Deliverable 2.3 (V1.0)

Intelligent operations systems and new technologies for intermodal logistics optimization

Dissemination level		
PU	Public — fully open (automatically posted online)	X
SEN	Sensitive — limited under the conditions of the Grant Agreement	

Cover and Control Page of Document	
Project Acronym:	ADMIRAL
Project Full Name:	Advanced multimodal marketplace for low emission and energy transportation
Grant Agreement No.:	101104163
Instrument:	Innovation Action in the European Union's Horizon Europe research programme
Start Date of Project:	01.05.2023
Duration:	36 months
Work Package:	WP2 Sustainable development of logistics & transport
Associated Task:	T2.3 Current (mega) trends for sustainable logistics
Nature[1]	R
Due Date	31.10.2024 (M18)
Actual Submission:	30.10.2024 (M18)
Lead Organisation:	LNEC
Primary Reviewer:	Marina Zanne (UL)
Secondary Reviewer:	Ville Hinkka (VTT) and Emma Mulhern (VTT)

Document Change History			
V	**Date**	**Author**	**Description**
0.1	10.10.2024	Elisabete Arsenio (LNEC), Principal Investigator & WP2 Leader Main contributor: João Tiago Aparicio (LNEC), Ph.D. Fellowship Collaboration of Marluci Menezes (LNEC)	First Draft completed
0.2	15.10.2024	Marina Zanne, University of Ljubljana	Primary Reviewer
0.3	22.10.2024	Ville Hinkka & Emma Mulhern, VTT	Secondary Reviewer
1.0	30.10.2024	Elisabete Arsenio (LNEC) and Emma Mulhern (VTT)	Edition of version 1.0 and final submission

[1] **DATA** = data sets, **DEC** = Websites, patent filings, videos, etc; **DEM** = Demonstrator, pilot, prototype, **ETHICS**; **OTHER**; **R** = Document, report.

Disclaimer

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Abbreviations

AI	Artificial Intelligence
BEV	Battery Electric Vehicle
B2B	Business-to-Business
B2C	Business-to-Consumer
CAVs	Connected and Automated Vehicles
CIS	Commonwealth of Independent States
CO2	Carbon Dioxide
CPPS	Cyber-physical production systems
DCSA	Digital Container Shipping Association
DLT	Digital Logistics Terminal
EC	European Commission
ECSR	European Corporate Sustainability Reporting EU Directive
eFTI	Electronic Freight Transport Information EU Directive
FTZ	Free Trade Zone
GHG	Greenhouse Gas
HSC	Humanitarian Supply Chain
IMO	International Maritime Organization
IoT	Internet of Things
ITS	Intelligent Transport Systems
JIT	Just-in-Time
LNG	Liquefied Natural Gas
ML	Machine Learning
MOPSO	Multi-Objective Particle Swarm Optimization
MTS	Multimodal Transport Systems
NPL	Natural Language Processing
OBOR	One Belt One Road
PPC	Production Planning and Control
RFID	Radio-Frequency Identification
RL	Reverse Logistics
RPA	Robotic Process Automation
SCoT	Universal Supply Chain of Things
SDGs	Sustainable Development Goals

SCR	Supply Chain Resilience
SCM	Supply Chain Management
TF-IDF	Term Frequency-Inverse Documents Frequency
TRL	Technology Readiness Level
TS	Text-to-Text Transfer Transformer
UURC	Ubiquitous and Ultra-Reliable Connectivity
V2X	Vehicle to Everything
WIPO	World Intellectual Property Organization
WP	Work Package
WPL	Work Package Leader

Publishable Executive Summary

The present report is the Deliverable from task 2.3 of the ADMIRAL – *Advanced Marketplace for Low Emission and Energy Transportation* project, funded by the European Union under the HORIZON-CL5-2022-D6-02 with Grant Number 101104163. ADMIRAL aims to transform supply chain management in freight transportation by developing a cutting-edge digital marketplace for multimodal logistics. It seeks to shift the focus on indirect emissions, reduce overall emissions in logistics and transportation and enhance transparency throughout the supply chain.

ADMIRAL WP2 – *Sustainable development of logistics & transportation* addresses key sustainability issues in the transportation and logistics sector such as zero (low) emissions logistics, reduction of energy consumption from fossil fuels in transportation and enhancement of collaborative logistics to reach common sustainability goals in the pilots to be implemented in Finland, Lithuania, Portugal-Spain and Slovenia-Croatia. Task 2.3 – Current (mega) trends for sustainable logistics aims:

- To identify global trends on innovative solutions to improve the sustainability performance of operations (Reverse logistics, Symbiotic logistics, etc.).
- To identify how companies/stakeholders are dealing with identified technological changes and adapting systems for digitalisation, automation and the creation of new services (IoT, autonomous delivery, robotics, circular supply chains, etc.).
- To analyse how the requirements for improving resilience and sustainability at the same time are considered and should be taken into account in the future.
- To identify/assess how intelligent systems are being used or planned to integrate all logistics stakeholders (producers, suppliers, ship owners, transport operators, support services, etc.), including sustainability performance indicators.
- To analyse how governance practices connect all levels of suppliers and service providers considering code of conduct and corporate reports to achieve sustainability goals.
- Mapping of innovative solutions, technological and social, including the contribution of each for a more efficient and sustainable supply chain (e.g., autonomous vehicles and delivery, factory ships with product finishing (customization), including industry 5.0 issues.

The research methodology included a systematic analysis of data of patenting technology trends and its connection with the evolution of the scientific papers, and an in-depth analysis of companies' practices through semi-structured interviews. Results are relevant to build a systemic framework (expected output from task 2.1), identifying the main gaps and best practices, and relating them to the KPIs and business strategies. This will provide a collaborative approach to achieve sustainability goals in the context of the project partners (Pilots) and stakeholders.

1 Introduction

1.1 Objectives

The present report «Intelligent operations systems and new technologies for intermodal logistics optimization » is one result of task 2.3 - Current (mega) trends for sustainable logistics, which integrates ADMIRAL WP2 - Sustainable development of logistics & transport. Following ADMIRAL's project Grant Agreement 101104163, the main goals of task 2.3 are as follows:

- To identify global trends on innovative solutions to improve the sustainability performance of operations (Reverse logistics, Symbiotic logistics, etc.).
- To identify how companies/stakeholders are dealing with identified technological changes and adapting systems for digitalisation, automation and the creation of new services (IoT, autonomous delivery, robotics, circular supply chains, etc.).
- To analyse how the requirements for improving resilience and sustainability at the same time are considered and should be considered in the future.
- To identify/assess how intelligent systems are being used or planned to integrate all logistics stakeholders (producers, suppliers, ship owners, transport operators, support services, etc.), including sustainability performance indicators.
- To analyse how governance practices connect all levels of suppliers and service providers considering code of conduct and corporate reports to achieve sustainability goals.
- To map innovative solutions, technological and social, identifying the contribution of each for a more efficient and sustainable supply chain (e.g., autonomous vehicles and delivery, factory ships with product finishing (customization), including industry 5.0 issues.

In this Deliverable the terms "transport" and "transportation" are used interchangeably.

1.2 Methodology

Considering that the ADMIRAL project is a research and innovation action we aimed to continuing responding to the challenge of the EC funding through the European Climate, Infrastructures and Environment Executive Agency (CINEA). Besides the comprehensive review of academic papers and other relevant documents such as EU-funded projects in the field of intelligent logistics and intermodal transport, including sustainability and resilience issues, we have developed a novel systematic data analysis considering the PATENTSCOPE database of the World Intellectual Property Organization (WIPO) and analysed 2138 records in the field of intelligent and sustainable logistics operations. To our best knowledge this is the first time the approach is conducted in the context. Additionally, these data are analysed in connection to the evolution of scientific paper contents. Through comparing patents and scientific papers, we have a comprehensive view of technological trends using the industry-academic evolving landscape.

The research methodology used in task 2.3 comprises the following:

a) Analysis of global trends on innovative solutions to improve the sustainability performance of operations, through a comprehensive literature review that included scientific papers, EU-funded projects, national projects and corporate reports. All documents were synthetized in a common review template updated for task 2.3, which were filled by all ADMIRAL partners.

b) A systematic data analysis of academic research (scientific articles) and patents on intelligent supply chains and sustainable transport operations, including intermodal transport freight transport, covering the period from 2013 to 2024. A long period of analysis was selected to enable the provision of more reliable trends. It was used the PATENSCOPE database of the WIPO and 2138 records of patents were used. We have used AI and data mining tools to develop the integrated analysis of patents and papers.

c) A sample of semi-structured interviews were conducted with companies between 14th June 2024 and 18th September 2024. These engaged worldwide companies of relevance to each Pilot. The engagement of companies was facilitated by all Pilot leaders (in alphabetic order), APS, STEVECO, TIA, PS, and supporting partners.

1.3 Report Structure

After presenting Deliverable 2.3 objectives and research methodology (sections 1.1 and 1.2), chapter 2 presents a comprehensive analysis of the scientific literature and projects in the field of intelligent logistics, including intermodal transport, to improve the sustainability performance of operations. Chapter 3 presents a systematic data analysis of academic and patents, the PATENTSCOPE database of the World Intellectual Property Organization (WIPO) and analysed 2138 records in the field of intelligent and sustainable logistics operations, covering the period from 2013 to 2024. The mapping of industry-research technological solutions is further analysed and developed in this chapter. Chapter 4 presents the analysis of semi-structured interviews that were conducted with companies between 14th June 2024 and 18th September 2024, proving further insights into the research goals outlined in 1.1, and the development of the ADMIRAL Pilots. Finally, section 5 concludes by summarizing the main contributions and findings.

2 Global trends on innovative solutions to improve the sustainability performance of operations: a comprehensive literature review

2.1 Searching the Scopus database

The main research aim is to understand **what the current trends regarding innovative solutions are to improve the sustainability performance of operations in freight logistics and transportation**. The objective is to understand **mega trends**, with the set of innovative solutions to enable **intelligent operations and logistics optimization of supply chains**. To perform this research, the Scopus database was selected. This database includes over 97.3 million records post-1969, with over 24.6 million open access items, and with over 7 thousand publishers.

Based on the above research purpose, a list of keywords was selected to identify the list of relevant scientific documents. The inclusion criteria were to extract publications accepted after 2013 and to be published during 2024, covering works worldwide. More specifically, after some iterations, the final search query is as follows:

- ("Trends" OR "Sustainability") AND ("Intelligent operation" OR "Smart operation") AND ("Logistics" OR "Supply chains" OR "Freight transport") AND PUBYEAR > 2013 AND PUBYEAR < 2025)

The search query above yielded **309 peer-reviewed papers** from the **Scopus database**. These papers were then distributed among the partners involved in Task 2.3 for review, and selection according to their expertise. To streamline the review process and ensure consistency across the participating institutions, an algorithm was developed to sort the papers according to semantic similarity criteria. This algorithm compared the keywords and abstracts of each paper to a list of critical predefined terms that included “AI”, “circular economy”, “intermodal”, “intelligent”, “digitalization”, “smart port”, “optimization”, “collaboration”, “industry 5.0”. This approach helped to ensure that no critical papers were overlooked in this phase.

The analysis of the extracted papers was performed using VOSviewer (version 1.6.20), a tool that helps to visualize and create maps based on network data. Figure 1 provides an illustration of the network of papers (309 records) based on their keywords co-occurrence links. The strongest links are represented by lines. In this step, a threshold was set to include only keywords with at least 5 occurrences across the corpus. Out of the total 2647 keywords, 90 met this threshold. This threshold ensures that the visualization focuses on terms that have a significant presence in the literature, reducing noise from rare or isolated keywords.

The network in Figure 1 shows the relationship between frequently co-occurring keywords in the selected papers. Each node (circle) represents a keyword, and the size of the node reflects the number of occurrences. Edges (lines) between nodes indicate that the terms co-occur in the same papers. The thicker the edge, the stronger the co-occurrence relationship.

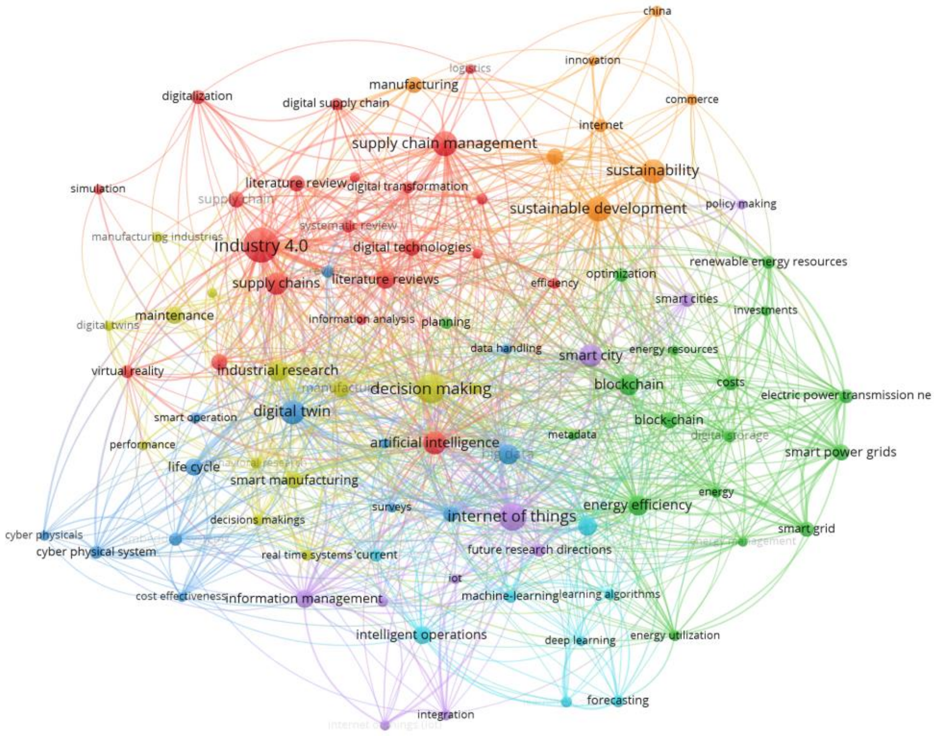


Figure 1: Network visualisation of 309 papers based on keywords co-occurrence links

Figure 1 shows that the network is divided into several clusters, each represented by a different colour. The analysis seems to point out that the different clusters reflect various research communities of different size:

- The red cluster focuses on Industry 4.0, highlighting the integration of technologies such as IoT, cyber-physical systems, and AI into manufacturing and logistics processes. In this context, Industry 4.0 serves as the focal point of the cluster, indicating that digital transformation is a major area of research interest. Within this cluster, keywords such as "supply chains" and "digitalization" show the crucial role that digital supply chains play in the Industry 4.0 ecosystem. Digital twins, another key term in this cluster, represent real-time virtual models of physical systems that allow for advanced simulations, predictive maintenance, and better decision-making. The red cluster highlights the intersection of new technologies with industrial processes and underscores how digitalization is reshaping the logistics landscape by enabling smart operations, IoT data management, and supply chain optimization.

- The green cluster is centred on sustainability and energy management, with most relevant keywords as "renewable energy," "smart cities," and "sustainable development" dominating this group. This cluster indicates that there is a significant focus on minimizing environmental impact in logistics and supply chain management. The terms "sustainability" and "sustainable development" reflect research that emphasizes the transition toward environmentally friendly processes, aiming to reduce emissions, optimize energy use, and manage resources more efficiently. The inclusion of "renewable energy" suggests interest in how logistics systems can integrate energy sources like solar and wind power to reduce their carbon footprint, while "smart cities" reflects the research community's focus on urban logistics and how transport networks can be optimized within sustainable urban environments. The green cluster underscores the increasing urgency surrounding environmental concerns and shows how the logistics research community is leveraging technology and innovation to meet sustainability goals.

- The (dark) blue cluster, defined by terms related to digital twins, IoT, and cyber-physical systems, highlights the technological backbone of modern logistics systems. The prominence of digital twin technology in this cluster demonstrates its growing importance in logistics, where real-time virtual replicas of physical systems allow businesses to simulate scenarios, manage risks, and optimize their logistics in real time. IoT, another key concept in this cluster, refers to networks of interconnected devices and sensors that share data. In logistics, IoT devices are used to track goods, monitor transport conditions, and streamline operations. Cyber-physical systems, which enable real-time interaction between digital models and physical assets, further enhance the decision-making process in logistics. This cluster emphasizes how integrating real-time data through IoT devices and leveraging digital twin technology helps companies enhance operational efficiency, reduce downtime, and make better decisions.

- Smaller clusters, including the yellow, purple, cyan, and orange clusters, represent niches but critical research areas. The yellow cluster focuses on decision-making and planning, exploring how advanced algorithms, simulations, and AI-based models can improve supply chain decisions. The purple cluster focus is on artificial intelligence and learning algorithms and reflects how machine learning and AI are being applied to optimize logistics processes like forecasting, route optimization, and inventory management. The cyan cluster, focused on blockchain and transparency, shows the increasing use of blockchain technology to enhance supply chain transparency and security, ensuring that transactions are verified, and products are ethically sourced. Finally, the orange cluster, centred on smart grids and energy efficiency, highlights research focused on integrating logistics systems with smart energy grids to optimize energy consumption and reduce waste.

It is interesting to note that while each cluster represents a distinct area of research, they are highly interconnected. For example, the strong connections between the blue cluster (IoT and digital twins) and the red cluster (Industry 4.0 and digital supply chains) indicate that digital technologies are the foundation of modern supply chain transformations. Similarly, the close link between the green cluster (sustainability) and the yellow cluster (decision-making) suggests that strategic planning in logistics frequently incorporates sustainability goals, and data-driven decision-making can play a key role in achieving these objectives. The **interconnectivity between these research communities highlights the increasingly multidisciplinary nature of logistics research**, which draws on fields as diverse as computer science, energy management, urban planning, and operations research. Rather than focusing on isolated aspects of logistics, researchers worldwide are adopting a more holistic approach that views technology, sustainability, and innovation as intertwined components of the supply chain ecosystem.

Figure 2 presents the analysis of the CSV data from the Scopus query and shows the top 10 most frequent keywords in the research field covering records in the period **2014-2024**. Results show that “Smart city” and “Sustainability” are the two most dominant keywords, followed by "Optimization", "Collaboration”, “Energy Management” and “Supply Chain Management”.

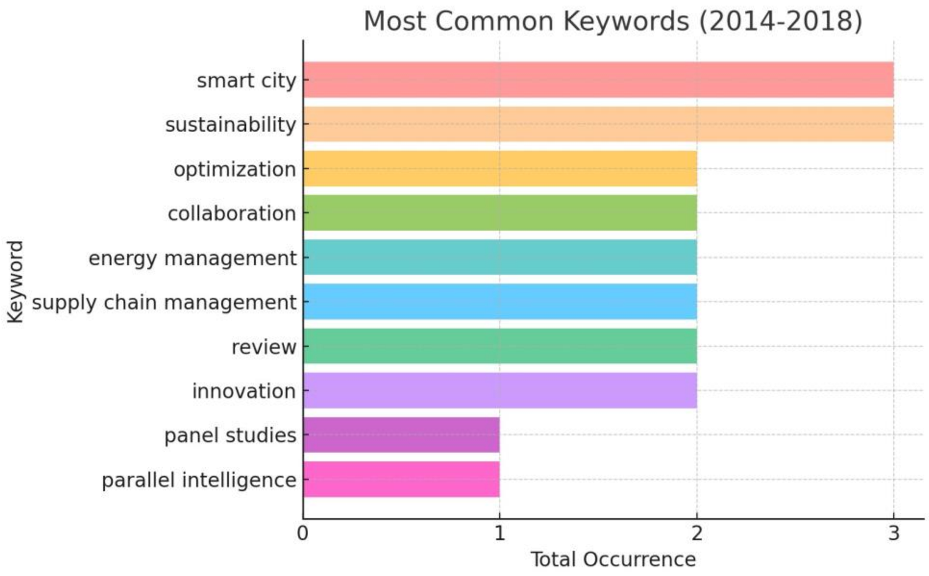


Figure 2: Top 10 most frequent keywords in the network covering 2014-2018

Figure 3 presents a similar analysis of the CSV data from the Scopus query and shows the top 10 most frequent keywords in the research field but covering the period from **2018 to 2024**. Results show that "Industry 4.0" is now the most dominant keyword, followed by "Digital Twin", "Internet of Things", "Sustainability" and "Artificial Intelligence". These keywords reflect the growth of works on integrating digital technologies into manufacturing and the digital transformation in logistics and supply chain management, with sustainability and artificial intelligence playing significant roles.

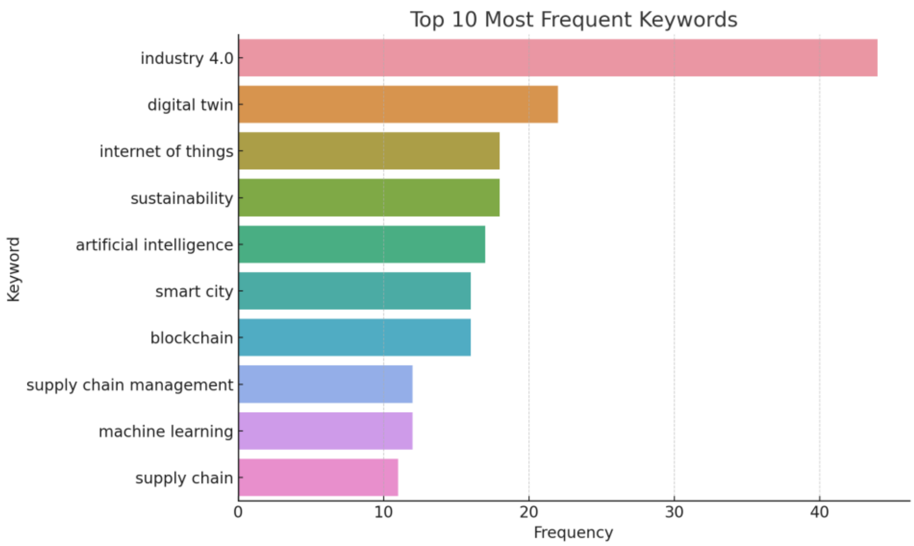


Figure 3: Top 10 most frequent keywords in the network covering 2018-2024

Figure 4 illustrates the temporal trends of the top 10 keywords. It shows how frequently these keywords appeared in publications from 2018 to 2024. More specifically, there was a surge in interest around "Industry 4.0" and "Digital Twin" between 2020 and 2022, aligning with the increasing focus on smart manufacturing and digitalization during that period. Meanwhile, sustainability-related terms like "Smart City" and "Blockchain" also saw fluctuating attention over the years, reflecting growing but variable interest in green technologies and transparent supply chains. It is also relevant to mention that the number of publications having "Industry 5.0" is a few (two). This fact reflects the ongoing transition from "Industry 4.0" to the renovated concept of "Industry 5.0" introduced in 2021, aiming to ensure that advanced technologies provide prosperity beyond jobs and growth, respecting the planetary boundaries and placing the wellbeing of the industry workers at the centre of the production process [2].

