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Blockchain adoption in the port industry: a systematic literature review

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ABSTRACT

The global port industry, known for its historical resistance to technological advancements, now faces a pivotal moment in the age of blockchain innovation. This systematic literature review provides an in-depth investigation into the adoption of blockchain technology within the port industry, aiming to assess the current state of knowledge, identify areas lacking research attention, and emphasize emerging research avenues by analyzing a corpus of 316 articles. Our review employs a robust framework centered around four key themes: barriers to adoption, the port's role in global value chains, sustainability considerations, and practical implementations of blockchain technology in ports. By analyzing these themes, we can gain valuable insights into the distinctive nature of the port industry and its potential transformation through blockchain technology. Theoretical contributions from this review emphasize adopting a Practice-Based View (PBV) perspective to examine the intricate interplay between barriers and practices in blockchain adoption. Furthermore, our innovative synthesis of the Technology Acceptance Model (TAM) and the Technology-Organization-Environment (TOE) framework sheds light on internal and external obstacles shaping the adoption landscape. A noteworthy aspect of this review is the recognition of the critical need to align theoretical frameworks with the unique characteristics of the port industry, emphasizing the importance of contextual relevance in research pursuits. It also highlights the scarcity and fragmentation of research in the domain of the port industry, encouraging future scholars to investigate the identified research gaps and theoretical perspectives. This article reveals that utilizing blockchain technology within ports can enhance the sustainability performance of the port industry.

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Operations Management; Supply Chain Management; Production, Operations & Information Management

1. Introduction

Over recent years, the global maritime sector has experienced a profound metamorphosis driven by technological progress and an escalating imperative for sustainable and efficient practices (Balci & Surucu-Balci, 2021). Given ports' pivotal role in facilitating international trade and commerce, their adaptability and performance in light of emerging technologies have taken on paramount significance. Blockchain technology has emerged as a focal point of attention among these technological innovations. Integrating blockchain into port operations can revolutionize conventional processes, augment transparency, and substantially contribute to achieving sustainable performance objectives (Wang et al., 2021).

Ports have functioned as pivotal hubs in the maritime domain, enabling the movement of goods, catalyzing economic expansion, and fostering international connectivity (Denktas-Sakar & Karatas-Cetin, 2012). Ports play a crucial economic role in offshore areas, functioning as gateways facilitating global trade by connecting sea and land transportation (Denktas-Sakar & Karatas-Cetin, 2012). Nevertheless, traditional port operations are often plagued by inefficiencies, opacity, and environmental apprehensions,

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impeding endeavors toward sustainable progress (Jiang et al., 2021). Inadequacies in cargo handling, delays in paperwork processing, and limited coordination among stakeholders disrupt the seamless flow of goods and the attainment of performance targets, such as reduced turnaround times and minimized ecological impact (Alamoush et al., 2022).

This literature review presents a comprehensive theoretical exploration of blockchain's applications in the port industry using a systematic literature review approach. Prior studies, like the one conducted by Javaid, have frequently emphasized the significance of blockchain technology within the broader maritime sector but have often overlooked the distinctive technological requirements specific to the port industry in the context of Industry 4.0 (Javaid et al., 2021). This paper examines past literature to distinguish between ports and other sectors. Additionally, it provides a holistic perspective on both the impediments hindering the adoption of blockchain in ports and strategies to surmount these challenges, complementing the previous studies (Balci, 2021; Balci & Surucu-Balci, 2021; Kouhizadeh et al., 2021). The advent of blockchain technology promises transformative impacts on the maritime shipping industry, heralding a new era of enhanced security, transparency, and efficiency across global supply chains (Guan et al., 2023; Jović et al., 2020). Recent studies highlight blockchain's potential to streamline operations, mitigate fraud, and foster stakeholder trust, albeit noting the nascent stage of its integration within maritime logistics (Badawy et al., 2022; Basheer et al., 2024; Rijanto, 2024). Concerns surrounding the technology's scalability, energy consumption, and compatibility with existing infrastructures pose significant challenges to its widespread adoption (Rijanto, 2024). The exploration of smart contracts within this domain suggests a paradigm shift in transactional processes yet raises questions about legal enforceability and the requisite standardization of contractual. As the maritime industry navigates these complexities, ongoing research and collaborative initiatives remain critical to unlocking the full potential of blockchain technology in reshaping maritime logistics (Guan et al., 2023).

Although the potential merits of blockchain in port operations are widely acknowledged, a comprehensive understanding of its integration and its effects on sustainable performance targets still needs to be explored. Prior research has touched upon various dimensions of blockchain's applicability in ports. Nevertheless, a methodical and holistic synthesis of the existing knowledge is imperative to offer insights into the current understanding, pinpoint gaps, and chart a course for future research (Saberi et al., 2018). This systematic literature review endeavors to bridge this gap by systematically dissecting and synthesizing the prevailing body of literature regarding the assimilation of blockchain technology in port operations and its implications for realizing sustainable performance goals.

The primary aim of this research is to extensively investigate the integration of blockchain technology into port operations and assess its potential to enhance sustainability efforts. The study outlines specific objectives to achieve this. First, the existing literature regarding the utilization of blockchain in ports must be thoroughly examined. Second, to identify critical obstacles, opportunities, and gaps in knowledge within the current landscape. Last, to offer recommendations for guiding future research directions and practical implementations. Three central questions are posed to facilitate this systematic literature review:

1. How does adopting new technology in ports differ from other industries?
2. What hindrances and practices accompany blockchain implementation within port ecosystems?
3. Which theoretical framework can provide the basis for comprehending these obstacles and mitigating strategies?

One of the significant theoretical contributions of our paper is to reveal that the PBV is the most adequate theory for enhancing our understanding of obstacles and facilitating the adoption of practices in the context of blockchain applications. Moreover, we find that combining TAM and TOE offers a more comprehensive explanation for the barriers encountered in blockchain applications.

We employ a comprehensive methodology to ensure a systematic and rigorous approach to this literature review. Thorough searches were conducted across academic databases and research journals. The structure of this literature review is designed to offer a cohesive and systematic examination of the current state of blockchain adoption within the port industry. Section 2 provides a theoretical exposition of blockchain technology, elucidating its foundational principles and exploring its potential applications

in port operations. Section 3 outlines the methodology and data collection approach used in this review. In Section 4, we analyze the existing literature. Finally, in Section 5, we discuss the insights derived from our analysis. Section 6 concludes by summarizing key findings and deliberating on potential future trends and opportunities for blockchain within the port industry.

2. Theoretical background

2.1. What is blockchain?

Blockchain is a groundbreaking technology that combines distributed data storage, peer-to-peer communication, consensus mechanisms, and cryptography. Its roots can be traced back to the publication of the Bitcoin white paper in 2008 by the pseudonymous Satoshi Nakamoto (Lohmer & Lasch, 2020). In its simplest form, blockchain is a secure and unchangeable sequential data structure maintained through cryptographic methods. However, it represents more than just data; it is a novel distributed infrastructure and computing paradigm. Utilizing blockchain-like structures, consensus algorithms, and smart contracts (Yadav et al., 2020), it is a distributed ledger technology fostering trust in multi-party collaborations. This ingenious design addresses challenges in business development, fuels innovation, and optimizes economic structures (Saberi et al., 2018; Zeadally & Abdo, 2019). Blockchain technology is increasingly finding applications in Industry 4.0 by revolutionizing supply chain management, enhancing product traceability, ensuring data security, automating processes through smart contracts, protecting intellectual property, and optimizing energy management, among other critical functions (Javaid et al., 2021). While blockchain offers significant advantages in Industry 4.0, it is essential to note that its adoption also poses challenges (Nuttah et al., 2023).

Blockchains come in three main categories based on their openness. Public blockchains, like Bitcoin, are open to anyone and offer high decentralization but lower transaction speed (Malik et al., 2023). Consortium blockchains are restricted to consortium members, balancing efficiency and privacy with mechanisms like Delegated Proof of Stake (Tan et al., 2022). Private blockchains are limited to internal individuals or entities, offering high efficiency but lower decentralization and privacy. Each category has advantages and applications, with consortium blockchains often preferred in scenarios requiring a balance between production efficiency and information confidentiality, such as container transportation and documentation chains (Nguyen et al., 2020).

The evolution of blockchain can be segmented into three stages (Malik et al., 2023). In Blockchain 1.0, the primary focus was on digital currency exchange and payment, with Bitcoin as the pioneering example. Blockchain 2.0 witnessed the application of blockchain technology to financial products like stocks and bonds, with Ethereum being prominent due to its introduction of smart contracts (Ellahi et al., 2023). In Blockchain 3.0, the technology expanded into various sectors, including government, logistics, healthcare, and beyond, adapting to different use cases. This evolution reflects blockchain's journey from its origins in cryptocurrency to a versatile technology with transformative potential across diverse industries (Bajwa et al., 2020).

2.2. Blockchain in the port industry

Initially introduced through Bitcoin, blockchain technology is the cornerstone for various applications across various sectors. In cryptocurrency, it underpins decentralized networks like Bitcoin, facilitating peer-to-peer transactions through transparent validation by miners and ensuring data integrity on a public ledger (Denktas-Sakar & Karatas-Cetin, 2012). Figure 2 shows that the electronic bill of lading (e-B/L) platform leverages blockchain to automate the issuance, circulation, and tracking of shipped goods. Shippers submit cargo details to carriers through the platform, with data secured and time-sequenced. Approved consignments are processed and issued as electronic bills, which are then submitted to government bodies for pre-customs checks. Upon approval, various private keys are generated, allowing control over cargo and facilitating transactions like financial settlements. Changes in consignee and cargo

control are managed through the platform, ensuring secure, transparent, and efficient handling of shipments from start to finish.

A bill of lading (B/L or BL) is essential in shipping and freight forwarding, serving as evidence of a transport contract, a goods receipt, and a title document (Ding, 2019; Gao et al., 2022; Surucu-Balci et al., 2024). Traditional paper bills are vulnerable to preservation issues, forgery, and inefficiencies, often leading to high costs and delays in cargo retrieval due to slow mail circulation (Balci & Surucu-Balci, 2021; de Langen, 2006; Farzadmehr et al., 2023). In contrast, blockchain-based electronic bills of lading enhance security and efficiency with features like Public Key Infrastructure (PKI) for secure, instantaneous transfers, decentralized and tamper-proof storage, and transparency regarding document holders. These features streamline transactions across the logistics chain, supporting stakeholders like financial institutions and carriers and integrating commerce, information, finance, and document flows (Acciaro et al., 2014; Balci & Surucu-Balci, 2021; Surucu-Balci et al., 2024). In the port industry, warehouse receipt pledging has become essential in port and logistics finance, with ports using receipts as collateral for bank loans, enhanced by blockchain technology. Additionally, blockchain enhances data integrity across distributed networks for systems like container weight Verified Gross Mass (VGM) data collection, managing data in layers with security features such as encryption and smart contracts for automated, secure data transfers (Guan et al., 2023; Halse & Jæger, 2019; Kouhizadeh et al., 2021; Liu et al., 2021).

3. Methodology

A systematic literature review (SLR) is crucial for comprehensively gathering and rigorously analyzing existing research on a topic, reducing bias, and providing a reliable foundation for evidence-based decision-making across disciplines (Rejeb et al., 2023). These reviews identify gaps in current knowledge, synthesize findings, assess study quality, and often include meta-analysis, contributing to more robust and precise conclusions (Feliciano-Cestero et al., 2023). By following established methodologies and publication standards, systematic reviews enhance transparency and facilitate knowledge synthesis, making them invaluable tools for researchers, policymakers, practitioners, and anyone seeking a thorough and credible understanding of a particular subject area (Haq et al., 2021).

The results of an SLR can offer valuable contributions to academia and industry practitioners. For researchers, it provides a consolidated summary of existing knowledge, highlighting areas where additional research is needed and potential avenues for innovation (Feliciano-Cestero et al., 2023). Industry stakeholders, such as port authorities and logistics companies, can benefit from the insights and recommendations derived from the SLR, which can inform their strategic decisions regarding blockchain adoption, resource allocation, and technology implementation (Liu et al., 2023). Thus, a well-executed systematic literature review becomes valuable for advancing our understanding of blockchain adoption in the port industry and facilitating its successful integration into this complex ecosystem (Khan et al., 2023).

