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Physical internet - where are we at? A systematic literature review

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Abstract: The Physical Internet (PI) concept represents a paradigm shift in how logistics and supply chain management can be conceptualised and implemented. Through a meticulous literature review, this study maps the current state of PI research, spotlighting the necessity for a deeper dive into unexplored areas. The analysis reveals significant opportunities for enhancing logistic efficiency and sustainability, providing a foundation for future research and practical applications. This work invites scholars and industry practitioners to explore the transformative potential of PI. In the face of the dynamically evolving discussion on the Physical Internet, this article offers an in-depth analysis of the literature on this concept, shedding light on current research trends in this new face of logistics, challenges, and unexplored areas. The focus is on optimization models, collaboration, and system architecture, identifying knowledge gaps in areas of human impact on the management of the future logistics system and flows, legal aspects, financial management, economic feasibility, social and environmental effects, readiness for cooperation, security, and cultural differences. The literature review emphasizes the importance of PI for sustainable development and the goals of Industry 4.0, pointing to its potential role in transforming global logistic processes. By examining challenges, proposing solutions, and highlighting the potential of PI principles in improving logistic processes, this work constitutes a valuable resource for researchers, practitioners, and policymakers aiming to understand and implement the concept of the Physical Internet.

1 Introduction

The term Physical Internet (PI) refers to a concept that aims to apply principles of information flow and coordination from the digital world to the physical movement of goods. It involves interconnected logistics networks, collaborative shipping, and the use of smart technologies to improve efficiency in freight transportation. The concept of the Physical Internet remains relatively unknown to many, yet the need for resource conservation and addressing the impact of human activities on climate change necessitates solutions that maximize the utilization of existing resources, promote resource sharing, and minimize the need for new infrastructure and fleet development that further exploit resources. In logistics, the Physical Internet serves as a viable approach to achieve these objectives.

Since the inception of this concept, numerous research efforts have emerged, and as this field develops and collaboration among stakeholders in the transport and logistics industry strengthens, new unexplored possibilities arise. Therefore, the aim of this article is to investigate the trends in the literature and identify research gaps. These gaps are crucial because entities already operating within networks that can be classified as the Physical Internet encounter practical challenges that have not been thoroughly explored by theorists. Defining and understanding these challenges can facilitate the identification of potential solutions.

Physical Internet emphasizes logistics and supply chain optimization, therefore the Author identified articles that contribute to understanding the flow of information and goods within the PI. The Physical Internet offers a holistic approach in managing all element of logistics – not only goods and information flows and management, but also financial flow optimization.

From the analysis of the presentations on the latest 9th Physical Internet conference in Athens, it becomes evident that the mindset remains a barrier to the advancement of the Physical Internet. However, research often neglects this topic, partly due to the intangible nature of mindset, which makes it challenging to measure. Unfortunately, if something cannot be measured, it cannot be improved. Nonetheless, openness to sharing is a key factor in the development of the Physical Internet since sharing and collaboration are the foundational principles of this concept, while logistics serves as the invisible backdrop of our daily lives. If societies are not prepared for degrowth concepts, which would enable resource conservation and sustainable utilization, the answer lies within the Physical Internet.

2 Methodology

The literature review methodology followed a systematic approach to identify relevant articles on the topic of the "physical internet." The search was conducted in the Scopus database using a specific search query. The search string employed was: TITLE-ABS-KEY ("physical internet") AND (LIMIT-TO (OA, "all")) AND (LIMIT-TO (EXACTKEYWORD, "Physical Internet")). This query aimed to retrieve articles that had the exact keyword match for "physical internet" and were also available as open access publications.

Upon retrieving the articles, a comprehensive evaluation was undertaken. All selected articles underwent a thorough reading to assess their relevance and quality. A total of 74 articles were deemed suitable for further analysis.

To gain insights into the thematic structure and research trends within the selected articles, a clustering technique was employed. The articles were categorized into thematic clusters based on their content, allowing for a systematic exploration of the topics and identification of research gaps within the field of the physical internet.

In addition to thematic analysis, an investigation of author affiliations was conducted to provide an understanding of the geographical distribution of contributors in this research domain. A map was created to visually represent the countries from which the authors' affiliations originated, shedding light on the global engagement in physical internet research.

To further delve into the interconnections between topics and keywords within the selected articles, the VosViewer tool was utilized. By employing network analysis techniques, the relationships and associations between different themes and keywords were explored, allowing for a comprehensive understanding of the conceptual landscape and knowledge interdependencies in the field of the physical internet.

Furthermore, to identify the key concepts and emphasize the recurring themes across the selected articles, a word cloud representation was generated. This visualization technique showcased the frequency and prominence of different keywords extracted from the articles, providing a concise summary of the main focus areas in the literature.

By employing this rigorous methodology encompassing search query construction, article selection, thematic analysis, author affiliation mapping, network analysis, and word cloud visualization, a comprehensive and scholarly examination of the literature on the physical internet was conducted, enabling a systematic understanding of the existing knowledge landscape, research trends, and research gaps in this domain.

3 Analysis and results

Since the inception of the Physical Internet concept, several papers have been published, with limited progress. However, during the pandemic period, a significant surge in research activity within this field has been observed. This phenomenon can be attributed to the heightened awareness that reliance on long and complex supply chains may not be sustainable, particularly in the face of disruptions. Additionally, the recognition of the detrimental consequences of independence and lack of collaboration has further underscored the need for reevaluation. Figure 1 shows the number of papers over the years.

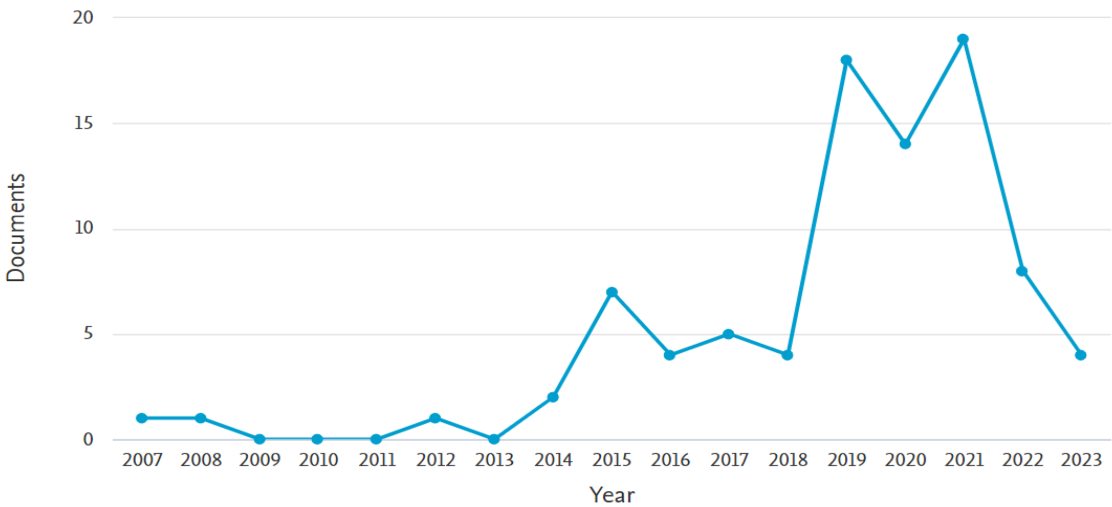

Figure 1 Documents by year
Source: Scopus database

Physical Internet is not limited to a few specific countries but involves a diverse international community, reflecting global interest and collaborative efforts in advancing the understanding and application of the Physical Internet concept (Figure 2).

Based on the number of authors and their affiliating countries in the field of Physical Internet, several conclusions it can be noticed that France has the highest number of authors with affiliations in the field of Physical Internet, indicating a strong presence and contribution from the French academic and research community. The United States follows closely behind France, suggesting significant engagement and research output from American scholars in the area of Physical Internet. The United Kingdom, China, and Canada also demonstrate a notable presence, with a considerable number of authors contributing to the literature on the Physical Internet. Germany, Belgium, Hungary, Morocco, and the

Netherlands exhibit moderate involvement, indicating active participation in research related to the Physical Internet. Other countries, including Austria, Hong Kong, Poland, Portugal, South Korea, and Vietnam, contribute with a smaller number of authors but still have a noteworthy presence in the field.