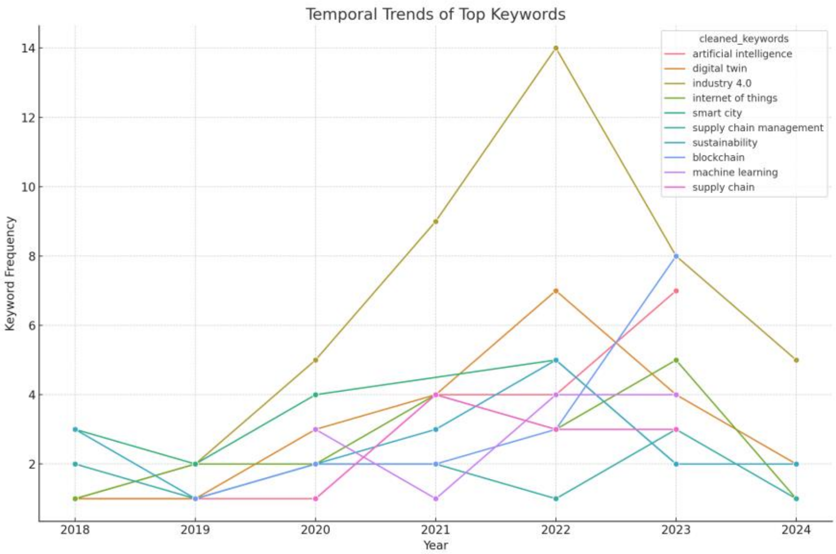


Figure 4: Evolution of top keywords in the network of papers covering 2018-2024

The relevant references have been summarized in review template forms to enable a uniform and comprehensive analysis.

2.2 Global trends on innovative solutions to improve the sustainability performance of operations

This section provides an overview of global trends on innovative solutions that have been identified across key studies to improve the sustainability performance of operations, that include intelligent technologies. As mentioned by Spector (2024) trends in logistics will always be linked to social and business developments, as well as technology improvements.

The review works comprise the identification of solutions addressing key challenges in supply chain management, energy consumption, emissions reduction, and overall sustainability performance. An integrated analysis of main trends, based on studies reviewed, is next presented.

Reverse logistics and circular economy

Reverse logistics is the movement of goods "upstream" through a supply chain, to return them from the end customer back to a retailer or manufacturer (DHL,2023). The study of Plaza-Úbeda et al. (2021) on main trends and challenges in the green logistics point out that **reverse logistics, green supply chain**

[2] EC Directorate-General for Research and Innovation (2021). Industry 5.0 – Towards a sustainable, human-centric and resilient European industry.

management, circular supply chains, are converging on circular economy. The study's authors underscore the importance of stable networks and relationships between members of the entire supply chain, including the final consumer due to its essential role in the reverse logistics process. Reverse logistics and sustainability are recognized as strategies to enhance the performance of supply chain processes and customer service and to reduce environmental impact, which is reflected in the planning of and reduction in costs throughout the production process (Salas-Navarro et al., 2024). In contrast to the linear economy, the circular economy framework aims to keep the resources "in the loop", maximizing resource utility and efficiency, the extension of the life of the resources/assets, while adding values through repurposing and recycling (Khan and Abonyi, 2022).

The systematic literature review study by Mishra et al. (2023) reveals that the **research in the domain of reverse logistics and closed-loop supply chains is in a growing phase**, and in recent years, a lot of attention has been given by researchers across the globe.

Studies by Ni et al. (2023) and Govindan et al. (2014) both emphasize reverse logistics as a key component of the circular economy, where waste is minimized, and materials are kept in use for as long as possible. Ni et al. (2023) highlight how advanced modelling techniques can **forecast e-waste generation, allowing for better recycling capacity planning and optimal return flows of materials**. These strategies align with the European Union's Circular Economy Action Plan[3], which is a key component of the European Green Deal, which points out the importance of reducing extraction of primary resources and improving material recovery along the value chain.

Govindan et al. (2014) further explain that reverse logistics—combined with waste elimination and cleaner production—enhances environmental sustainability by creating **closed-loop supply chains**. **Cleaner production minimizes resource input and waste output**, which can be seamlessly integrated into reverse logistics operations. This supports industries in meeting stringent EU sustainability targets by reducing emissions and enhancing resource recovery. However, Govindan et al. (2014) also point out that logistical flexibility (e.g., flexible transportation and sourcing) may not significantly impact sustainability, suggesting that firms should focus on direct environmental strategies such as **material recovery and risk management**.

Connected, cooperative and autonomous vehicles

Autonomous trucks are expected to respond to the shortage of truck drivers which is one of the most pressing issues facing road freight companies across the world. The United States has a shortage of more than 80,000 drivers and the number is expected to double by 2030 and, in Europe about 7 percent of total truck driving jobs are unfilled (McKinsey, 2023). Germany alone will have a shortage of around 185,000 truck drivers by 2027 (DHL Freight, 2022).

Singh et al. (2021) study on the deployment of **freight autonomous trains** shows that the rail industry is also moving towards more connected and cooperative systems with increasing grades of automation of train operations. Several technologies are used in combination such as high-speed internet technology (5G), infrared and ultrasonic cameras, dedicated short-range communications, accelerometers, tachometers and sensors, as automated trains also use onboard data measurement

[3] https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

devices to support the early detection of track problems and other functionalities. Following the mentioned authors, the **deployment of automated trains with the full automation level is a key strategy to achieve sustainability**.

Sahoo et al. (2019) address autonomous underwater vehicles (AUVs), which optimize propulsion technologies to improve energy efficiency. This technological leap reduces energy consumption in logistical operations and offers a template for other sectors, such as road transport, where similar autonomous technologies can be implemented. By **integrating AUVs with IoT systems**, companies can streamline operations, reducing idle times and energy use, thus lowering carbon footprints. These trends reflect the growing importance of automation and data-driven logistics solutions in achieving sustainability goals, particularly in energy-intensive sectors like maritime logistics.

Smart technologies and IoT in logistics

Zhao et al. (2023) examined the impact of smart transportation technology on green total factor productivity (GTFP) in China. The study underscored that little attention had been paid to the pathways towards the GTFP goal.

Xue et al. (2022) and Chen et al. (2019) provide insights into the role of **IoT and smart technologies** in enhancing sustainability within urban transport and port operations. Singh et al. (2022) consider **AI technology** and **blockchain** the main key innovations for intelligent transportation such as high-speed trains, autonomous trains and connected and automated vehicles. However, the same authors outline emerging challenges with blockchain applications of AI-based algorithms that can process large datasets, e.g. due to storage capacity, scalability issues, policy and regulations. Xue et al. (2022) focus on smart urban rail systems that utilize IoT and big data to reduce energy consumption and enhance operational efficiency. This contributes to the development of smart cities, where infrastructure is optimized for both performance and sustainability, ensuring lower emissions and improved energy use.

Chen et al. (2019) focus on the role of **smart ports**, where IoT-enabled systems enhance asset tracking, predictive maintenance, and emission reductions. Ports are major contributors to global carbon emissions, and smart port technologies are critical in meeting the decarbonization targets set out in global and European climate agreements. Through real-time monitoring, these systems can optimize operations, reducing idle times and emissions from port activities.

Prashar (2022) contributes to state of the art in context of Industry 4.0, innovative solutions such as energy-aware production scheduling and **big data analytics for renewable power forecasting** represent substantial advancements aimed at improving the **sustainability performance of operations,** addressing the following performance outcomes: **operational flexibility, cost reduction, product/process quality, delivery time reduction and productivity.** As shown in Figure 5, the integration of enabling technologies like IoT, AI, big data, and **cyber-physical production systems** (CPPS) transforms traditional production processes by increasing real-time visibility, traceability, and adaptability across the entire supply chain. These innovations are pivotal for optimizing energy consumption, reducing waste, and enabling the seamless incorporation of reverse logistics and symbiotic logistics strategies. For instance, CPPS connects physical and digital systems, enabling smart systems to autonomously manage the flow of resources, materials, and information. This not only enhances operational flexibility but also ensures resource efficiency, which is crucial for symbiotic logistics models where waste from one process becomes a resource for another. Moreover, by integrating real-time decision-making capabilities, companies can dynamically adjust production, and logistics plans to minimize energy use, aligning with **green manufacturing** goals and contributing to carbon neutrality targets. The introduction of **cloud manufacturing services** also allows firms to scale operations while maintaining a focus on **sustainable energy usage**.

The morphological framework used in the study by Prashar (2022) reveals that **companies adopting energy-efficient production scheduling and carbon tax assessments as part of their planning will be better equipped to reduce their carbon footprint**. **This transition is essential for achieving long-term sustainability goals**, as it not only reduces the reliance on fossil fuels but also enhances resilience by enabling the system to adapt to disruptions in supply chains.

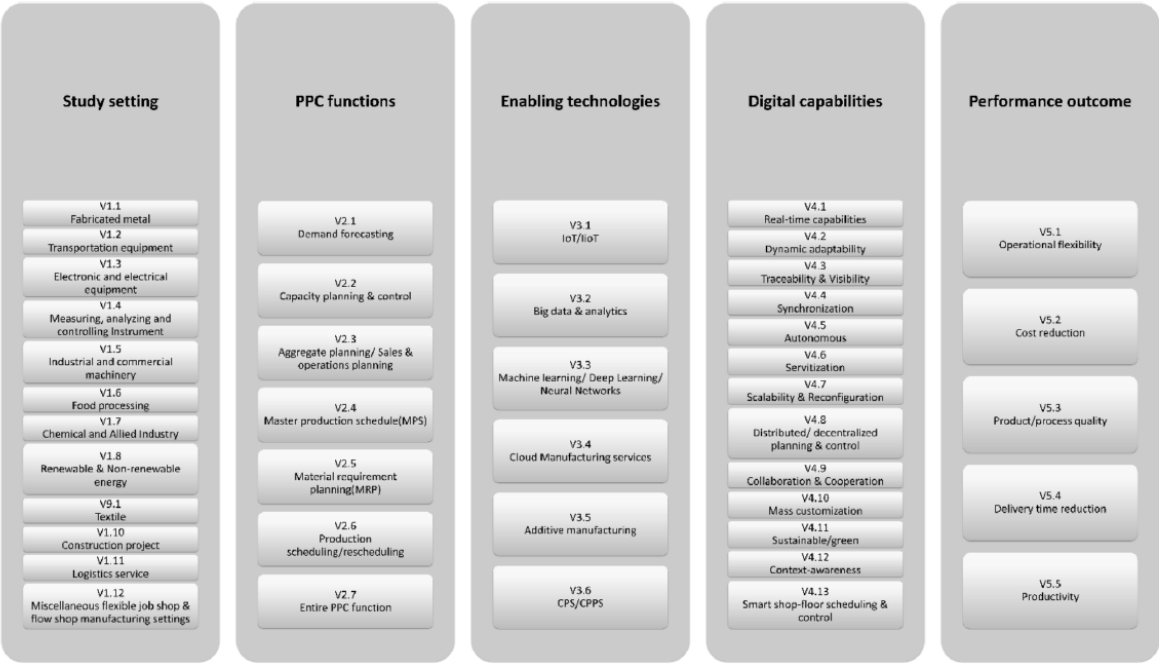


Figure 5: Dimensions and variants to Physical Production Systems by Prashar (2022)

Blockchain, digital twins and transparency in supply chains

Saha et al. (2023) and Ivanov et al. (2019) explore blockchain and digital twin technologies, which significantly improve transparency and efficiency in supply chains. Blockchain ensures data integrity and traceability, reducing inefficiencies such as overproduction and spoilage. These inefficiencies are key contributors to waste and energy consumption, and **blockchain solutions can indirectly enhance sustainability by providing a clear record of materials/resources as they move through the supply chain**. In the context of reverse logistics, blockchain can verify the authenticity of returned products, ensuring that they are properly recycled or repurposed.

Ivanov et al. (2019) take this further by proposing Digital Supply Chain Twins—**real-time digital replicas of physical supply chains** that predict disruptions and reconfigure operations dynamically to minimize waste. This proactive approach ensures that operations run smoothly, reducing downtime and optimizing resource use. **Digital twins are particularly useful in symbiotic logistics, where multiple**

stakeholders share logistics hubs and resources. A visualization of digital twins adjusting a supply chain network could be a useful tool for logistics operators to track and improve their sustainability performance in real-time.

Dolgui et al. (2022) provide a comprehensive overview of how 5G technology serves as a pivotal infrastructure in the digital transformation of supply chain and operations management. It conceptualizes the **role of 5G** across five major capabilities: **intelligence, visibility, dynamic networking, connectivity, and end-to-end transparency.** These facets underpin the creation of cyber-physical supply chains where real-time data-driven decision-making and operational flexibility become possible. The authors highlight the theoretical underpinnings, application areas, challenges, and future transformations in value creation enabled by 5G. They discuss both the operational processes, such as transformations in manufacturing and warehouse operations, and strategic perspectives, including business model transformations and network structure adaptations.

Mittal et al. (2024) emphasize the role of cybersecurity measures in safeguarding the integrity of IoT systems used in predictive maintenance. Ensuring the security of these systems is essential to maintaining the reliability and transparency of sustainability data across the supply chain.

Symbiotic logistics, collaboration of stakeholders and logistics optimization

Chabba et al. (2022) points out the importance of enterprises to invest in logistics collaborations to address sustainability in supply chains. Aloui et al. (2021) provide a systematic literature review of collaborative sustainable transport, offering perspectives for future. These authors note that social performance is difficult to measure with quantitative indicators, for example due to the fact that social welfare issues relate to multiple stakeholders.

Ayadi et al. (2021) offer a fuzzy multi-criteria decision-making framework for logistics platform location selection, incorporating sustainability as a key factor. Their approach balances economic, environmental, and social criteria to optimize the location of logistics hubs. **In the symbiotic logistics context—where multiple companies share logistics resources—a balanced approach is critical for maximizing sustainability benefits** by reducing emissions, optimizing transport routes, and minimizing resource use. The fuzzy approach also allows logistics operators to adapt to changing sustainability objectives, ensuring that their operations remain aligned with long-term environmental goals.

Hussain et al. (2022) presents several insights into how intelligent systems, specifically IoT, Edge computing, Fog, and Cloud technologies, enhance the integration of logistics stakeholders across the midstream oil and gas sector. These technologies are not merely focused on operational efficiency but also indirectly contribute to sustainability by improving real-time monitoring, predictive maintenance, and safety measures (Figure 6). For instance, the use of **platoon coordination systems** and **optimal routing** in transportation not only streamlines logistics but reduces emissions by cutting unnecessary fuel use. Moreover, **predictive maintenance in pipelines** directly minimizes leakages and operational failures, which otherwise could lead to significant environmental damage. Additionally, the implementation of **Tank Information Systems** for O&G storage optimizes the alignment between supply and demand, preventing resource wastage. In the context of safety, **real-time monitoring of emissions and toxic gas leaks** enhances early hazard detection, preventing environmental contamination. The security measures proposed, including **cyber protection and physical equipment**

monitoring, ensure that the entire supply chain remains resilient against operational disruptions, contributing to both sustainability and risk management. While these systems are primarily designed for operational control, they inherently support sustainability goals by lowering energy consumption, preventing resource overuse, and reducing potential environmental hazards, showcasing the broader impact of digital integration in this sector.

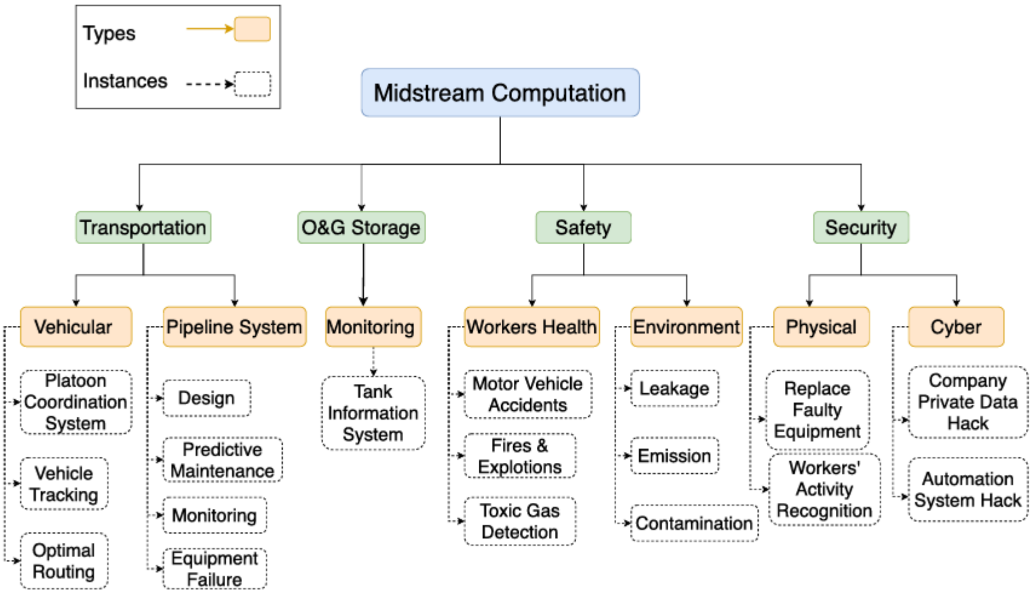


Figure 6: Midstream computation taxonomy structure by Hussain et al. (2022)

The cloud-network integration architecture presented in Zhang et al. (2023) offers significant contributions to **improving sustainability performance** in operations, particularly by enhancing digital infrastructure in telecommunications, which can be extrapolated to logistics frameworks like **reverse logistics** and **symbiotic logistics**. Figure 7 shows the functional architecture of the system by Zhang et al. (2023), detailing how business, operational, and management domains are integrated to streamline cloud-network operations.

The core concept of cloud-network convergence introduces a more **adaptive and intelligent system** for managing resources, which is crucial for ensuring efficient logistics and sustainability. By using cloud-based infrastructure, the system reduces the need for physical servers and onsite resources, directly lowering energy consumption. In the context of reverse logistics, where the return and reprocessing of goods require optimized tracking and data sharing, this system enables real-time visibility and faster decision-making. The platform's intelligent orchestration of network operations could reduce inefficiencies in resource allocation, critical for handling returned goods more sustainably. The architecture shown in Figure 7 allows for **scalable operations**, which is crucial in **symbiotic logistics**, where diverse stakeholders (from producers to recyclers) need to coordinate activities. The seamless interaction between cloud and network systems allows for dynamic resource reallocation, reducing the environmental footprint by optimizing transportation and storage. As logistics operations grow, this flexibility ensures that sustainability goals are met without requiring significant infrastructure changes, thus keeping operational overhead and carbon emissions low. The ability of this system to integrate **real-time data flows across multiple stakeholders** has profound implications for sustainability. In reverse logistics, where operations rely on feedback loops and accurate tracking of materials, the cloud-network integration provides a continuous stream of data that enhances decision-making. Whether tracking returned products for reprocessing or optimizing routes for collection, intelligent data analytics provided by the system can substantially reduce unnecessary trips and emissions, improving both sustainability and profitability.

In a broader sense, **cloud-network integration also underpins the circular economy** by enabling the symbiotic relationship between various logistics stakeholders. For example, companies handling waste or reusable materials in a symbiotic logistics framework can rely on this integrated system to align their operations more efficiently, **ensuring that waste is minimised, and materials are reused or reprocessed as part of a closed-loop supply chain**. The real-time coordination between suppliers, recyclers, and manufacturers could drastically reduce the environmental impact of material flows.

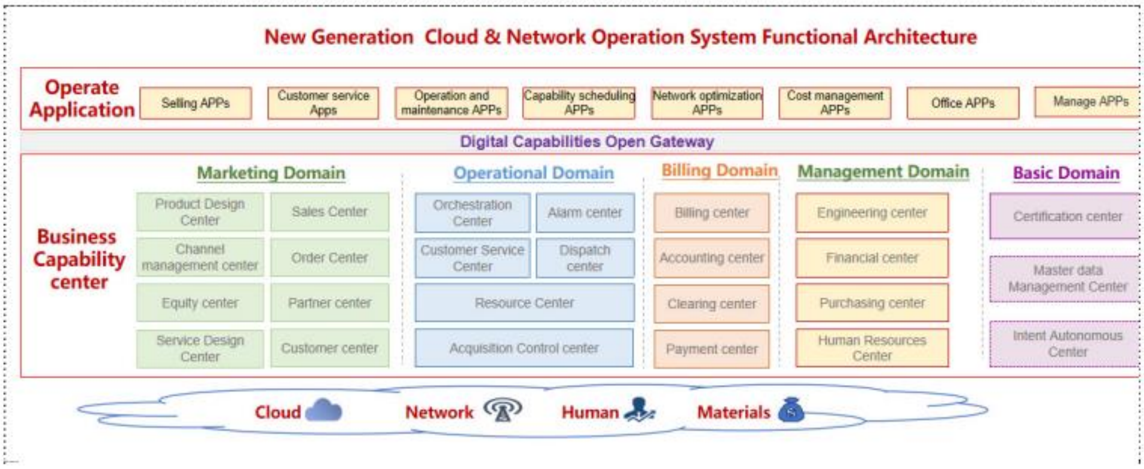


Figure 7: Functional architecture of the system detailing how business, operational and management domains are integrated to streamline cloud-network operations (Zhang et al., 2023)

Collaborative green initiatives involving customers and third-parties logistics (3PLs) are also highlighted in the works of Evangelista & Sweeney (2014) on research on green action adoption. A company's culture positively influences the adoption of environmental sustainability strategies, driven by a corporate desire to "do the right thing." The adoption of intermodal road-rail transport is also motivated by the role of customers and competitors in reducing carbon emissions and improving environmental performance.

Intelligent monitoring for energy efficiency and carbon neutrality

Mittal et al. (2024) showcase the role of **predictive maintenance** in transportation fleets, highlighting how **IoT sensors** can optimize vehicle component maintenance, reducing waste and extending the lifecycle of vehicle components. This technology supports reverse logistics by ensuring that fewer vehicle components are discarded prematurely, thus enhancing recycling efforts and reducing landfill waste.

Liao et al. (2022) discuss innovations in carbon-neutral pipeline operations that optimize pump efficiency to reduce energy use. The integration of intelligent monitoring systems ensures that pipeline performance is continuously optimized, aligning with the European Green Deal's carbon neutrality targets. Predictive maintenance, enabled by IoT sensors, further contributes to reducing energy use and emissions. These enabling technologies are applicable not only to pipelines but to other energy-intensive logistics systems, such as reverse logistics operations, where resource recovery processes can be made more energy-efficient through real-time monitoring and optimization.

Open-source freight optimization and synchromodal logistics

The studies by Agbo and Zhang (2017) and Giusti et al. (2018) address synchromodal logistics and open-source freight optimization tools, which are critical for improving sustainability in complex logistics networks. Agbo and Zhang's research on **synchromodal logistics - enabling real-time switching between transport modes based on market conditions and energy consumption**, is particularly relevant for industries with multimodal transportation needs. The ability to dynamically shift between modes—such as rail, road, and sea—helps reduce energy consumption and emissions by optimizing for the most sustainable option at any given time.