To commence our comprehensive review, we cast a broad temporal scope from 2017 to 2024, intentionally refraining from imposing any restrictions on the publication dates of the papers we sought to examine. In navigating this extensive realm of knowledge, we devised specific parameters tailored to the Web of Science database Figure 1, encompassing the 'TOPIC' and 'TITLE' fields. Concurrently, while conducting our inquiries within the Web of Science, Scopus, Science Direct, and other relevant databases, we confined our search to the domains of 'Article title', 'Abstract', and 'Keywords'. Our exploration extended to embrace all document types available within these databases. The keywords guiding our investigation encompassed 'Blockchain AND Seaport', 'Blockchain AND Maritime', 'Blockchain AND Barriers', 'Blockchain AND Enabler', and 'Blockchain AND Practice/Activities'. In this literature review, it is essential to recognize the inherent limitations and biases in the selected studies to ensure a comprehensive understanding of the research context. These include a constrained scope of literature, which may not capture the full spectrum of knowledge; a tendency towards publication bias, which overrepresents studies with positive outcomes; and methodological limitations within the studies themselves, which can affect their generalizability. Additionally, selection biases in literature curation and interpretation biases stemming from researchers' perspectives can skew the review's findings. Cultural and socio-economic factors further

complicate the applicability of results across different contexts. By transparently addressing these constraints, this review aims to provide a balanced and critical examination of the existing literature, acknowledging the complexities that underpin the research landscape and paving the way for future inquiries.

In Figure 2, our initial sweep yielded 1275 publications covering various aspects of blockchain, sourced from Web of Science, Scopus, Science Direct, and other relevant databases. This figure shows the yearly trend in publications from 2017 to 2024. The number of publications has steadily increased from 7 in 2017 to a peak of 328 in 2023, indicating a growing interest or research focus in the field. We identified and filtered a total of 316 research articles that align with the objectives of our research Figure 1. Once this list was compiled, we meticulously reviewed the titles of these papers, intending to categorize them by their respective research domains (Deepa et al., 2022). Articles that did not centralize the blockchain, such as those addressing port engineering, were excluded due to their tangential relevance to blockchain knowledge. Additionally, technical studies about blockchain systems were excluded, as they needed to align with our primary focus on the managerial implications of blockchain adoption. Subsequently, all identified records underwent consolidation in reference management

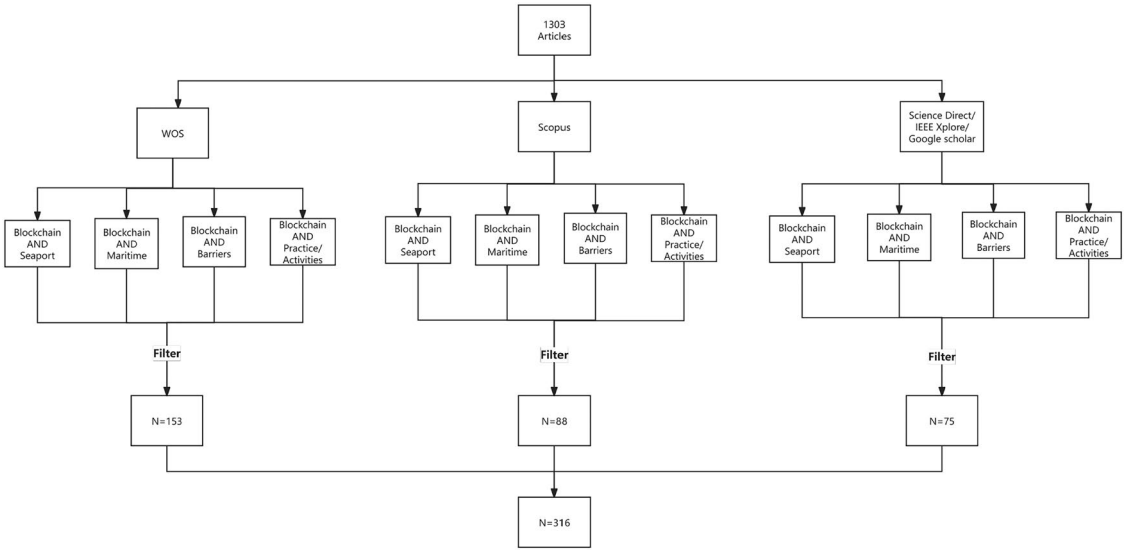

Figure 1. Article selection process.

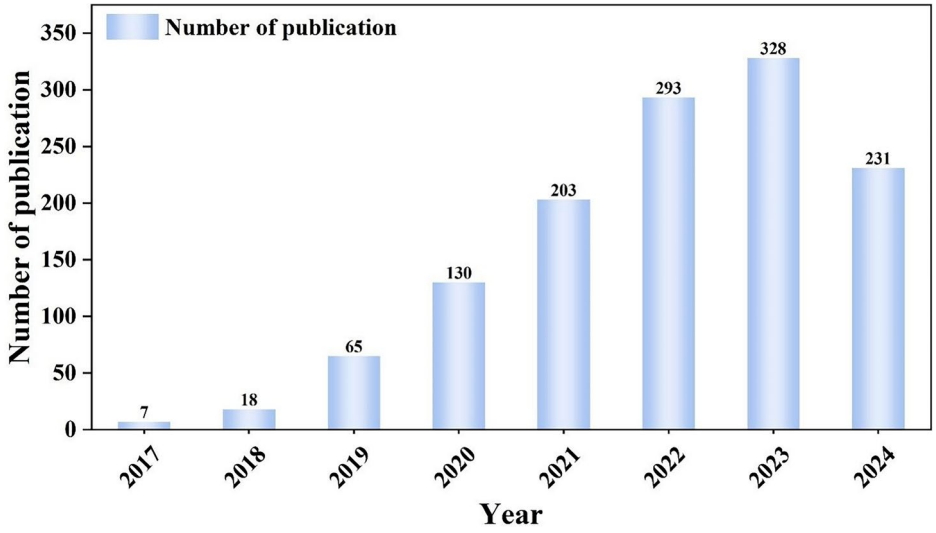

Figure 2. Number of publication.

software, which facilitated the removal of any remaining duplicates. Following this, the titles and abstracts of the remaining documents underwent screening to identify studies with potential relevance. A comprehensive examination was then undertaken to verify the presence of designated search terms within the publications' titles, abstracts, or complete manuscripts, adhering to formal selection criteria. Notably, the search term 'Blockchain AND Seaport' yielded fewer results, reflecting the narrower scope associated with the topic of seaports. During the second phase of our review, we further refined our inclusion criteria, accepting only those articles that specifically addressed blockchain adoption within the maritime or port industry context. We considered reports that either exclusively focused on this theme or provided substantial insights into it. This entailed delineating the port industry context and its implications for blockchain adoption, with findings firmly rooted in this contextual framework. Articles that merely introduced blockchain technology to establish context for research unrelated to engineering were excluded.

We employed VOSviewer to conduct network analyses of our sample papers. VOSviewer is a valuable tool that enables researchers to visually map and explore relationships among research papers, authors, and topics. This makes identifying key authors, emerging trends, and thematic clusters easier. Arshad et al. utilized VOSviewer to analyze literature about the environmental impact of blockchain, while Guo et al. employed VOSviewer to study the visualization aspects of blockchain literature (Guo et al., 2021). Additionally, Bolbot et al. used VOSviewer to analyze literature related to network security in the maritime industry (Bolbot et al., 2022). Their findings highlight the versatile roles that VOSviewer plays in literature reviews (Bolbot et al., 2022; Guo et al., 2021). VOSviewer supports bibliometric analyses, which assist in assessing research impact and uncovering influential works. Through its ability to visually summarize extensive literature, VOSviewer enhances comprehension and streamlines the process of conducting comprehensive and insightful literature reviews (Bolbot et al., 2022). VOSviewer primarily relies on citation, co-citation, and co-word analyses, making it an indispensable tool in scientometrics and bibliometrics, particularly for visualizing relationships within academic literature. Researchers use the Web of Science and Scopus databases as data sources when employing this tool (Cheung et al., 2021).

4. Analysis of literature

The port industry has recently witnessed a surge in interest and research regarding adopting blockchain technology (Bolbot et al., 2022; Cheung et al., 2021; Pham, 2023). Our network analysis shows the co-citation relationships among crucial papers in the field. Notably, it highlights the central role of papers by Perez (Pérez-Morón, 2021) and Cheung in shaping the discourse on blockchain adoption in the supply chain. These studies have been in conjunction with Creazza's and Ghadge's research (Creazza et al., 2022; Ghadge et al., 2019).

In port operations, literature exploring the application of blockchain technology sheds light on emerging research trends and critical aspects within this field. Recently, scholars and experts in port management and logistics have increasingly directed their attention toward the utilization of blockchain technology as a means to enhance transportation, traceability, and transparency (Lu et al., 2016). Below are some critical insights about blockchain's role in port applications: Literature indicates a gradual surge in interest among researchers in the port sector regarding blockchain technology. There was a noticeable upswing in academic publications addressing how blockchain can improve various facets of cargo tracking, supply chain transparency, and overall maritime management (Balci & Surucu-Balci, 2021; Pu & Lam, 2020). This reflects the swift acknowledgment of blockchain's potential within the port industry and the concerted efforts to implement this technology to enhance operational efficiency. The growing demand for blockchain technology can be attributed to the increasing need for digitalization within the port industry, traditionally perceived as a sector with low technological advancement (Notteboom, 2016; Notteboom et al., 2017). Balci (2021) suggest that there is likely a consensus or acknowledgment within the academic or industry community that blockchain has both potential and obstacles in port management. This co-citation may lead to discussions on how to harness the potential while addressing the challenges effectively. The recognition and valuation of blockchain in ports are not merely theoretical but backed by real-world examples or statistics (Gurtu & Johny, 2019; Zeadally & Abdo, 2019). This indicates that ports have started to see the value in adopting blockchain technology, even facing challenges. Below, we provide specific analysis results of SLR.

4.1. Hot topic analysis

The 316 paper encompassing the years 2017 to 2024 regarding the publication of papers related to the keywords 'blockchain AND seaport', 'blockchain AND maritime', 'blockchain AND shipping', 'blockchain AND barriers', 'blockchain AND enabler', and 'blockchain AND practice' illustrates a striking trend of escalating interest and research at the intersection of these themes (Figure 3). There were few publications on the subject in the initial years: three in 2017 and seven in 2018. However, from 2019, there was a marked increase in research, peaking at 85 papers in 2023. This trend emphasizes the rising importance of blockchain in areas like port operations, maritime transport, and sustainability in transportation. Notably, 2020 to 2023 saw a dramatic increase in publications, highlighting an intensified focus on the connections among these keywords. This could be due to the potential of blockchain to enhance port efficiency, streamline maritime logistics, and promote sustainable practices. It should be noted that the sample was compiled until mid-2024 and did not include all publications for that year.

Using VOSviewer, we identified keywords that appeared at least five times and created a co-occurrence network, as shown in Figure 4. This network features numerous keywords, but only relationships occurring ten times or more are displayed for simplicity. This keyword co-occurrence network visualizes the prevailing research trends at the intersection of technology and industry, highlighting a scholarly emphasis on 'blockchain', 'sustainability', 'management', 'challenges', 'technology', and 'smart contracts' from 2017 to 2024. The visualization captures the dynamic interplay between these domains, with the size and connectivity of nodes reflecting the frequency and co-occurrence of terms in literature. The prominence of terms like 'blockchain' and 'technology' alongside 'sustainability' and 'management' underscores a research narrative focused on integrating advanced technologies for enhanced transparency, sustainability, and efficiency in supply chains. This aligns with a broader industry pivot towards Industry 4.0 paradigms, where combining digital technologies with conventional business processes is crucial for competitive advantage and sustainable growth. Figure 5, 25 keywords indicate various terms' strengths and beginning and end periods from 2017 to 2024. Noteworthy keywords include 'smart contracts', 'distributed ledger', 'secure', 'business model innovation', 'privacy', and 'peer-to-peer computing', reflecting diverse research interests and technological advancements over the years. The data highlights the increasing importance of governance, resource management, electric vehicles, transparency, and sustainable supply chains, pointing towards evolving priorities in the research community and industry (Sedlmeir et al., 2022).