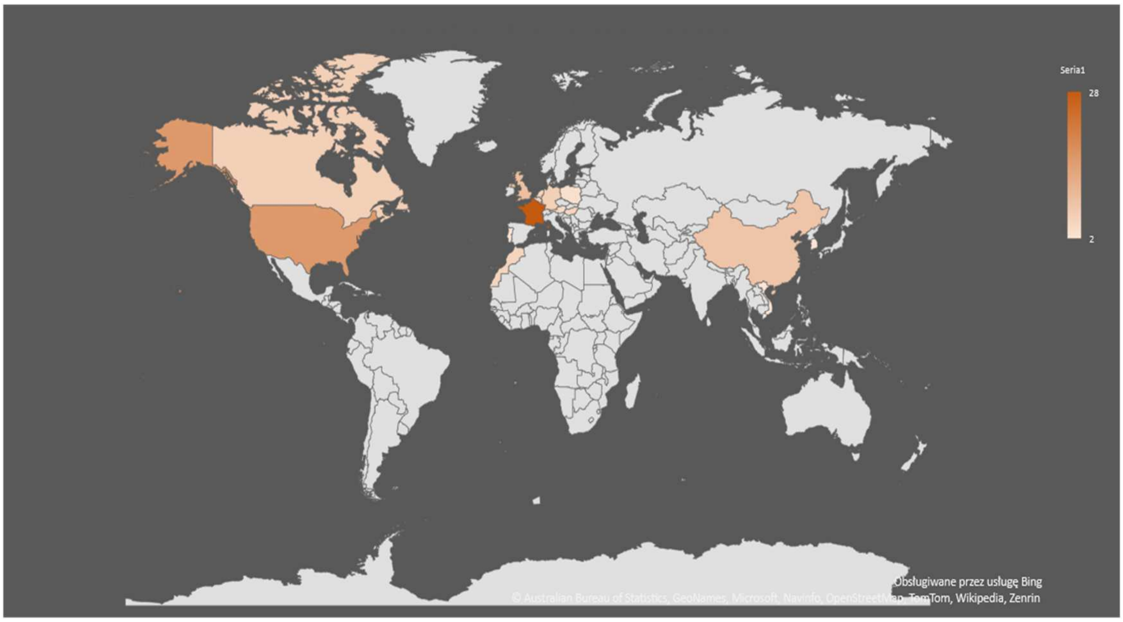

Figure 2 Countries of authors' affiliating institutions
Source: Own elaboration

As for possible reasons possible reasons for France having a high number of authors in the field of Physical Internet it can be indicated that France possesses a robust academic and research system, including renowned scientific institutions and universities, including Physical Internet Chair in MINES ParisTech, PSL Research University. Another possible reason are numerous research projects, contributing to the increase in the number of authors in the field of Physical Internet. All this makes France having a high level of awareness and interest in the topic of Physical Internet among its scientists and researchers. Research institutions and universities in the country may actively promote and support studies related to this area.

This interdisciplinary approach is crucial for developing comprehensive solutions and understanding the broader implications of implementing the Physical Internet concept. Figure 3 shows the subjects areas of analyzed papers.

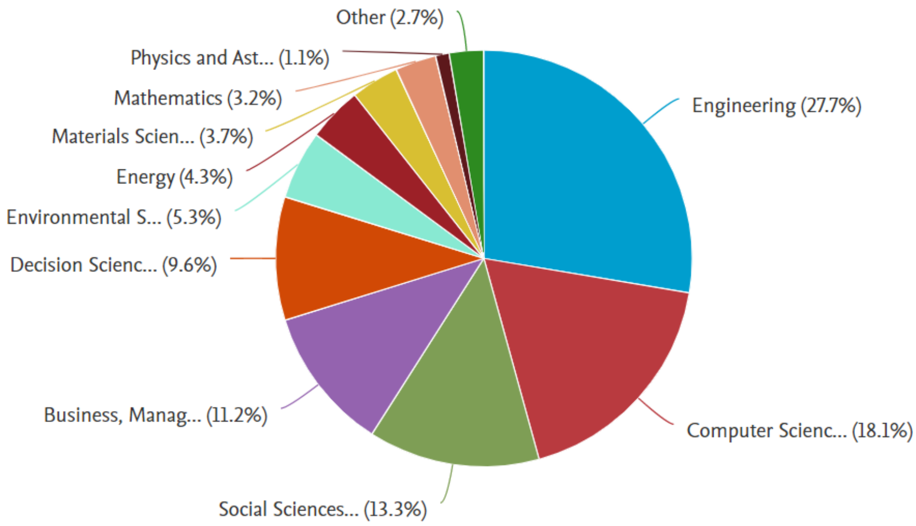

Figure 3 Documents by subject area
Source: Scopus database

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Based on the distribution of documents by subject area in the field of Physical Internet, several conclusions can be drawn.

Engineering has the highest representation among the subject areas, accounting for 27.7% of the documents. This suggests that a significant portion of research in the field of Physical Internet focuses on engineering aspects, such as infrastructure design, transportation systems, and logistics optimization. Computer sciences follow closely behind, comprising 18.1% of the documents. This highlights the importance of computational methods, data analysis, and information systems in advancing the understanding and implementation of the Physical Internet concept. Social sciences have a significant presence, representing 13.3% of the documents. This indicates the recognition of the societal impact and implications of the Physical Internet, including its influence on supply chain management, collaboration, and sustainable development. Business and management contribute to 11.2% of the documents, showcasing the recognition of the economic and managerial aspects of implementing the Physical Internet in organizations and supply chains. Decision sciences and environmental sciences have moderate representation, with 9.6% and 5.3% of the documents, respectively. This highlights the focus on decision-making frameworks and the consideration of environmental sustainability in the context of the Physical Internet. Energy, materials sciences, mathematics, and physics have relatively lower representation, ranging from 4.3% to 1.1%. These findings indicate the multidisciplinary nature of research on the Physical Internet, with contributions from engineering, computer sciences, social sciences, and various other fields.

When analyzing the keywords of the reviewed papers (Figure 4) we can observe the most frequently mentioned issues. The keywords mention various mechanisms such as auction-based mechanisms, hybrid modeling, and peer-to-peer mechanisms. These mechanisms are likely related to economic models, logistics systems, and decision-making processes. Also, keywords often mention multi-objective optimization, sensitivity analysis, and Pareto principle. These concepts are often used in the context of finding the best solutions or trade-offs in complex systems, such as freight transportation, supply chain management, and logistics networks. Urban planning and transportation are keywords that indicate research on urban planning, urban transportation, and logistics in urban areas. This suggests a focus on understanding and optimizing the movement of goods and services within cities, taking into account factors such as sustainability, efficiency, and decision-making processes. There are also keywords related to maritime ports, port selection, and port performance evaluation. These keywords indicate a focus on optimizing port operations, analyzing port-related factors, and improving efficiency in maritime logistics. Ports and other terminals, serve as critical nodes in the PI, facilitating the flow of goods, information, and financial resources and PI promises enhancing port efficiency and integration. Some keywords mention blockchain technology, smart contracts, and supply chain management. This suggests an interest in exploring the potential applications of blockchain for improving transparency, traceability, and security in supply chain operations. We can also observe the “digital twin” phrase, which refers to a digital representation or simulation of a physical object, system, or process. This concept involves creating a virtual model that mirrors real-world entities, enabling simulation, analysis, and control. The keywords mention digital twins in the context of supply chain management, logistics systems, and real-time evaluation. There are also keywords related to sustainability, sustainable development, carbon footprint, and energy efficiency. These keywords indicate a focus on incorporating environmental considerations and reducing the impact of logistics and transportation activities. Finally, the keywords mention various decision-making approaches, such as multi-criteria decision analysis, Markov decision processes, and heuristic algorithms. These techniques are often used to support decision-making processes and optimize complex systems.