Similarly, the SYNCHRO-NET platform by Giusti et al. (2018) allows logistics operators to **optimize routes and transportation modes using open-source technologies**. **Smart steaming**—where ships reduce speed to save fuel without compromising delivery times—is a key feature of SYNCHRO-NET and provides a direct sustainability benefit by reducing greenhouse gas emissions. These open-source tools give logistics companies the flexibility to experiment with different strategies for achieving their sustainability goals, making them valuable resources for logistics planners and operators.

Intelligent risk management for sustainable logistics

Alzaharani et al. (2023) addresses the problem of predicting the supply chain risk in the logistics business and offers a hybrid deep learning (DL) approach, convolutional neural network (CNN) and bidirectional gating recurrent unit (BiGRU) solution, applied to natural disasters on shipping operations. These authors review related works in the field of machine learning and deep learning techniques for intelligent supply chain risk prediction systems. The proposed solution by Alzaharani et al. (2023) show that the combined BiGRU and the CNN model outperformed the baseline models, with an accuracy of 93 percent, and have the potential to help business owners to make judgements of bounded risks before exporting their products.

The study by Shankar et al. (2018) proposes an integrated risk assessment model for sustainable freight transportation systems, emphasizing that most sustainability risks are socially induced. This insight is critical for reverse logistics and symbiotic logistics operations, where social factors such as public perception, regulatory pressures, and stakeholder engagement play significant roles in shaping sustainability outcomes. By integrating risk management into logistics planning, and applying intelligent solutions to address it, companies can proactively address potential disruptions, ensuring that their operations minimize environmental impacts while remaining more resilient to uncertainty.

Lean, resilient and green supply chain management

The integration of lean, green, and resilient supply chain practices, as outlined by Govindan et al. (2014), forms a foundation for improving sustainability performance in logistics operations.

Supply chain resilience (SCR) acquired increasing importance after the global pandemic caused by COVID-19 and the various geopolitical conflicts, due to the potential high impact that disruptions of food and materials shortages or extended delivery times have in the economy. Around 63% of companies in the survey launched by PwC to more than 1000 senior supply chain executives globally mentioned that they are adapting supply chains to manage disruption (PwC, 2024). Supply chain executives also expect disruptive trends to intensify in the next decade.

Tukamuhabwa et al. (2015) presents over twenty definitions for SCR found in the literature and considered two as the most comprehensive. For example, the one following Ponomarov (2012), where SCR can be defined as the adaptive capability of a firm's supply chain to prepare for unexpected events, respond to disruptions, and recover from them in a timely manner by maintaining continuity of operations at the desired level of connectedness and control over structure and function. To fully address resilience, supply chain collaboration is needed.

Govindan et al. (2014) provide a robust conceptual model that integrates lean, resilient, and green **supply chain management (SCM)** practices to achieve significant improvements in sustainability performance across environmental, social, and economic dimensions (Table 1). The proposed model reflects a deeply interconnected approach to **supply chain optimization**, where waste elimination, cleaner production, and risk management are synergized to foster both operational efficiency and environmental responsibility. Each of these components offers distinct, yet complementary, contributions to creating a more sustainable and resilient supply chain. The **waste elimination** principle in lean SCM primarily addresses inefficiencies throughout production and logistics processes. This practice, typically focused on minimizing non-value-added activities (e.g., overproduction, waiting, transport), has evolved to incorporate broader sustainability goals. In Europe, particularly in the automotive and electronics industries, the convergence of **lean** and **green** SCM principles is increasingly evident.

From an **engineering standpoint**, waste elimination is no longer confined to reducing costs and improving operational efficiency; it also involves minimizing the **environmental footprint** of supply chains. The **Just-in-Time (JIT)** methodology, while effective in reducing inventory costs, can lead to increased emissions due to the frequent, small-volume transportation it necessitates. To address this, Govindan et al. (2014) propose integrating **reverse logistics** into lean systems, which enables the recovery, reuse, and recycling of materials, creating a more circular and sustainable supply chain. This is particularly valuable in high-resource industries like automotive manufacturing, where the recovery of components reduces reliance on raw materials and minimizes waste.

Waste elimination should be viewed holistically across the entire supply chain. Optimizing transportation flows, reducing fuel consumption, and improving route planning can have a profound impact on reducing the overall environmental footprint. For instance, adopting **automated systems** for warehousing and material handling reduces energy consumption, and when integrated with **renewable energy sources**, supply chains become both leaner and greener.

European regulations, such as the Circular Economy Action Plan, push industries beyond compliance, fostering the development of zero-waste manufacturing models. This is particularly critical for urban logistics, where the rise of **urban consolidation centres** offers a tangible application of lean principles to optimize last-mile delivery. By aggregating freight and reducing transport congestion, these centres reduce emissions and improve the efficiency of supply chains—essential for achieving both economic and environmental goals in densely populated areas.

Table 1: Lean, resilience and green supply chain management practices (Govindan et al, 2014)

SCM practices	Upstream	Focal company	Downstream
Lean	• Supplier relationships (Panizzolo, 1998; Perez and Sanchez, 2000; Berry et al., 2002; Sezen and Turkkantos, 2013) • Just-in-time (Panizzolo, 1998; Berry et al., 2002; Shah and Ward, 2003) • Suppliers involvement in product development (Perez and Sanchez, 2000; Olorunniwo and Jolayemi, 2014)	•Lot size reduction (Shah and Ward, 2003; Saleem et al., 2013; Manna et al., 2013; Hozak, 2013) •Total quality management (Shah and Ward, 2003; Doolen and Hacker, 2005) • Cycle/Setup time reduction (Doolen and Hacker, 2005) • Waste elimination (Schulze and Störmer, 2012)	• Just-in-time (Panizzolo, 1998) • Delivery flexibility (Perez and Sanchez, 2000; Niranjan and Ciarallo, 2013; Sharma and Bhat, 2013) • Customer relationships (Perez and Sanchez, 2000; Doolen and Hacker, 2005)
Resilient	• Sourcing strategies to allow switching of suppliers (Rice and Caniato, 2003) • Flexible supply base/flexible sourcing (Tang, 2006) • Developing visibility (Christopher and Peck, 2004)	• Minimal batch sizes (Christopher and Peck, 2004) • Lead time reduction (Viskari and Karri, 2013; Bansal et al., 2014; Christopher and Peck, 2004) • Supply chain risk management (Christopher and Peck, 2004)	• Flexible transportation (Tang, 2006) • Silent product rollover (Tang, 2006) • Demand-based management (Iakovou et al., 2007)
Green	• Environmental collaboration with suppliers (Vachon and Klassen, 2006) • To encourage suppliers to take back packaging (Rao and Holt, 2005) • Certification of suppliers' environmental management systems (Vachon and Klassen, 2006)	• Cleaner production practices (Rao and Holt, 2005) • To minimize waste (Rao and Holt, 2005) • To decrease the consumption of Hazardous and toxic materials (Zhu et al., 2005) • ISO 14001 certification (Rao and Holt, 2005; Vachon and Klassen, 2006)	• Reverse logistics (Zhu et al., 2005; Jindal and Sangwan, 2013) • Environmental monitoring by customers (Zhu et al., 2005; Vachon and Klassen, 2006) • Discuss with customers about changes in existing packaging (Zhu et al., 2005)

Intermodal transport and synchromodality

Following MAERSK (2024), **intermodal shipping can be a game-changer for businesses** looking for efficient and cost-friendly ways to move their goods worldwide. It can use multiple modes of transport to move cargo until it reaches the destination, with the cargo stays in the same ISO containers along the entire journey. White (2022) questions the effectiveness of policymaking for intermodal freight transport to foster sustainability, e.g. due to the absence of objective targets. This also points out to the perspective of Saeedi et al. (2022) on the importance of performance measurement metrics in intermodal freight transport systems.

Rentschler et al. (2022) address **synchromodal transportation to advance sustainability**. The concept is somehow related to intermodal transport, but it comprises the synchronization of physical resources, business processes, and the parallel use of transportation modes in a mode-free way to offer shippers a more flexible and sustainable means of freight transportation (Agbo et al, 2017). Behdani et al. (2021) present synchromodal transportation as a flexible and sustainable logistics solution, particularly for inland waterways. Synchromodality enables real-time modal shifts, optimizing both energy use and operational efficiency. This directly supports the EU's goals of reducing CO_2 emissions by encouraging shifts from road to water and rail transport—both of which have lower carbon footprints. The ability to dynamically **reroute cargo based on real-time data** is crucial in minimizing environmental impacts while maintaining operational efficiency. The system's flexibility ensures it is well-suited to both long-haul international transport and urban logistics environments.

El Yaagoubi et al. (2022) present a new logistics model for **intermodal rail/road freight transportation** between Le Havre and the Paris region, focused on reducing carbon emissions and enhancing energy efficiency. By leveraging massified rail transport, the model seeks to offer an environmentally friendly and cost-effective alternative to all-road freight. Key contributions of the study include the reduction of carbon emissions by shifting freight from road to rail, cutting CO_2 emissions by up to 34% compared to traditional road transport. The model also optimizes terminal design and operations through simulations, resulting in reduced energy consumption and increased efficiency, with shorter routes, night services, and compact terminal layouts improving energy efficiency and reducing operational costs. The intermodal service not only provides a competitive alternative to road transport but also ensures profitability for investors, making the system economically viable while achieving significant environmental benefits. The study further evaluates the environmental impact by comparing CO_2 emissions from different transport modes and shows that using electric trains and efficient trucks for post-haulage further reduces emissions, promoting sustainability. It adopts a multidisciplinary approach by integrating modelling, simulation, and economic analysis to ensure alignment with carbon neutrality and green energy efficiency objectives. Figure 8 shows the logistic chain and its analysis into four main links, from the port of Le Havre to clients in the Paris region, focusing on terminal operations such as loading/unloading and storage optimization. Figure 9 illustrates the process of loading/unloading trains and trucks at the Moissy-Cramayel terminal, showcasing efficient storage scheduling and real-time container handling management.

Bhattacharya et al. (2014) developed a traffic flow analysis and decision support model to optimize schedules of road and rail within the context of an intermodal transport network, using spatio-temporal data mining, support vector machines and mixed integer programming, that was applied to existing fast moving consumer goods in India. Okyere et al. (2018) focus on how multimodal transport systems (MTS) improve logistics responsiveness through the integration of various transport modes—road, rail, and waterway—via intelligent systems. The use of IoT, cloud-based platforms, and AI plays a significant role in ensuring that real-time data is accessible to all stakeholders, including suppliers, transport operators, and logistics service providers. This real-time data exchange enhances decision-making processes, allowing stakeholders to quickly adjust operations in response to delays, environmental factors, or changes in demand. Intelligent systems embedded within MTS help track CO2 emissions, energy efficiency, and transport mode efficiency. By providing stakeholders with insights into the environmental impact of their operations, companies can make informed decisions that prioritize sustainability while meeting customer needs. For example, the use of IoT sensors in trucks and rail systems allows for more accurate tracking of fuel consumption and emissions, which can then be optimized to minimize environmental harm. The research seems to underscore the **importance of sustainability performance indicators to be embedded in the future into MTS decision-making frameworks**, ensuring that the environmental impact of each transport mode is monitored in real time. This data should then be fed back into the governance structure to ensure compliance with corporate and regulatory sustainability goals.

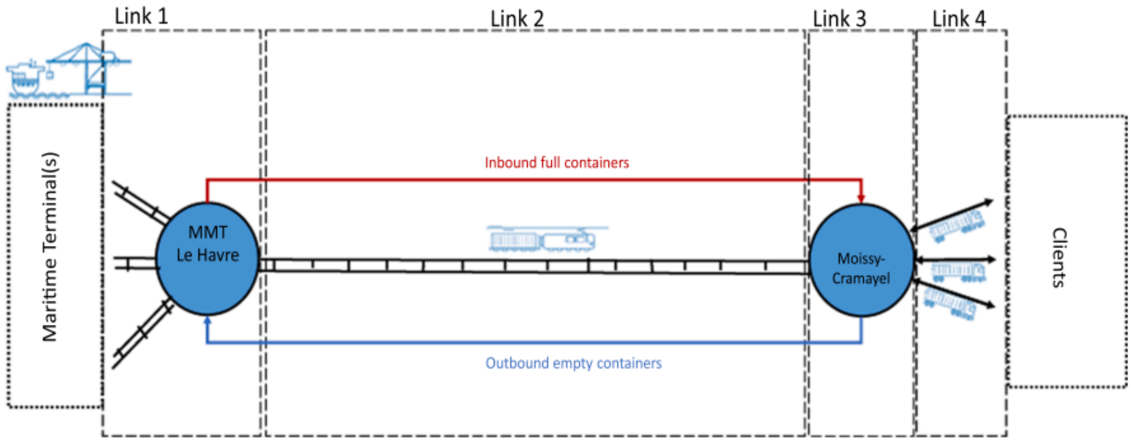


Figure 8: Logistic chain and its links in the study by El Yaagoubi et al. (2022)

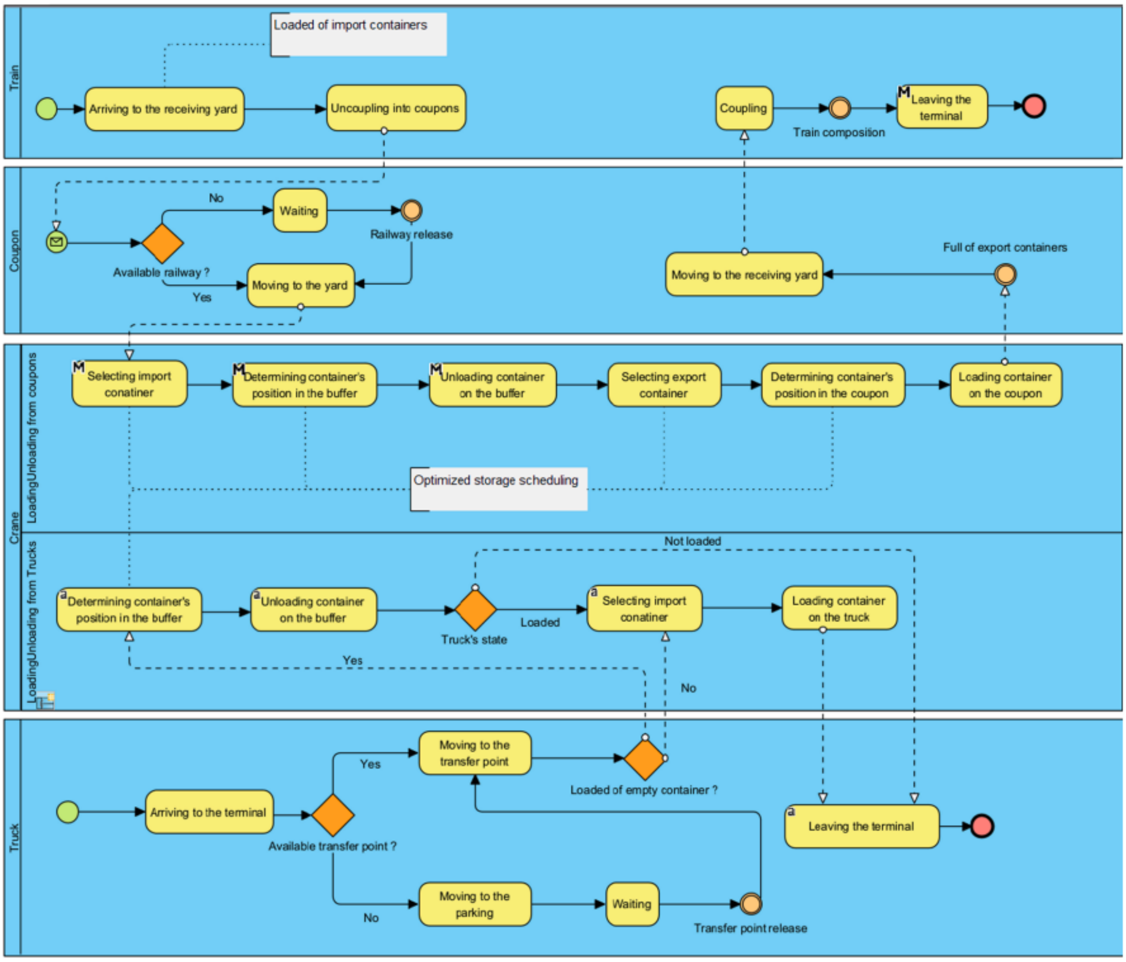


Figure 9: Operations in the El Yaagoubi et al. (2022) study: in the rail yard, only two coupons can be handled simultaneously by the crane to unload full/inbound containers and load empty/ outbound containers. As concerns trucks, they start arriving after the train's departure

Rail and maritime transport are increasingly seen as vital components of green corridors that connect major logistics hubs across Europe. The development of dedicated rail freight corridors, supported by advanced traffic management systems like the European Rail Traffic Management System (ERTMS), is a critical part of the EU's strategy to enhance the competitiveness and sustainability of rail freight. The success of rail freight initiatives depends on the continued liberalization of the sector and the removal of barriers to cross-border operations. Investments in rail infrastructure, including the modernization of freight terminals and the electrification of rail lines, will be essential to achieving greater modal integration. For maritime transport, the focus will be on improving the efficiency of port operations and hinterland connections, as well as reducing emissions from shipping through cleaner fuels and vessel designs.

Agile logistics and digitalization of supply chains

Agile logistics results from the fusion of cutting-edge technology like artificial intelligence (AI), the Internet of Things (IoT), and predictive analytics. By studying every component involved in real-time, these new technologies or processes allow for the optimization of the supply chain while addressing several performance criteria. Indeed, AI and machine learning methods are enablers to support the optimisation of internal processes, the reduction of CO_2 emissions across the entire supply chains and address sustainability performance. Management of warehouse and inventory management can also become smarter and stock levels optimized to changes in demand and context, e.g., anticipate shortage of critical goods in the market and secure its supply on-time by moving quicker based on data-driven decisions. The study by Pasupuleti et al. (2024) leverages advanced machine learning (ML) techniques to enhance logistics and inventory management using historical data from a multinational retail corporation, including sales, inventory levels, order fulfilment rates, and operational costs. Results show a 12% improvement in lead time efficiency and 8% reduction in replenishment errors.

The EU Regulation 2020/1056 on **Electronic Freight Transport Information (eFTI)** aims to digitalize freight transport across the EU by replacing paper-based documents with electronic data across all transport modes (road, rail, inland waterways, and air transport), being key for the agility of supply chains. The digital exchange of information by the competent authorities and the companies involved in freight transport and logistics is **expected to transform the way businesses operate until 2030**, enabling each company to comply with regulations and improve transparency, data security and efficiency of cross-border logistics.

Intelligent automation and self-driving delivery robots

Intelligent automation is the combination of robotic process automation (RPA), AI and soft computing such as cognitive computing (Ng et al., 2021). Performance outcomes include increased operational efficiency, improved risk assessment, adherence to quality and compliance, and value creation for stakeholders. Robotics in warehousing is not just about replacing human labour but rather about enabling real-time adaptation to demand fluctuations, improving warehouse energy consumption and reducing operational waste.

Advancements in robotic systems represents a promising way and includes to adapt **automated guided vehicles** to move cargo, **drones**, and **functional robots** to improve efficiency and contactless delivery. Service robots perform useful tasks for humans or equipment, and these are distinct from industrial automation applications (ISO 8373:2021, 3.7 and ISO 31101:2023). Sostero (2020) provides a comprehensive survey on the use and diffusion of robots in the EU and proposes a general taxonomy for automation in the service sector. Chen et al. (2021) addressed the adoption of self-driving delivery robots in last mile logistics through introducing a mixed-integer linear programming model to solve the vehicle routing problem with time windows and delivery robots.

2.3 Insights from case studies on practice

This section provides further insights from the network of papers to understand how companies/stakeholders are dealing with identified technological changes and adapting their systems for digitalisation, automation and the creation of new services; how the requirements for improving resilience and sustainability at the same time are considered; how intelligent systems are being used or planned to integrate all logistics stakeholders (producers, suppliers, ship owners, transport operators, support services, etc.), including sustainability performance indicators.

How companies/stakeholders are dealing with identified technological changes and adapting systems for digitalisation, automation and the creation of new services

He and Haasis (2019) research highlight that **companies in the retail/postal industry aim to leverage emerging transport modes to balance economic benefits with environmental externalities such as CO_2 emissions** by freight activities, **through the implementation of electric vehicles, modular e-vehicles, cargo bike, delivery drones, public transit system, robotic vehicles, taxi, inland waterway, parcel lockers, mobile depots and delivery robots** (Figure 10). Their research mentions that 73% of companies had approved the implementation growth of emerging technologies such as autonomous vehicles, drones, robots, and driverless transport systems, thus seeing these options with significant opportunities for future. Emerging innovations such as delivery drones, autonomous vehicles, modular vehicles, and urban waterway logistics remain in the development and testing phase, while more established solutions like electric vehicles and cargo bikes are already in operation and undergoing further improvement. **Parcel lockers, particularly in the parcel and B2C industries, have become a common logistical solution in urban freight transport** (He & Haasis, 2019).

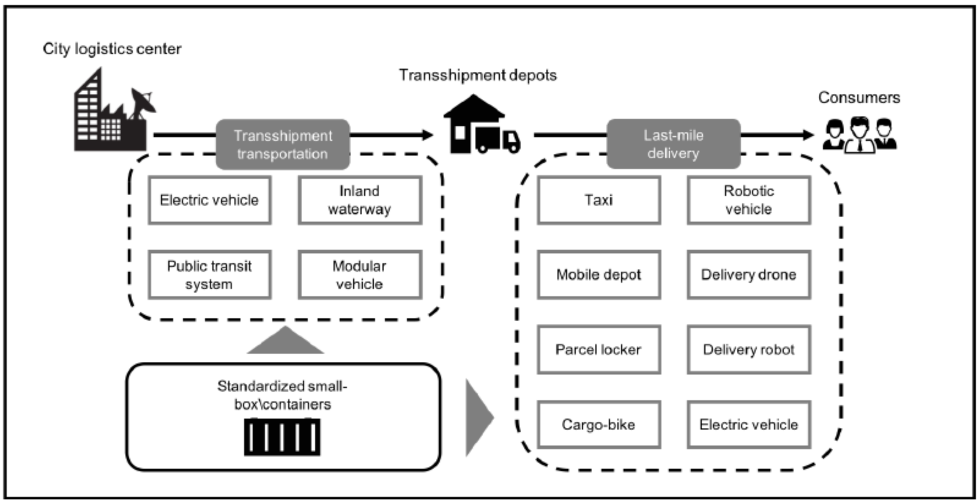


Figure 10: The concept of sustainable inner-Reconfigurable Supply Chain and Digital Twin Systems

Dolgui et al. (2020) propose the concept of a "Reconfigurable Supply Chain (SC)," emphasizing the importance of digital twins in managing complexity and variability focusing in four dimensions (Figure 11 left) and topological structure complexity (Figure 11 left).