Figure 6 illustrates a detailed co-occurrence network of keywords in academic research, visualized using VOSviewer. It provides a comprehensive understanding of the evolving focus areas in blockchain and related fields. Central keywords such as 'blockchain', 'sustainability', 'management', 'technology', 'challenges', and 'smart contracts' dominate the network, indicating their high frequency and relevance in the research landscape. Keywords like 'security', 'internet', 'logistics', 'supply chain', and 'barriers' are highly interconnected, reflecting their interrelated nature in blockchain research. The color of the nodes,

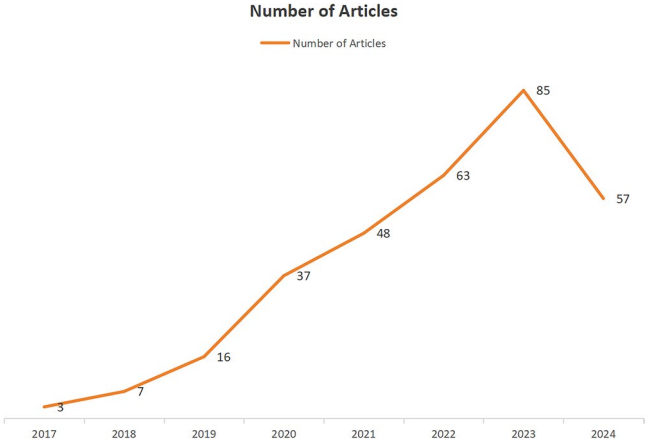

Figure 3. Posting fluctuations of related keywords.

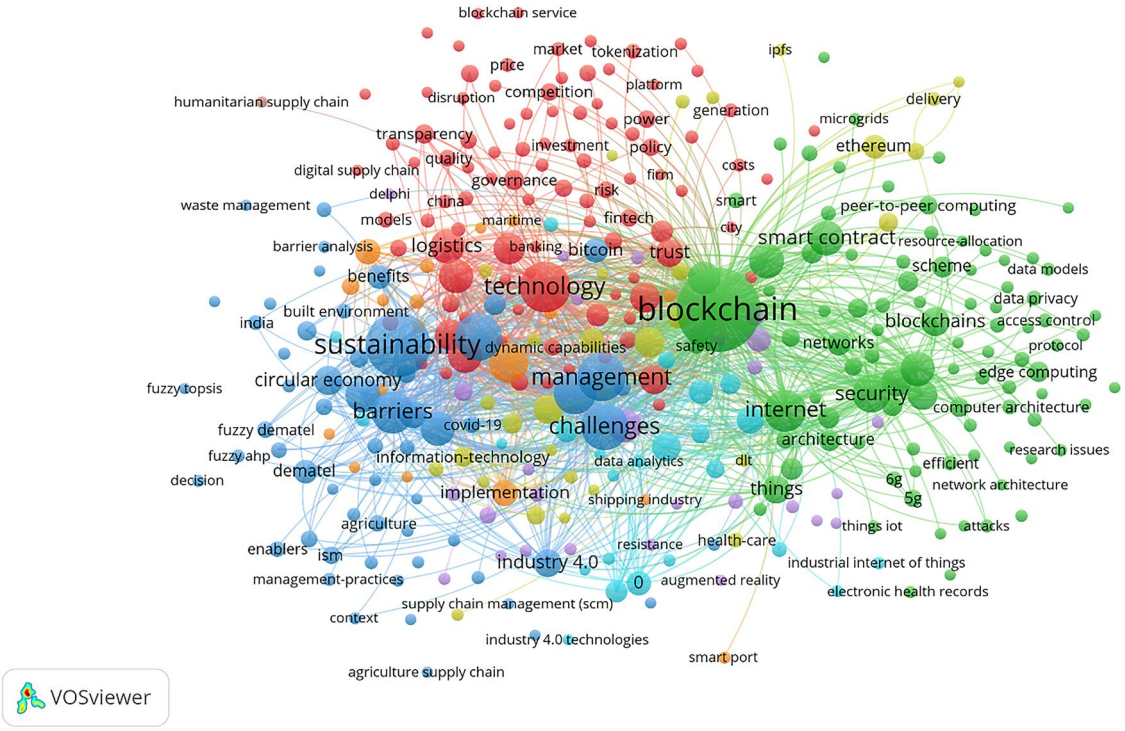

Figure 4. VOSviewer keywords connection.

ranging from blue to red, shows a visual timeline of research trends, with more recent research interests highlighted in shades of yellow to green.

'Sustainability' is a critical keyword in the co-occurrence network, indicating its high frequency and relevance in blockchain research. Its central role in the network and its large node size signifies its importance and widespread interest among researchers. The keyword 'sustainability' is closely connected to other significant keywords such as 'blockchain', 'management', 'technology', 'challenges', 'logistics', and 'circular economy'. This demonstrates that sustainability is an integral aspect of various research themes and is often studied in conjunction with these areas. Recent research focus on sustainability, particularly from 2021 to 2023, reflects a growing recognition of the need to incorporate sustainable practices in blockchain applications, especially in industries like port operations, maritime transport, and logistics.

Thematic clusters in the network reveal several key research areas. 'Sustainability' forms part of a larger cluster that includes keywords such as 'circular economy', 'management', 'barriers', and 'challenges', highlighting the interconnected research themes focusing on integrating sustainable practices and overcoming implementation barriers. The connection between 'sustainability' and technology-related keywords like 'blockchain', 'smart contracts', and 'internet' indicates that technological advancements are being leveraged to achieve sustainable outcomes. From 2017 to 2019, initial research primarily focused on foundational topics like 'blockchain' and 'technology'. However, from 2021 onwards, there has been a noticeable shift towards incorporating sustainability into blockchain research, evidenced by the significant attention paid to the 'sustainable supply chain', the 'circular economy', and 'sustainable development'. This trend highlights the interdisciplinary nature of sustainability research, integrating technology, management, logistics, and supply chain processes to promote eco-friendly and sustainable practices.

4.2. Stakeholders

The port industry operates within a complex and interconnected web of stakeholders (see Figure 7). This web comprises diverse groups like shipping companies, terminal operators, and government agencies, each with unique goals. Navigating these differing interests and enhancing collaboration is challenging (Balci & Surucu-Balci, 2021). Managing regulatory compliance, security, labor relations, infrastructure

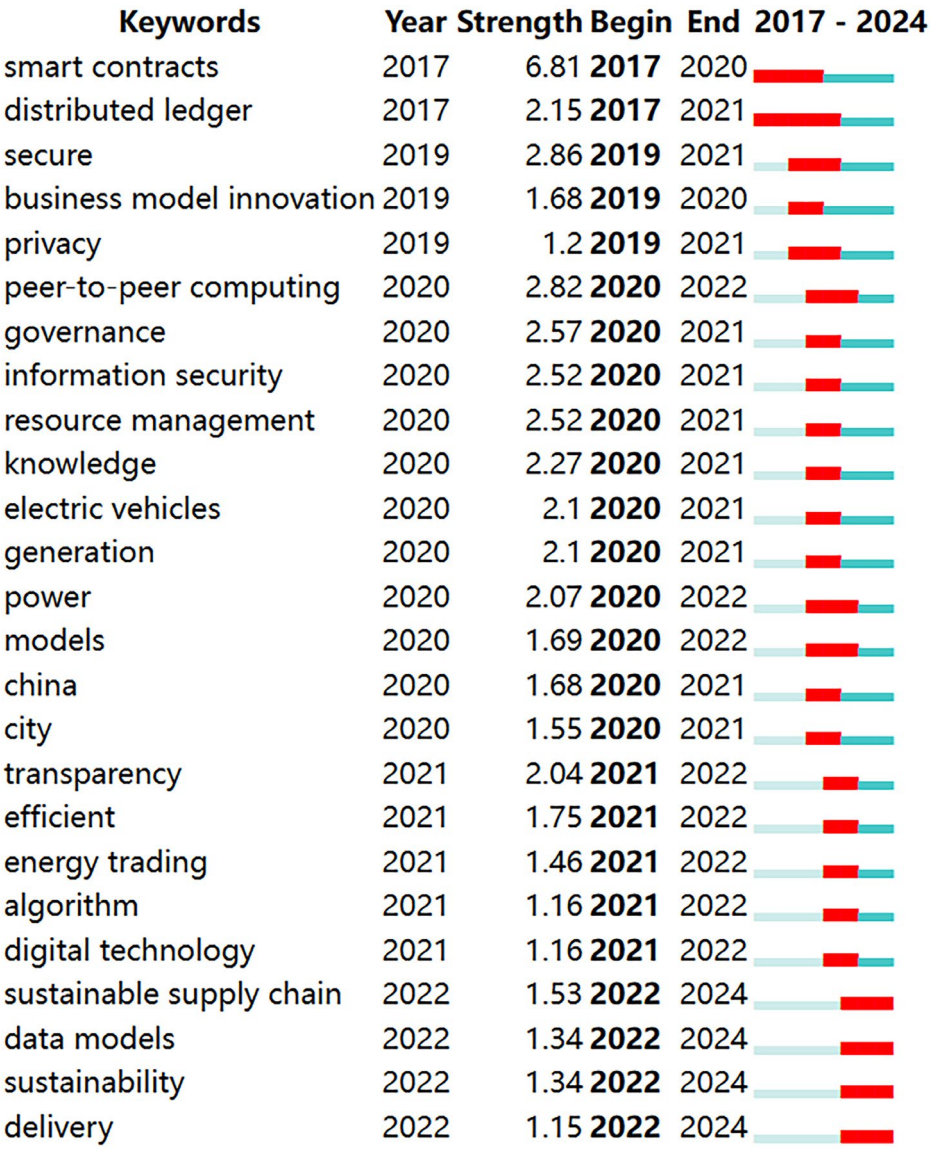

Figure 5. Top 25 keywords with the strongest citation bursts.

development, and technological integration while meeting the demands of global supply chains necessitates efficient communication, negotiation, and coordination among these multifaceted stakeholders (Denktas-Sakar & Karatas-Cetin, 2012).

Port management recognizes various stakeholder categories (refer to Appendix A and Figure 7). Internal ones, like port authority employees and shareholders, have a direct stake in the port's achievements (Farzadmehr et al., 2023). External stakeholders, such as terminal operators and shipping agencies, are integral to the port's economic dynamics (de Langen, 2006). Like trading companies, port clients are pivotal to port operations due to their reliance on port services (de Langen, 2006; Dooms et al., 2013).

Legislative and public policy stakeholders, including government departments, ensure port operations adhere to legal and environmental benchmarks (Ha et al., 2019). Community stakeholders, such as the public and media, can shape port activities by voicing environmental or social concerns (Farzadmehr et al., 2023).

Integrating port stakeholders requires leveraging several resources (Denktas-Sakar & Karatas-Cetin, 2012). This entails emphasizing critical organizational assets, including finances, relationships, and top management support. The influence of external stakeholders, especially supply chain ones, on port management is profound. Engaging with their needs and aligning goals is crucial for the port's sustainable growth (Ha et al., 2019).