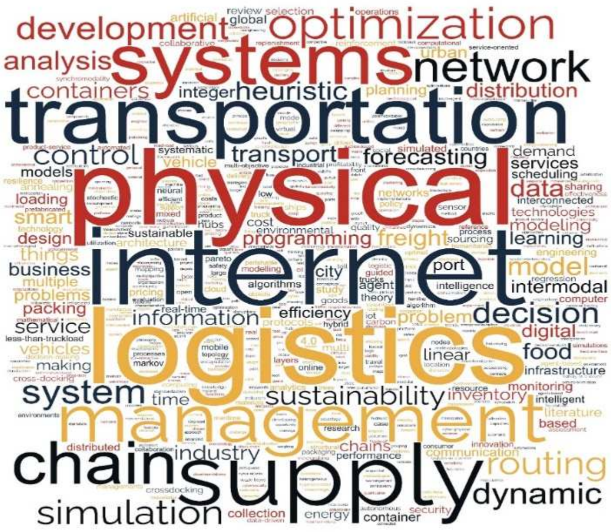

Figure 4 Keywords used in analyzed papers
Source: Own work using Wordclouds.com

Figure 5 and Figure 6 show how authors most commonly combine selected topics.

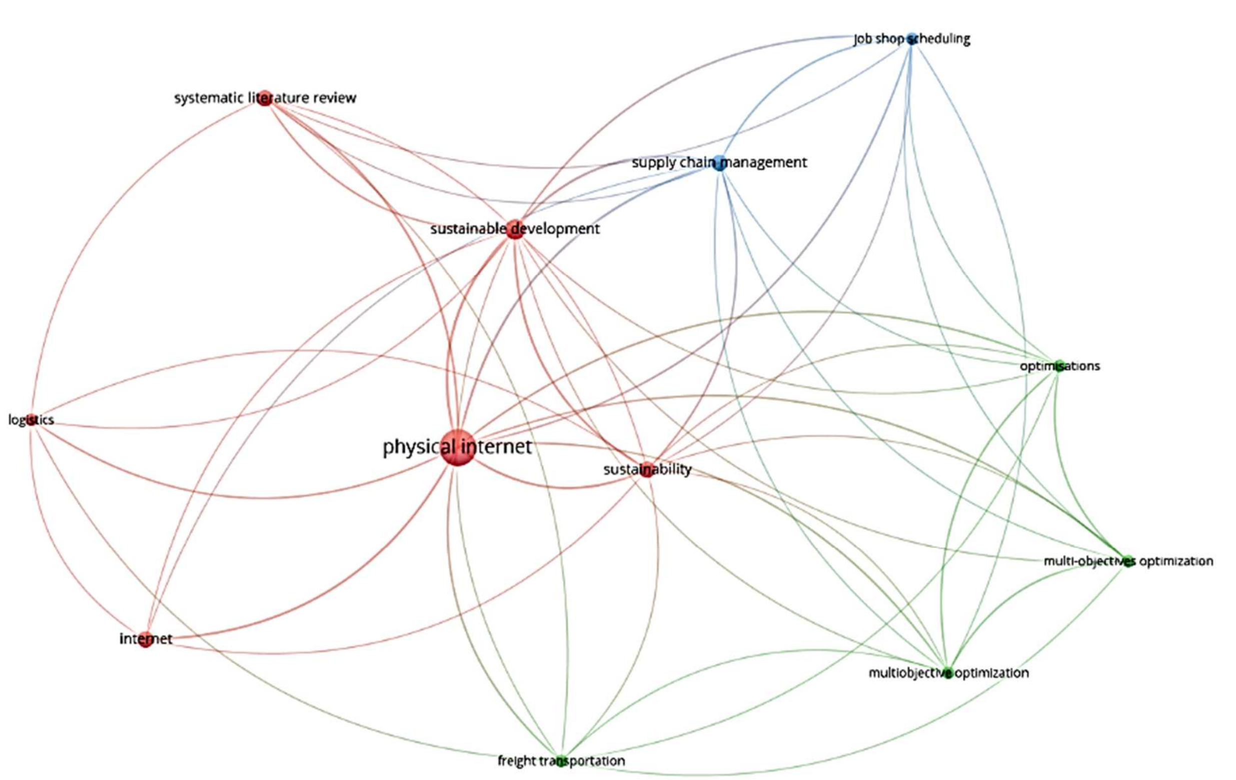

Figure 5 Phrases most often connected in the reviewed literature

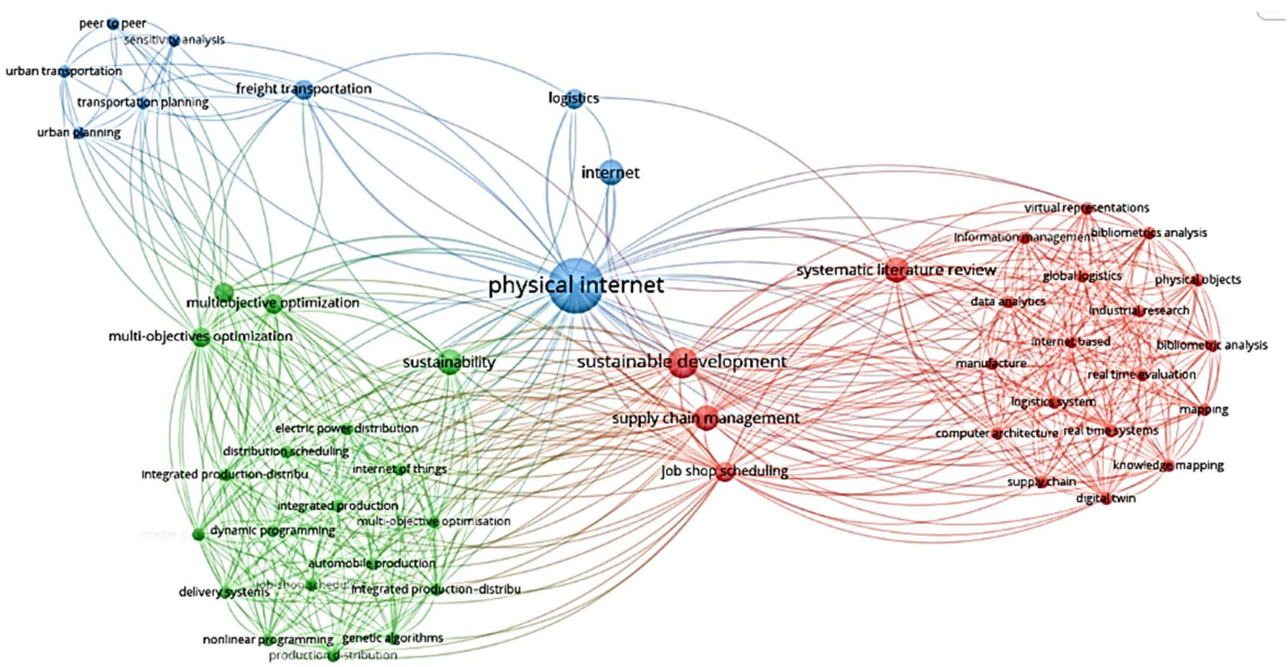

Figure 6. Clusters of phrases most often connected in the reviewed literature

Figure 7 - Figure 10 depict individual clusters of concepts and their associated connotations in the examined articles.