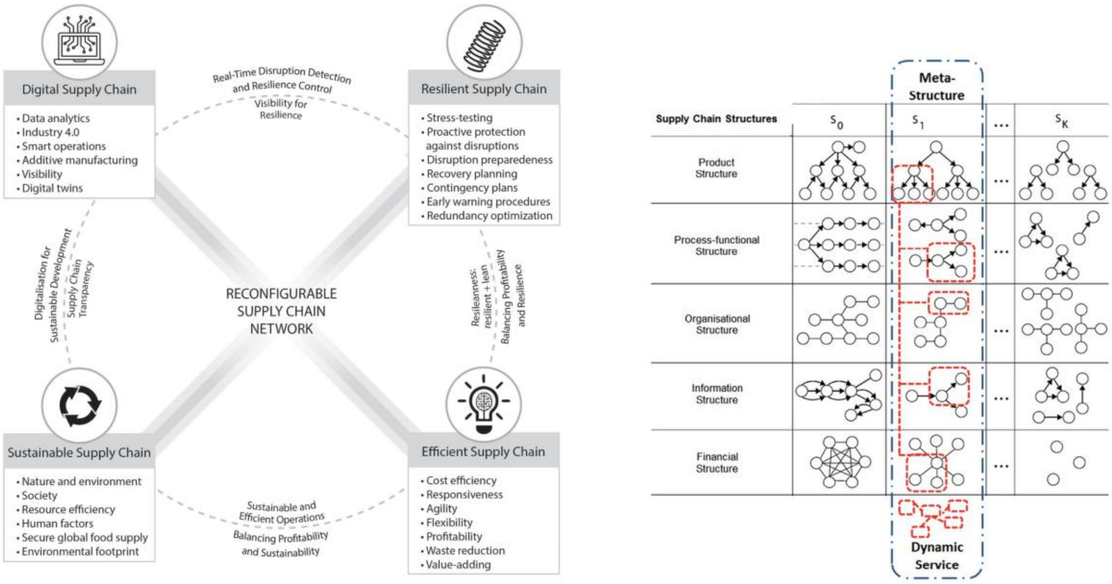


Figure 11: Design of a reconfigurable Supply Chain – left and topology structure - right (Dolgui et al., 2020)

By creating dynamic SC structures, companies can flexibly adjust to supply and demand fluctuations. The integration of **autonomous services** and **dynamic meta-structures** enables firms to maintain SC resilience and efficiency during disruptions. The reconfigurable SC design model by Dolgui et al. (2020) integrates three levels: network reconfigurability (structural level), plan reconfigurability (process level), and technology reconfigurability (plant level), including design and implementation principles and practical enablers as shown in Table 2. For example, the main implementation principles at the structural level are structural diversity, redundancy, segmentation and sustainability, and the digital infrastructure (cyber-physical systems and IoT) is considered as an enabler (Dolgui et al., 2020).

Table 2: Reconfiguration design principles and practical enablers by Dolgui et al. (2020)

Supply chain reconfiguration levels	Reconfiguration design principles and practical enablers			
	System design principles	Implementation principles	Organization and management	Technologies
Structural Level: Reconfigurable Networks	• Open and dynamic systems • Self-organization and self-learning • Self-adaptation • Visibility, monitoring and feedback control • Information Feedbacks • Coordination • Learning • Transparency	• Structural diversity • Structural redundancy • Structural segmentation • Structural sustainability	• Digital supply chain • Industry 4.0, smart and cloud manufacturing • Collaborative industry • Circular economy and industrial symbiosis • Closed-loop SCs	• Infrastructure technology (cyber-physical systems and internet-of-things); • Communication technology (cloud services; Blockchain).
Process Level: Reconfigurable Plans	• Data-driven analysis, modeling, learning and control • Digital SC twins • Collaborative supplier portals; • SC visibility • Sustainable systems	• Risk pooling • Socio-ecological process learning • Process agility • Responsiveness	• Demand analytics • Real-time inventory control • Flexible capacity • Risk mitigation inventory • Backup-transportation routes • Multiple sourcing • Product substitution • Resource preservation	• Data analytics technology (big data analytics and artificial intelligence)
Plant Level: Reconfigurable Technology	• Digital twins in manufacturing • Reconfigurable manufacturing systems • Collaborative manufacturing platforms	• Process modularity • Alternative energy chains • Human-machine collaborative networks	• Customized assembly and modular production; • Industry 4.0-based technology design • Energy-efficiency	• Engineering technology (collaborative robots, additive manufacturing; AGV and mobile robots; drones; augmented and virtual reality); • Communication technology (M2M; sensors)

Implementing **digital twin technology** to simulate real-time SC performance enables more agile decision-making and can improve adaptability under changing market conditions. In predictive maintenance applications in smart factories, digital twins were found to reduce maintenance costs up to 25% (Mihai et al, 2022).

Gizetdinov (2024) highlights how the Commonwealth of Independent States (CIS) and Western countries are **transitioning to digital platforms for logistics management**, focusing on electronic documentation, digital payments, and real-time tracking. This digital transformation is reducing lead times and improving transparency in supply chains. Western companies are leveraging automation for international freight, giving them a **marginal efficiency boost**. Transition to **digital documentation systems** and **IoT-enabled tracking** to streamline logistics operations and reduce processing times.

Vida et al. (2022) address how Logistics 4.0 leverages cyber-physical systems, AI, and robotics to optimize intermodal freight, particularly for rail-road container transhipment. The proposed **automated horizontal container handling system** can reduce container handling times and increase capacity utilization, aligning with EU environmental goals to shift freight from road to rail. Investment in automated container handling systems for intermodal terminals can reduce processing times and support environmental sustainability objectives.

You et al. (2023) introduce **truck platooning** to cut fuel consumption by 10-20% in multi-trip container drayage operations. In truck platooning, semi-autonomous trucks follow a lead vehicle, reducing aerodynamic drag and fuel costs, while also alleviating labour shortages in the logistics sector. Yamamoto and Ishiguro (2016) present an **automated rail-road intermodal courier system**, utilizing Intelligent Transportation Systems (ITS) and robotics for small parcel delivery. This system addresses challenges like long exchange times and large container sizes by improving speed and flexibility, reducing courier service times. The deployment of **ITS-aided robotic systems** in intermodal freight is found to be associated to faster and more efficient small-packet deliveries, particularly in urban logistics networks.

Kine et al. (2022) assess the potential of digitalization and automation for intermodal freight transport in low-income countries. Technologies like **wireless communication, web-based platforms, and sensor-based monitoring** are identified as crucial for enhancing logistics in regions with infrastructure constraints. Adopting these technologies could increase logistics efficiency. Introducing sensor-based systems and EDI platforms in intermodal logistics for low-income countries to improve transparency and reduce operational costs.

Muñuzuri et al. (2020) address the **use of IoT-based systems to optimize port and intermodal supply chains**. The introduction of FIWARE - an **open-source platform for container tracking and rail management** has enhanced real-time visibility, reduced congestion, and improved coordination between shippers and terminal operators. Efficiency improvements were observed. Implementing IoT tracking systems for real-time container and cargo management to reduce congestion and enhance supply chain visibility, potentially cutting transit times.

Wu et al (2019) proposed a “Universal Supply Chain of Things” - **the SCoT platform**: operate various intelligent processes, including quality measurement, production integration, and decision making (Figure 12). Therefore, ubiquitous and ultra-reliable connectivity (UURC) is defined to connect the entire SCoT for data collection and system control. Four use cases of UURC are defined for four fundamental applications that include identification, tracking, monitoring, and management. The IoT standard of IEE P2668 Maturity Index (IDex) was there proposed. At present, companies are utilizing **IDex's** extra functions[4], such as advising on solutions for quality improvement, integration guidance, and performance prediction, to enhance productivity and innovation in the supply chain ecosystem.

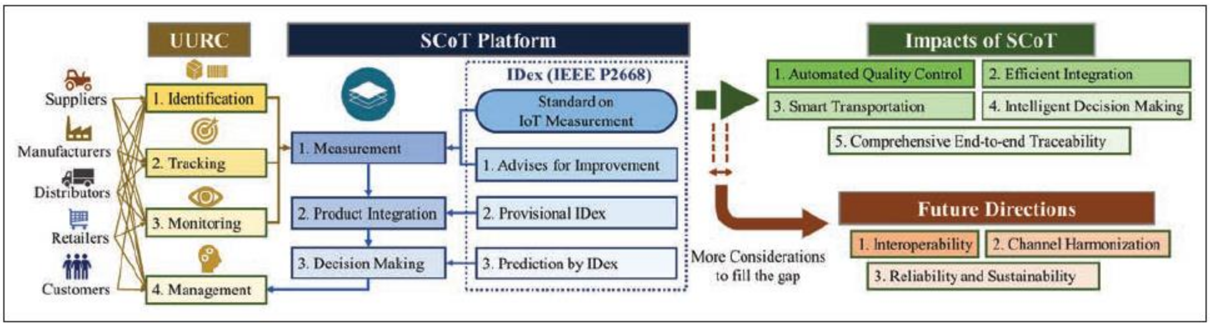


Figure 12: The SCoT Platform by Wu et al. (2019)

In the study by Patil et al. (2023), the focus is on the potential benefits of **digitalization in humanitarian supply chains (HSCs),** emphasizing how adopting digital technologies can improve various facets of the supply chain, including coordination, data sharing, and operational efficiency. The integration of digital systems in HSCs is critical for enhancing visibility, transparency, and overall responsiveness in disaster relief operations. The study highlights several key drivers for digitalization, such as data transparency and security, tracking and traceability, and sustainability-focused practices. These drivers illustrate a growing shift towards leveraging technology for improving performance, especially through innovative solutions like blockchain, RFID, IoT, and AI. One of the key insights from the works by Patil et. (2023) is **the integration of stakeholders—suppliers, service providers, and technology partners—within the HSC ecosystem.** Digital technologies play a pivotal role in fostering trust, enhancing collaboration, and improving overall coordination between these parties. Managerially, the study also underscores the importance of setting clear objectives, ensuring alignment between technological tools and organizational goals, and involving stakeholders in the development and application of these technologies.

Amouei et al. (2024) proposed a conceptual model for companies to integrate sustainability into digital supply chains. The study works focus on digital supply chains in manufacturing companies in Iran. Amouei et al. (2024) note that as companies face significant technological challenges, they are increasingly adopting digitalization, automation, and new services like IoT, autonomous delivery, and robotics to enhance supply chain operations. One non-trivial aspect of this transition is that **companies are not merely automating existing processes but are reengineering their supply chain frameworks to integrate data-driven insights and real-time analytics**, that leads to improved decision-making and resource allocation. For instance, IoT and AI-driven platforms allow for greater supply chain visibility, enhancing inventory management, predictive maintenance, and minimizing downtime, leading to cost reductions and sustainability improvements.

[4] P2668/D5, 2022 - IEEE Standard for Maturity Index of the Internet of Things – Evaluation, Grading, and Ranking.

How intelligent systems are being used or planned to integrate all logistics stakeholders

Intelligent systems are revolutionizing the logistics sector by fostering the integration among diverse stakeholders such as producers, suppliers, shipowners, transport operators, and support services. These systems, enabled by advancements in **IoT**, **AI**, **blockchain**, and **automation**, not only enhance operational efficiency but also focus on improving sustainability performance through real-time data tracking, energy optimization, and emissions reduction. Below is a breakdown of how these intelligent systems are specifically being applied across various logistics processes, targeting both optimization and sustainability metrics.

According to Liu et al (2023) blockchain technology is being leveraged in the maritime supply chain to enhance traceability, transparency, and automation, thus integrating all logistics stakeholders—producers, suppliers, ship owners, transport operators, and support services. The works show the use of blockchain technology applications for **smart contracts** by several worldwide companies such as Blockshipping, CargoSmart, COSCO, DP World HNA Group, Maersk, MSC, PSA, PIL, SIPG (Table 3).

Table 3: Applications of blockchain technology by worldwide shipping companies by Liu et al. (2023)

Time	Organisation	Events
June 2015	HNA Group	Launch a blockchain-based aviation maritime financial settlement and data service management platform – AirPay Insurance
November 2016	Rotterdam, ABN AMRO Bank, Technische Universiteit Delft	Launch a blockchain logistics contract information sharing application platform
August 2017	PSA, PIL e IBM	Jointly sign a Memorandum of understanding to promote supply chain business network innovation based on blockchain technology
August 2017	K-Line, MOL and NYK	Announce the formation of an alliance to develop a trade data sharing platform using blockchain technology
September 2017	HNA Group	Intelligent container management operation platform project
September 2017	Enrst&Young and Guardtime	Announcing the creation of the world's first maritime insurance blockchain platform
November 2017	Star shipping, Sparx Logistics and Wave	Complete the pilot project of a paperless bill of lading based on blockchain technology
January 2018	Shangai Customs, COSCO and SIPG	Sign the development of a bid data platform for cross-border trade management based on blockchain technology
January 2018	Maersk and IBM	Jointly develop a blockchain-based global trade digital platform
August 2018	Maersk and IBM	Launch the digital industry platform TradeLens with the aim of applying blockchain technology to the global maritime supply chain
September 2018		MarineX, the first maritime blockchain platform in mainland China, announces official establishment
November 2018	DP World, PSG, SIPG, and COSCO	Cosign to create a blockchain alliance for the Global Business Shipping Network (GBSN)
April 2019	Maersk, MSC, Hapag-Lyold and ONE	Officially announce the establishment of the Digital Container Shipping Association (DCSA)

June 2019	Samsug SDS and ABN AMRO Bank	Develop a blockchain-based logistics pilot project to track container shipments from South Korea to the Netherlands
April 2020	CargoSmart, COSCO, SIPG, and Tesla	Complete the pilot application of digital transformation of the existing cargo release process, which is the first batch of pilot applications projects in the maritime industry to realise real-time freight data exchange between ocean carriers and quay operators through blockchain technology
June 2020	China Merchants Port, Alibaba Group and Ant Financial Services Group	Sign the “Strategic Cooperation Framework Agreement” to open the full link of port business through Ant blockchain technology and to reconstruct the multiparty cooperation system of port trade and logistics
June 2020	China (Shanghai) Pilot Free Trade Zone	Actively deploy and promote the construction of a shared ecosystem of blockchain technology and international shipping
September 2020	Blockshipping	The World’s largest shared container platform GSCP

Figure 13 shows smart contracts as the key intermediary that connects exporters, logistics companies, shipping companies, and government systems. These **smart contracts automatically execute functions such as receiving orders, tracking shipments, and updating logistics information, thus ensuring continuous feedback loops between stakeholders**. The blockchain-driven system improves traceability, allowing stakeholders to monitor not only the flow of goods but also critical sustainability indicators such as carbon emissions and energy usage through real-time tracking and data analytics.

From a sustainability standpoint, blockchain's ability to provide immutable records enhances accountability, particularly in terms of adhering to corporate codes of conduct and reporting frameworks. This can help stakeholders uphold sustainability goals by ensuring transparency in operations, reducing inefficiencies, and fostering a governance structure that integrates all actors under a unified digital platform. Furthermore, the system allows for better compliance with environmental standards, as it offers real-time data on the environmental impact of each shipment, helping companies align with carbon neutrality objectives.

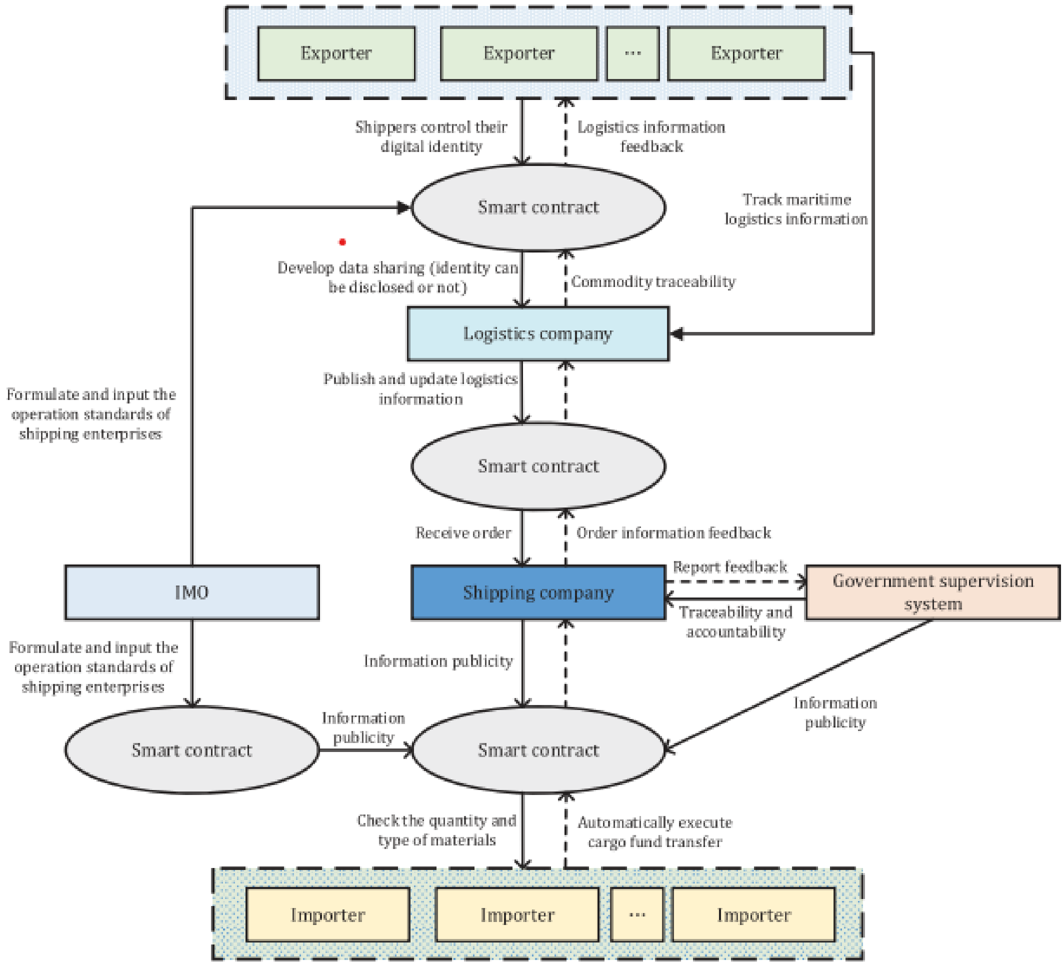


Figure 13: Operation and Management processes of blockchain and smart contracts by Liu et al. (2023)

Gerken et al. (2020) outline the stakeholder involvement strategy in the Digital Logistics Terminal (DLT) project, which focuses on inclusive participation and varied contributions from diverse stakeholders. The project invites logistics providers and other entities to contribute with capital, expertise, or resources, fostering broad participation. Stakeholders are encouraged to invest financially or provide knowledge, land, equipment, or labour, thus ensuring that contributions come in various forms to meet the project's diverse needs. The project offers compensation mechanisms, such as usage fees, even for indirect contributors, making participation attractive for a wide range of entities. This inclusive approach not only promotes engagement but also supports the project's financial viability. Risk-sharing mechanisms further enhance project stability by distributing financial risks among the stakeholders, mitigating the burden on any single participant. Effective governance is critical in this framework, as clear roles, decision-making processes, and transparent governance structures help establish trust and collaboration among stakeholders.

By optimizing resource utilization and ensuring sustainable project development, the DLT by Gerken et al. (2020) supports the transition toward more efficient, resilient, and sustainable logistics practices. The strategy ensures that all contributors benefit, strengthening the project's foundation and encouraging investment in green, energy-efficient technologies.

IoT-based systems play a critical role in enhancing data acquisition and processing across intermodal supply chains. Muñuzuri et al. (2020) describe the application of IoT for optimizing container transport operations along intermodal corridors. By integrating container tracking, rail management, and inland navigation, IoT systems enable seamless data sharing between shippers, port operators, and inland terminals. This technology, operational at the Port of Seville, provides **real-time updates on container movement, ensuring that decisions made by transport operators and shipowners are synchronized**, reducing idle times and energy consumption (Figure 14).

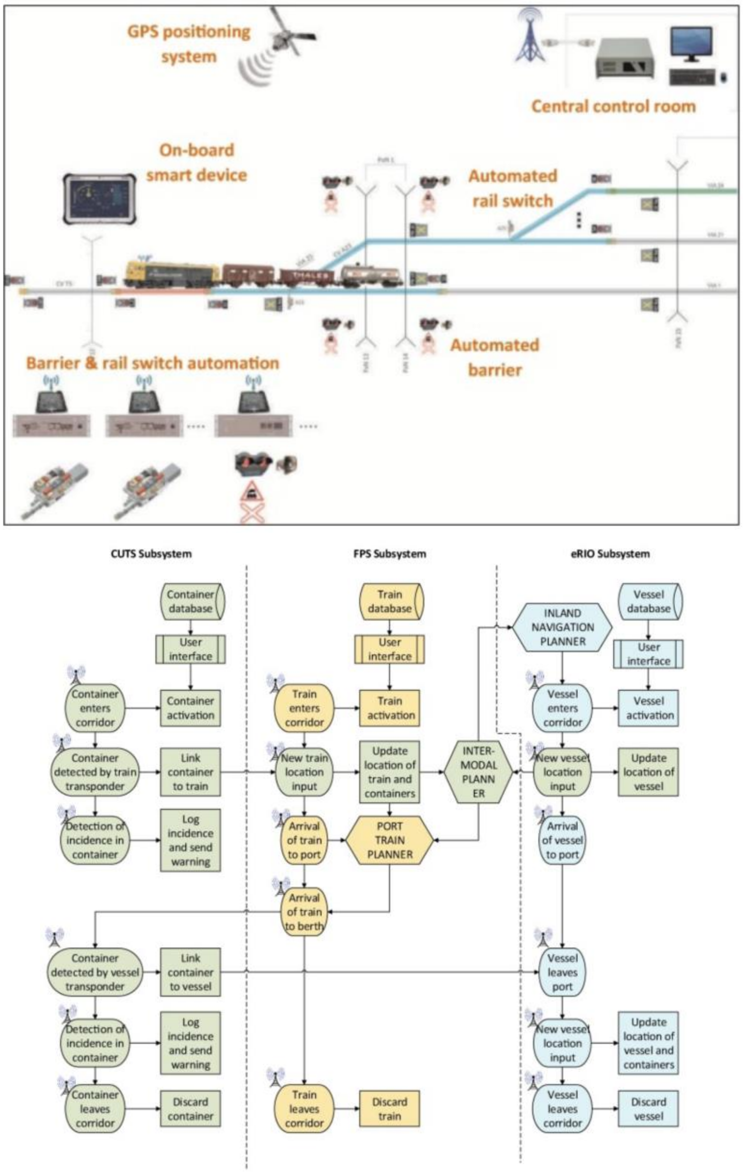


Figure 14: Rail-Port system and subsystem architecture by Muñuziri et al. (2020)

The stakeholders involved in the works of Muñuziri et al. (2020) are represented in Figure 15

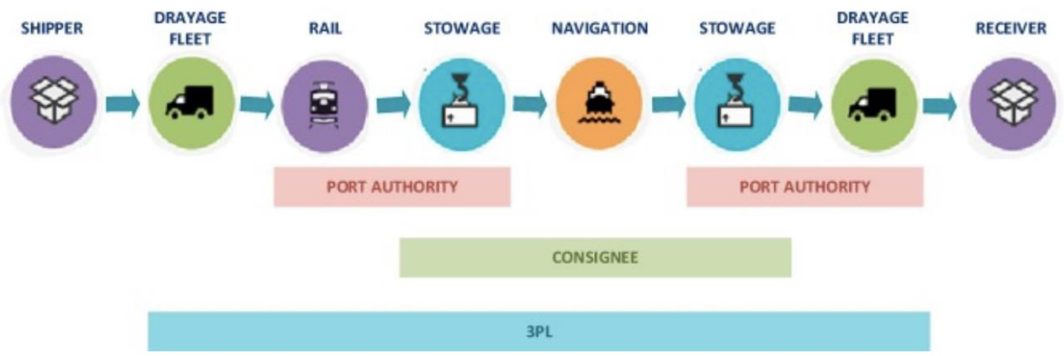


Figure 15: Involved stakeholders in a logistic chain from Canary Islands to Madrid route by Muñuzuri et al. (2020)

Tufano et al. (2023) mentioned that the introduction of data-driven fourth party logistics 4PL IT platforms aim to collect data from multiple stakeholders in a supply chain network. These platforms monitor processes, assess the state of the network, and provide valuable information services to support decision-making from a network perspective. The authors emphasize the value of data in understanding processes, improving performance, and supporting decision-making in supply chains. The data-driven 4PL IT platforms in the logistics industry also represents a shift towards new business models based on the value of data and network effects.