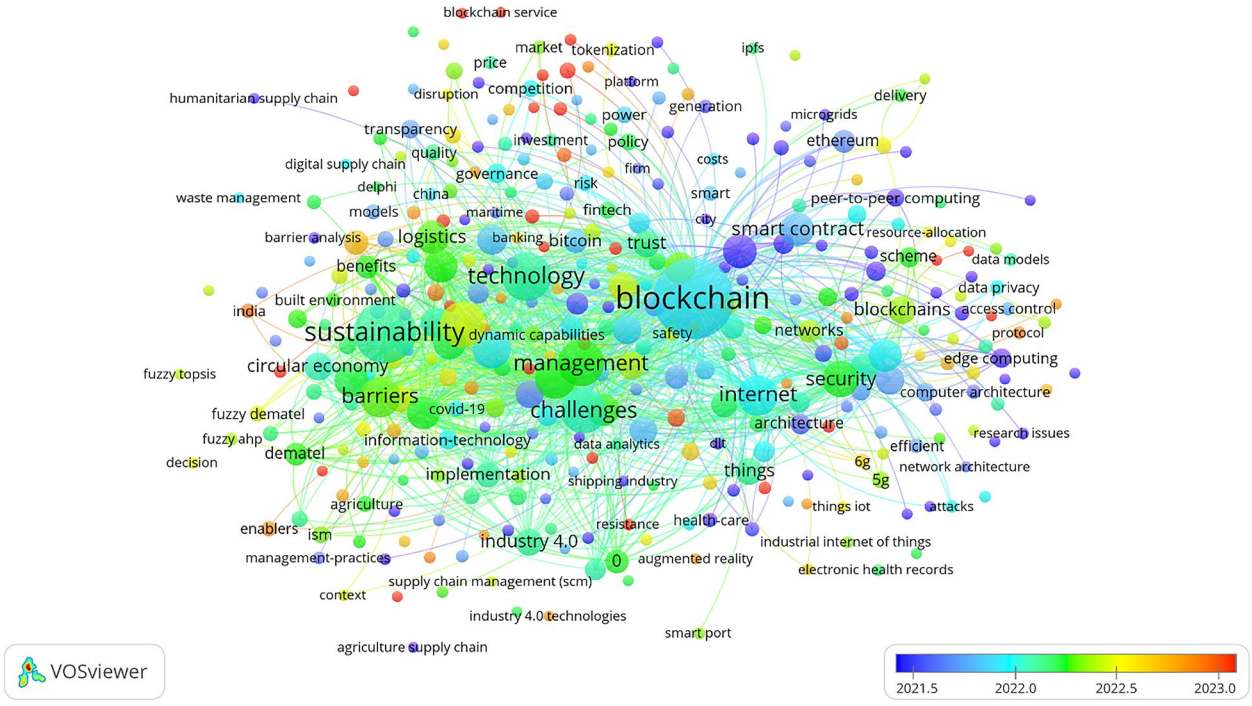

Figure 6. Hotspot and times.

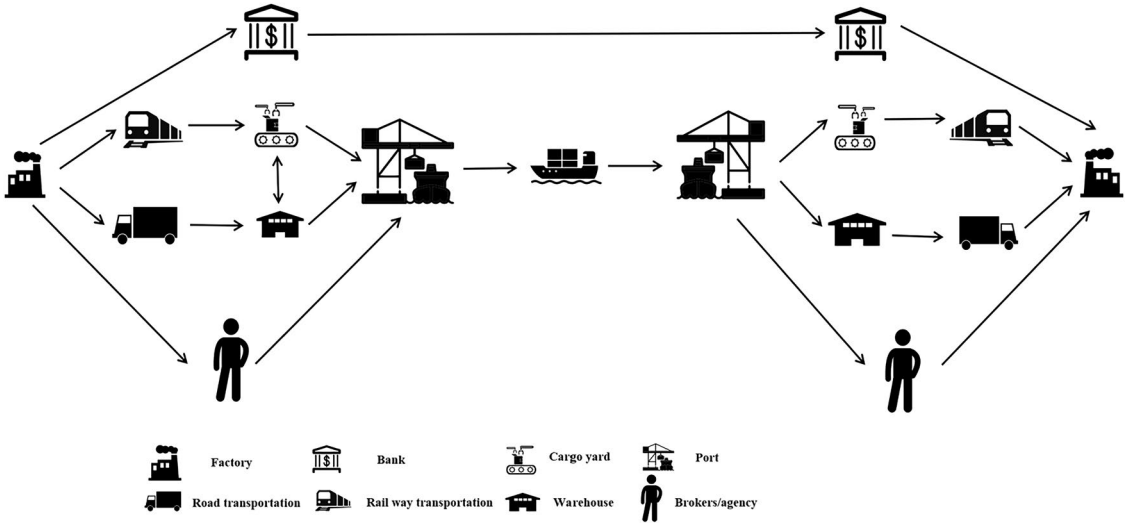

Figure 7. Port stakeholders.

4.3. Blockchain application in port analysis

Blockchain technology rapidly emerges as a transformative force with diverse applications in the port industry. Electronic documents, such as Electronic Bills of Lading and Electronic Delivery Orders, offer enhanced transparency, efficiency, and automation (Table 1). With 47 articles on the subject, the significance of blockchain in streamlining documentation is clear. Blockchain also enhances port operations, with tools like electronic seals improving security and tracking. Though only 19 articles mentioned this, it signifies a rising interest in refining port activities using blockchain.

Maritime finance and marine re/insurance sectors must also catch up. Innovations like Initial Coin Offerings (ICOs) for fundraising, cross-border payment facilitation, and decentralized marketplaces for insurance claims management are gaining traction. With 23 articles on maritime finance and 17 on marine re/insurance, it is evident that the industry is keen on leveraging blockchain for trust, efficiency,

Table 1. Blockchain adoption in seaports.

Field	Major Blockchain Applications	Number of Articles
Electronic documents	1. Electronic Bills of Lading 2. Electronic Delivery Order (EDO)	47
Port Operations	1. Electronic seals 2. Accurate Verified Gross Mass (VGM) of the cargo	19
Maritime Finance	1. Initial Coin Offerings (ICOs) 2. Cross-Border Payment 3. Escrow 4. warehouse receipt financing	23
Marine Re/Insurance	1. Underwriting 2. Claims Management 3. Fraud Reduction	17

and accountability. Blockchain's wide-ranging applications signal a transformative shift in maritime operations.

Take the electronic bill of lading system as an example (Figure 8); the shipper submits cargo details to the carrier via an application platform (Irannezhad & Faroqi, 2021). This data is securely and chronologically stored on the servers of the involved parties. If the carrier agrees to the shipment, an electronic bill of lading is prepared detailing cargo specifics and delivery arrangements (Ding, 2019). Upon cargo loading, the carrier formally signs the electronic bill of lading, finalizes the bill, provides private keys to stakeholders, and completes the issuance (Pu & Lam, 2020).

Private keys are essential during the cargo's journey (Irannezhad & Faroqi, 2021). For finances, the shipper transfers their key to the bank, taking control (Pu & Lam, 2020). When activated, the shipper's private key becomes inactive, transferring power to the financial institution. When the consignee pays, they gain control over the cargo via a key from the bank. Changes in the consignee are made on the platform with required confirmations (Ding, 2019). Upon cargo arrival, the consignee uses their key to claim it, voiding it afterward. All steps are meticulously recorded on servers, ensuring clarity and accountability (Lin et al., 2023).

The port industry is increasingly adopting blockchain technology, with 316 articles attesting to its transformative potential (Table 2). Blockchain promotes transparency and trust in the intricate maritime logistics chain. When combined with GPS, AIS, RFID, and IoT, blockchain offers real-time cargo and vessel tracking, enhancing efficiency. The integration further supports smart contracts, minimizing paperwork and reducing fraud.

The inclusion of AI (19 articles), Big Data (9 articles), and GIS (14 articles) indicates an industry shift towards integrating advanced analytics, especially with blockchain. AI enhances tasks like route planning, while GIS provides geospatial insights. The rising focus on 5G technology, with 18 articles, signals a foundation for robust blockchain networks catering to the maritime sector's data demands. Overall, the article's distribution showcases an evolving technology ecosystem around blockchain that is set to advance the maritime and port industries.

4.4. Port sustainability

Historically, ports prioritized economic gains over sustainability, often sidelining environmental and social considerations (Denktas-Sakar & Karatas-Cetin, 2012). Gaps in regulation and unawareness of environmental and social repercussions intensified this trend. Though sustainability initiatives often demand initial high investments and technological upgrades, their adoption faced resistance due to short-term financial worries and aversion to change (Chen & Lam, 2018). The port industry's recent mindset has evolved significantly. Driven by heightened environmental rules, stakeholder demands, and insights into sustainability's lasting advantages, ports are now emphasizing sustainable efforts (Bjerkan et al., 2021). Recognizing the merits of addressing environmental and societal issues, ports see opportunities to boost their image, cut costs, and guarantee lasting success. This shift marks a positive direction, with ports globally integrating sustainability deeply into their operations and ethos (Lim et al., 2019; Saberi et al., 2018).

Port sustainability encompasses strategies and endeavors ensuring current and future needs while conserving resources (Denktas-Sakar & Karatas-Cetin, 2012). It is built on sustainable development's pillars: environmental, social, and economic facets (Jum'a et al., 2022). The goal is to balance safety, societal

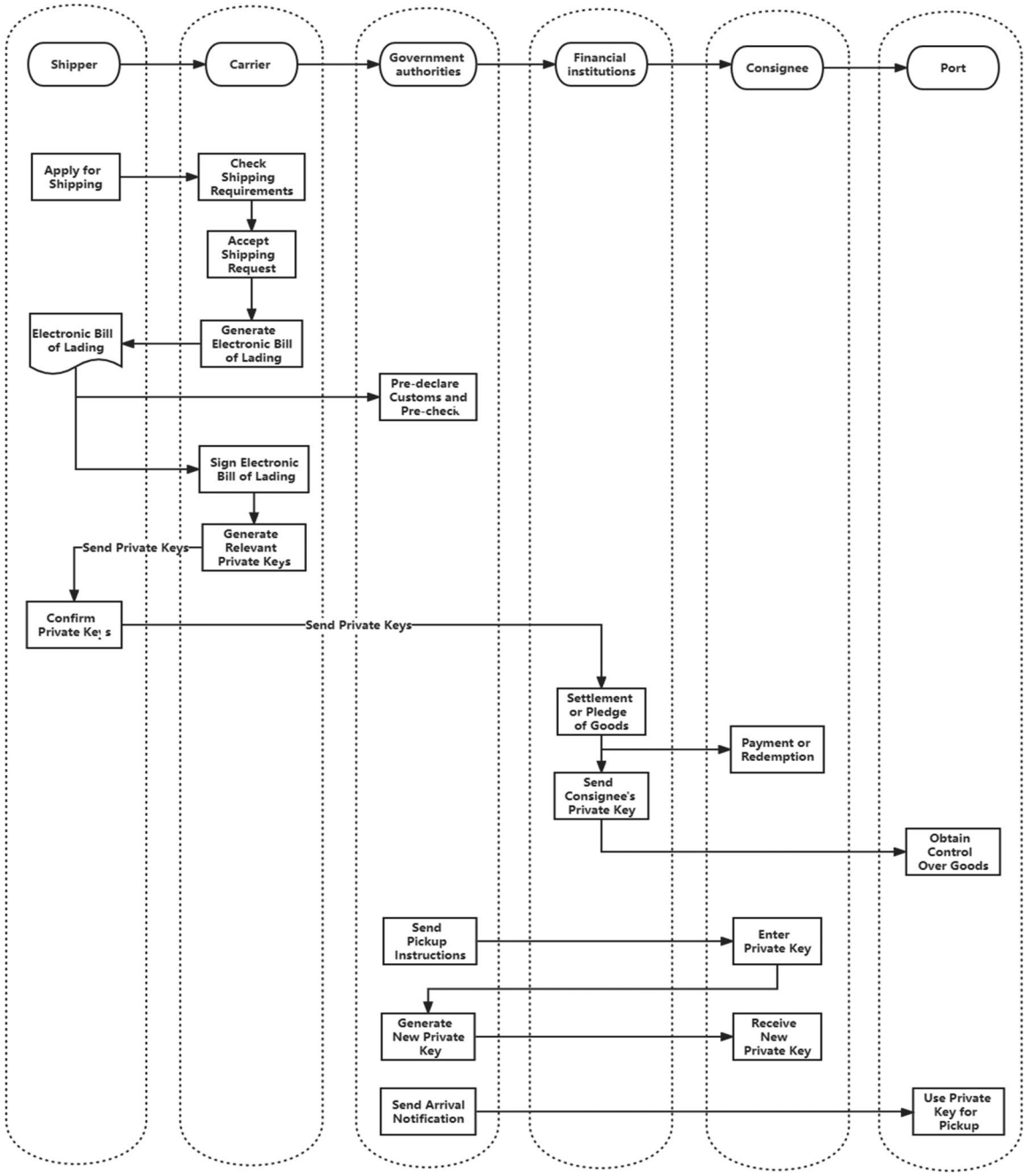

Figure 8. Blockchain-based electronic Bill of Lading application platform [adapted from (Ding, 2019; Irannezhad & Faroqi, 2021; Wang et al., 2021)].