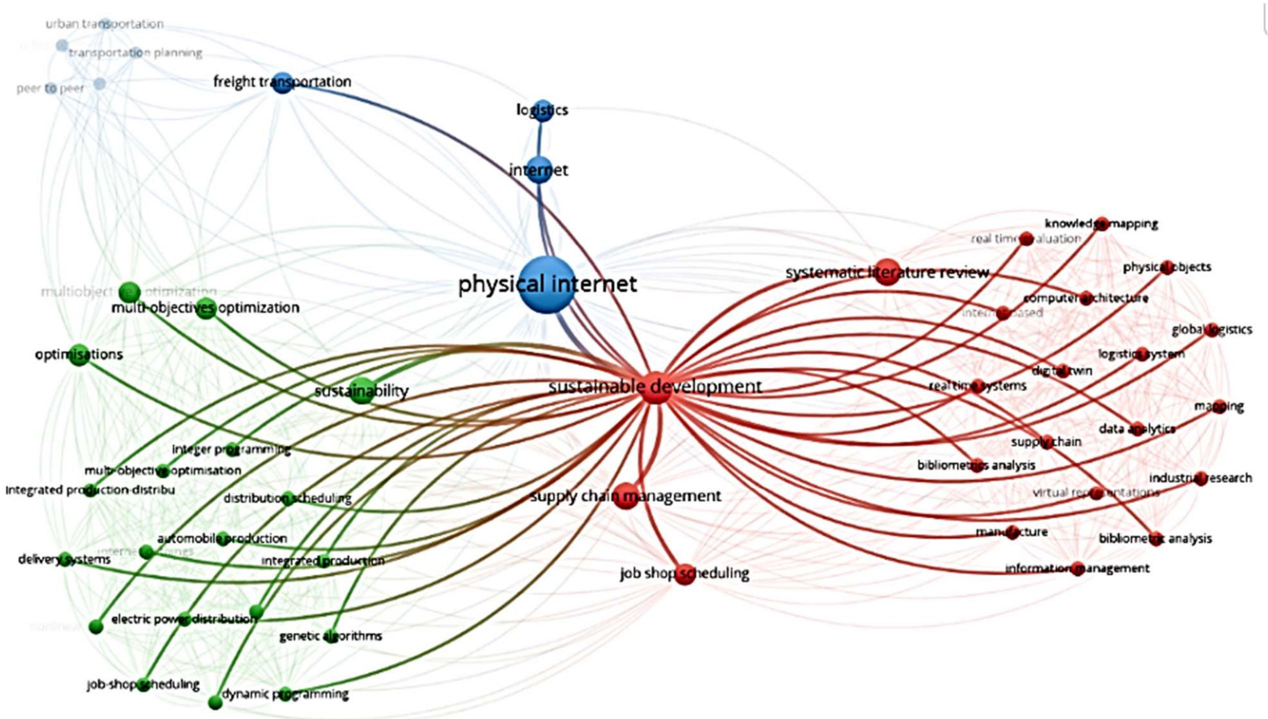

Figure 7 The cluster of phrases most often connected with the phrase 'sustainable development' reviewed literature

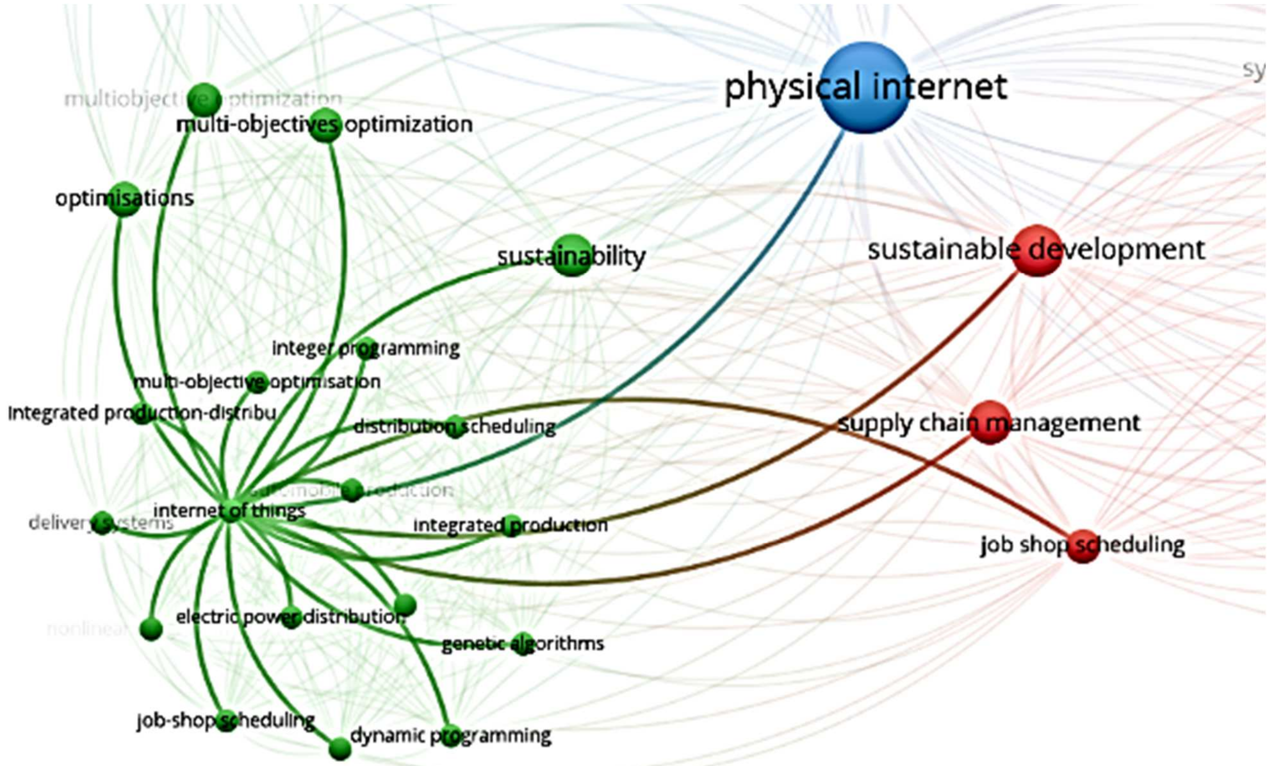

Figure 8 The clusters of phrases connected with the phrase 'internet of things' in the reviewed literature

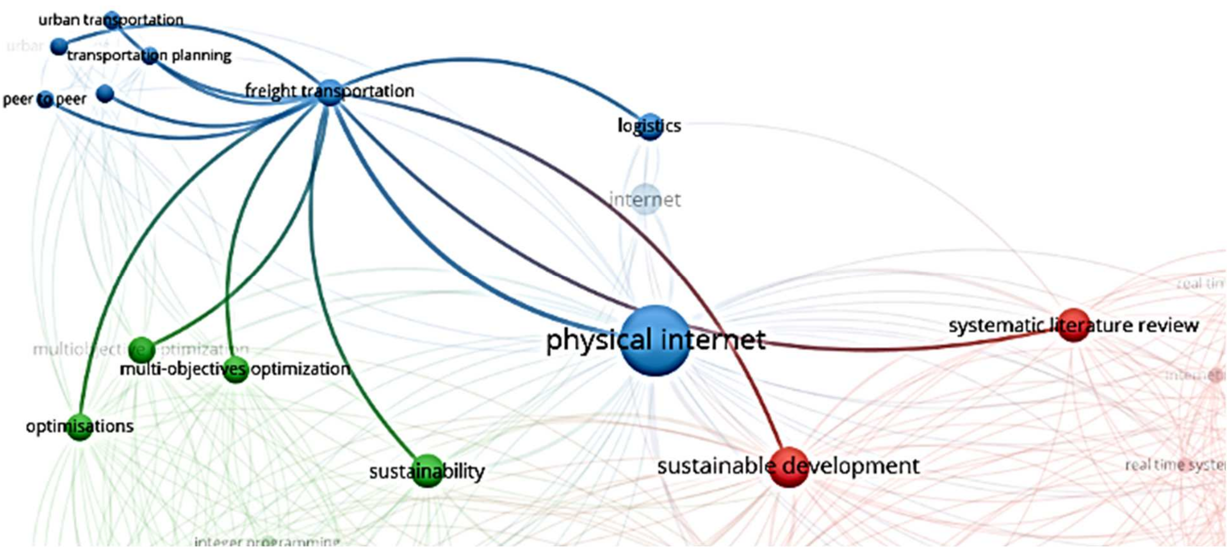

Figure 9 Clusters of phrases connected with the phrase 'freight transportation' in the reviewed literature