The works by Tufano et al (2023) on **data-driven logistic platforms for barge transportation** networks illustrate the interdependencies and flow exchanged between actors in a real-world case study developed for a 4PL IT platform operating in the port of Rotterdam. This platform receives transport orders from barge operators (share of around 5% of the containers transported in the port area) and provides them booking options in advance, aiming to achieve real-time allocation of containers to barges. Tufano et al. (2023) used operational data from different actors to structure the functional model that allows the tracking of container movements, inventory of the vessels and productivity of terminals. As shown in Figure 16, there are many actors involved in the planning, control, and execution of **container logistic operations**, such as **suppliers** (representing any production or storage system connected to a terminal by road, rail, or inland waterways), **freight forwarders** (the operators in charge of organising door-to-door shipping), **logistic agents** (e.g. barge operators), **conveyance operators** (e.g., barge owners), **terminal operators** (they perform loading and unloading of handling units at the terminal), and **consumers** (they receive the goods at the end of the transport operation).

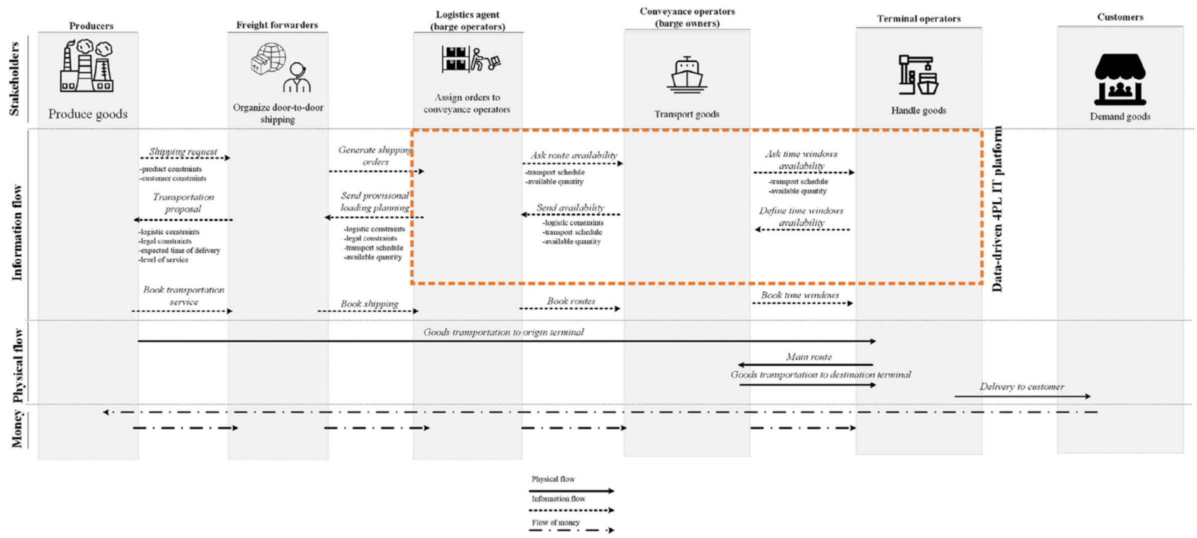


Figure 16: Stakeholders interdependencies flows by Tufano et al. (2023)

Companies are on their way to adopt IoT-based tracking systems across logistics nodes to improve decision-making processes, enhance coordination, and lower energy use by automating container handling and movement. Dry ports are often critical bottlenecks where intelligent systems can have the highest environmental and operational impact. A key challenge is **data integration across inland rail and maritime ports**, which can be mitigated by standardized data protocols and blockchain-based documentation systems to ensure seamless cargo handoffs. Jeevan et al. (2022) focus on challenges faced by the dry ports in Malasia and Nepal, that represent a costal country and a landlocked country respectively. In their works they conducted face-to-face and phone interviews with several stakeholders, including port operators, legislative personnel and public policy actors. Results show that further works are required to overcome current limitations in capacity and connectivity, cross-border transactions, seaport-dry port integration and the supportive regulatory tools. In the future, intelligent systems, including IoT-enabled tracking and real-time monitoring systems, are vital in synchronizing the operations between seaports and dry ports. This allows for seamless communication between stakeholders, particularly in landlocked countries where the integration between inland terminals and coastal hubs must be efficient to reduce transport delays. Dry ports using IoT systems can monitor cargo movement, manage inventory in real-time, and ensure optimal scheduling of containers between nodes. This integration supports sustainability by reducing fuel consumption through optimized container movements, reducing CO_2 emissions, and promoting better utilization of transport modes. The integration of IoT for emissions tracking can be extended to measure specific sustainability indicators such as real-time fuel consumption, idle times, and emissions per container moved. These metrics can be considered in corporate sustainability goals and can be tracked at the port level.

Eswari and Yogeswari (2019) identify key sustainability indicators for port operations in India, showing how integrating energy-aware information systems helps port authorities and terminal operators reduce energy consumption during cargo handling and storage. These systems track energy use in real-time, enabling port authorities to optimize operations by shutting down non-essential equipment during low-traffic periods and prioritizing energy-efficient transport options.

Baccelli and Morino (2020) emphasize the crucial role of port authorities in promoting **logistics integration, especially between ports and the development of the railway system in port hinterlands** in Italy. In the case study, the research gathered views of the following public and private actors: terminal operator, shipping line, forwarders, railway company, inland terminal operator and dry port operator, public stakeholders/local government (region), port authority and labour union. Although the opinions towards the development of intermodal systems were distinct for each stakeholder, common positive views were achieved for the integration of the railway system in port hinterlands. The research noted the role of the governance model of the Systemic Port Authorities and their capacity to articulate with the State and regions and engage stakeholders to achieve the proposed goals.

Göçmen and Erol (2018) propose a mathematical model that optimizes container allocation across different transport modes (rail, road, and sea), factoring in ecological and social considerations. This model integrates sustainability performance indicators such as carbon emissions and fuel efficiency into logistics planning, ensuring that transport operations balance economic and environmental goals. The approach aids port operators, terminal managers, and transport operators in reducing the environmental footprint of logistics operations Larsen et al. (2019) highlight how model predictive control in synchromodal transportation allows for dynamic route adjustments in real-time. This technology optimizes the allocation of containers and vehicles across rail, road, and sea routes, directly involving stakeholders such as transport operators and freight forwarders. The system enhances coordination by reducing underutilization of transport modes and synchronizing shipments between different logistics players. This approach cuts inefficiencies and lowers carbon emissions through optimized transport choices.

Saha et al. (2023) address how blockchain technology integrates diverse supply chain stakeholders, including producers, suppliers, and transport operators, by providing a transparent and secure platform for data exchange that could combat food fraud in the agri-food supply chain. Blockchain ensures traceability and immutability, reduces fraud and enables all parties to access real-time data on shipments and include sustainability metrics such as carbon footprints. By embedding sustainability performance indicators, blockchain allows stakeholders to make informed decisions that align with environmental goals.

Yu et al. (2023) and Liao (2017) discuss how AI systems are used to dynamically optimize vehicle routing, minimizing both economic costs and environmental impact. AI algorithms can handle complex multi-variable inputs, such as real-time traffic conditions, fuel efficiency, and route availability, to provide transport operators and logistics coordinators with optimal scheduling recommendations. These intelligent systems also incorporate sustainability metrics, calculating carbon emissions and adjusting routing strategies to minimize them. Mittal et al. (2024) emphasize the role of IoT in monitoring vehicular data for predictive maintenance. By equipping transport fleets with sensors, companies can monitor key performance indicators (KPIs) such as fuel consumption, engine wear, and tire pressure. These systems enable early detection of potential vehicle failures, preventing downtime and improving fuel efficiency. Stakeholders such as fleet operators and service providers can coordinate on maintenance schedules, reducing waste and emissions.

AI and VR Technologies are being used in manufacturing to improve material use and enhance training, leading to better sustainability outcomes (Oliveira et al., 2023). Figure 17 provides the range of applications reviewed in the study covering logistics and intelligent manufacturing.

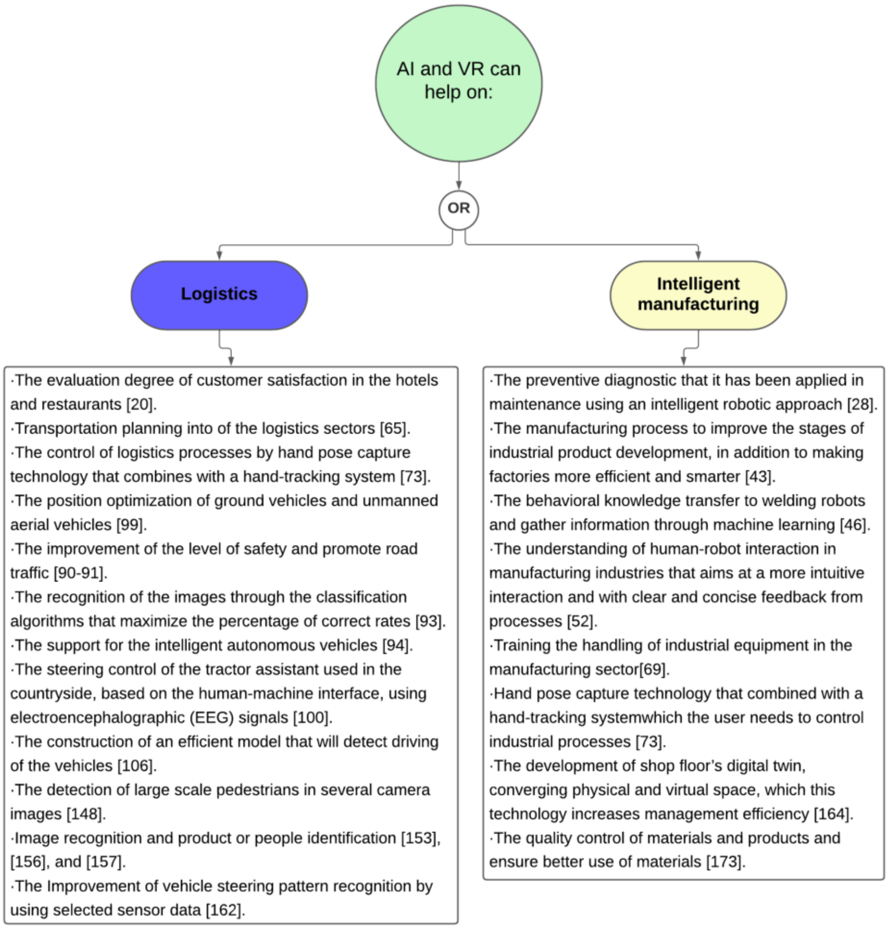


Figure 17: AI and VR technology in logistics and intelligent manufacturing by Oliveira et al. (2023)

How the requirements for improving resilience and sustainability are considered

The integration of **resilience** and **sustainability** in logistics and infrastructure systems is becoming increasingly crucial, especially given the rising frequency of disruptions caused by natural disasters, climate change, and operational uncertainties. A thorough examination of recent research shows that the requirements for improving resilience and sustainability are deeply interconnected and should be addressed concurrently in future planning.

Mao et al. (2022) establish a baseline for road network restoration during post-disaster scenarios by evaluating recovery times and the associated emissions. This study emphasizes the need for resilient road networks to minimize traffic disruptions and reduce post-disaster emissions. By optimizing road restoration schedules based on resilience metrics, the study highlights that improved resilience can also lead to better sustainability outcomes, such as lower carbon emissions during recovery phases. Zhou et al. (2021) suggest that maritime logistics can be transformed through Industry 4.0 and resilient port management innovations, with a **decision support system (DSS) playing a crucial role in planning and real-time operations to optimize equipment configuration and minimize disruption impacts**. The development of the **digital-twin enabled decision support** could be extended to other traditional industries as well (Figure 18).

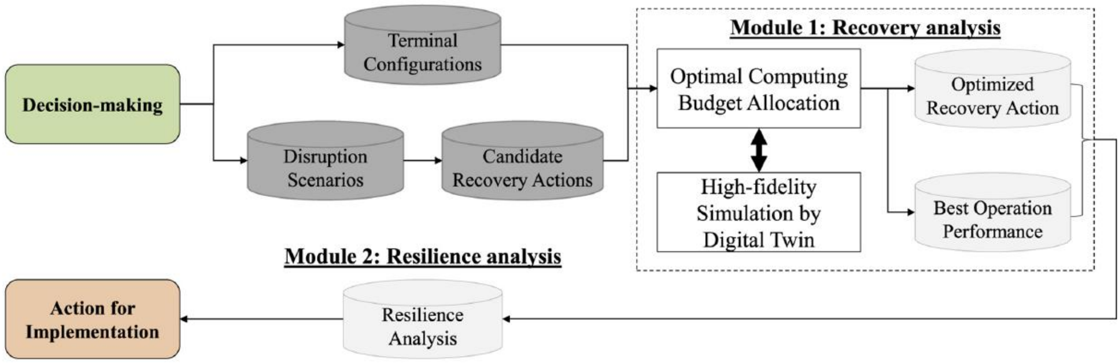


Figure 18: Digital twin DSS architecture for maintaining a resilient port by Zhou et al. (2021)

The deployment of **smart grids** and **IoT-enabled systems** plays a key role in enhancing resilience while promoting sustainability. Moore and Gheisari (2019) highlight how technologies like **virtual and mixed reality** improve operational safety and planning processes, reducing waste and enhancing energy efficiency. These technologies ensure that logistics systems can adapt to disruptions while simultaneously minimizing their environmental footprint. Theodosiou et al. (2015) present an optimization model for energy systems that considers both environmental and resilience factors. By integrating these elements into energy systems design, the study shows how optimization can simultaneously enhance sustainability and resilience.

Heinold and Meisel (2020) simulation work focused on emissions and transit times in large freight shipments in the European rail/road transport and emphasize that **resilience and sustainability are closely linked in intermodal transport networks.** Sustainable routing combined with resilience is key to ensure that intermodal systems maintain continuity even in the face of disruptions.

According to Proedrou (2018), a steady-state energy policy that aligns with ecological and economic principles to ensure resilience and sustainability. The work suggests a **shift away from fossil fuel dependency towards low- or no-carbon systems** as a political project that involves social justice and international governance. It also highlights the importance of domestic and international cooperation in addressing climate change challenges and the role of states in directing market players towards climate-friendly solutions. The future considerations involve cosmopolitan justice and a collective action approach that transcends traditional state-centric views, focusing on the global middle class as the main driver of carbon emissions. The research compares steady-state and mainstream energy policies, offering clear insights into how resilience and sustainability can be simultaneously achieved: **sustainability in the steady-state model adheres to biophysical limits and prioritizes reversing harmful energy production and accelerating the energy transition**. In contrast, mainstream policies allow for excess energy use and perpetuate unsustainable practices, implying that future energy policies must focus on strict adherence to ecological boundaries and fast-tracking ambitious climate goals; **security of supply** in the steady-state model emphasizes local ownership and predictable energy access, while mainstream policies expose energy systems to geopolitical risks and volatility. This suggests that resilience can be enhanced through local renewable energy production, reducing foreign dependence; **affordability** highlights the steady-state's focus on stabilizing renewable energy costs, in stark contrast to the mainstream's reliance on subsidized, volatile fossil fuel markets. Future policy must shift to transparent energy pricing that reflects true costs, promoting renewables over fossil fuel subsidies. Lastly, **core energy policies** in the steady-state model advocate caps on energy use and moratoriums on fossil fuel exploration, which are crucial for long-term sustainability, while mainstream policies fail to limit fossil fuel expansion. The implication is that **strict energy use limits and fossil fuel restrictions are vital for ensuring both resilience and sustainability**.

Kulkarni et al. (2022) propose designing logistics networks that are inherently resilient to disruptions and also operate efficiently under varying conditions. This type of network design integrates sustainability by ensuring that logistical frameworks remain operational despite challenges such as supply chain disruptions or shifts in demand. The robust nature of these networks ensures that sustainability goals, such as reducing carbon emissions, can still be met even when under stress. Vergara et al. (2023) offer a comprehensive framework combining resilience and sustainability through fuzzy multi-criteria decision-making techniques (MCDM). The study highlights how **modern supply chains must balance flexibility, agility, and collaboration to ensure they can respond to disruptions** (resilience perspective) while maintaining environmental and social responsibilities (sustainability). The authors provide a fuzzy method to assess the interdependence of performance indicators and cause-effect relationships. The dimension criteria considered for resilience accounted for the following effects - flexibility, collaboration, visibility, information sharing, leadership and SCRM culture impacting on the agility cause. In the work, flexibility allows supply chains to manage rapid changes, while agility helps adjust to disruptions. Collaboration with suppliers and logistics operators becomes essential for minimizing the environmental impact while ensuring resilience during shocks. The study emphasizes waste minimization and product lifecycle management as critical criteria to balance sustainability with resilience. For example, integrating waste recovery systems into logistics can enhance both resilience (by reducing dependency on primary materials) and sustainability (through lowering carbon emissions). Beil & Putz (2023) advocate for modal shifts from road to rail and water transport to enhance resilience and sustainability. These shifts reduce reliance on oil and help logistics networks withstand fluctuations in fuel prices and emission regulations. The transition to these more sustainable transport modes improves the resilience of supply chains to environmental and economic disruptions. Ivanov et al. (2019) highlight the use of simulation and optimization technologies to predict and mitigate supply chain disruptions. By simulating various disruption scenarios, these technologies help companies maintain operational sustainability, ensuring that emissions and environmental impacts remain low even during adverse events. Ahmed et al. (2019) explore the integration of Connected and Automated Vehicles (CAVs) in disaster scenarios, which enhances the resilience of transportation systems. CAVs help maintain operational continuity during disruptions, reducing traffic congestion and emissions. This integration is crucial for sustaining logistical operations while minimizing the environmental impact.

Prashar (2022) and Lee et al. (2022) both emphasize the role of smart systems in ensuring supply chain continuity during disruptions. By maintaining operations and reducing waste through optimized logistics processes, these smart systems directly contribute to environmental sustainability.

Dalivand & Torabi (2024) proposes a multi-objective mathematical model designed to address resilience and sustainability in seaport-dry port networks. Intelligent systems, including intermodal transportation and advanced optimization algorithms, such as **multi-objective particle swarm optimization (MOPSO)**, play a central role in improving the integration of stakeholders in the logistics chain. Here, IoT-based container tracking systems and real-time data are used to monitor and optimize the flow of goods between seaports and dry ports. By incorporating **proactive** and **reactive** strategies **for handling disruptions** (e.g., rail or dry port outages), intelligent systems can dynamically reroute shipments, preventing bottlenecks and ensuring operational continuity.

Figure 19 illustrates the main resilience capabilities and metrics: i) proactive capability includes strategies to increase the capacity of the rail transportation system and intermodal transport, enabling one mode to replace the other, in case of malfunctions and disruptions; ii) reactive capability integrates strategies to guarantee a maximum tolerable period of disruption (customer satisfaction), implement minimum business continuity objectives (minimum operational level for each key network function) and responsiveness of a supply chain/transportation network (ratio of the fulfilled demands to the total demands of customers); and iii) design quality capability that requires the analysis of node criticality and network complexity. As mentioned by Kazemian et al. (2022) cited by Dalivand & Torabi (2024), a node is critical “when the sum of its inbound and outbound links (i.e. its degree) is higher that a determined target value provided by the top manager”. The network complexity is related to the network size and is defined by the number of active nodes (e.g., number of established dry-ports in the transportation network). These strategies not only reduce economic losses but also optimize the energy usage of alternative routes (Dalivand & Torabi, 2024).

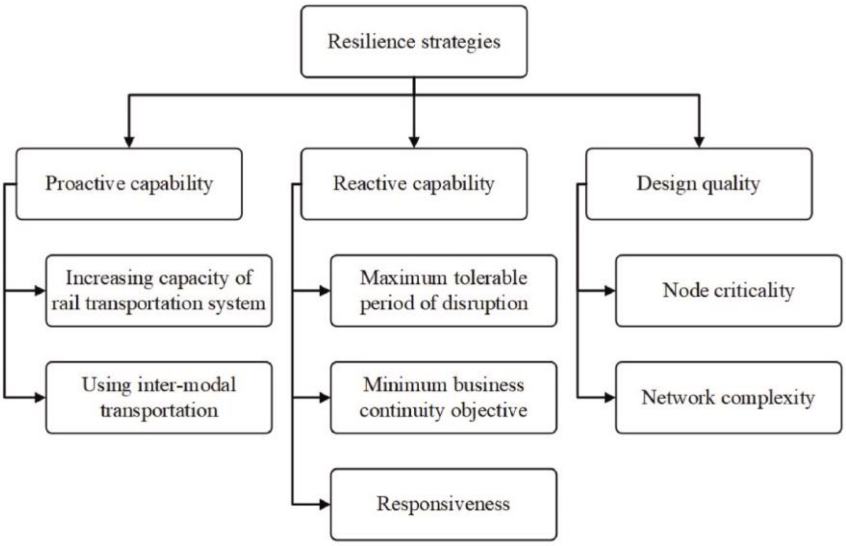


Figure 19: Resilience strategies by Dalivand & Torabi (2024)

Peng et al. (2022) presents a forward-looking approach to transportation systems by integrating intelligent, sustainable, and resilient practices. Future transportation systems are envisioned to adapt to growing urbanization, climate change, and advancements in technology, including connected and autonomous vehicles (CAVs), electric vehicles (EVs), and shared mobility platforms. The work introduces several key concepts that directly address the intertwined challenges of resilience and sustainability in transportation networks. Peng et al. (2022) emphasize the transformative role of **connected and automated vehicles (CAVs)** in creating a more **resilient** and **sustainable** transportation system. CAVs leverage **Vehicle-to-Everything (V2X) technologies**, enabling communication between vehicles and infrastructure, pedestrians, and other vehicles. This technology fosters real-time data exchange that enhances both safety and efficiency. Communications ensure that vehicles can reroute dynamically, avoiding disrupted zones or unsafe conditions. Real-time traffic management systems, powered by AI and machine learning algorithms, can continuously adjust traffic flows in response to external stressors, significantly reducing congestion during crises and ensuring the resilience of urban mobility. The increasing adoption of **electric vehicles (EVs)** is also discussed, being critical for reducing **greenhouse gas emissions** and improving **air quality** in urban areas. However, the paper identifies the **development of charging infrastructure** as a key bottleneck in promoting EV adoption.