Table 2. The blockchain-based port industry uses technologies.

Technology	Articles
Blockchain Technology (Totally)	316
Global Positioning System (GPS)	18
Automatic Identification System (AIS)	3
Radio-Frequency Identification (RFID)	27
Electronic Data Interchange (EDI)	24
Internet of Things (IoT)	23
Artificial Intelligence (AI)	19
Big Data Analytics	9
Fifth Generation Mobile Network (5 G)	18
Near-Field Communication (NFC)	5
Geographic Information System (GIS)	14
Digital Twin Technology	2
Navigation Telex	1
Vessel Traffic Service (VTS)	2

approval, eco-friendliness, and financial profitability. Achieving this demands a holistic management approach with data-driven sustainable responsibility assessments (Jum'a et al., 2022; Saberi et al., 2018). Port operations highlight three fundamental sustainability facets: environmental, social, and economic. Environmental sustainability prioritizes reducing port activities' adverse effects using eco-friendly methods (Lim et al., 2019). Social sustainability targets improving life quality in port areas through job creation, educational prospects, and societal equilibrium. Meanwhile, economic sustainability focuses on achieving financial goals while preserving societal and environmental values, underlining the need to harmonize growth with sustainable actions (Purvis et al., 2018).

Blockchain technology is pivotal for port sustainability (Tsai & Lu, 2021). It offers transparency and traceability. (Tsai & Lu, 2021). Environmentally, it helps manage emissions, encourage green practices, and curb carbon footprints (Jum'a et al., 2022). For social sustainability, blockchain ensures fair labor practices, worker safety, and equitable treatment of employees while facilitating community engagement (Yang et al., 2023). Economically, it enhances efficiency, cuts costs, and strengthens competitiveness through real-time insights and automation (Kouhizadeh et al., 2021).

Achieving previous sustainability via blockchain mandates collaboration across stakeholders like port authorities, shipping firms, communities, governments, and tech vendors (Dooms et al., 2013; Valenza & Damiano, 2023). Addressing tech challenges and regulatory hurdles while fostering inclusive decisions is essential to harness blockchain's full benefits (Zhou et al., 2022). Embracing blockchain can catalyze a positive cycle for ports, driving comprehensive benefits and a brighter, sustainable future for all stakeholders (Valenza & Damiano, 2023).

4.5. Theoretical lenses

Three significant theories adopted in the literature are the Technology Acceptance Model (TAM), the Technology-Organization-Environment (TOE), and The Practice-Based View (PBV). Chatterjee suggests that applying the TAM can elucidate how these technologies are adopted and utilized (Chatterjee et al., 2021). TAM is a theoretical framework in information systems and technology management. Developed by Fred Davis in the late 1980s (Chintalapati & Daruri, 2017), TAM seeks to explain and predict how users adopt new technologies by considering two core factors: perceived usefulness (whether users believe the technology will benefit them) and perceived ease of use (how user-friendly they perceive it to be). According to TAM, these factors directly influence a user's intention to use technology, with a positive perception of usefulness and ease of use leading to greater acceptance (Bryan & Zuva, 2021). TAM has been widely applied across various industries to understand and improve technology adoption, making it a valuable tool for organizations and researchers (Abu-Taieh et al., 2022).

However, Guan et al. (2023) hold an alternative perspective, contending that the TOE framework offers a more comprehensive vantage point for comprehending the adoption of blockchain's novel technology. The TOE framework is a comprehensive model that analyzes the factors influencing an organization's successful adoption of new technologies or innovations (Qin et al., 2020). It considers three key sets of factors: the characteristics of the technology itself, the internal attributes of the adopting organization, and the external environmental factors in which the organization operates (Katebi et al., 2022). By considering these interrelated elements, the TOE framework provides a structured approach for organizations to assess and strategize their technology adoption efforts, helping them make informed decisions and adapt effectively to the ever-changing landscape of technological advancements and market dynamics to remain competitive and innovative (Chatterjee et al., 2021).

The Technology Acceptance Model (TAM) highlights stakeholder challenges in seaport blockchain integration. Perceived usefulness barriers include doubts about blockchain's merits and concerns over cost and security, while perceived ease-of-use barriers involve complexity and stakeholder integration (Chatterjee et al., 2021). Regulatory issues and infrastructure availability further affect its perceived usability. Using TAM, seaport authorities can tackle these challenges, promoting blockchain's broader acceptance and optimizing seaport operations.

Applying the TOE for blockchain adoption in seaports reveals technology challenges like blockchain complexity and system compatibility. Organizational issues might involve skill gaps and adaptability, while environmental challenges include regulatory uncertainties and stakeholder influence. Seaport

authorities can strategize to overcome obstacles by assessing these factors, promoting blockchain's success, and boosting efficiency and transparency in maritime operations.

Relying solely on TAM or TOE is often insufficient for understanding blockchain integration in port operations (Bryan & Zuva, 2021). An integrated TAM-TOE model combines TAM's focus on user perspectives, like perceived usefulness, with TOE's emphasis on organizational and environmental factors, providing a holistic view of blockchain adoption challenges (Scherer et al., 2019).

RBV is also used in the port literature to analyze blockchain adoption. Nandi et al. (2020) characterized blockchain technology as a valuable asset for businesses, one that is not readily available. RBV is a strategic management framework highlighting the significance of a firm's unique resources and capabilities in achieving and sustaining competitive advantage (Bromiley & Rau, 2016). It posits that a firm's resources, encompassing tangible and intangible assets, must be Valuable, rare, Inimitable, and Non-substitutable (VRIN) to provide a sustainable competitive edge (Silvestri et al., 2023). RBV underscores the importance of dynamic capabilities for adapting to changing environments and acknowledges that resource heterogeneity among firms can lead to divergent competitive outcomes. RBV shifts the strategic focus from external factors to internal strengths, encouraging firms to leverage their distinctive resource portfolio for long-term success in the marketplace (Nandi et al., 2020).

4.6. Challenge for blockchain adoption in port

Using the analytical framework developed by Lincoln et al. and drawing upon the TAM (Technology Acceptance Model) and TOE (Technological, Organizational, and Environmental) theoretical frameworks, we classify barriers into internal and external obstacles (Wood et al., 2016). The balance between efficiency and security is crucial in the increasingly automated maritime world. With its potential to revolutionize seaport data management, blockchain stands out (Liu et al., 2021). The adoption of blockchain in seaports has been slow due to various internal and external challenges.

Internally, in seaports, there is resistance to adopting new technologies due to past IT failures and a need for more technical knowledge among administrators, making it hard to see the benefits of blockchain (Kaur et al., 2022).

Externally, seaport challenges include outdated regulations and strict data privacy rules, making businesses wary of new technologies like blockchain. Slowly changing industry standards also make it hard for them to justify investing in these fast-evolving technologies (Öztürk & Yildizbaşi, 2020). The specific barriers need to be addressed, as outlined in Table 3.

To overcome these barriers (see Table 3), companies must handle distrust, resistance to change, and uncertainty about new technology (Kaur et al., 2022). A positive mindset and dedication are vital for technology success. Adapting to company differences and cultures is critical for effective implementation.

Table 3. List of organizational internal barriers.

Internal barriers	Description	References
I1 - Lack of Management Commitment Support	Lack of dedication from management team executives and skepticism about technology alignment can hinder progress. Executive commitment is crucial for unlocking blockchain's potential. Academic research on value evaluation is limited.	(Kouhizadeh et al., 2021; Liu et al., 2021; Vafadarnikjoo et al., 2021)
I2 - Lack of Internal Information Transparency	Concerns about data confidentiality and privacy hinder adoption. Lack of clear information-sharing policies results in data silos, impeding analysis and planning.	(Balci & Surucu-Balci, 2021; Kaur et al., 2022; Kouhizadeh et al., 2021; Lohmer & Lasch, 2020; Sedlmeir et al., 2022)
I3 - Lack of New Organizational Policies	The absence of suitable policies challenges adoption. Organizations need policies aligned with best practices, regulations, and objectives for responsible blockchain adoption.	(Öztürk & Yildizbaşi, 2020; Saberi et al., 2018)
I4 - Lack of Knowledge and Expertise	Inadequate understanding of blockchain and supply chains hinders implementation. Organizations need expertise to embrace the technology effectively.	(Agi & Jha, 2022; Saberi et al., 2018; Sun et al., 2022)
I5 - Difficulty in Changing Organizational Culture	Resistance to change and geographic/cultural variations hinder transformation. Incorporating sustainability practices into the vision is essential—organizational and technological resistance waste resources.	(Li et al., 2022; Vafadarnikjoo et al., 2021)
I6 - High Cost	High investment and maintenance costs discourage adoption. Uncertainty about costs and benefits, ROI, and implementation challenges due to costs hinder progress.	(Moretto & Macchion, 2022; Öztürk & Yildizbaşi, 2020)

Table 4. List of external organization barriers.

External barriers	Description	References
S1 - Lack of Customer Awareness	Customer understanding of blockchain's relevance to supply chain sustainability is lacking. Ineffective communication and collaboration among partners contribute to this awareness gap. Engaging stakeholders is crucial for harnessing blockchain's potential.	(Kouhizadeh et al., 2021; Li et al., 2022; Öztürk & Yildizbaşi, 2020)
S2 - Lack of External Stakeholders' Involvement	There is a need for more support from influential stakeholders (NGOs and communities) for sustainable practices and blockchain adoption.	(Balci & Surucu-Balci, 2021; Öztürk & Yildizbaşi, 2020)
S3 - Collaboration and Coordination Challenges	Challenges in collaborating with diverse partners due to cultural and geographical differences. Inconsistent performance systems and varying values, customs, and traditions complicate collaboration among supply chain partners, and stakeholders are reluctant to collaborate due to trust issues or concerns.	(Farooque et al., 2020; Kaur et al., 2022; Liu et al., 2021; Lohmer & Lasch, 2020)
E1 - Lack of Governmental Policies/ Standardization	There must be clear government regulations and standardized frameworks for blockchain in sustainability. A lack of incentives may lead to a perceived financial burden.	(Kouhizadeh et al., 2021; Vafadarnikjoo et al., 2021)
E2 - Market Competition and Uncertainty	Time-consuming sustainable practices and blockchain adoption affect market competitiveness. Uncertainty about sustainable product demand and future sales adds to challenges.	(Kouhizadeh et al., 2021; Vafadarnikjoo et al., 2021)
E3 - Lack of Early Adopters	Limited early adopters hinder adoption for organizations interested in observing adoption trends.	(Balci & Surucu-Balci, 2021)

Challenges in using blockchain in ports come from external factors like government, industry, institutions, and community concerns (Kouhizadeh et al., 2021). These include a need for government policies, unpredictable market competition, and limited stakeholder involvement in sustainability and blockchain adoption (Zheng et al., 2010).

Upon scrutinizing these external barriers through internal and external lenses, they can be further divided into two distinct categories (Kouhizadeh et al., 2021). See Appendix B:

a. Supply Chain Obstacles: Challenges in integrating blockchain into port operations include issues with data sharing, reluctance to change, and the need for joint efforts among stakeholders. These can hinder the smooth adoption of blockchain technology.
b. External Obstacles: Beyond the supply chain, factors like regulations, economic conditions, geopolitical impacts, and tech trends can hinder the adoption of blockchain in port operations.