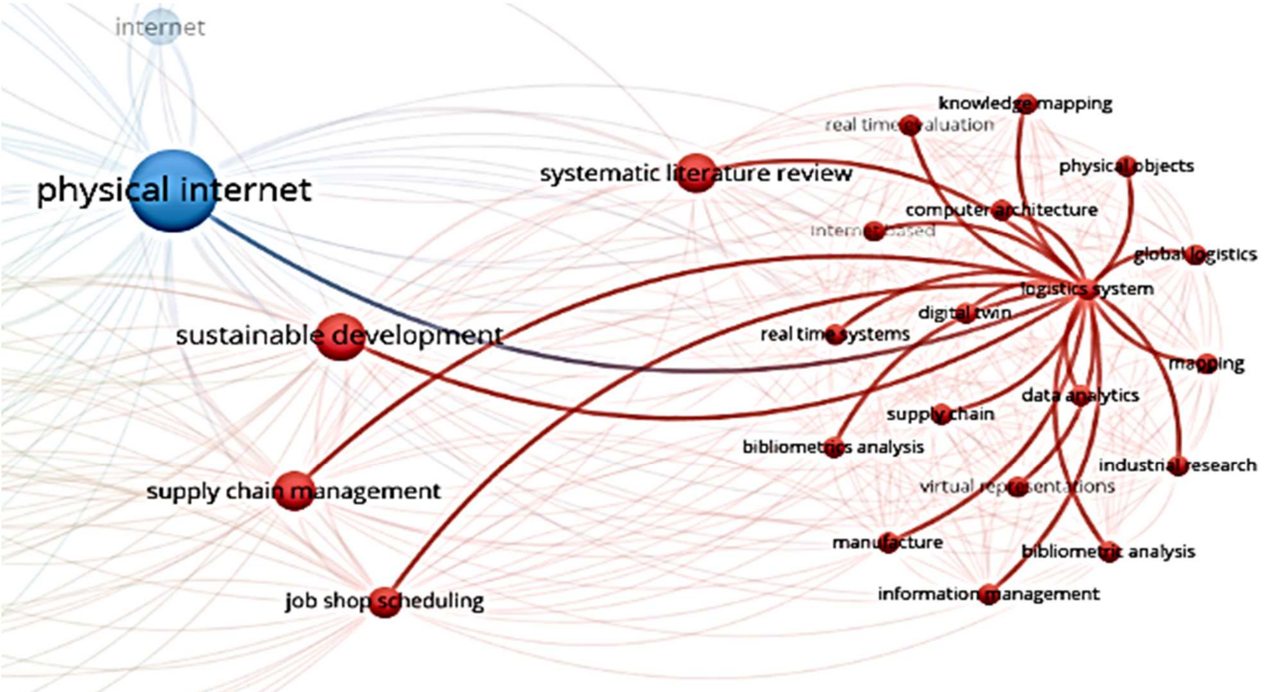

Figure 10 Clusters of phrases connected with the phrase 'logistics system' in the reviewed literature

Table 1 (in general) and Table 2 (in detail) describe the trends, thematic groups, and specific topics addressed by the authors of the analyzed texts.

Table 1 Areas discussed in the reviewed papers

The most frequently discussed aspects of the Physical Internet	**Examples**
Efficiency and sustainability: The Physical Internet is seen as a solution to improve the economic, environmental, and social efficiency of global logistics systems.	• Global logistics sustainability and efficiency • Conceptual framework and network models for PI • Application and verification of PI principles in economic practice
Logistics transformation: The Physical Internet aims to redefine supply chain configurations, business models, and value-creation patterns by introducing an open global logistics system.	• Open logistics interconnection reference model for PI

Industry 4.0: The Physical Internet is considered a practical solution to support the requirements of Industry 4.0, which involves addressing the challenges of incorporating new technologies, information systems, and physical facilities.	• Logistics Web and Industry 4.0 • Digital transformation and its implications for PI • Blockchain and smart contracts in hyperconnected logistics • Lean thinking and value stream mapping for the transition to PI
Interoperability and modularity: The concept of the Physical Internet emphasizes the need for interoperability between different logistics systems and the modular design of logistics services.	• Design and characteristics of PI containers
Smart product-service systems: The integration of smart product-service systems within the Physical Internet is explored as a way to tackle complex logistics systems and improve efficiency.	• Smart product-service systems in interoperable logistics • Order bundling and transparent user networks
Collaboration and networking: The Physical Internet envisions collaborative networks and information exchange among logistics stakeholders as a means to achieve sustainable logistics practices.	• Motives and success factors for collaboration in PI networks

Table 2 The examined articles are sorted by thematic groups

Subject area	**Literature summary**
Physical Internet Concept and Framework these summaries demonstrate the focus on developing an efficient and sustainable logistics web, incorporating modular units, real-time planning, information exchange, communication infrastructure, and IoT-enabled services. The Physical Internet aims to address the challenges of the evolving manufacturing industry and urban logistics while requiring further research and innovation for its successful implementation	Physical Internet aims to enable an efficient and sustainable Logistics Web - Logistics Response to the Industry 4.0 [1]. The evolving manufacturing industry necessitates the development of suitable information systems, physical infrastructure, and technologies to meet future economic needs, with the Physical Internet being a proposed solution that requires further in-depth research [2]. The NOLI model is compared and contrasted with the OSI and TCP/IP models of the Internet, and it is also integrated with Montreuil's OLI model for the Physical Internet. Contrasts between the NOLI model presented here and the aforementioned models primarily manifest in the way physical object definitions are structured across various layers, extending beyond the lowest layer [3]. The idea of implementing Physical Internet principles in logistics operations underscores the significance of modular transport components, dynamic planning, data sharing, and communication infrastructure. It also encourages future exploration into comprehensive solutions for all facets of the Physical Internet [4]. Exploring the connections and collaborative dynamics between these elements leads to the concept of Hyperconnected City Logistics systems, encompassing nine core principles that provide a robust framework for creating effective and eco-friendly urban logistics and transportation systems. The chapter closes with a set of research and innovation hurdles to address [5]. Information framework and service-oriented architecture for the Internet of Things (IoT) applied in logistics operations, highlighting the potential benefits of IoT-enabled logistics services in the Physical Internet [6].
Logistics and Supply Chain Optimization (include optimization models for carrier revenue, inventory management, container flows, lean paradigms, introducing additional service points, collaboration within Physical Internet networks, supply chain modeling, data clustering, vehicle technology innovations, last mile delivery, cross-docking, synchromodality, dynamic pricing for carriers, and the integration of the Physical Internet with Industry 4.0 practices.	A model for optimizing carrier revenue within the context of the Physical Internet is created by integrating Dynamic Programming and Integer Programming techniques. In this model, carriers submit bids for incoming Less-Than-Truckload (LTL) requests of varying volumes and destinations, with the aim of maximizing their profits [7]. Inventory management in the Physical Internet, where interconnected hubs enable multiple source selection options and transshipments, leading to cost reduction and improved customer service levels compared to current centralized inventory control policies [8]. The correlation between Lean principles and the Physical Internet is examined, with a particular focus on the role of value stream mapping as a tool to facilitate the attainment of goals outlined in Alliance for Logistics Innovation through Collaboration roadmap for logistics innovation. Additionally, it aids in aligning the Physical Internet principles with the predefined timelines [9]. The study investigates the consequences of integrating extra service points into pre-established dedicated freight routes in a service-oriented company, as part of the broader Physical Internet vision. This vision seeks to reshape conventional logistics networks into transparent open systems that can be accessed by a diverse range of users [10]. The study delves into the motivations behind and key drivers for collaboration within a Physical Internet (PI) network. It employs an interpretive case-based research methodology involving shippers and logistics service providers. This research offers valuable insights into why organizations become part of a PI network and the essential prerequisites for ongoing cooperation. Notably, this represents a pioneering study in a multi-industry setting [11]. Existing supply chain models review and proposal of enhanced approach for modeling the digital supply chain [12]. The introduction of a refined metaheuristic algorithm, named ISCA, focuses on data clustering to augment PI-SCN decisions. This algorithm is designed to offer decision-making support for