Peng et al. (2022) also noted **charging infrastructure resilience** as a critical issue. During power outages or natural disasters, EV networks could become non-operational, compromising the mobility of entire cities. Therefore, integrating **renewable energy sources** such as solar-powered charging stations or **smart grid technologies** into the EV network can provide **energy autonomy**, ensuring continuity during disruptions. Future transportation systems must incorporate **renewable energy-powered EV charging stations** to enhance both resilience and sustainability. Policymakers should prioritize investment in **distributed energy systems** that provide grid-independence for critical transportation infrastructure during crises. Regarding sustainability, EVs inherently reduce the environmental impact of transportation by decreasing emissions. However, ensuring the **sustainability** of EV networks requires not only renewable energy but also efficient use of resources. **Smart charging algorithms** should be deployed to balance grid demand, ensuring that vehicles are charged during periods of low demand or when renewable energy is abundant. Intelligent **demand-response mechanisms** should be developed for EV charging stations, optimizing energy use based on grid conditions and the availability of renewable energy. Peng et al. (2022) also stress the importance of designing transportation infrastructure that can withstand extreme weather events and other natural disasters. This concept, known as **adaptive infrastructure**, involves building systems that can recover quickly from disruptions or even **self-repair** using technologies like **smart materials** and **sensor networks**. The resilience of transportation infrastructure is paramount for ensuring that cities can maintain mobility during crises. **Smart infrastructure**, such as **bridges and roads equipped with sensors**, can detect structural weaknesses, monitor traffic, and automatically reroute vehicles away from danger zones in real-time. Governments and city planners must integrate **sensor-equipped smart infrastructure** in high-risk areas, enabling **real-time monitoring** and **automated response systems** to reduce the likelihood of catastrophic infrastructure failure during extreme events. Sustainable infrastructure requires the use of **low-carbon materials** and designs that minimize environmental impact over their lifecycle. The construction of **resilient and sustainable infrastructure** also means reducing material waste, using recycled materials, and deploying **energy-efficient technologies**. Future infrastructure projects should be evaluated not only on their resilience but also on their **carbon footprint**. **Lifecycle assessments** should be mandated for all major transportation infrastructure projects to ensure alignment with long-term sustainability goals.

How does governance practice connect all levels of supplies and service providers to achieve sustainability goals

The integration of governance practices within supply chains and service providers is a crucial factor in achieving sustainability goals, particularly when considering the growing complexity of logistics networks, use of advanced technological systems, stringent and evolving environmental regulation landscapes, mixed with increasing levels of uncertainty. This section provides a few insights to this complex theme, using the reviewed paper case studies of higher relevance for the ADMIRAL pilots.

Chen et al. (2023) developed a **governance framework for a green and smart port** that considers six dimensions (of several levels each) obtained from the industry and academic works. The dimension themes are **greenness, agility, personalisation, cooperation, intelligence and liberalization**. Each has several levels, and a total of **20 critical influencing factors** is modelled using interpretative structural modelling (ISM), as shown in Table 4. The hierarchical structure of the model is represented in Figure 20.

Table 4: Factors modelled in the interpretative structural model for green and smart Port by Chen et al. (2023)

Dimension	Serial No.	Critical Influencing Factors	Descriptions
Greenness	S_1	Energy-saving and emission-reducing capability	Port's capability in saving energy and controlling pollutant discharges
	S_2	Pollution treatment capability	Responsiveness and degree of a port in treating pollutants
	S_3	Efficient utilization of resources	Whether a port has the capability to utilize resources effectively to reduce resource waste
	S_4	Environmental protection concept and policy system	Knowledge and practices of port management personnel and policy-makers in green concepts
Agility	S_5	Agile production capability	Port's capability in fully utilizing the limited resources and quickly responding to orders
	S_6	Comprehensive logistic capability	Levels of a port's comprehensive logistic services and supply chains
	S_7	Refined operation capability	Whether a port adopts refined operation modes and has JIT capabilities
Personalization	S_8	Port-differentiated service levels	Levels of a port's services that are different from those at other ports
	S_9	Personalized service levels for customers	Levels of personalized services provided by the port to customers
	S_{10}	Emergency and quick response capabilities	Port's response capabilities to multiple emergencies and adjustability to changes
Cooperation	S_{11}	International port-shipping cooperation	Degree and model of international port-shipping cooperation
	S_{12}	Port-city integration	Port-city cooperation
	S_{13}	Cooperation between subsidiary and parent ports	Cooperation between subsidiary and parent ports (international dry ports, feeder ports and inland port areas)
	S_{14}	Intelligent production infrastructure and operation	Intelligence degree of port infrastructure operation and production
Intelligence	S_{15}	Intelligent administration	Intelligence degree of port administration
	S_{16}	Intelligent facility security	Intelligence degree of port facility security
	S_{17}	Innovative R&D and technology application	Port's technical innovation R&D capability and degree of application
Liberalization	S_{18}	Liberalization of trade and economic policies	Port's liberalization degree in domestic and foreign trade
	S_{19}	Facilitation of logistics and customs clearance	Port's coordination with the Customs and quarantine departments and degree of cargo transportation facilitation
	S_{20}	Openness of investment and financing	Openness of a port in market investment and financing

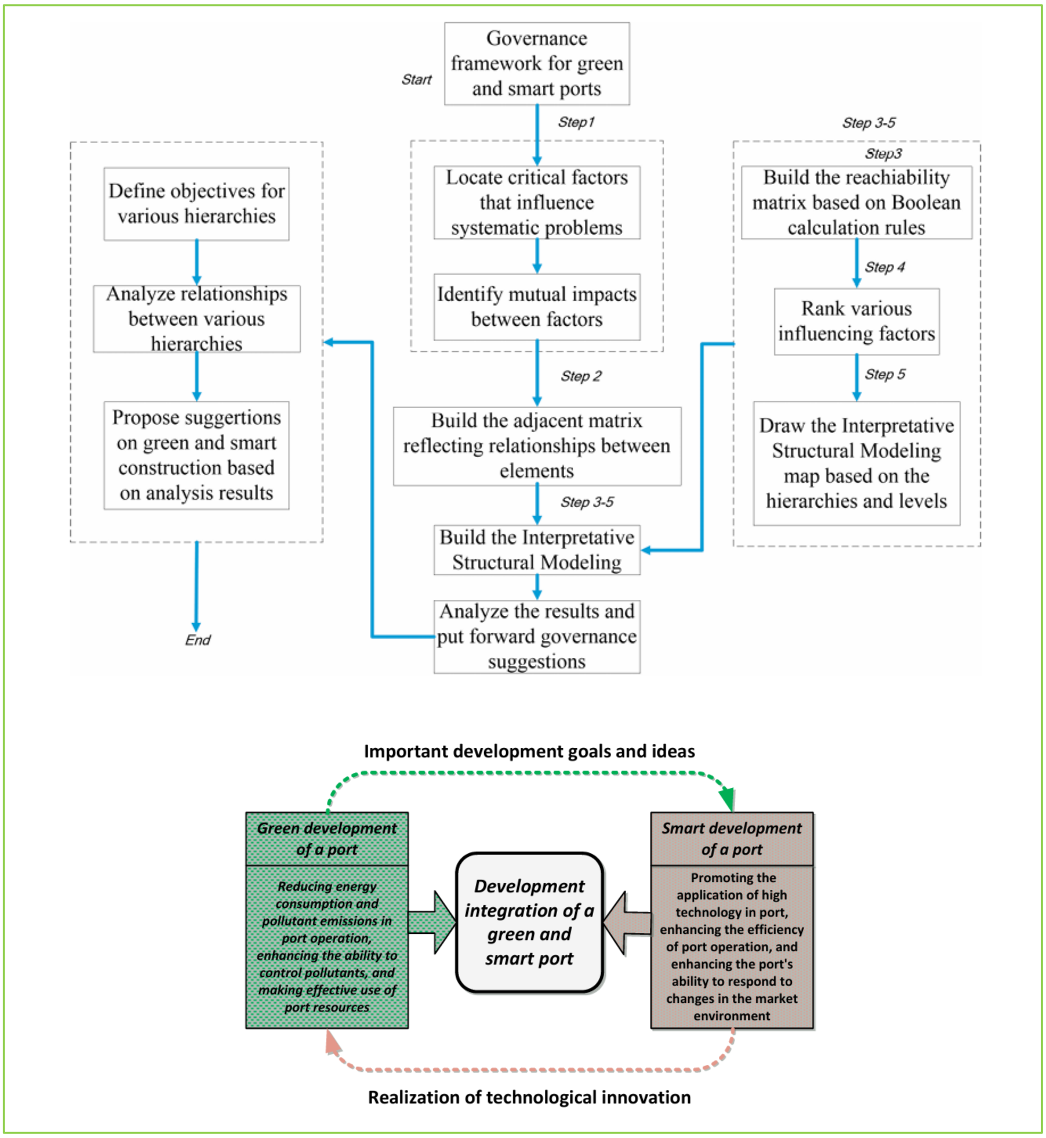


Figure 20: Green and intelligent port and the ISM model by Chen et al. (2021)

The governance framework (Figure 20) begins by defining objectives for various hierarchies, ensuring that sustainability goals such as carbon reduction and energy efficiency are aligned across all levels of operation. This includes producers, suppliers, ship owners, transport operators, and support services, who are connected by the governance system, ensuring their roles are in sync with sustainability practices. Step 1 identifies critical factors affecting systematic problems, like emissions from port production and transportation, which disproportionately affect the environment (notably around 60-90% during ship berthing periods). Step 2 focuses on stakeholder collaboration and the mutual impact between these factors, such as the joint promotion of green and smart ports between shipping departments and ports. This foster improved transparency and cooperation in sustainability practices. Step 3 to 5 involve building and analysing hierarchical models that identify the interactions between these factors, which, in the context of governance, ensure all supply chain actors follow a unified code of conduct. This facilitates mutual accountability in sustainability reporting, particularly in monitoring carbon emissions and energy consumption.

The **incorporation of advanced technologies such as big data, IoT, and intelligent transportation systems into governance structures** is a key trend in promoting sustainability across the logistics network. Heilig et al. (2017) discuss the integration of IT systems to facilitate real-time information sharing among suppliers and service providers. This approach ensures that sustainability related data, such as carbon emissions, energy consumption, and operational efficiency, are continuously monitored and shared across the supply chain. This promotes accountability and ensures all stakeholders align their operations with corporate sustainability goals.

Wang et al. (2023) discuss the **use of blockchain for governance purposes, facilitating cooperation between different stakeholders** and ensuring that operations align with sustainability goals. Blockchain technology allows for secure data sharing and ensures that all parties within the supply chain, from local suppliers to global operators, can trace the environmental impact of their activities. This level of transparency is also vital to ensure compliance with corporate sustainability governance goals.

Ambra et al. (2021) discuss the importance of governance within intermodal and synchromodal transport systems for achieving sustainability objectives. These systems rely heavily on the coordination of various stakeholders, including rail, road, and maritime operators, to optimize logistics routes that reduce emissions and energy consumption. **Governance structures that integrate cross-modal collaboration are crucial to ensuring that these diverse stakeholders work towards common sustainability goals.**

Governance frameworks, particularly in the post-pandemic, should focus on ensuring that energy systems are both resilient and sustainable. Ibrahim et al. (2022) suggest that modular designs for logistics facilities, combined with UV disinfection systems, can improve both safety and sustainability. This highlights how **governance frameworks must evolve to integrate resilience and sustainability simultaneously**, ensuring that logistics networks can withstand disruptions while minimizing their environmental footprint. Companies should integrate microgrids and renewable energy into their governance practices, ensuring that all logistics facilities and supply chain nodes are designed to be both energy-efficient and resilient. This could be achieved by setting governance policies that mandate the use of renewable energy in all new logistics developments and retrofitting existing facilities with energy-efficient technologies.

Governance practices also involve **corporate strategies for green servitisation**, which align product and service offerings with sustainability goals. Kumar et al. (2024) note that **industries are embedding sustainability into governance practices through the adoption of green servitisation**, ensuring that both products and services are developed with sustainability in mind. This involves the integration of sustainability performance indicators into product life cycle assessments (LCAs), ensuring that suppliers and service providers adhere to the same sustainability standards.

The study by Kumar et al. (2024) shows that Industry 4.0 and green practices positively affect green servitisation and **green supply chain (GSC) performance** while moderating ESG compliance. It also reveals that green servitisation mediates and ESG compliance moderates the association between Industry 4.0, green practices, and GSC performance. Based on these results, company managers should **adopt green servitisation to boost GSC performance**.

Beil & Putz (2023) emphasize the importance of regulatory measures such as emission standards and weight limits in ensuring compliance with sustainability goals. These governance measures require collaboration between various stakeholders, including transport operators, suppliers, and government agencies, to ensure that sustainability standards are met across the entire logistics network. Companies should develop corporate governance policies that embed sustainability into every aspect of their product and service offerings, from design to delivery. This could involve mandating LCAs for all products and ensuring that suppliers meet strict environmental standards before being approved for partnerships.

The study by Ďurišová et al. (2019) explores how governance practices and corporate performance measurements can drive both competitiveness and sustainability in transport enterprises. The work introduces several concepts for linking performance with sustainability goals, focusing on pricing mechanisms that account for both economic efficiency and environmental impact.

The integration of governance, performance metrics, and sustainability indicators is critical for ensuring that all levels of suppliers and service providers are aligned with corporate sustainability goals. This connection is achieved through the Economic Value Added (EVA), Cash Flow Return on Investment (CFROI), Rentability on Net Assets (RONA), and Cash Return on Gross Assets (CROGA), which provide quantitative insights into how well a company is balancing financial performance with its sustainability objectives. Economic Value Added (EVA) measures how much value a transport enterprise creates beyond the cost of capital. EVA accounts for both financial performance and the cost of sustainability initiatives, ensuring that capital investments into sustainable technologies (e.g., electrification, fuel-efficient vehicles) are justified by returns. Cash Flow Return on Investment (CFROI) highlights the return on invested capital from a cash flow perspective. This is particularly relevant for assessing the impact of investments in sustainability projects (e.g., renewable energy or energy-efficient logistics hubs). CFROI helps quantifying whether sustainability investments are financially viable over time. Governance practices should mandate that **sustainability initiatives be tracked using** adequate **metrics to ensure that investments in green technologies or processes yield measurable returns**. For example, if a transport enterprise invests in electric vehicle fleets, the CFROI should reflect the long-term savings from reduced fuel costs and lower carbon emissions.

Suppliers and service providers must adapt performance metrics by aligning their own operations with the sustainability expectations of the transport enterprise. For instance, **suppliers providing low-emission vehicles or sustainable logistics solutions should be rewarded through performance-based contracts** that include EVA and CFROI as key decision-making criteria.

Pricing is a crucial mechanism for connecting corporate performance to sustainability. Ďurišová et al. (2019) works emphasizes that pricing in transport enterprises must account for not only direct costs but also the externalities of transport services, such as emissions, noise pollution, and traffic congestion. To align pricing with sustainability goals, transport enterprises may **implement dynamic pricing models that incorporate real-time data on fuel consumption, emissions, and external costs.** For instance, pricing models should adjust based on a carbon tax or cap-and-trade system that rewards companies for reducing their environmental footprint. Return on Net Assets (RONA) measures the efficiency with which a transport enterprise uses its assets to generate profits. By tracking the net impact of sustainability investments (e.g., installation of energy-efficient logistics infrastructure), RONA can show whether these investments increase long-term profitability. It can be said that transport operators, suppliers, and logistics providers should be incentivized to reduce their carbon footprint through performance-based pricing mechanisms. Governance frameworks should **standardize carbon accounting across the supply chain, ensuring that environmental costs are accurately reflected in contracts with suppliers**. Governance practices must be aligned with corporate codes of conduct and sustainability standards, ensuring that all levels of suppliers and service providers are compliant.

Shifting to more sustainable freight transport modes can lead to significant carbon savings. In the study by Beil and Putz (2023), several **policy measures** are discussed to promote a modal shift from road transport to more eco-friendly alternatives such as rail and waterways. These measures are framed to enhance environmental sustainability within the transport sector by addressing taxation, regulation, infrastructure development, information dissemination, standardization, and financial incentives. **Taxation measures and financial charges**: taxation-based measures are a mechanism to internalize external costs (e.g., environmental costs related to GHG emissions), where financial charges are imposed on road transport to encourage the use of more sustainable modes like rail or waterways. The goal is to modify market prices, making road transport less competitive in relative terms, thereby pushing companies toward greener alternatives.

Beil and Putz (2023) also discuss **regulation measures**, including setting weight and speed limits on road freight vehicles, which reduce their efficiency and competitive advantage. Additionally, environmental standards such as stringent emission limits for road vehicles serve to shift the transport landscape toward less polluting options by increasing the compliance costs for road transport operators. **Infrastructural measures** and their enhancement such as expansion of rail networks and increase capacity in alternative modes to car can also support rail and water-based transport. Also, the development of intermodal terminals allows for seamless transfers between different transport modes, while the improvement of inland waterways facilitates better navigability and port services, encouraging more use of water-based transport.

Other measures suggested by Beil and Putz (2023) include **informative measures** to focus on raising awareness and changing the behaviour of logistics stakeholders. **Education and training programs** are directed to improving the knowledge of logistics operators about the benefits of using rail and water-based transport. The **use of IT tools** is also highlighted, as it enables the visualization of route options and logistics scenarios that favour eco-friendly transport modes, demonstrating their advantages. **Standardization and Harmonization Measures** can ensure that different transport systems work together seamlessly for modal shifts. **Interoperability standards** across various transport systems, particularly across international rail networks, are essential for smooth transitions between modes. Similarly, **unified regulations** help harmonize transport practices across borders, reducing bureaucratic hurdles and improving the efficiency of international freight operations. Lastly, Beil and Putz (2023) note that **financial Incentives** are a way to make eco-friendly transport modes more attractive. This may include offering subsidies to logistics companies that opt for rail or water transport, along with discounts and rebates on port fees or rail tariffs. **Investment grants** are also proposed to fund infrastructure projects that support the expansion and modernization of rail and waterway facilities.

Governance frameworks can mandate that all suppliers and service providers adhere to sustainability standards. This can be achieved through the integration of environmental criteria into supplier evaluation processes and contract negotiations. Transport enterprises should also work with suppliers to develop continuous improvement plans that gradually increase their sustainability performance. All levels of the supply chain, from raw material suppliers to third-party logistics providers, must implement governance frameworks that include sustainability KPIs. This will ensure that sustainability is embedded at every stage of the supply chain, from procurement to last-mile delivery.

Gultekin et al. (2022) study uncertainties and **risks faced by logistics service providers** (LSPs) during the COVID-19 pandemic, providing a detailed framework for assessing these risks. The research uses a methodology that combines qualitative in-depth interviews and the fuzzy DEMATEL method to prioritize uncertainties and risks, with a focus on their cause-effect relationships. The uncertainty and risk framework for LSPs classifies **uncertainties and risks into supply, demand, internal, and external categories.** This categorization is vital for governance practices, as it allows LSPs to develop tailored mitigation strategies for each type of risk, ensuring resilience and alignment with sustainability targets. Specifically, supply chain disruptions, government regulations, and demand change are identified as key uncertainties affecting the broader system. Regarding governance practices and compliance, The study authors note that employee welfare is a crucial internal uncertainty, which is often overlooked. By establishing governance frameworks that include welfare as a core metric, LSPs can promote more sustainable operations. This directly ties into corporate responsibility and governance, as companies must adopt internal policies that prioritize employee health and safety, especially during crises. **Governance practices that incorporate employee welfare into the decision-making process are increasingly seen as essential for achieving long-term sustainability** (Gultekin et al., 2022).

The study's cause-effect model of uncertainties and risks, in Figure 21, demonstrates how external uncertainties (e.g., government regulations, COVID-19 risks) significantly impact internal operations, such as financial stability and delivery delays. Hence, governance must focus on creating robust reporting mechanisms to monitor these interdependencies. Highlighting employee welfare as a central uncertainty brings forward a novel governance requirement for LSPs. By focusing on employee health, LSPs can align their internal governance practices with sustainability goals, showing compliance not just with environmental but also with social governance (ESG) criteria. A key recommendation is the development of integrated systems that allow real-time data sharing across all supply chain actors, ensuring that compliance with sustainability goals is monitored at every step of the logistics process. This connects governance with operational transparency, which is increasingly demanded in corporate sustainability reports (Gultekin et al., 2022).

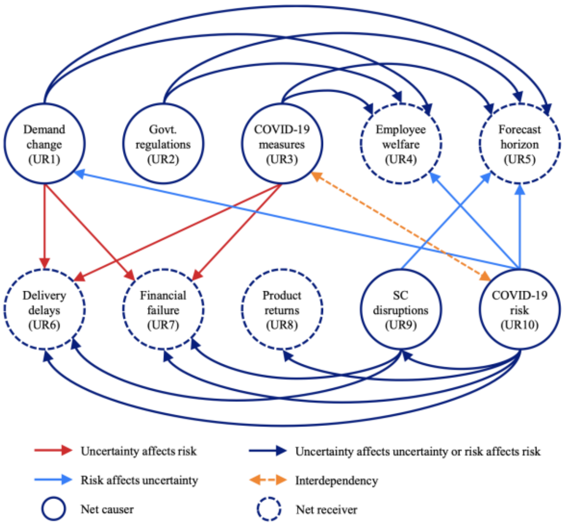


Figure 21: Cause-effect model of uncertainties and risks by Gultekin et al. (2022)

Notteboom & Yang (2017) provides crucial insights into institutional governance layering, policy impacts such as **One Belt One Road (OBOR), and free trade zones (FTZs) that deeply influence the integration of global logistics stakeholders with sustainability goals.** The concept of *institutional layering* (Notteboom & Yang, 2017) illustrates how the incremental addition of policies without discarding the existing governance framework has allowed for multi-level coordination, especially among seaports. Despite decentralization since the Port Law of 2004, the Chinese port system maintains flexibility by layering new initiatives (OBOR, FTZs) onto existing structures, ensuring compliance with both national and international environmental standards while also enhancing cooperation between port operators, hinterland development, and external stakeholders (foreign investors, logistics operators). Governance frameworks emphasize a dual-direction approach: integrating foreign investments and promoting internationalization of Chinese port companies, as part of the "Go West" China's policy strategy, enabling to link Western Pacific with the Baltic Sea, through the designated "Silk Road Economic Belt" (e.g., comprising rail-based investment), along with the "Maritime Silk Road", as shown in Figure 22.

