1].

Although the Port of Koper is not as developed as the Port of Rotterdam, it presents a good example of a port in development that has recognized the importance of digital transformation in order to achieve competitiveness. The first step was the implementation of blockchain technology. In August 2018, the first processed container was released in the mentioned port using the blockchain-based CargoX's "Smart Bill of Lading". CargoX is an independent supplier of documentation transaction systems that provide a fast, secure, reliable, and cost-efficient way of processing shipping documents globally [74]. The bill of lading for this shipment was electronically issued and transferred using an extremely secure and reliable public blockchain network in minutes instead of days or more, and the chances of theft, damage or loss of the Bill of Lading were reduced to almost zero [75]. India's Ministry of Shipping has given the green light to launch test the shipments with bills of lading, submitted on CargoX's technology via the country's Port Community System [76]. According to Alejandro Gutierre, founder of Forward Together (a logistics network), the ability to conduct shipment transactions and ownership transfers without the need for physical interaction creates a breakthrough case for logistics and freight forwarding, especially when health measures are of importance [77]. CMA CGM have recognized the importance of blockchain technology as well in order to offer a paperless and secure bill of lading [78].

Stakeholder collaboration plays a very important role in achieving sustainable business [79]. The following case demonstrates the importance of the blockchain (an enabler of digital transformation [80]) and the importance of collaboration. Maersk and IBM jointly developed a blockchain solution in order to digitalize global trade, calling it TradeLens. According to IBM, a joint blockchain initiative could significantly reduce the cost and complexity of trading [81]. CMA CGM and Mediterranean Shipping Company S.A. have recognized the importance of blockchain and joined TradeLens. According to [82], TradeLens enables the connecting of participants, information exchange and collaboration in the shipping supply chain. Members gain a comprehensive insight into their data and can collaborate digitally as the cargo moves globally, helping to create a secure, transparent, and unchanging transaction record. According to [27], Maersk managed to save billions of dollars after joining with IBM to manage the maritime containers via the blockchain.

The Port of Rotterdam is involved in several blockchain projects, for example the IBM and Maersk TradeLens [83]. Furthermore, the Port of Rotterdam presented a new pilot project based on the blockchain to handle the containers more safely and efficiently by eliminating the use of a pin code [84]. Blockchain technology applied to port management will make it possible to store and share the information on ship loads and improve financial operations and contracts, among many other possibilities [85]. The possible positive impact of the blockchain is visible in the Blockchain Port Community System. The port of Veracruz, Mexico, has contracted a blockchain logistics company dexFreight to develop a proof-of-concept project for a blockchain Port Community System [86]. The goal is to improve the efficiency of the freight and logistics at the port as well as the optimizing and streamlining the carrier onboarding processes.

Another case is blockchain-powered Cargo Community System in the Port of Marseille Fos. Data in the Cargo Community System is collected from a variety of sources, for example the freight forwarders, shippers, customs, port agents, and road transporters [87]. The aim is to streamline and accelerate the exchange of cargo data between all the involved stakeholders (public and private) [88]. According to [47], the implementation of the blockchain and smart contract solutions breaks down the central control and information system architecture, and by doing so, in the frame of port logistics processes, fosters existing as well as novel entrepreneurial collaborations of different actors in the comprehensive port environment and along the supply chain. This is especially interesting and beneficial for SMEs due to the low participation costs.

According to [89], digital transformation may represent a challenge for a company, but integrating IoT with blockchain eases it due to the nature of digital emergence. This cohesion increases business efficiency and productivity, providing the collaboration and secure communication between the stakeholders. For example, Maersk has invested in the Internet of Things and the blockchain to improve the security, transparency, and cost-effectiveness of its maritime cargo. It is estimated that the blockchain will save billions of dollars for the shipping industry through more precise container tracking and automation of the shipping transactions [90]. However, blockchain technology's shortcomings are the general lack of standards and the knowledge gap. For this reason, blockchain technology has been slow to catch on in the enterprises [91]. Blockchain technology is considered potentially disruptive for transport systems according to the Catapult Transport Systems report. In parallel, numerous experts participating in a survey on blockchain trends do not appear to be well informed about this emerging technology [92].

According to [47], the implementation of IoT sensors with a direct linkage to the blockchain could provide the distributed and decentralized network with real-time data at all times about the cargo condition and location. The Nautical Institute in partnership with Navozyme has developed a maritime industry specific educational program titled "Blockchain for Maritime Decisionmakers" (BMD) for the IMO Member States and international organizations [93,94]. The BMD Program's objective is to raise awareness of maritime leaders about digital transformation issues and specifically about the applications of blockchain technology for the maritime industry. The BMD Program's larger goal is to equip the global community of maritime changemakers with the knowledge, confidence, skills, and mindsets that can act as a catalyst to transform and futureproof the maritime industry [93].