	business owners. Its robustness is verified through comparisons with five other metaheuristics, using established benchmark datasets [13]. In a PI-SCN within case study in Morocco, utilizing a hybrid method that combines artificial neural networks with an enhanced slime mould algorithm metaheuristic has been examined for its effectiveness in reducing costs and shortening lead times. [14]. Hubs and online design in dynamic hubs at the tactical [15]. The potential of a collaborative and interconnected logistics system, inspired by the Physical Internet concept, to improve last mile delivery and vehicle dispatching, with a focus on reducing empty vehicle movements and carbon dioxide emissions for a more sustainable green freight transport [16]. Flexible model to consider the different needs of the companies [17]. Synchromodality, a flexible and dynamic approach to transportation, utilizes multiple modes of transport to promote environmentally friendly options like rail and inland waterways, while maintaining responsiveness and service quality, with a proposed decision rule that integrates parallel usage and real-time switching of transport modes to induce a modal shift towards low carbon options [18]. The rise of e-commerce and the Physical Internet has transformed the role of showcasing in the supply chain, allowing for fast and reliable delivery of goods from connected sources, leading to the need for a decision support system to optimize showcasing value, as demonstrated through a model focusing on recreational vehicle dealerships [19]. An evolving pricing challenge for less-than-truckload carriers arises across multiple auction cycles in the context of the Physical Internet. This challenge takes into account the forecasting of peak demand. The Physical Internet is characterized by the interconnection of logistics networks through accessible PI-hubs, featuring a multitude of transportation requests. Carriers engage in a series of auction rounds to bid for these requests [20]. Exploring the interaction between resilience and sustainability within Physical Internet (PI)-enabled supply chains, this study suggests a novel hybrid approach. This approach melds a method for scoring performance based on resilience and sustainability with mixed-possibilistic programming. It aims to optimize cost, sustainability, and resilience levels. The results demonstrate the superior sustainability and resilience performance of PI-enabled supply chains when coping with disruptions, as compared to traditional supply chains [21].
Technology and Digital Transformation in the Physical Internet (these papers shed light on the role of emerging technologies and digital transformations in optimizing logistics operations, improving visibility, enhancing collaboration, and achieving efficiency and sustainability within the Physical Internet framework.). Technology such as blockchain, IoT devices and smart contracts are crucial to ensure transparency, security, and efficiency within the PI logistics networks, to manage information and financial flows.	The integration of blockchain, IoT devices, and smart contracts provides heightened transparency and safeguards against fraud in the olive oil supply chain, granting a distinct competitive advantage. The widespread adoption of blockchain technology in all food supply chains with quality verification enhances visibility and delivers a competitive edge to industry participants [22]. The potential for reconfiguring platoons within the Physical Internet system through the establishment of a virtual transfer point [23]. Embracing Digital Transformation (DT) within the context of the Physical Internet (PI) fosters increased connectivity and compatibility through intermodal hubs, collaborative protocols, and standardized containers. This presents both challenges and opportunities for future research in the pursuit of an efficient and sustainable global logistics system [24]. The potential of smart Product-Service Systems (PSS) in service-oriented, intelligent interoperable logistics, highlighting their promising potential in the Physical Internet (PI) and suggesting the need for further research to advance the field and usher in a new era of intelligent interoperable logistics [25]. Demonstrating a concrete implementation, this explores how blockchain and smart contracts hold promise for integration into hyperconnected logistics [26]. Proposing a conceptual framework for examining the Physical Internet (PI) with inspiration drawn from the well-established Digital Internet (DI). This framework emphasizes the necessity of tackling both the reachability problem and optimization issues within the PI network. It includes the incorporation of logistics-related metrics such as cost, emissions, and delivery time [27]. Deep reinforcement learning is emerging as a promising avenue for addressing sequential decision-making challenges, particularly when the optimal policy structure is not well-understood. When applied within supply chain control towers, it has the potential to streamline and enable collaborative shipping in the context of the Physical Internet [28]. A decentralized system, known as the Cyber-Physical Internet of Things System (CPIoTS), supported by blockchain technology. This system is designed to reduce latency, guarantee secure consensus, and ensure dependable resource coordination within edge-cloud computing. These objectives are accomplished through the implementation of an efficient resource allocation algorithm that leverages policy-based Deep Reinforcement Learning (DRL) techniques [29]. The FreightShare Lab Platform is dedicated to fostering horizontal collaboration in freight logistics. It achieves this by implementing collaborative operational plans and decision support

	algorithms. This approach empowers logistics service providers and freight operators to maintain their profit margins while also sharing the benefits of improved efficiency, as showcased in a case study involving a UK freight operator [30]. An agent-based simulation is utilized to replicate interactions between mobile resource units and the physical infrastructure within a rail-road transport network. This simulation illustrates the advantages of the Physical Internet, particularly in diminishing the occurrence of empty truck journeys. Additionally, it highlights the role of the Physical Internet in facilitating digital transformation within urban rail transit systems for both distribution and passenger transport [31]. Analyzing the incorporation of Industry 4.0 practices reveals that, although previous suggestions have led to only minor adjustments, there is an increasing focus on Industry 4.0 principles, with a notable emphasis on physical internet hubs [32].
Port Operations and Physical Internet (these papers emphasize the significance of ports in the Physical Internet and provide insights into the areas where ports can contribute, the information architecture required, the role of autonomous decision-makers, and the evolution of Port Community Systems to enhance supply chain performance and efficiency within the Physical Internet framework.):	The scheduling and routing problem in a Rail-Road PI-Hub terminal, aiming to minimize energy consumption and cost through the use of PI-containers, and presents optimal solutions using a Multi-Objective Mixed-Integer Programming model and meta-heuristics [33]. Strategic approaches for ports to support the Physical Internet's growth and deployment encompass enhancing transport infrastructure, promoting standardization, developing advanced terminal areas, upgrading ICT hardware, improving information systems and platforms, and focusing on sustainability management. [34]. The proposed information architecture in the Physical Internet (PI) ports integrates real-time decision-making and dynamic cargo bundling, facilitated by an open interface platform and the use of PI containers, which requires reevaluating existing information systems and understanding future requirements for satisfying their needs [35]. The functioning of maritime ports in the context of the PI is still underexplored [36]. Two autonomous decision-makers, intelligent containers and ships, for evaluating port performance and selection in the Physical Internet (PI). It identifies future evaluation criteria and their importance based on expert surveys [37]. The evolution guidelines of Port Community Systems (PCS) and the business factors that improve supply chain performance. It highlights the transition from isolated supply chains to open supply chains and the improvement of supply chain efficiency [38].
Urban Logistics and City Systems (these papers provide insights into the potential applications and benefits of the Physical Internet in logistics and urban areas. They explore collaborative planning, facility location, shared networks, and optimization models, highlighting the need for efficient and sustainable transportation systems within the context of the Physical Internet.). City logistics does not only mean urban freight distribution, it is important to highlight the significance of managing human flows and information flows in urban logistics systems, supported by the PI concept, to promote sustainable and efficient city systems.	The potential for collaborative planning within an urban logistics system supporting the Physical Internet, functioning as a central hub for freight transportation with multiple e-commerce warehouses [39]. The Internet of Perishable Logistics (IoPL) introduces a layered architecture model based on the cyber Internet for distributing perishable goods. It explores the synergies between IoPL and the cyber Internet, shedding light on research opportunities emerging from these synergies [40]. In the innovative domain of the Physical Internet, the development of efficient PI-cross-docking hubs that enable rapid, efficient, and adaptable container transfers is a fundamental aspect [41]. An optimization model is devised for the collaborative coordination of deliveries within a multi-tier hyperconnected urban logistics system. This model specifically concentrates on tactical planning within the initial tier, where a consortium of carriers and logistic operators pool resources and information flows to provide more efficient and sustainable delivery services [42]. The potential of shared networks within urban areas to mitigate congestion and transportation costs is explored. This is achieved by analyzing and modeling a system where high-capacity freight vehicles operate between Key Freight Areas, addressing the inefficiencies of general freight transport within large metropolitan regions [43]. The perspectives of transport service providers in Austria concerning horizontal collaborations and the Physical Internet are examined, emphasizing the significance of awareness and information sharing during the implementation process [44]. Bridging the gap by introducing a framework that integrates multi-layer decision-making and the Physical Internet methodology, with a focus on the functional aspects of operational challenges in City Logistics systems and optimization. The aim is to enhance integration, cooperation, and the utilization of logistic infrastructure [45]. Facility location within a Physical Internet environment is considered [46]. Dynamic Multiple Depots Vehicle Routing explores feasible solutions for routing transportation between PI-hubs and retailers within the same cluster [47]. The potential of mobile access hub deployments for urban parcel logistics is investigated. It identifies the impact of design parameters on economic and environmental performance, with results highlighting design flexibility and pronounced advantages in highly variable environments [48]. UCC as a realization of the Physical Internet concept within cities are discussed [49].
Artificial Intelligence and Optimization Algorithms (these papers contribute to the	The asynchronous multimodal process approach is presented as a valuable addition to existing Physical Internet concepts, where modeling, analysis, and optimization of a supply chain are discussed. [50].