This review discusses blockchain's advantages in ports and the obstacles to its use (Table 4). Internal and external challenges need attention to harness blockchain's potential in ports. The research method chapter will delve deeper into these issues, filling knowledge gaps about blockchain's challenges and prospects in the port sector.

4.7. Practices for blockchain adoption in port

Ports should pinpoint operations, like business process re-engineering (BPR) or improving cargo tracking transparency, that blockchain can enhance. By refining these practices and promoting industry collaboration for standard protocols, blockchain can be seamlessly integrated, ensuring enhanced efficiency and security (Bromiley & Rau, 2014).

Given blockchain's fast-paced evolution, port operators must stay updated on new trends to remain competitive. Ports can fully utilize blockchain and tackle emerging challenges by encouraging constant learning and sharing within the industry. This strategy supports effective blockchain adoption and prepares ports for a constantly evolving tech environment where adaptability is crucial.

Table 5 lists practices to improve blockchain use in port operations, and we discuss them specifically as follows:

4.7.1. Management team and their role in blockchain adoption

Blockchain integration in freight logistics largely depends on strong support from top management. This support includes providing direction, resources, and guidance for effective blockchain use (Godavarthi et al., 2023). High-level management team endorsement boosts IT initiatives and improves organizational

Table 5. List of organization practices to adopt blockchain.

References	Year	Article	Journal	Practice
(Battilani et al., 2022)	2022	Business Process Re-engineering in Public Administration: The Case Study of Western Ligurian Sea Port Authority	Sustainable Futures	BPR (Business Process Reengineering)
(Jia et al., 2021)	2021	The Business Process Reconstruction of Railway-River Combined Transportation Cloud Platform Taking China Container Export as an Example	Journal of Advanced Transportation	
(Borgianni et al., 2015)	2015	Business Process Reengineering driven by customer value: a support for undertaking decisions under uncertainty conditions	Computers in Industry	
(Goel & Chen, 2008)	2008	Can business process reengineering lead to security vulnerabilities? Analyzing the reengineered process	International Journal of Production Economics	
(Attaran, 2004)	2004	Exploring the relationship between information technology and business process reengineering	Information & Management	
(Islam et al., 2013)	2013	Reengineering the seaport container truck hauling process	Business Process Management Journal	
(Patil et al., 2023)	2023	Behavioral drivers of blockchain assimilation in supply chains – A social network theory perspective	Technological Forecasting and Social Change	Organization Culture
(Ahmady et al., 2016)	2016	Effect of Organizational Culture on Knowledge Management Based on the Denison Model	Procedia - Social and Behavioral Sciences	
(Dubey et al., 2022)	2022	Impact of artificial intelligence-driven big data analytics culture on agility and resilience in humanitarian supply chain: A practice-based view	International Journal of Production Economics	
(Kant & K. Patil, 2014)	2014	Knowledge management adoption in supply chain	Journal of Modelling in Management	
(Salim et al., 2022)	2022	The mediator and moderator roles of perceived cost on the relationship between organizational readiness and the intention to adopt blockchain technology	Technology in Society	
(Godavarthi et al., 2023)	2023	Blockchain Integration with the Internet of things for employee performance management	The Journal of High Technology Management Research	Management team support
(Ahmady et al., 2016)	2016	Effect of Organizational Culture on Knowledge Management Based on the Denison Model	Procedia - Social and Behavioral Sciences	
(Dubey et al., 2022)	2022	Impact of artificial intelligence-driven big data analytics culture on agility and resilience in humanitarian supply chain: A practice-based view	International Journal of Production Economics	
(Heimann et al., 2020)	2020	Tell us about your leadership style: A structured interview approach for assessing leadership behavior constructs	The Leadership Quarterly	
(Nuttah et al., 2023)	2023	Understanding blockchain applications in Industry 4.0: From information technology to manufacturing and operations management	Journal of Industrial Information Integration	
(Raza et al., 2023)	2023	Digital transformation of maritime logistics: Exploring trends in the liner shipping segment	Computers in Industry	Increase Organization agility
(Pantouvakis & Bouranta, 2015)	2021	Agility, organizational learning culture, and relationship quality in the port sector	Total Quality Management & Business Excellence	
(Fosso Wamba, 2022)	2022	Impact of artificial intelligence assimilation on firm performance: The mediating effects of organizational agility and customer agility	International Journal of Information Management	
(Sun et al., 2022)	2022	Sustainable organizational performance through blockchain technology adoption and knowledge management in China	Journal of Innovation & Knowledge	

results. With their deep understanding of company resources, senior executives often borrow successful strategies from other organizations (Adegoke et al., 2021; Marikyan et al., 2022).

4.7.2. The influence of organizational culture on blockchain implementation

Organizational culture impacts various aspects of a company, such as behavior, performance, and innovation. It can drive change or maintain stability. For blockchain adoption, cultural shifts are crucial (Raza et al., 2023). Leaders must create an environment that promotes empowerment, experimentation, and continuous learning, vital for successful blockchain projects (Ahmady et al., 2016).

4.7.3. Enhancing seaport operations through Business Process Reengineering and blockchain

Business Process Reengineering (BPR) helps enhance organizational processes, aiding blockchain integration in seaports (Borgianni et al., 2015). Blockchain optimizes seaport activities, boosts transparency, and promotes collaboration. It automates processes, improves supply chain visibility, lowers costs, and ensures data integrity, enhancing reliability in the seaport sector (Attaran, 2004).

4.7.4. The role of organizational agility in blockchain adoption:

Organizational agility supports successful blockchain adoption in seaports due to changing trade, regulations, and technology (Fosso Wamba, 2022). Agile seaports can quickly adjust to the challenges and opportunities of blockchain, optimizing its benefits (Fosso Wamba, 2022). Cultivating adaptability lets seaports address challenges and integrate blockchain effectively into their operations (Saheb & Mamaghani, 2021).

5. Discussion

The discussion section explores the integration of blockchain technology in port operations in depth. Challenges such as complex stakeholder relations, heavy regulations, and resistance to change within the traditional port industry are highlighted. The synergistic benefits of combining blockchain with emerging technologies like GPS, RFID, and AI are discussed, emphasizing improved data accuracy and security. The Practice-Based View (PBV) is introduced as a more adaptable framework for understanding blockchain adoption, highlighting the role of organizational practices. The connection between barriers and practices is emphasized, emphasizing the need for a balanced approach between existing routines and adaptability (Bromiley & Rau, 2014, 2016). The TAM-TOE framework is introduced as a comprehensive tool for analyzing adoption barriers, both internal and external. Finally, the discussion shifts to how blockchain enhances port sustainability across economic, social, and environmental dimensions, emphasizing cost savings, efficiency gains, fair labor practices, and reduced ecological impact. The discussion provides a comprehensive overview of the challenges and opportunities of integrating blockchain in port operations and its potential to improve sustainability and efficiency. This chapter addresses the unique challenges that emerge when introducing new technology in the context of ports, distinct from other industries. It also offers guidance for future research, focusing on identifying the barriers that arise from adopting blockchain in ports and exploring the behaviors and practices that can effectively mitigate these barriers.

Merging the insights from the Practice-Based View (PBV) with the comprehensive lens of the integrated Technology Acceptance Model (TAM) and Technological, Organizational, and Environmental (TOE) framework offers a strategic pathway to navigate the complexities of blockchain adoption in the port industry. By emphasizing the critical role of management's support, fostering an innovative culture, and reengineering business processes for blockchain compatibility, the PBV approach addresses internal organizational dynamics and the need for agility in adapting to blockchain's evolving landscape. Concurrently, the TAM-TOE framework broadens the perspective by highlighting the importance of addressing internal stakeholders' perceptions and external regulatory and market challenges. This dual approach ensures a holistic assessment of blockchain adoption barriers, promoting a seamless integration that leverages blockchain's potential to enhance transparency, security, and efficiency in port operations. Ports can overcome inherent adoption challenges through this unified strategy, ensuring a successful digital transformation that fosters industry-wide collaboration and innovation (Quayson et al., 2024).

5.1. The distinctiveness of integrating novel technologies in port operations

Ports involve diverse stakeholders with varied interests, challenging coordination, and consensus on technological changes (Farzadmehr et al., 2023; Ha et al., 2019). Blockchain technology, different in ports compared to other sectors, offers secure data sharing, making its features like distributed ledgers and smart contracts vital (Balci & Surucu-Balci, 2021). The multiple stages in port operations, like cargo handling, benefit from blockchain's traceability, reducing disputes and enhancing accountability. Permissioned blockchain networks can also address privacy concerns in sharing trade data (Dai et al., 2014).

The port industry is often seen as behind in technology due to its long history of traditional practices and complex stakeholder relations (Farzadmehr et al., 2023). Heavy regulations, crucial for safety and environmental concerns, further slow technological adoption despite their importance (Ha et al., 2019).

Port authorities, often governmental entities, oversee port operations and development, making ports different from private industries (Valenza & Damiano, 2023). The complex relationship between governments, port authorities, and managers complicates blockchain adoption in ports (Lu et al., 2016). The dense regulations require any technological innovation, like blockchain, to undergo thorough checks,

potentially demanding major regulatory shifts (Venkatesh et al., 2017). Blockchain's transparency may also conflict with data privacy concerns, causing apprehension and hesitancy among governmental bodies (Dooms et al., 2013; González Laxe et al., 2019).

The port industry's traditional culture often resists change, making it hard to invest in blockchain technology (Battilani et al., 2022). Authorities worry about disruptions, high start-up costs, and merging blockchain with existing systems. The organizational culture, often resistant to tech shifts, and lack of solid management support add to the challenges (Dooms et al., 2013). Encouraging stakeholders to accept blockchain is challenging, especially if they do not see its benefits. Overcoming this requires collaboration, education, and combined efforts from both public and private sectors.

5.2. The synergistic integration of blockchain and emerging technologies

The adoption of blockchain technology in the port industry is greatly enhanced when combined with a suite of complementary technologies (Ding, 2019). Firstly, integrating GPS, RFID, and IoT ensures the real-time tracking and monitoring of goods and assets within a port, creating a trustworthy data source for blockchain (Zeadally & Abdo, 2019). This synergy leads to more accurate and immutable records, as location data is reliably recorded and tamper-proof. Technologies like EDI facilitate seamless data exchange between stakeholders, ensuring interoperability and streamlining processes. Smart contracts powered by AI and Big Data can further automate and optimize operations based on real-time data, such as weather conditions and cargo volumes, driving efficiency and responsiveness. Finally, 5 G connectivity and encryption enhance the security of data transmission, safeguarding sensitive information during its journey through the supply chain. In summary, combining blockchain with GPS, RFID, EDI, IoT, AI, and 5 G creates a robust, efficient, and secure ecosystem that modernizes and revolutionizes the port industry, offering end-to-end visibility, compliance, sustainability, and scalability (Lohmer & Lasch, 2020).

Using blockchain in ports becomes more effective with other technologies, and integrating GPS, RFID, and IoT offers real-time tracking, producing trustworthy data for blockchain (Ding, 2019; Zeadally & Abdo, 2019). This ensures accurate, secure records. EDI aids data sharing between stakeholders, while AI and Big Data-powered smart contracts can automate tasks based on current data. 5 G and encryption boost data security. Combining blockchain with GPS, RFID, and AI optimizes and secures port operations, providing clear visibility and scalability (Ding, 2019).

Combining blockchain with technologies like GPS, RFID, EDI, IoT, AI, and 5 G offers numerous benefits to the port industry. This mix boosts data accuracy and security, ensuring reliable tracking of goods (Han et al., 2022). Interoperability is improved through EDI, as it enhances data sharing between stakeholders, while AI-powered smart contracts automate operations based on real-time data (Ding, 2019). 5 G ensures fast data transfer, and IoT gathers essential data. This holistic approach modernizes ports, promoting transparency and efficiency in global trade (Ahmed & MacCarthy, 2023).