One of the benefits of blockchain technology is the improved security. The sophisticated data encryption greatly reduces the risk of cyber-crime and dishonest and disloyal competition, whereby a fairer deal is secured for all parties involved, [42], affecting the social aspect of sustainability. Blockchain provides some preventive mechanisms to mitigate cyber-attack threats (e.g., cryptography and distributed consensus) [38].

4.2. Challenges and Barriers to Successful Blockchain-based Information Exchange

According to [7], the effective implementation of blockchain to trace sustainable practices starts with defining the barriers and challenges that need to be managed. In this respect, the authors have analyzed and identified the challenges and barriers to successful blockchain-based information exchange in Table 3. All stakeholders should understand and prepare for these challenges in order to successfully adopt and implement the blockchain.

Table 3. Challenges and barriers to successful blockchain-based information exchange.

Challenges and Barriers	Sources
Data storage and transmission = Each blockchain network node requires significant storage capacity, because the data is stored multiple times in each node, resulting in the waste of storage entry; Not suitable for storing large quantities of data, although there are various ways to bypass it	[27,39,58]
Development and implementation cost and risk = Increased device costs, costs of training, operation costs, and maintenance costs; The companies' operations are vulnerable to disruption when technical problems appear; The necessity for updates on materials, facilities, and machines in order to reduce GHG emissions, energy consumption, water pollution, carbon footprints, and waste; Risks: the lack of legal frameworks, possible cyberattacks, etc.	[3,7,27,37,39,67]
Issues regarding performance and scalability = All nodes within the chain must process all transactions—an issue when it comes to large (and particularly global scale) roll-outs; Performance issues: system flexibility, throughput performance, and low interoperability	[3,7,37,38,41,58,67]
Lack of data protection = No protection against intentionally manipulated input data, even stemming from sensors or RFID tags	[3]
No central authority = No central authority to notify in case of an apparent breach of security; Supply chain stakeholders are used to the trust mechanism that is supported by some form of a centralized authority; Lower confidence about the effectiveness of a thrustless distributed paradigm	[37,38,58]
Lack of consensus and standards = Present in a range of issues ranging from building immutability through proof-of-work activities to industrial use case adoption; The lack of standard tools, indicators, and methods, etc., presents an obstacle to the successful implementation of sustainability practices in a blockchain environment; The creation of data structure standards is needed for efficient communication between different blockchains	[5,7,37,38,45,46,53,55,59]
Lack of solid rules for information sharing or for lost and stolen data = The lack of rules related to the exchange of information or to lost and stolen data ultimately affects the cooperation between partners	[7,51,67]

Table 3. *Cont.*

The absence of regulation leads to insecurity = Some aspects of smart contract technology may be adopted by the logistics industry, just to be overregulated, or even considered illegal	[27,38,51,55,59,67]
Lack of government and industrial policies and willingness to guide and encourage sustainable and safe practices = Unclear government laws and regulations regarding the use of blockchain	[7]
Stakeholders' hesitation and resistance to change = Changes in organizational hierarchy or culture caused by the transition to new systems; Stakeholders' hesitation and resistance; Scepticism towards the transparency of blockchain	[7,22,27,59]
Energy intensiveness = The consumption of energy required for key algorithms, computations and processing; Significant processing power consumed by proof calculations	[37,38,45,48,55,57,58,65]
Reduced privacy, unwillingness to share information = Central authority does not exist; Strong interest to keep transaction data private, even forfeiting smaller efficiency gains; Information may be assumed as a competitive advantage by some organizations	[3,7,27,37–39,41,45,53,58,59,65]
Immaturity = Immaturity and high technological uncertainty of blockchain technology	[3,7,37,38]
Data quality = Dependence on the input data quality	[3]
Network effect = Only creates value for participants given sufficient diffusion of the technology	[3]
Lack of management commitment = Absence of management commitment hinders the integrity of business sustainability practices and poses a challenge to resource allocation and business decisions	[7,27]
Lack of the required new organizational policies = Lack of new organizational policies needed to clarify the use of blockchain technology	[7]
The policy barriers of blockchain adoption = Dependence on the nature of trade, which is inherently inter-jurisdictional; The existence of a range of regulatory environments, in accordance with various rules	[5]
Inadequate knowledge and technical expertise regarding the blockchain technology usage = The limited number of blockchain applications and developers	[7]
Challenge of connecting the physical and the digital = Large investments needed to connect physical and non-digitized elements to the digital space using various communication technologies (NFC, RFID, IoT, etc.)	[22]

One of the identified challenges and barriers is the lack of consensus and standards. According to [53], many standards are at an early stage of development, limiting the structured governance. The standards are currently being generated by institutions such as the Blockchain in Transport Alliance, a trucking industry consortium [31]. The blockchain in Transport Alliance was founded to drive the adoption of the blockchain technology in the transport industry [95]. Furthermore, the lack of regulation results in insecurity, as the logistics market could adopt some segments of smart contract technology, just to be over-regulated or even considered illegal [96]. According to [5], the development of blockchain standards can result in two broad approaches: standards that are open or closed. The closed standards run the risk of being defined and developed by an "early" dominant player. If several small parties will control the development of standards, this can ultimately limit the entrepreneurial contestability of constructing this economic infrastructure [5]. A solution may be the creation of open standards that allow the entrepreneurs to adapt the rules within which the blockchain solutions can be applied and to allow the later solution interoperability [5].