Figure 22: The Silk Road Economic Belt (one Belt) and 21st century Maritime Silk Road (one Road) by Notteboom & Yang (2017)

A strong example of connecting logistics stakeholders through governance is the emphasis on *hinterland development*. This is where governance frameworks directly impact sustainability:

Corridor and Dry Ports Development: Port authorities under central governance have encouraged inland terminal and dry port development. The introduction of dry ports connected to major seaports like Dalian and Tianjin allows for reducing transport emissions by promoting efficient intermodal connections (Notteboom & Yang, 2017). This also ensures that sustainability standards are met not only at the port level but across the entire supply chain—from inland logistics providers to international shipping lines—by reducing unnecessary road traffic and leveraging rail systems for cargo movement.

OBOR Initiative and Sustainable Logistics: The OBOR policy integrates hinterland corridors (rail and inland waterways) directly into global trade routes. By emphasizing rail connectivity, especially through the OBOR's land-based Silk Road Economic Belt, this policy promotes both sustainability (reducing carbon-intensive road freight) and resilience (diversifying transport modes to mitigate disruption risks). Here, governance plays a critical role in enforcing environmental regulations for new infrastructure, ensuring all stakeholders comply with sustainability performance indicators.

Dadsena et al. (2023) explore the **key barriers to supply chain digitalization** and its alignment with Sustainable Development Goals (SDGs). The study groups these barriers into four major categories—Economic, Administrative, Political & Policy, and Technical. It identifies that Administrative Barriers, particularly the **lack of coordination, collaboration, and cooperation, are the most significant inhibitors to progress.** This finding is crucial for governance practices in supply chain digitization, as it shows **the need for governance systems that facilitate better integration across multiple stakeholders.** By connecting suppliers, logistics operators, and service providers through a clear code of conduct and strategic governance practices, companies can overcome this lack of collaboration and coordination, directly addressing the identified barriers and improving both sustainability and operational efficiency. The lack of skilled human resources and infrastructure within the administrative category also emerges as a critical issue, indicating the need for investment in training and infrastructure to support digital transformation. To achieve carbon neutrality and green energy efficiency, governance frameworks must prioritize not just digital adoption but also the alignment of supply chain activities with sustainability goals. This involves incentivizing investments in green technologies and harmonizing international regulations for a more integrated global supply chain, as suggested by the need for standardized practices in the policy and technical domains.

According to Janssen et al. (2019) government must focus on enhanced vision for IoT to develop domain specific strategies for IoT including green building, smart-grids, industrial monitoring, agriculture, healthcare, connected homes, telematics and supply chain, among others. The authors develop a framework to address the interconnected IOT challenges (Figure 23). Governance practices in supply chains are essential for connecting suppliers and service providers to achieve sustainability goals, particularly by addressing complex challenges highlighted in the model. In Figure 23, **lack of IoT governance and management support** (C4) hinders the integration of real-time monitoring systems, which are crucial for sustainability metrics such as emissions tracking. Effective governance provides structured oversight, enabling consistent performance metrics across all stakeholders. **Complexity problems (C7)** are mitigated through governance by establishing protocols that streamline the integration of IoT systems, reducing operational ambiguity. This ensures that all stakeholders, from manufacturers to transport operators, can efficiently adopt digital tools for sustainable practices, like energy-efficient routing. **Stakeholder collaboration issues (C12)** are a major barrier, but governance frameworks enforce collaborative efforts across the supply chain, enhancing accountability and transparency. These frameworks mandate that all actors contribute to emissions reduction and energy conservation goals through shared data and reporting systems. **Public acceptance issues (C14)** are addressed by governance, ensuring that sustainability initiatives, such as carbon-neutral logistics, are communicated effectively and integrated into corporate reports. This drives both consumer trust and stakeholder compliance. **Security and privacy issues (C1)** are critical when using IoT for tracking sustainability metrics. Governance practices enforce strict cybersecurity measures to protect data integrity, ensuring that sustainability efforts, such as energy tracking, are reliable and secure across the supply chain. In addressing **standardization and network flexibility (C15)**, governance enforces uniform standards that allow different IoT systems to work together, essential for optimizing resources and reducing emissions across the supply chain. Through these measures, governance practices ensure a unified, sustainable approach that aligns with carbon neutrality and energy efficiency targets.

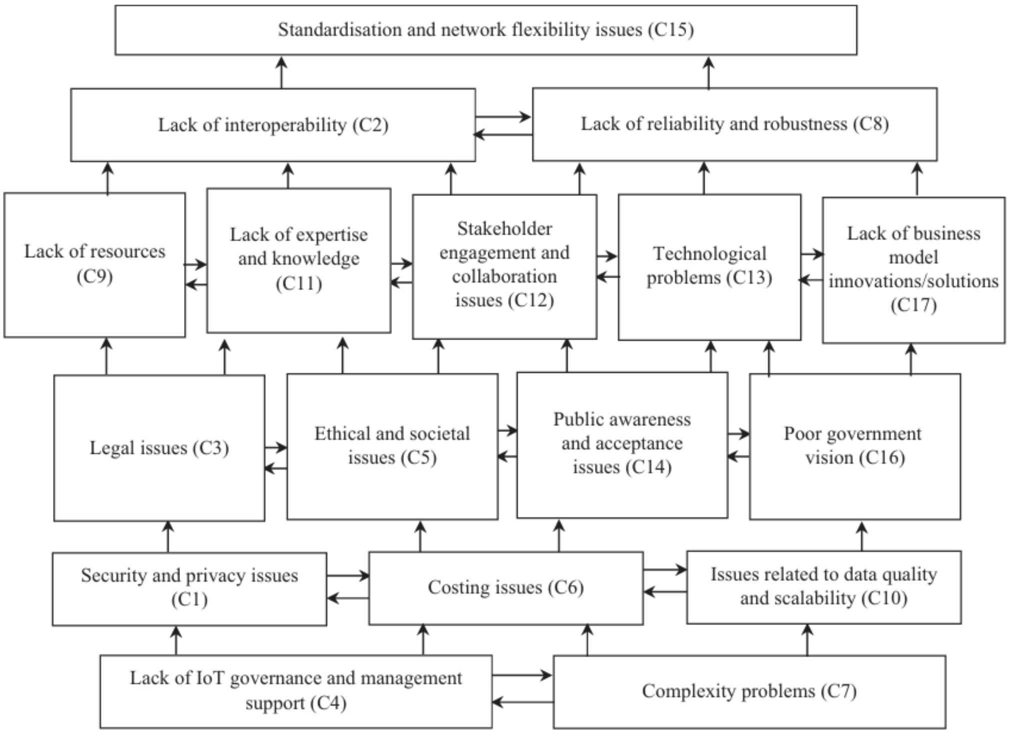


Figure 23: Hierarchical model of IoT challenges by Janssen et al. (2019)

Farahani et al. (2018) emphasize the need for a governance framework that connects all levels of suppliers and service providers through clear objectives and strategies, aligning with corporate sustainability goals. Governance practices in this context play a role in ensuring that sustainability goals, such as carbon emission reduction and energy efficiency, are incorporated across the supply chain. Figure 24 by the same author illustrates the **complexity of managing energy consumption across various factors within the supply chain**, **such as packaging, transportation, and inventory policies**. Governance practices connect these elements by establishing standardized guidelines for each category, ensuring that all stakeholders (suppliers, producers, transport operators) adhere to energy-saving practices. For example, governance frameworks could mandate the use of energy-efficient technologies or policies that minimize transportation distances, leading to reduced energy consumption across the supply chain. Figure 24 highlights the key areas where governance can enforce accountability and transparency through metrics like energy consumption, carbon footprint, and compliance with sustainability performance indicators. The study develops the SySCEA tool to support the different dynamics of a synchromodal supply chain, accounting for the relationship between energy cost and consumption and the supply chain design and operation

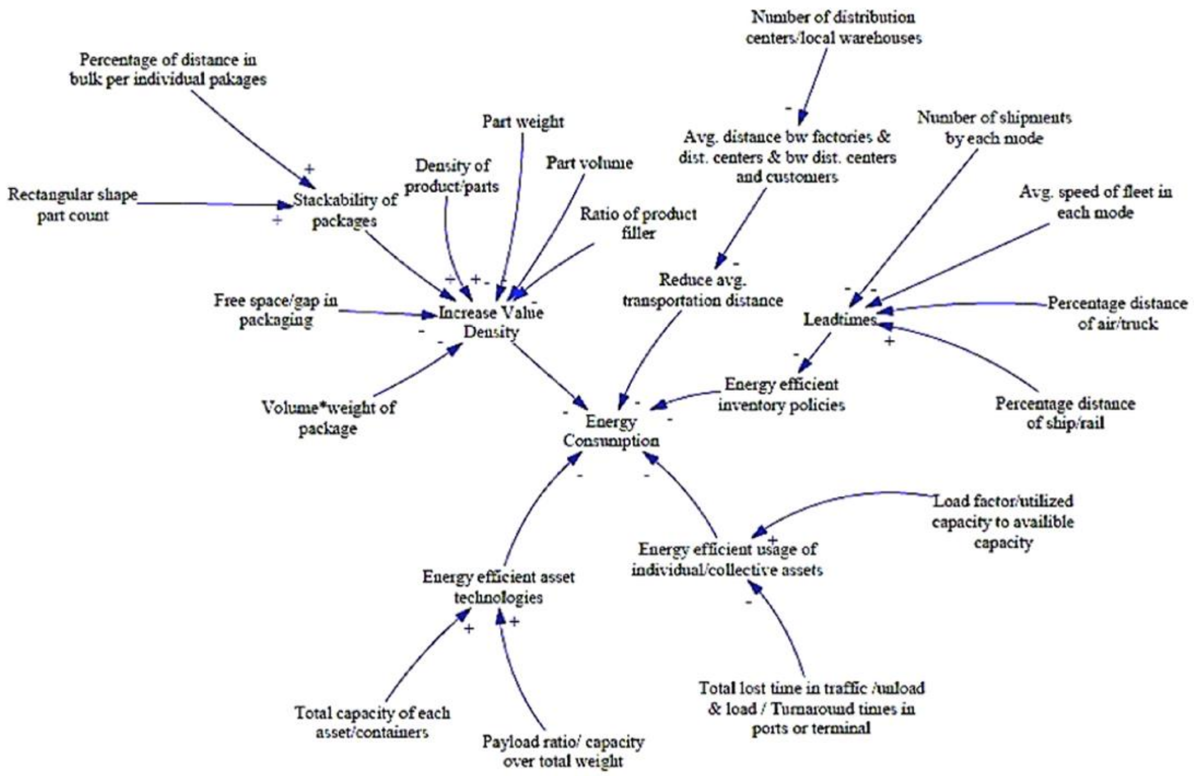


Figure 24: Cause-and-Effect Diagram for Energy Savings in Supply Chain Logistics by Farahani et al. (2018)

Farahani et al. (2018) also developed a comprehensive table of energy consumption in supply chains that breaks down the decision factors that influence energy consumption, such as transport modes, asset usage, and supply chain setup (e.g., nearshoring or optimizing packaging for higher value density). Governance practices provide a structured approach to these variables by setting clear targets and accountability measures for each. For instance, companies can be required to report on their energy usage per mode of transport or demonstrate how they are minimizing wasted capacity through improved load factor utilization. Governance through corporate codes of conduct and sustainability reports ensures these energy-saving variables are consistently applied across all levels of the supply chain, fostering collaboration and adherence to sustainability goals.

2.4 Insights from EU-projects

This section considers the insights given from the analysis of several recent EU-funded projects developed (or under development) around the topic of intelligent logistics and intelligent transport covering all modes. This considered the Transport Research and Innovation Monitoring and

Information Systems (TRIMIS) that provides open-access information on transport research and innovation.

Table 5 to

Table 9 provide useful information on the contributions of each project to understand what are the emerging innovative solutions to improve the sustainability performance of operations (Table 5), how companies/stakeholders in the project are dealing (or plan to deal) with technological changes and adapting systems for digitalisation, automation and the creation of new services (Table 6), how intelligent systems are being used or planned to integrate all logistic stakeholders (Table 7), how the requirements for improving resilience and sustainability are considered (Table 8), and how governance practices connect all levels of supplier and service providers to achieve sustainability goals (

Table 9).

Table 5: Innovative solutions to improve the sustainability performance of operations

Project	Innovative solutions
SEAMLESS (2023-2026) https://trimis.ec.europa.eu/project/safe-efficient-and-autonomous-multimodal-library-european-shortsea-and-inland-solutions	**Autonomous systems** will be integrated to ensure safe, resilient, efficient, and environmentally friendly operation to **shift road freight movements to hinterland waterways**, while enhancing the performance of the TEN-T network. The service will be delivered 24/7 by a fleet of autonomous cargo shuttles, with humans-in-the-loop located in Remote Operation Centres (ROCs), which efficiently cooperate with automated and autonomous shore-side infrastructure and safely interact with conventional systems. **Real-Time Information for Planning Optimization:** The services will rely on a redesigned logistics system enabling seamless freight flows by **minimising delays at intermodal nodes**. A digital bird's-eye view of the supply chain allows the exploitation of real-time information for planning optimisation and reconfiguration to support resilient logistics, incl. digitalised administrative procedures. **Verification and Validation through Full-Scale Demonstrations:** Transferability will be fully demonstrated in selected use cases that cover a wide range of transport applications and geographical regions throughout Europe. Based on a structured methodological framework evaluating sustainability criteria, they will act as guidance for the replication of the project results beyond the project scope and time-span.
DECARBOMILE (2022-2026) https:// trimis.ec.europa.eu/project/five-pillars-decarbonize-last-mile-logistics	DECARBOMILE will rely on developed methodologies to implement the new solutions and delivery methods in collaboration with all relevant local stakeholders, based on their needs and behaviours. The relation with and between stakeholders will be facilitated by the creation of a collaborative urban consolidation logistics framework that will include **a digital platform**, methodologies for collaboration, and **ICT** and **IoT** tools (app for driver and track and trace technologies). The delivery methods will be strongly improved with **urban consolidation centres**, **micro urban consolidation centres** including **smart lockers**, **innovations on cargo bikes** and how they can be used with load pooling for instance, electric barge and more. **Logistics vehicles optimisation**, especially regarding cargo-bikes and their combinations with transportation modes alternative to the road and conventional trucks (river, rail).

GREEN-LOG (2023-2026) https://trimis.ec.europa.eu/project/cooperative-and-interconnected-green-delivery-solutions-towards-era-optimized-zero-emission	**Cargo-bike** based innovations for sustainable micro-consolidation design and deployments, multimodal parcel deliveries integrating public transportation. **Logistic as a Service platform** for interconnected city logistics and automated delivery concepts with the use of autonomous vehicles and delivery droids. **Automated delivery concepts** with the use of autonomous vehicles and delivery droids.
NextETRUCK (2022-2025) https://trimis.ec.europa.eu/project/efficient-and-affordable-zero-emission-logistics-through-next-generation-electric-trucks	**Electric powertrain innovations** for medium duty freight transport. **Tools for optimized design** and **Total Cost of Ownership (TCO) reduction.** **New business models** for end-user increased acceptance and increased market uptake. **Digital twin** design, fleet management tools and virtual integration of Zero-Emission Vehicle (ZEV). Flexible **ultra-fast charging** concepts.
ZEFES (2023-2026) https://trimis.ec.europa.eu/project/zero-emission-flexible-vehicle-platforms-modular-powertrains-serving-long-haul-freight-eco	**Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs)**: ZEFES is deploying nine different long-haul truck configurations, including six BEVs and three FCEVs, to demonstrate zero-emission freight transport across Europe. **Modular Vehicle Platforms**: The project focuses on creating flexible and modular vehicle platforms that can be adapted for various missions. This modularity helps in customizing vehicles to specific needs, which can enhance efficiency and reduce operational costs **Advanced Charging and Refuelling Infrastructure**: develop and demonstrate an interoperable Megawatt Charging System (MCS) and strategically deploy hydrogen refuelling stations (HRS). These infrastructures are crucial for supporting the widespread adoption of BEVs and FCEVs by ensuring they can be charged and refuelled efficiently along key transport routes **Digital Twin Technology**: The project incorporates digital twin technology to create virtual replicas of logistics operations. This technology allows for real-time monitoring and optimization of freight transport, providing valuable data for predictive maintenance, eco-driving, and better logistics planning.
URBANE (2022-2026) https://trimis.ec.europa.eu/project/upscaling-innovative-green-urban-logistics-solutions-through-multi-actor-collaboration-and	**Combining Green Automated Vehicles with Shared Space Usage Models**: URBANE prioritizes advancing the transition towards safe, efficient, and sustainable last-mile transport by combining green automated vehicles with shared space usage model. **Innovation Transferability Platform comprising Digital Twinning Tools**: digital twinning tools and a data-driven impact assessment radar to evaluate the effectiveness of last-mile delivery solutions. **Blockchain Technology-led Smart Contracts:** blockchain technology-led smart contracts to facilitate transparent and efficient transactions within the urban delivery network. **Leveraging Digital Twinning Tools and Data-Driven Impact Assessment Radar:** Digital twinning tools and a data-driven impact assessment radar to evaluate the effectiveness of last-mile delivery solutions. **Innovation Transferability Platform:** The project develops an Innovation Transferability Platform comprising digital twinning tools, open models, and smart contracts governed by blockchain technology. This platform facilitates the adaptation and replication of successful **last-mile delivery solutions** demonstrated in Wave 1 Living Labs to additional cities in Wave 2 Living Labs, thereby scaling up the impact of sustainable urban logistics innovations across Europe.
STREnGth_M (2023-2026)	**Electrification of Transport**: the global progress of electric mobility will be tracked while measuring the feasibility of innovative

https://trimis.ec.europa.eu/project/stimulating-road-transport-research-europe-and-around-globe-sustainable-mobility	solutions for prospective and emerging markets in Africa, Asia and Latin America.
LogisticsBrain (2022-2024) https://trimis.ec.europa.eu/project/self-learning-ai-based-transport-optimization-software-service-most-complex-logis-tics	**AI-Powered Optimization**: the project leverages AI algorithms to optimize transport routes, reducing fuel consumption and emissions. This helps in minimizing the environmental impact of logistics operations. **Self-Learning Capabilities over time**: The software continuously learns from operational data, improving its efficiency over time. This adaptive learning enhances the sustainability of logistics by refining routes and schedules based on real-time data. **Comprehensive Logistics Management**: By integrating various aspects of logistics, the software ensures more efficient use of resources, reducing waste and promoting sustainable practices throughout the supply chain.
NLNGHIVE2 (2018-2022) https://lnghive.com/lnghive2-infrastructure-and-logistics-solutions/?lang=en	**Liquefied Natural Gas (LNG) regasification plants** in Huelva and Valencia to offer bunkering and small-scale services and the **introduction of LNG fuel in a maritime-rail green corridor between the Port of Huelva and the dry port of Seville** by retrofitting a diesel-hauled locomotive to LNG and building a LNG station. Installation of a **multi-truck to ship system** to provide efficient LNG bunkering services in Huelva port
MultiRELOAD (2022-2025) https://trimis.ec.europa.eu/project/port-solutions-efficient-effective-and-sustainable-multimodality	Enhance the efficiency, effectiveness, and sustainability of port operations by focusing on three key innovation areas: **Smart Multimodal Logistics**: This area aims to shift 5% of freight transport from road to rail and inland waterways. This modal shift is expected to reduce congestion, lower emissions, and enhance the sustainability of logistics operations. **Digital and Automated Multimodal Nodes** and Corridors: By 2025, the goal is to increase operational efficiency within multimodal inland terminals by 20% and raise handling capacity. This involves integrating digital and automated solutions to streamline processes and improve the coordination between different transport modes. **Innovative Business Models**: it aims to develop and validate seven new business models aimed at reducing the cost of freight transport by 10%. These models will ensure the market uptake of the solutions developed, promoting a more efficient and sustainable logistics sector.
AUTOFLY (2022-2023) https://trimis.ec.europa.eu/project/gps-free-beyond-visual-line-sight-navigation-logistics-drones-urban-environments	**Delivery Drones**: can perform complex tasks autonomously, such as navigation, obstacle avoidance, and inspection, without the need for human intervention. By incorporating cutting-edge **Computer Vision and Artificial Intelligence algorithms**, the drones can "see and understand" their surroundings, enabling them to operate safely and effectively in diverse environments. **Platform** that utilises advanced algorithms for vision-based orientation and navigation, real-time detection and tracking, visual positioning and autonomous inspection. **Real-Time Communication and Analytics** to enable constant communication and real-time broadcast of analytics from drones to mission control, using minimal network bandwidth.

Table 6: How companies/stakeholders are dealing/plan to deal with technological changes and adapting systems for digitalisation, automation and the creation of new services

Project	How companies/stakeholders in the project are dealing (or plan to deal with technological changes…
SEAMLESS https://trimis.ec.europa.eu/project/safe-efficient-and-autonomous-multimodal-library-european-shortsea-and-inland-solutions	**Autonomous Systems:** integrate them into their operations. This includes the development and deployment of **autonomous cargo shuttles for waterborne freight transport,** as well as the establishment of Remote Operation Centres (ROCs) to oversee and coordinate these autonomous systems. **Redesigning Logistics Systems:** redesigned logistics systems **to accommodate digitalization and automation**. This involves streamlining processes to minimize delays at intermodal nodes and enable seamless freight flows. **Development of Novel Business Models:** support the adoption of digitalization, automation, and new services. These models aim to minimize investment risks for companies seeking to implement innovative technologies and practices. **Addressing Regulatory Challenges:** Companies and stakeholders are actively addressing regulatory challenges associated with technological changes. This includes **identifying gaps** in existing regulations, particularly **related to autonomous vessel operation**, and providing recommendations to policymakers.
GREEN-LOG (2023-2026) https://trimis.ec.europa.eu/project/cooperative-and-interconnected-green-delivery-solutions-towards-era-optimized-zero-emission	Inclusive **Stakeholder Urban Living Labs:** The project establishes city platforms comprising inclusive stakeholder Urban Living Labs. **Innovative simulation environment** for scenario building combining different solutions that allow the integration of last-mile delivery interventions with the highest possible impact on environmental sustainability and traffic reduction, while considering their financial viability.
NextETRUCK (2022-2025) https://trimis.ec.europa.eu/project/efficient-and-affordable-zero-emission-logistics-through-next-generation-electric-trucks	**Collective and collaborative** action from the research organizations, business strategists, technology companies and OEMs. Decarbonization of the road freight vehicle fleets, via demonstrating next generation **e-mobility** concepts consisting of holistic, innovative, affordable, competitive and synergetic zero emission vehicles and ecosystems for tomorrow's medium freight haulage Knowledge at component, vehicle, fleet, infrastructure and ecosystem levels, **via innovations** at **e-powertrain components and architectures, smart charging infrastructure and management**, **improved thermal design of the cabin, fleet management systems with IoT and digital tools**.
ZEFES (2023-2026) https://trimis.ec.europa.eu/project/zero-emission-flexible-vehicle-platforms-modular-powertrains-serving-long-haul-freight-eco	**Deployment of Zero-Emission Vehicles**: The project focuses on real-world demonstrations of Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs) across Europe. This involves **testing nine different long-haul truck configurations** in various use cases along important TEN-T corridors. The goal is to make these zero-emission vehicles more affordable, reliable, and efficient. **Creation of New Business Models**: The project is developing and validating new business models to ensure the market uptake of innovative solutions.
URBANE (2022-2026) https://trimis.ec.europa.eu/project/upscaling-innovative-green-urban-logistics-solutions-through-multi-actor-collaboration-and	Using the Internet's concept of hierarchical aggregation in autonomous systems overseeing ever smaller internal autonomous systems and local area networks, the URBANE project's concept is to employ a **physical distribution architecture in which large consolidation centres** distribute goods to ever smaller region-district-neighbourhood shared distribution centres to efficiently and effectively manage the ever-increasing volumes of last mile goods for delivery.