understanding and advancement of modeling, optimization, and analysis within the Physical Internet framework. They explore approaches for improving supply chain efficiency, addressing information communication issues, optimizing vehicle exchange, and forecasting container flows.):	An innovative approach to cost reduction and lead time enhancement within a physical internet supply chain network is explored. This approach employs a hybrid framework that combines artificial neural networks with an improved slime mold algorithm. The study underscores the effectiveness of this approach in comparison to other metaheuristics, particularly for training feed-forward neural networks [51]. The PI-BIMS (Physical Internet-based Business Information Management System) facilitates real-time data collection, communication, and visualization across various stages of production, transportation, and on-site assembly [52]. A virtual hub facilitates the swapping of vehicles among platoons. The study introduces a reinforcement learning-based model aimed at enhancing efficiency in situations with high volumes of incoming vehicles and short dispatch intervals. However, it notes that heuristic models tend to outperform in environments characterized by fewer vehicles [53]. A framework for forecasting inbound container volumes encompasses three distinct phases: data preprocessing, training through convolutional neural networks and recurrent neural networks, and evaluation based on accuracy metrics such as mean absolute error [54]. The Physical Internet-enabled hyperconnected order-to-delivery system incorporates IoT-enabled machines for communication. Additionally, a multi-objective genetic algorithm is utilized to optimize sustainable production-distribution scheduling within the Physical Internet-enabled hyperconnected manufacturing system [55].
Collaboration and Collaboration Models (these papers contribute to various aspects of freight transport and the implementation of the Physical Internet, including organizational approaches, applications of technology and optimization methods, UCC development, and potential benefits in different contexts.):	Gamification methodology to investigate the centralization and decentralization of the market. A freight transport game was developed for simulation [56]. The application of heuristic and reinforcement learning (RL) models to enable collaborative logistics and innovation in vehicle technology, specifically focusing on multiple platoon collaboration, and evaluates their efficiency based on transportation cost, highlighting the advantages of RL for high vehicle numbers and low dispatch interval, and heuristics for low vehicle numbers [57]. The potential benefits of adopting the Physical Internet paradigm in developing countries, considering the challenges they face in managing supply chain and logistics networks, and proposes options for assessment and research methodology design [58]. The performance characteristics for each PI-hub and for the whole PI-hub network [59]. The study explores how imbalances within the logistics network can lead to either a shortage or excess of supplies at various network points. It investigates solutions to address these challenges. [60]. A multi-agent reinforcement learning algorithm is utilized to simulate the strategic bidding behavior of carriers and shippers in the freight transportation market. This research incorporates a game-theoretical approach and numerical analysis, focusing on extracting insights into their behaviors [61].
Sustainability and Environmental Impact (he papers discuss different aspects of supply chain management, logistics operations, sustainability, and the application of technology in transportation. They highlight the potential benefits and challenges associated with adopting new approaches, such as the Physical Internet, artificial intelligence, and data analytics, in the logistics and transportation industry).	The application of Physical Internet (PI) principles within humanitarian organizations is examined as a means to amplify their operational efficiency and effectiveness in supply chain and logistics endeavors. This entails considering the integration of PI principles in transportation, storage allocation, and inventory management, despite the associated expenses and the necessity for comprehensive logistical and legal reconfiguration [62]. Theoretical perspectives related to sustainable industrial systems within the transportation sector are explored, with specific attention directed towards the On-board Unit in Electronic Toll systems. This exploration delves into the utilization of artificial intelligence and Industry 4.0, employing kernel density analysis. It underscores the significance of regulatory frameworks and protective measures for technological advancements in artificial intelligence and robotics [63]. Anonymized microdata obtained from the European Road Freight Transport Survey is harnessed to identify recurring patterns in logistics operations across EU and EFTA countries. This analysis underscores the value of data analytics in enhancing the efficiency of logistics operations and addressing sustainability imperatives [64]. Innovative methods for tracking parcels within the network are introduced [65].
Smart containers (he papers cover topics such as the learning capabilities of smart containers, information sharing challenges, logistics system architectures, modular box development, design of PI-containers, optimization models for PI-hubs, and strategies for truck loading	In a self-organizing logistics environment, smart containers collectively acquire bidding policies through information sharing, despite their limited lifespan, utilizing a reinforcement learning algorithm. Nevertheless, carriers may exhibit disincentives to share information, emphasizing the necessity for further exploration into the interplay between smart containers and transport services [66]. An investigation into how recent global standards and technologies are applied in a multi-companies open network, particularly concerning the management of reusable pallets [67]. The methodical development process leading to the creation of modular box prototypes incorporates a holistic approach that encompasses all the requirements of the shipping network [68].

and container grouping in the Physical Internet context)	Emphasis is placed on the design of such containers, with particular attention to their associated activeness. After outlining the physical and informational prerequisites linked to PI-containers, the concept of activeness is delineated, and the primary research challenges in this domain are presented [69]. A multi-objective mathematical model is introduced to optimize operations within Road-Road PI-hubs, with a focus on minimizing truck delays and reducing energy consumption during the transfer of PI-containers. This model serves as a foundation for prospective research in the context of the Physical Internet concept [70]. Strategies are developed to optimize truck loading by leveraging the use of active containers, focusing on the scheduling of both incoming and outgoing trucks, as well as organizing PI-containers in train wagons and outgoing trucks for efficient transport [71]. An exploration into how the design and characteristics of PI-containers will influence the flow of containers within a domestic network context [72].
Passenger transport The Physical Internet primarily focuses on optimizing the flow of goods and information in supply chains by applying principles such as standardization, modularization, and collaboration. While the concept of the Physical Internet may inspire ideas for optimizing passenger transport, such as shared mobility or interconnected transportation systems, it is important to note that the application of the Physical Internet concept to passenger transport would require significant adaptation and research. The requirements and dynamics of passenger transportation, including safety, comfort, and individual preferences, differ significantly from those of goods transportation.	The proposal suggests deploying the concept of the Physical Internet for passenger air transport to increase resource efficiency and reduce emissions, with potential benefits for airlines, and calculates that implementation in the EU could reduce emissions by 9.3 Mt (13.5%) compared to 2019 levels [73].