5.3. Practice-Based View (PBV): a complementary theory to Resource-Based View (RBV)

Despite the Resource-Based View (RBV) emphasizing the significance of rare and inimitable resources for a firm's competitive advantage (Bromiley & Rau, 2014), the context of blockchain, notably in port operations, suggests otherwise. Hardware and software, such as those used by Walmart on the IBM Blockchain platform to monitor food supply chains, are readily accessible and imitable (Brömer et al., 2019). Therefore, the RBV might not be the most appropriate framework, particularly when considering the influence of blockchain practices on an organization's structure, culture, and operations (Silva et al., 2018). Bromiley and Rau (2014) highlighted the importance of continuously refining blockchain practices to overcome technological barriers.

In contrast, the Practice-Based View (PBV) offers a more pertinent perspective (Bromiley & Rau, 2014). Unlike RBV's focus on rare resources, PBV emphasizes the impact of common practices on performance (Silva et al., 2018). Given the ubiquity of blockchain technology, implementing distinct practices proves critical (Nandi et al., 2020). Dubey delineates the integration of blockchain technology and the associated operational steps as customary practices within an enterprise (Dubey et al., 2022). The Practice-Based View (PBV) is a strategic management framework that centers on how firms cultivate and maintain

competitive advantages through accumulating and refining organizational routines and practices (Bromiley & Rau, 2014). It underscores the importance of these routines as the foundation of a firm's capabilities, highlighting their role in shaping its ability to adapt to changing environments, develop tacit knowledge, and foster collective learning among employees (Brömer et al., 2019). PBV recognizes that a firm's historical choices and routine investments can significantly impact its future strategic decisions, ultimately aiming to illuminate how effective management and evolution of these internal processes enable firms to excel in dynamic business landscapes (Dubey et al., 2022).

Within the port domain, the PBV framework provides vital perspectives on incorporating blockchain technology, underscoring the evolution of deep-seated routines and methodologies. As Tiwari et al. (2020) pointed out, port regulators, maritime firms, and logistics professionals are devising fresh operational guidelines anchored on a blockchain, facilitating secure, transparent dealings, merchandise monitoring, and supply chain enhancement. This shift, as Dubey et al. (Dubey et al., 2022) describe, is intertwined with the growth of implicit know-how and blockchain proficiency among personnel in these institutions, fostering group-oriented learning that aids the sector in adjusting to emerging norms and directives (Silva et al., 2018). This transition marks a move from conventional paper-driven procedures, tapping into blockchain's promise to amplify efficacy and safeguarding. We found that PBV's relevance is accentuated by its pertinence to organizations' digital evolutions, wherein they frequently adopt adaptable approaches that might not consistently resonate with optimal strategies tailored to their specific functions. PBV centers on performance results and introduces adaptability to cater to assorted situational aspects, positioning it as an apt paradigm to grasp the repercussions of replicable strategies across varied settings (Bromiley & Rau, 2014).

The PBV and RBV are strategic management paradigms, presenting different angles on securing a competitive edge. RBV underscores the importance of an organization's singular assets, whereas PBV focuses on the evolving character of methodologies and routines. The selection between these frameworks is contingent upon the research backdrop, with RBV being appropriate for scrutinizing advantages rooted in resources. Conversely, PBV offers a more fitting lens for delving into how daily operations and societal engagements mold competitive leverage, especially within sectors where habitual actions and educational mechanisms are essential.

To address blockchain challenges, organizations should integrate blockchain practices, experiment with various methodologies, and consistently adapt to enhance their abilities. The Practice-Based View (PBV) emphasizes the influence of common practices on performance, making it more adaptable for operations management than the Resource-Based View (RBV), which centers on rare and inimitable resources (Bromiley & Rau, 2016; Silva et al., 2018). Bromiley and Rau (2016) argue that the RBV overlooks organizational performance variations and faces measurement challenges. RBV also has a narrow focus on sustained competitive advantage and reliance on resources that may be challenging to secure (Dubey et al., 2022; Tiwari et al., 2020). In the blockchain context, while the technology is accessible, its practical use requires unique practices (Dubey et al., 2022).

The Practice-Based View (PBV) is more appropriate in the context of blockchain because it emphasizes the influence of common practices on organizational performance rather than the acquisition of rare and inimitable resources. Given the accessibility of blockchain technology, distinct implementation practices determine success. The PBV offers a more adaptable framework, especially when considering the nuances and variability of performance in operations management. In contrast, the Resource-Based View (RBV) faces criticism for its narrow focus on sustained competitive advantage and challenges in measurement, making it less suited for the dynamic and widely accessible nature of blockchain technology.

5.4. Connecting 'barriers' and 'practices' through Practice-Based View (PBV)

Adopting blockchain in the port industry requires several vital practices. Management's active support is essential for providing direction and resources for blockchain implementation (Dai et al., 2014). A culture of innovation encourages employees to harness blockchain's transformative nature (Zheng et al., 2010). Business Process Reengineering optimizes processes for blockchain integration, enhancing transparency and cutting costs (Battilani et al., 2022). Organizational agility is also crucial, enabling ports to adapt swiftly to industry changes and maximize blockchain's benefits.

The practice-based view highlights the double-edged nature of organizational practices in technology adoption. While established routines can facilitate the integration of new technologies by providing shared knowledge and guidance, they can also act as barriers if they conflict with the latest technology or foster resistance to change, potentially stifling innovation (Bromiley & Rau, 2016). Successful blockchain integration requires a balance between utilizing existing practices and fostering adaptability. It is about understanding the technology and how it reshapes existing organizational practices (Bromiley & Rau, 2014). Effective technology integration demands aligning it with current practices or adapting those practices for a seamless fit (Surucu-Balci et al., 2024).

Through the practice-based lens, challenges in blockchain adoption arise not just from its technical aspects but also from the practices and routines that define an organization (Bromiley & Rau, 2014). Resistance often emerges from ingrained habits. It is crucial to highlight the technology's benefits and illustrate its integration with minimal disruption to existing workflows to mitigate resistance.

The practical implementation of blockchain in ports relies on pinpointing and refining key areas such as business process re-engineering and cargo transparency enhancement. Establishing standard protocols through industry collaboration is essential for blockchain's smooth integration. The management team's support is critical in steering through technological changes and cultivating a culture of innovation and adaptability. Emphasizing organizational agility and continuous learning is crucial due to blockchain's evolving nature, requiring ports to be adaptable to new developments. This comprehensive approach highlights blockchain's transformative potential for port operations, contingent on a collaborative effort from both practitioners and policymakers to address the associated complexities.

5.5. The integrated TAM-TOE framework: a comprehensive understanding of blockchain adoption barriers

Scholars have used both the Technology Acceptance Model (TAM) (Balci, 2021) and the Technological, Organizational, and Environmental (TOE) framework (Guan et al., 2023) to understand obstacles to blockchain adoption in ports. The preferred approach combines both into the TAM-TOE framework, providing a comprehensive tool to analyze internal and external adoption barriers (Bryan & Zuva, 2021). Internally, it is crucial to understand blockchain's benefits for stakeholders, such as customs authorities and shipping companies, and address perceived usefulness (PU) (Chatterjee et al., 2021). Addressing perceived ease of use (PEOU) requires collaborating with IT teams and ensuring user-friendly interfaces alongside relevant training (Katebi et al., 2022). Challenges like limited information transparency, high costs, and resource constraints should be tackled through resource allocation and training for smooth blockchain integration.

The regulatory landscape is vital for external blockchain adoption in ports. Navigating maritime regulations demands collaboration with industry groups to shape beneficial policies. Government policies, market shifts, stakeholder awareness, and industry standards influence adoption. Ensuring interoperability requires adhering to or setting industry standards. Competitive dynamics and stakeholder engagement, including dialogues with entities like customs authorities, further shape external barriers, emphasizing the need for cooperative strategies (Valenza & Damiano, 2023).

Port authorities can holistically assess barriers to blockchain adoption using the TAM-TOE model. The strategy should focus on improving perceived benefits and ease of blockchain use, ensuring organizational readiness, adhering to regulations, setting industry standards, and managing external influences (Haq et al., 2021). This thorough approach boosts the chances of successful blockchain integration, elevating transparency, security, and efficiency in maritime operations and promoting industry collaboration and innovation (Javaid et al., 2021).

As highlighted through various scholarly perspectives, exploring barriers and practices regarding blockchain adoption in the port industry underscores the complexity and multifaceted nature of integrating this emerging technology. Internally, seaports face significant resistance to the adoption of blockchain due to past IT failures and a prevalent lack of technical knowledge among administrators, which obscures the potential benefits of blockchain. These internal barriers are compounded by external challenges such as outdated regulations, strict data privacy laws, and the slow evolution of industry standards, making it difficult for ports to commit to the rapid advancements inherent in blockchain technology. Addressing these barriers requires a nuanced understanding of both the technological

acceptance model (TAM) and the technological, organizational, and environmental (TOE) framework, suggesting a need for a strategic approach that balances efficiency with security in the increasingly automated maritime domain.

5.6. Blockchain enhances port sustainability performance

By implementing effective practices, ports can improve sustainability and overcome challenges in blockchain adoption. The Triple Bottom Line (TBL) theory assesses blockchain's impact on port sustainability across economic, social, and environmental dimensions (Jum'a et al., 2022). Economically, blockchain offers cost savings and new revenue streams for ports (Wang et al., 2021). Efficiency gains arise from process automation, reduced overhead, and minimized risks of disputes, fraud, and delays via transparent tracking and automated settlements (Gao et al., 2022). Socially, blockchain bolsters the welfare of those tied to port operations, supporting fair labor and safety (Chen & Lam, 2018). It boosts consumer trust by verifying product origins and blocks the movement of illegal or harmful goods, safeguarding nearby communities (Shiau & Chuang, 2013). Environmentally, blockchain minimizes the ecological impact of port operations (Denktas-Sakar & Karatas-Cetin, 2012). Ports can align with environmental standards by transparently monitoring carbon emissions and waste, promoting cleaner operations (Yadav et al., 2020).

Blockchain addresses sustainability issues in ports. Business process re-engineering with Blockchain offers a transparent ledger documenting sustainability metrics like emissions, waste, and supply chain practices (Battilani et al., 2022). It enables the creation of a transparent and immutable ledger that records sustainability-related data accurately and securely. This data encompasses carbon emissions, energy consumption, waste management, and supply chain practices (Bhubalan et al., 2022). Streamlining these on blockchain helps ports monitor and report sustainability, pinpointing inefficiencies and bolstering trust in their eco-efforts (Ellahi et al., 2023; Saberi et al., 2018). Blockchain provides management with real-time data, enabling informed sustainability decisions, resource allocation, and progress tracking (Galati, 2021). This aligns port strategies with sustainability, emphasizing its role in long-term competitiveness and signaling a commitment to eco-conscious operations (Park & Li, 2021). Furthermore, blockchain enhances collaboration among port stakeholders. By securely sharing data on a blockchain platform, port authorities, shipping companies, and environmental agencies can work collectively toward sustainability (Galati, 2021). Smart contracts automate sustainability compliance, streamlining efforts, reducing non-compliance risks, and ensuring consistent eco-practices (Almasoud et al., 2020).

Specific examples and case studies indicate that enhancing sustainability performance in the port industry through blockchain technology can significantly impact operations. For instance, the Port of Marseille Fos implemented a blockchain-powered Cargo Community System to streamline and accelerate the exchange of cargo data among stakeholders (Jović et al., 2020), such as freight forwarders, shippers, customs, port agents, and road transporters. This system aims to improve efficiency in the port's freight and logistics operations, optimize processes, and reduce delays and errors associated with traditional paper-based systems.