Distributed trust as well as security and privacy are at the center of blockchain technologies, and can make them successful or cause failure [97]. According to [8], the use of the blockchain in the shipping industry and environmental protection is a positive step, but all stakeholders, particularly the shipping companies, should recognize the advantages of blockchain technology. The advantages of the blockchain can change the entire shipping industry and the trading processes, but the risks related to the blockchain should be properly mitigated [37].

5. Discussion and Conclusions

Although the blockchain has been one of the most discussed topics in the recent years, there is still a lack of research regarding the blockchain-based information exchange in the maritime transport sector. The authors have first analysed the positive impacts of the blockchain-based information exchange in the maritime transport sector, including all three aspects of sustainability. Although attention is often being paid to the economic or environmental aspects of sustainability in the maritime transport sector, research has proved the importance of the blockchain-based information exchange on the social aspect of sustainability as well. The social aspect is usually related to the trust among stakeholders and data security, the reduction of human errors, the reduction of rework and recall, and enhanced job performance. All three aspects of sustainability are closely related, which can be proved by the following example. Although loading and unloading are among the main activities in seaports, unnecessary waiting for cargo due to the inefficient and outdated document exchange causes environmental issues, such as the increased CO_2 emissions. The paper documents exchanged between the seaport stakeholders slow down the business processes (e.g., due to human errors) and create higher costs, affecting both the economic and social aspects of sustainability.

Despite the many positive effects of the blockchain on maritime transport, the maritime industry is considered to be the least technologically advanced, compared to the other industries. One reason is the resistance of stakeholders to change, who continue to use traditional ways of exchanging documents, despite the inefficiency. Additionally, shipping is very diverse and not as uniform as other sectors of the transport industry, and each company in the market searching for its own solution is failing to drive new synergies across the supply chain [98,99].

Although the authors of this paper have singled out 20 positive impacts of blockchain-based information exchange, they have also singled out 20 challenges and barriers to successful blockchain-based information exchange, which proves that the blockchain technology can further be improved. One of the barriers is the lack of consensus and standards, since the stakeholders can still implement their own blockchain solutions and platforms, which can ultimately lead to interoperability issues. One of the barriers related to the environmental aspect of sustainability is the large energy consumption required for processing, key algorithms and computations within the blockchain. One of the challenges is the resistance and the hesitation of individuals and organizations; however, the only way to successfully implement blockchain technology is to engage the stakeholders and build trust among them. The blockchain can enable collaboration among stakeholders, consequently reducing the energy consumption and the carbon emissions, and increasing profitability, affecting all the aspects of sustainability. Some of the players in the maritime industry, such as Maersk and IBM, have recognized the importance of the blockchain and have begun to develop alliances in order to utilize the advantages of blockchain technology. Despite the slow acceptance of blockchain technology in the maritime transport, it should eventually streamline and accelerate the information exchange between the involved stakeholders, positively affecting all three aspects of sustainability.

Although the studies such as [51,52] analyse the blockchain applications in the shipping industry extensively, the goal of this paper was to provide a deeper insight of the challenges and barriers as well (by using the same methodology as for identifying the positive impacts in order to simplify the comparison between positive impacts and challenges and barriers). From this work, it is possible to clearly see that the numerous challenges and barriers exist, despite all the benefits that the blockchain-based information exchange provides. The rapid changes in blockchain technology continuously raise new challenges. This paper (when compared to previous research) focuses on sustainability, providing a clear insight into the impact of the blockchain-based information exchange from the economic, environmental, and social aspects of sustainability. This research is based on the literature review (which also presents the main limitation of the research), and as such offers an initial overview of the importance of the positive impacts, challenges and barriers of the blockchain-based information exchange. As the lack of studies that offer a comprehensive overview of the blockchain in the maritime transport sector is particularly pronounced, it is necessary to analyse this topic further. Future research will be focused towards investigating the specific nature of maritime transport in relation to the other industries in terms of acceptance of disruptive technologies such as the blockchain, and the role of government authorities in terms of the acceptance and use of the blockchain in the maritime transport sector, since the rapid technological change poses new challenges for the government authorities.

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