Source: Own elaboration based on the reviewed papers

4 Discussion

Based on the analysis, we can identify the following popular topics and trends in Physical Internet research.

Many studies focus on developing mathematical optimization models and strategies to enhance the efficiency and effectiveness of operations within the Physical Internet. These models often aim to minimize energy consumption, costs, delays, and improve resource allocation.

Given the complexity and open nature of the Physical Internet, researchers are exploring the application of information systems, data analytics, and technologies like artificial intelligence and Industry 4.0 to facilitate real-time data collection, communication, visualization, and decision-making. These efforts aim to improve the monitoring, management, and coordination of parcels and resources within the network.

Collaborative logistics and coordination among various stakeholders, including carriers, shippers, and logistics service providers, are important areas of research. Studies investigate the potential benefits of collaborative planning, information sharing, and decision-making to enhance the efficiency and sustainability of supply chains within the Physical Internet context.

Researchers recognize the need for innovative system architectures that can support the requirements of new and shared logistics models. Efforts are being made to integrate technologies, such as global standards, to enable interoperability and traceability in the management of resources like reusable pallets.

There is significant research interest in designing modular, reusable, and smart containers (PI-containers) that encapsulate goods within the Physical Internet. Researchers are exploring the physical and informational requirements associated with these containers and investigating their activeness. The role of smart containers in enhancing the technical elements of logistics by facilitating efficient flow management of materials through advanced tracking and optimized loading strategies.

There are still areas the seem to be neglected in the research on PI. While there is some research on bidding policies and decision-making by carriers and shippers, more studies could focus on understanding the behavior and motivations of various actors within the Physical Internet system. Investigating incentives, disincentives, and behavioral insights can provide valuable insights for system design and optimization. The texts do not extensively discuss the legal and regulatory aspects of implementing the Physical Internet. Further research is needed to understand the legal implications, potential barriers, and necessary legal restructuring required for the adoption of Physical Internet principles and practices. While efficiency and sustainability are emphasized, there is a need for research that addresses the economic viability and cost-benefit analysis of implementing the Physical Internet. Evaluating the financial implications, return on investment, and cost-effectiveness of adopting Physical Internet concepts can help decision-makers assess its feasibility and potential benefits.

The texts touch on sustainability, but there is limited exploration of the broader social and environmental impacts of the Physical Internet. Research could delve into the social equity implications, carbon footprint reduction, and the overall societal benefits and challenges associated with implementing the Physical Internet. To achieve the sustainability goals and reduce environmental impact, logistics operations mut be optimized and PI helps managing material and information flows.

The willingness of stakeholders to collaborate and cooperate is crucial for the successful implementation of the Physical Internet. While some studies touch on collaboration and information sharing among carriers, there is a need for further research to understand the factors influencing stakeholders' willingness to cooperate within the Physical Internet framework. This includes examining incentives, trust-building mechanisms, and the identification of barriers and challenges that may hinder collaboration.

Ensuring the security of goods, data, and operations is a critical aspect of the Physical Internet. As the system relies on interconnected networks and information sharing, there is a need for robust security measures to protect against cyber threats, data breaches, and unauthorized access. Further research should focus on developing security frameworks, protocols, and technologies to address these concerns and maintain the integrity and confidentiality of Physical Internet operations.

While research specifically focusing on cultural aspects in the context of the Physical Internet is limited, it is essential to consider cultural factors when designing and implementing logistics systems. Cultural differences can influence the level of trust and willingness to collaborate among stakeholders. Cultures that prioritize individualism may have a different approach to cooperation compared to cultures that emphasize collectivism. Understanding cultural preferences and norms regarding collaboration can help in designing appropriate incentives and strategies to promote cooperation within the Physical Internet framework. Cultural variations in communication styles, decision-making processes, and power dynamics can impact information sharing and decision-making within the Physical Internet. Different cultures may have distinct preferences for hierarchical or consensus-based decision-making, which can influence the effectiveness of collaborative efforts and information flow. Cultural variations may lead to differences in regulatory and legal frameworks related to logistics and data sharing. Cultural norms and values can shape the development of policies and regulations that affect the implementation and operation of the Physical Internet. Understanding these differences is crucial for addressing legal and compliance issues across different cultural contexts. Cultural attitudes towards technology adoption and innovation can influence the acceptance and implementation of technological solutions in the Physical Internet. Cultural predispositions towards risk-taking, openness to change, and technological literacy can impact the adoption of new technologies and processes within logistics systems. Considering cultural differences and predispositions is important to ensure that the design and implementation of the Physical Internet align with the cultural context of the regions or countries involved. This may involve tailoring strategies, communication approaches, and regulatory frameworks to accommodate cultural nuances and promote successful adoption and collaboration. Further research is needed to explore the specific cultural factors and their implications for the Physical Internet. By addressing these research gaps, researchers can further advance the understanding, implementation, and impact of the Physical Internet concept.

5 Conclusions

Based on the summary provided, it is evident that the discourse surrounding the Physical Internet revolves around several key points. Firstly, there is a strong emphasis on enhancing efficiency and promoting sustainable development in the realm of logistics. The Physical Internet is perceived as a solution aimed at enhancing economic, environmental, and societal efficiency in the worldwide transportation, warehousing, and distribution of tangible goods. Furthermore, the advent of digital transformation in the logistics industry is a crucial aspect of the Physical Internet. This transformation brings about significant implications for the development and implementation of an efficient and sustainable logistics system on a global scale.

Collaboration and the sharing of information constitute essential foundations of the Physical Internet concept. The concept entails the sharing of logistical resources and the exchange of information within an open network. It is believed that the introduction of the Physical Internet can greatly contribute to the development of sustainable logistics. Important elements of the implementation process include raising awareness and facilitating the exchange of information among stakeholders.

In addition, researchers have focused on exploring the utilization of technologies such as blockchain and smart contracts to optimize logistical processes within the Physical Internet framework. These technologies hold promise in streamlining operations and improving efficiency.

Nevertheless, it is noteworthy that the summary also underscores certain underexplored or omitted areas within the context of the Physical Internet. These encompass a detailed examination of the Physical Internet's influence on various industries and economic sectors, the feasibility of its large-scale adoption, the resolution of obstacles such as legal and administrative complexities to stimulate cooperation among logistics firms, and research concentrated on the real-world applications of the Physical Internet within the corporate sphere. These areas warrant further investigation to gain a comprehensive understanding of the full potential and practical implications of the Physical Internet concept.

Furthermore, it appears that contrary to the initial assumptions, the Physical Internet has the potential to expand into passenger transportation, and this area represents the largest research gap and, thus far, an overlooked gap in knowledge. Some authors mention the possibility of sharing infrastructure and even fleets within cities, but it seems that we can go further and begin managing human flows in accordance with the principles of the PI.

The literature review presented in the provided text explores various aspects of the Physical Internet (PI) concept and its potential implications. It highlights the foundational ideas behind the PI, with the goal of transforming the global transportation and storage of physical goods, with an emphasis on enhancing economic, environmental, and societal efficiency and sustainability. The review underscores the importance of the Physical Internet (PI) in tackling the challenges of 17 Sustainable Development Goals and advancing the objectives of Industry 4.0. It highlights the necessity for well-suited information systems, physical infrastructure, and technologies to align with the evolving demands of the economy. The review acknowledges the need for further research on the proposed logistics paradigm and identifies the challenges associated with implementing the PI as a practical solution. It highlights the potential of blockchain, smart contracts, lean thinking, and value stream mapping in enhancing PI practices and fostering the transition from traditional logistics.

Additionally, the literature review touches upon the verification of PI principles in economic practice, showcasing the possibilities of applying PI solutions to optimize logistics processes and enhance communication infrastructure.

Overall, the literature review provides a comprehensive overview of the key concepts, challenges, and potential opportunities associated with the Physical Internet, offering insights into its potentially transformative impact on global logistics systems.

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