6. Conclusion

The imperative role of blockchain technology in the evolution of port operations amidst the rapidly advancing global trade and logistics landscape underscores the essence of this systematic review. Our endeavor aimed to dissect the prevailing corpus of knowledge meticulously, spotlight the lacunae in research, and chart out the nascent research trajectories that could steer future scholarly endeavors within this burgeoning domain. Central to our exploration was the aim to demystify the complexities of adopting blockchain technology across port operations. This article outlines six internal and six external challenges hindering blockchain technology's integration within port operations. It also identifies four practices commonly employed by ports to navigate these obstacles effectively. Furthermore, the discussion delves into the intricate web of stakeholder relationships within the port sector, examining how this complexity influences the adoption of blockchain, particularly concerning key players like port authorities. Furthermore, integrating blockchain with complementary technologies such as GPS, RFID, EDI, IoT, AI, and 5G, among others, is crucial for the seamless digital transition of port operations. This article reveals that leveraging blockchain technology can significantly enhance the sustainability performance of ports.

This scholarly contribution has further enriched theoretical discussions by championing a shift towards a practice-based view (PBV) from a traditional resource-based view (RBV) to comprehend better the interplay between adoption barriers and operational practices in blockchain integration. The novel amalgamation of the Technology Acceptance Model (TAM) with the Technology-Organization-Environment (TOE) framework illuminated the myriad internal and external factors influencing the adoption milieu. A salient insight from this review is the paramount significance of contextual appropriateness in selecting theoretical frameworks, advocating for a bespoke approach in theory application that resonates with the unique contours of the port sector. Highlighting the industry's inherent reticence towards technological innovations, this review emphasizes the pressing need for digital transformation in tandem with the imperatives of economic globalization and contemporary trade dynamics.

To advance blockchain integration in seaports, future research should pivot towards longitudinal studies to assess the enduring impact of blockchain solutions, emphasizing their sustainability and scalability. A critical examination of the interplay among various adoption barriers identified in the literature is crucial to facilitate smoother integration and address systemic fragmentation in the port industry. Additionally, empirical research through in-depth case studies and practical applications is essential to uncover real-world challenges and successes in blockchain adoption within maritime sectors. Investigating the formation, structure, and operational dynamics of blockchain consortiums in seaports will also offer insights into how collaborative efforts can cultivate a unified blockchain ecosystem, bolstering innovation and operational efficiency in maritime logistics and supply chain management.

Disclosure of interest

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data used in this systematic literature review, titled 'Blockchain Adoption in the Port Industry: A Systematic Literature Review', was collected from publicly published articles available in databases such as Web of Science (WOS), Scopus, and ScienceDirect. Data available on reasonable request from the corresponding author.

As per the data-sharing policy of Taylor & Francis, we are committed to sharing data and materials supporting the results or analyses presented in this paper upon reasonable request.

In cases where data cannot be shared due to ethical, privacy, or security concerns, we will explain the limitations and reasons for non-disclosure upon request.

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Appendix A. Port industry stakeholders list.

Group		Stakeholders	Role and Responsibilities
Internal Stakeholders (Balci & Surucu-Balci, 2021; de Langen, 2006; Ha et al., 2019)		Port Authorities	Manage and operate specific ports and make development decisions
		Port Management Board or Committee	The board or committee is responsible for strategic decisions and governance of the port
		Shareholders	Most national ports function as state-owned enterprises, while specific private terminals and ports may possess shareholders
		Port Workers and Various employees	Carry out cargo handling, administrative tasks, maintenance, and security
		Labor Unions	Collaborate for labor rights
Supply chain Stakeholders (Balci & Surucu-Balci, 2021; de Langen, 2006; Farzadmehr et al., 2023)		Terminal Operators	Companies that manage and operate specific terminals within the port
		Shipping Companies	Rely on ports for cargo loading, unloading, and transshipment
		Shipping Agents and Brokers, freight forwarders/3PLs	Facilitate communication and assist with documentation and logistics
		Cargo Owners and Importers/ Exporters	Rely on ports for the timely movement of goods
		Logistics and Transportation Companies (Air/Railways / Road transport companies)	Depend on ports for cargo exchange between transportation modes
		Technology Providers	Develop and offer technological solutions for port operations
		Other service providers	Bunkering, Towing, Warehouse, Equipment rental providers, etc
		Investors and Financial Institutions	Provide funding or financial services for port infrastructure projects, like Bank and insurance companies。
Environment Stakeholders (Balci & Surucu-Balci, 2021; de Langen, 2006; Farzadmehr et al., 2023)	Community Stakeholders	Environmental Groups	Advocate for environmentally friendly port practices
		Local Communities	Voice concerns about environmental impact and quality of life
		Resource-competing firms	Companies utilizing identical resources but not within the exact supply chain
		Security and Law Enforcement Agencies	Ensure port security and prevent illegal activities
	Legislation and Public Policy Stakeholders	National Government/Authorities	National Regulate, license, oversee, and develop port operations
		Non-governmental organizations	IMO (International Maritime Organization)
		Customs and Border Protection Agencies/trade associations	Regulations Regarding Imports and Exports
		Local and Regional government	Contribution to the regional economy, contribution to regional tax income, practical transformation of port/city interface

Appendix B. Barriers resource.

References	Year	Title	Journal Name	Barriers
(Bag et al., 2020)	2020	Barriers to the adoption of blockchain technology in green supply chain management	Journal of Global Operations and Strategic Sourcing	Lack of management vision. Hesitation and workforce obsolescence Privacy concerns. Financial constraints Dependence on blockchain operators Collaboration challenges Cultural differences by supply chain partners Regulatory uncertainty Difficulty in changing organization culture Lack of acceptance in the industry Paybacks are unclear Market barriers and uncertainty
(Öztürk & Yildizbaşi, 2020)	2020	Barriers to implementation of blockchain into supply chain management using an integrated multi-criteria decision-making method: a numerical example	Soft Computing	Lack of IT personnel High investment cost Lack of research and development Units Lack of funding for technological infrastructure Lack of financial subvention for blockchain technology Strong hierarchical structure and bureaucracy Strict administrative control. 8. Information-sharing obstacles The mindset of people needs to be changed. Social and environmental barriers Information Sharing Wasted resources

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Appendix B. (Continued)

References	Year	Title	Journal Name	Barriers
(Yadav et al., 2020)	2020	Blockchain technology adoption barriers in the Indian agricultural supply chain: an integrated approach	Resources, Conservation, and Recycling	Lack of proper government regulation and regulatory uncertainty Tremendous resource (energy, infrastructure) and initial capital requirement Security and privacy concerns Lack of interoperability and standardization Lack of collaboration for consortia creation Lack of trust among agro-stakeholders or public perception Lack of scalability and system speed Lack of agro-stakeholder awareness and ease of use The complexity of blockchain-based system design Agro-stakeholder resistance to Blockchain culture
(Vafadarnikjoo et al., 2021)	2021	Analyzing blockchain adoption barriers in manufacturing supply chains by the neutrosophic analytic hierarchy process	Annals of Operations Research	Challenges in scalability Collaboration, communication, and coordination Cultural differences Customers' awareness Ethical industry involvement External stakeholders' involvement Financial constraints Governmental policies High sustainability costs Immaturity Immutability Implementation tools Information disclosure policy Knowledge and expertise Legal and regulatory uncertainties Managerial commitment Market Competition and Demand Uncertainty Negative public perception Organizational culture change Organizational policies
(Liu et al., 2021)	2021	Barriers to sustainable food consumption and production in China: A fuzzy DEMATEL analysis from a circular economy perspective	Sustainable Production and Consumption	Weak legal enforcement and implementation Inadequate infrastructure Cultural barriers Lack of investment in advanced equipment/technologies Limited expertise in Circular Economy strategies Lack of cross-sector collaboration Economic constraints Absence of economies of scale, particularly Need for environmental education and accountability. Lack of benchmarking, standards, and sustainability practices
(Mathivathanan et al., 2021)	2021	Barriers to the adoption of blockchain technology in business supply chains: a total interpretive structural modeling (TISM) approach	International Journal of Production Research	Business Owner's unwillingness Unfamiliarity with Technology Data privacy/security concerns Regulatory uncertainty Technological infeasibility Complexity in set up/use Uncertain benefits Dependence on Blockchain operators Lack of Cooperation among SC Partners
(Balci & Surucu-Balci, 2021)	2021	Blockchain adoption in the maritime supply chain: Examining barriers and salient stakeholders in containerized international trade	Transportation Research Part E: Logistics and Transportation Review	Lack of government regulations Lack of trust toward blockchain technology (BT) Privacy and business information sharing concerns Lack of knowledge/understanding of BT Lack of support from influencing stakeholders Resistance of some stakeholders to adopt Perceived resource and initial capital requirements Lack of early adopters

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Appendix B. (Continued)

References	Year	Title	Journal Name	Barriers
(Kouhizadeh et al., 2021)	2021	Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers	International Journal of Production Economics	Financial constraints and limited resources Lack of commitment and support from management Absence of new organizational policies Insufficient knowledge and expertise Difficulty in changing organizational culture Hesitation to transition to new systems Lack of tools and standards Lack of customer awareness and understanding Challenges in collaboration, communication, and coordination Issues related to information disclosure policies Difficulties in integrating sustainable practices and blockchain technology Cultural differences among supply chain partners Lack of supportive governmental policies Market competition and uncertainty Lack of external stakeholders' involvement Lack of industry involvement in blockchain adoption and ethical practices Lack of rewards and incentives
(Wang et al., 2021)	2021	Blockchain technology for port logistics capability: Exclusive or sharing	Transportation Research Part B: Methodological	The flexible investment decision
(Saheb & Mamaghani, 2021)	2021	Exploring the barriers and organizational values of blockchain adoption in the banking industry	The Journal of High Technology Management Research	Governance Business Process Management Lifecycle Marketing noise, confusion, and mistrust (Credibility of blockchain) Lack of compatible business models Potential security threats Network scaling & Transaction Throughput Status Quo Mindset Lack of understanding by top managers Intellectual property concerns Lack of compelling business case for the use of blockchain technology Uncertain ROI Firm size Illegal dApps and protocols
(Kaur et al., 2022)	2022	Barriers to blockchain adoption for supply chain finance: the case of Indian SMEs	Electronic Commerce Research	Problems in collaboration, communication, and coordination in the supply chain. Lack of information disclosure policy between supply chain partners Market competition and uncertainty about using blockchain technology Legal and regulatory challenges Lack of blockchain knowledge. 6. Lack of standardization Resistance to convert to new systems
(Marikyan et al., 2022)	2022	Blockchain adoption: A study of cognitive factors underpinning decision-making	Computers in Human Behavior	Subjective knowledge Objective knowledge
(Li et al., 2022)	2022	Blockchain implementation in the maritime industry: critical success factors and strategy formulation	Maritime Policy & Management	Internal leadership Human resources capability Knowledgeable and experienced staff. Organizational culture Financial resource. Customer's acceptance Shareholders' support Supportive external stakeholders Market competition consideration Regulation and incentives
(Moretto & Macchion, 2022)	2022	Drivers, barriers, and supply chain variables influence the adoption of the blockchain to support traceability along fashion supply chains.	Operations Management Research	Difficult to understand how the technology works The high cost of the technology

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Appendix B. (Continued)

References	Year	Title	Journal Name	Barriers
(Dehghani et al., 2022)	2022	High interest, low adoption. A mixed-method investigation into the factors influencing organizational adoption of blockchain technology	Journal of Business Research	New governance model Acceptability Organizational readiness Business model organizational transformation Risk of error for complex business rules Trust Top management support Organizational size Business model readiness
(Kumar et al., 2022)	2022	Integrated blockchain and internet of things in the food supply chain: Adoption barriers	Technovation	Lack of trust. High resource consumption Low attitude toward adoption Legal Permission. High cost of technology
(Hamidi et al., 2024)	2024	A three-stage digital maturity model to assess readiness for blockchain implementation in the maritime logistics industry	Journal of Industrial Information Integration	High initial and ongoing costs for blockchain implementation Regulatory and compliance issues Technological maturity and integration challenges Resistance to change and cultural adoption issues
(Farah et al., 2024)	2024	A survey on blockchain technology in the maritime industry: Challenges and future perspectives	Future Generation Computer Systems	High energy consumption for blockchain networks Integration and implementation costscompliance difficulties Scalability and interoperability challenges Privacy and data protection issues Regulatory