	By employing a **digital twin to model city logistics flows** and exploring the application of collaboration protocols based on game theoretic concepts for optimality, URBANE's goal is to demonstrate that a PI like approach to urban logistics can achieve significant reductions in environmental impacts of last mile deliveries while at the same time fairly sharing costs and social/environmental benefits amongst all collaborating partners
STREnGth_M (2023-2026) https://trimis.ec.europa.eu/project/stimulating-road-transport-research-europe-and-around-globe-sustainable-mobility	**Analyse research, innovation and cooperation capacities in Member States, explore funding instruments** on national and regional level and assess potentials of national and regional roadmaps.
LogisticsBrain (2022-2024) https://trimis.ec.europa.eu/project/self-learning-ai-based-transport-optimization-software-service-most-complex-logis-tics	Partial routes are linked to form a network flow by **crowdsourcing**. This allows for **real time optimization of transport simply using one software** – instead of more than three individual solutions as today.
MultiRELOAD (2022-2025) https://trimis.ec.europa.eu/project/port-solutions-efficient-effective-and-sustainable-multimodality	**Implementing Digital Twins**: The project is developing a digital twin platform for ports, which serves as a central visualization point for data from various sources. **Enhancing Data Sharing and Integration**: Stakeholders are improving data sharing between actors within and between logistics nodes. This increased transparency and collaboration aim to boost operational efficiency and optimize the use of assets and infrastructure. **Developing and Testing New Business Models**: The project focuses on creating and validating new business models to ensure the market uptake of innovative solutions. These models aim to reduce the cost of freight transport and make multimodal logistics more attractive and efficient. **Increasing Automation and Digitalization**: By implementing automated and digital solutions at multimodal nodes and corridors, the project seeks to increase operational efficiency and handling capacity. This involves the use of advanced technologies like AI and big data analytics to enhance the coordination and performance of supply chains (ETP Logistics EU). **Collaborative Efforts and Stakeholder Engagement**: it emphasizes collaboration **among diverse stakeholders, including technology and IT providers, intermodal and logistics operators, organizations, ports authorities, and consulting firms.** Workshops, interviews, and user forum meetings are organized to validate results, business models, and ensure the alignment of innovations with market needs
AUTOFLY (2022-2023) https://trimis.ec.europa.eu/project/gps-free-beyond-visual-line-sight-navigation-logistics-drones-urban-environments	The project will validate, qualify, and commercialize Sightec's safety solution, which represents an enabling technology helping to unlock the full potential of drones for Europe and the world. Using cutting-edge Computer Vision and Artificial Intelligence (AI) algorithms, which provides vision-based navigation, safe landing, obstacle avoidance and safe delivery, **Sightec's software turns the drone's camera into a smart and affordable sensor** - enabling the drone to "see and understand its surroundings" like a human pilot. In February 2021 their capabilities were demonstrated through a successful flight of a delivery drone across five routes in southern Israel, beyond line-of-sight and without the use of GPS. R&D activities within this project focus on finalization of algorithm development to enable full functionality of the minimum viable product (MVP) daytime navigation system under all operational conditions. The pilots and demonstration activities involve testing the navigation, landing, and delivery capabilities of drones in urban settings, demonstrating their potential to address logistical challenges and **improve last-mile delivery efficiency**.

Table 7: How intelligent systems are being used or planned to integrate all logistic stakeholders

Project	How companies/stakeholders in the project are dealing (or plan to deal with technological changes…
SEAMLESS (2023-2026) https://trimis.ec.europa.eu/project/safe-efficient-and-autonomous-multimodal-library-european-shortsea-and-inland-solutions	**Novel business models** will be thus developed and provide a framework for implementing the SEAMLESS service to minimise investment risk for first movers. **Regulatory gaps and challenges related to autonomous vessel operation (e.g., social aspects) will be identified,** and recommendations for policy makers to allow the smooth and safe deployment of fully automated services will be provided. **Blockchain** could be used for stakeholder management. **Smart Contracts** – to embed the project's funds and protect all the contractors and supply chain stakeholders against insolvency as well as automating the payment principles.
DECARBOMILE (2022-2026) https:// trimis.ec.europa.eu/project/five-pillars-decarbonize-last-mile-logistics	The **relation with and between stakeholders will be facilitated by the creation of a collaborative urban consolidation logistics framework** that will include a digital platform, methodologies for collaboration, and ICT and IoT tools. This common framework, along with tailored innovative business models and recommendations on local policies, will allow for a strong collaboration during the project, **allow to learn more about the end-users' needs and behaviours.** DECARBOMILE is committed to collaborating with local stakeholders through multi-stakeholder methodologies to ensure the success of their solutions. Three main categories of actors will be involved: firstly, **local workforce or end-users** who will provide feedback on delivery needs and adaptation to local context. Secondly, **local businesses and logistics companies** who will support feasibility studies, installation, and sustainability of the solutions. Finally, **local institutions at the regional level** who will contribute their large-scale vision to support the installation and replicability of the solutions.
GREEN-LOG (2023-2026) https://trimis.ec.europa.eu/project/cooperative-and-interconnected-green-delivery-solutions-towards-era-optimized-zero-emission	The plan is to develop **city platforms** of **inclusive stakeholder Urban Living Labs for nurturing social innovation**, designing and deploying innovative delivery solutions while allowing the most effective exchange of ideas, the development of robust, harmonized regulatory and policy frameworks, and cooperative business models that build upon effective public/private-sector collaboration and joint investments. The solutions are supported by **networked city logistics dataspaces** that supply dynamic services for proactive ecosystem optimisation while respecting the interests of stakeholders including consumers, businesses, and the city. In Ispra site in the province of Varese (Italy), the companies Measy and Yape, respectively, have implemented these technological solutions that now need to be intensively tested in a real-world environment, collecting useful feedbacks that will allow to finalise their product and close the gap to the market. The region of Flanders has announced the ambition to introduce **zones for zero emission urban freight** in cities. Although the three cities are unique, they share the consideration of introducing low/zero emission zones for urban freight. These cities want to help actors of the urban logistics supply chain to deal with policy measures taken, by presenting them sustainable alternatives. This Living Lab will consider indicators such as fill rate, stop densities, routes, and parking issues on the one hand, and demand insights such as detailed origin-destinations and consumer requirements on the other. These data will allow: (i) to understand how the LaaS can function as efficiently as possible, i.e. what are

	the roles for the different stakeholders? Are there efficiency gains? etc. (ii) in the LaaS, to link demand (e.g. urban freight shipments, on-demand requirements, storage requirements, need for certain type of vehicles) and supply (e.g. the provision of sustainable logistics services, warehouse space, availability of cargo bikes) as to maximally improve the sustainability.
ZEFES (2023-2026) https://trimis.ec.europa.eu/project/zero-emission-flexible-vehicle-platforms-modular-powertrains-serving-long-haul-freight-eco	**Collaboration Across the Value Chain**: ZEFES brings together a diverse group of stakeholders, including automobile manufacturers, logistics operators, technology providers, and research institutions. This collaborative approach ensures that the developed solutions are robust, scalable, and meet the needs of all participants in the logistics ecosystem. **Real-World Demonstrations and Data Sharing**: By conducting extensive real-world demonstrations of BEVs and FCEVs, the project collects valuable data that is shared among stakeholders.
URBANE (2022-2026) https://trimis.ec.europa.eu/project/upscaling-innovative-green-urban-logistics-solutions-through-multi-actor-collaboration-and	**Intelligent systems** are being planned to integrate all logistics stakeholders within the URBANE project. Specifically, the project employs a digital twin to model city logistics flows and explores the application of collaboration protocols based on game theoretic concepts for optimality. These **intelligent systems enable stakeholders to simulate and optimize logistics flows in a digital environment**, facilitating the integration of all logistics stakeholders. By leveraging digitalization and collaboration protocols, the project aims to ensure efficient and effective coordination among stakeholders, ultimately leading to the achievement of sustainable and resilient last-mile delivery operations. Through this project, it is expected to foster cooperation between private logistics operators and local businesses while establishing new models for addressing the governance and management of logistics operations through improved regulations, procurement and white-label schemes.
STREnGth_M (2023-2026) https://trimis.ec.europa.eu/project/stimulating-road-transport-research-europe-and-around-globe-sustainable-mobility	**Research and Innovation Networks**: the network of research institutions and consultancies will foster innovation and ensure that the latest technological advancements are integrated into logistics operations. This will contribute to strengthen existing and even forge new links between European, national and regional programmes and support structures for international cooperation task forces. The partners will also identify barriers that may exist for the deployment of research results on European and on international level and they will identify education and training actions to contribute to capacity building.
NLNGHIVE2 (2018-2022) https://lnghive.com/lnghive2-infrastructure-and-logistics-solutions/?lang=en	**Adaptation of the only two LNG regasification plants on the Iberian Peninsula** that are not yet capable of supplying LNG to small barges. **Construction of an LNG station in the dry port of Seville to provide LNG supply services to a new LNG-fuelled train l**ocomotive. **Introduction of LNG fuel in a green maritime rail corridor** between the Huelva seaport hub and the Seville dry port (Mediterranean NCC), through the conversion of a diesel locomotive to LNG Installation of a **multi-truck to ship system** (MTTS) for the provision of LNG bunkering services in the port of Huelva. **Construction of a new multi-fuel (including LNG) barge** which will provide LNG bunkering services in the Strait of Gibraltar area and which will load LNG at the Huelva LNG plant.
MultiRELOAD (2022-2025) https://trimis.ec.europa.eu/project/port-solutions-efficient-effective-and-sustainable-multimodality	MultiRELOAD is expected to **enhance the collaboration between different freight nodes in Europe** to jointly test innovations and create favourable market conditions for multimodal freight transport solutions.

Table 8: How the requirements for improving resilience and sustainability are considered

Project	How the requirements for improving resilience and sustainability are considered
STREnGth_M (2023-2026) https://trimis.ec.europa.eu/project/stimulating-road-transport-research-europe-and-around-globe-sustainable-mobility	Innovation in Europe by identifying future research needs in the field of road transport, by updating and supporting the coordination of strategic research agendas and roadmaps in the field and by facilitating continuous exchange between road transport research related Horizon Europe partnerships and platforms.
SARIL (2023-2026) https://trimis.ec.europa.eu/project/sustainability-and-resilience-infrastructure-and-logistics-networks	**Sustainability And Resilience for Infrastructure and Logistics networks.** It will broaden the understanding of logistics resilience for multiple threat scenarios. The study of sustainability aspects based on environmental considerations will be an integral part of the project's work. Key performance indicators that gauge the system's resistance to disruptions and assess the environmental impact of freight transport as well as threat prevention and mitigation measures will be collected based on extensive stakeholder engagement. Furthermore, simulation methodologies will be employed to provide recommendations for resilient logistics. SARIL aims to complement the classic definition of resilience, which focuses on threat prevention, robustness and system recovery, by green aspects. (…) While the regional (Italy) and national (Spain/Portugal) scenarios focus on natural hazards which become more threatening due to climate change, the international scenario (Northern/Central Europe) considers the disruptions due to pandemics (like Cov19) or wars (like the Russian war against Ukraine). Although the three scenarios will be modelled with varying levels of detail, SARIL aims at a universal understanding of green resilience by using a common framework.
RESIST (2018-2022) https://trimis.ec.europa.eu/project/resilient-transport-infrastructure-extreme-events	**RESilient transport InfraSTructure to extreme events**. The overall goal of RESIST is to increase the resilience of seamless transport operation to natural and man-made extreme events, protect the users of the European transport infrastructure and provide optimal information to the operators and users of the transport infrastructure. The project will address extreme events on critical structures, implemented in the case of bridges and tunnels attacked by all types of extreme physical, natural and man-made incidents, and cyber-attacks. The RESIST technology will be deployed and validated at 2 pilots in real conditions and infrastructures.
SmartResilience (2016-2019) https://trimis.ec.europa.eu/project/smart-resilience-indicators-smart-critical-infrastructures	**Smart Resilience Indicators for Smart Critical Infrastructures**. Making the infrastructures "smarter" usually means making them smarter in normal operation and use: more adaptive, more intelligent… But will these smart critical infrastructures (SCIs) behave equally "smartly" and be "smartly resilient" also when exposed to extreme threats, such as extreme weather disasters or terrorist attacks? The proposal answers through. 1. By identifying existing indicators suitable for assessing resilience of SCIs. 2. By identifying new "smart" resilience indicators (RIs) – including those from Big Data. 3. By developing a new advanced resilience assessment methodology (TRL4) based on smart RIs ("resilience indicators cube", including the resilience matrix). 4. By developing the interactive "SCI Dashboard" tool. 5. By applying the methodology/tools in 8 case studies, integrated under one virtual, smart-city-like, European case study. The SCIs considered (in 8 European

	countries!) deal with energy, transportation, health, water… Results #2, #3, #4 and #5 are a breakthrough innovation. This approach will allow benchmarking the best-practice solutions and identifying the early warnings, improving resilience of SCIs against new threats and cascading and ripple effects. The benefits/savings to be achieved by the project will be assessed by the reinsurance company participant.
SUSTAIN (2012-2017) https://trimis.ec.europa.eu/project/sustain-national-transport-planning-sustainability-institutions-and-tools	**SUSTAIN - National transport planning - sustainability, institutions and tools.** A widespread consensus exists internationally and in Denmark about the relevance of pursuing goals for sustainable transport development but only limited research about how national transportation planning can become a pillar in this process. The goal of SUSTAIN is to expand this research and consolidate a framework on three core domains for a National Sustainable Transport Planning (NSTP): **sustainability, institutions and tools**.
Transport 2030 (2007-2030) https://trimis.ec.europa.eu/project/transport-2030	The objective of transport policy is well-being for Finland. Essential journeys and business related transport operations are carried out both nationally and internationally every day, providing people with a good quality of life, making business competitive and injecting life into the regions. Travel and transport are safe and the transport system is ecologically, socially and economically sustainable. The objective of this framework is **to manage the change in direction of transport policy so that competitiveness of the logistics sector and the ease of people's daily travel are preserved while reducing greenhouse gas emissions.** It is possible to reconcile these challenges, but this will require new kinds of sustainable choices in transport policy, innovation in operations and cooperation between the various actors. The transport policy framework is a comprehensive approach that will enable the amount of greenhouse gas emissions to be reduced and simultaneously ensure the ease of daily travel and the competitiveness of logistics for business. The aspects of the framework dealing with operating methods aim to improve the productivity of the transport sector and emphasise the importance of networks and cooperation in administering increasingly broader questions of transport policy. Implementing the framework will require a long-term approach and a commitment to development work from those in authority. To reduce greenhouse gas emissions from transport, it is important to stop the dispersion of community structures and the growth in travel by private car. Transport policy in isolation will not achieve this. The support of land use planning and tax policy and other economic steering mechanisms is needed. A common will to stop the trend towards the dispersion of community structures is also required as well as effective cooperation to reach these goals.

Table 9: How governance practices connect all levels of supplier and service providers to achieve sustainability goals

Project	How governance practices connect all levels of suppliers and service providers to achieve sustainability goals
SEAMLESS https://trimis.ec.europa.eu/project/safe-efficient-and-autonomous-multimodal-library-european-shortsea-and-inland-solutions	**Regulatory gaps and challenges will be identified across suppliers and service providers focusing on the autonomous vessel operation**. **Recommendations for policy makers** to allow the smooth and safe deployment of fully automated services will be provided.

STREnGth_M (2023-2026) https://trimis.ec.europa.eu/project/stimulating-road-transport-research-europe-and-around-globe-sustainable-mobility	**Research, innovation and cooperation capacities in Member States**, explore funding instruments on national and regional level and assess potentials of national and regional roadmaps. **Collaboration and Integration**: it brings together a wide range of partners, including industry leaders, research institutions, and government bodies, to foster collaboration. This collective approach ensures that different perspectives are considered, enhancing the resilience of transport systems by integrating advanced technologies and sustainable practices **Education and Standardization**: it emphasizes the need for education, training, and the development of standardized practices across Europe. This includes organizing events, workshops, and dissemination activities to share knowledge and best practices **International Cooperation**: it project extends its efforts globally, particularly focusing on emerging economies in Africa, Asia, and Latin America. This international cooperation aims to exchange knowledge and technologies, helping to build resilient and sustainable transport systems worldwide.
SARIL (2023-2026) https://trimis.ec.europa.eu/project/sustainability-and-resilience-infrastructure-and-logistics-networks	SARIL aims for **recommendations to reach a resilient and sustainable transport system addressed to stakeholders and decision makers.** While the regional (Italy) scenario focuses on the coupled threat of floods and cyber-attacks on monitoring systems, the national (Spain/Portugal) scenario focus on natural hazards which become more threatening due to climate change, and the international scenario (Northern/Central Europe) considers the disruptions due to pandemics (like Cov19) or wars (like the Russian war against Ukraine).

2.5 Insights from other projects

Table 10 summarizes technological solutions addressed in other projects, focusing on the countries involved on the ADMIRAL Pilots (by alphabetic order): Croatia, Finland, Lithuania, Portugal, Slovenia and Spain. The funding programs include EU programs such as the Recovery and Resilient Program Facility and the Cohesion Policy Funding, the Ministry of Science, Education and Sports of the Republic of Croatia, the Finish Ministry of Transport and Communications, The Ministry of Infrastructures in Portugal, Government of the Republic of Slovenia, and the Spanish State Research Agency (AEI), and other State Agencies.

Table 10: Project solutions to improve performance of logistics and transport

Project acronym	Project solutions to improve performance
Luka.DT (2022 - 2024)	Digital transformation of processes in the Port of Koper - Industrial/Business Digital Transformation Programme, in Slovenia. Project activities included collecting big data, introducing **IoT solutions, AI, digital twin, advanced VR technologies, and automatising business processes**.
DEEP-SEA (2021- 2024)	The EuroHPC JU-funded project DEEP-SEA has successfully delivered a **programming environment needed for future European exascale systems[5], adapting all levels of the software stack to this revolutionary computing capacity**.

[5] Exascale system: computing system capable of performing at least one quintillion (10^{18}) floating point operations per second (1 exaFLOT), thus allowing for complex simulations and data analysis.

	The software stack includes computation and communication libraries, resource management tools, and low-level kernel modules, which are small software packages that can be added to an operating system.
SMARTWAGONS (2022- …*) (*) expected end: 30-06-2025	**Intelligent wagons for freight transport by rail,** in Portugal. This ongoing project led by the company MEDWAY (active stakeholder in the ADMIRAL project) aims to reinvent the production capacity of vehicles through **advanced technology and sensor systems, including predicted maintenance methods**, improve energy and environmental efficiency for a more competitive and attractive rail offer, aiming to develop smarter, safer and more efficient operations with lower operating costs, lower maintenance and communication/monitoring problems.
CLEAN ENERGY solutions	Clean energy projects in Finland. Two of the projects utilise renewable hydrogen in the production of electrofuels, two projects significantly increase solar power generation, and two projects electrify industrial processes. For example, Vantaa Energia will produce renewable methane and St1 renewable methanol; projects will demonstrate the **production of electrofuels on an industrial scale by utilising renewable hydrogen**. The projects combine the production of renewable hydrogen, capture of carbon dioxide and the methanol or methanation process in a new way. At the same time, the projects utilise the waste heat generated in the production process.
Analysis of intermodal transport development and principles of management of logistics centres 2024	**Analyse of intermodal transport development and principles of management of logistics centres in Lithuania.** The most general case of multimodal transport is defined as follows: freight the possibility of at least two different modes of transport. More information at: https://trimis.ec.europa.eu/project/analysis-intermodal-transport-development-and-principles-management-logistics-centres
BLUE BALTICS (2016-2020)	Provides investment into **LNG infrastructure & mobile equipment in Lithuania**, Sweden and Estonia making available LNG as fuel for maritime and road transport. Blue Baltics deploys industrial solutions for ship-to-ship & shore-to-ship LNG bunkering as well as reloading in a group of ports.
HERMES **(2016-2019)**	**Tool for management and decision-making aid in rail system maintenance.** The developed platform will allow the implantation of a **predictive maintenance** strategy that will ensure the **optimization of means and times**, the reduction of the maintenance costs and a better control of the operation risks.
CIFIL **(2016-2019)**	**Development of a system for the Characterization of Railway Infrastructures using Lidar Image.** New system for recognition and inspection of railway infrastructures based on Laser Imaging Detection and Ranging (LIDAR technology) by developing new equipment and systems, adapting data processing algorithms and software**.**
GoalHUB **(2017-2019)**	**Automatic and optimized planning tool for highly-congested railway stations.** Development of an **automatic and optimized railway traffic planning tool** that would guarantee the efficient exploitation of

	train traffic capacity in highly-congested stations, so that the achieved operational usage of each station would be close to its full capacity**.**
SoilNoisVib (2016-2019)	**Quantification and solutions development for the railway induced noise and vibration problem.** Development of a **numerical model for the simulation of railway induced noise and vibration propagation** phenomenon. Analysis of soil structure interaction effects on the vibrational response of railway bridges. Development of a simplified and fast solution for the assessment of vibration levels in constructions built in the vicinity of railway lines. Experimental validation of the numerical results obtained in the different project phases.
ROBOTRACK (2015-2018)	**Robotization of commissioning systems for a new concept of lightweight track.** The project proposes innovations in design, materials and processes which would allow the product to be much more competitive with respect to ballastless tracks that currently exist in the market.
OPTICON (2015-2018)	**Tool to aid decision-making in the optimization of the electric consumption of railway systems based on the flow of vehicles and infrastructure.** The developed platform: model of the power supply network, including all components of the electrical infrastructure such as traction substations, catenary or converters; model of consumption of the traction system, which would include the dynamics of the train as well as the auxiliary consumptions. The result is a tool capable to simulate in a reasonable time the whole rail network in terms of energy consumption.
RECOVER (2015-2018)	**Comprehensive sustainable anti-pollution treatment for the creation of green railway corridors.** Innovative solution to improve the sustainability performance of operation: **a system design to capture and eliminate heavy metals and hydrocarbons in the ballast and soil adjacent to railway tracks** and **generate pollution-free zones associated with the circulation of trains**. the project designed several systems to capture and remove heavy metals and hydrocarbon pollutants through different technologies: • Sol-gel ballast coating composed of silicon oxide and complexing functional groups capable of absorbing heavy metals, and photocatalytic titanium oxide capable of degrading hydrocarbons. • Ballast modification by fixing ionically printed polymers based on polyurethanes. • Soil microbial population phytoremediation and bioaugmented processes.
PREDIVIA (2014-2017)	Development of a detection and monitoring system of mechanical failures based on acoustic emission for the predictive maintenance of track diversions**. The continuous monitoring** of such elements resulted in a **substantial increase in infrastructure security** as well as **a reduction in operating and maintenance costs,** while **maximizing the availability of the infrastructure, increasing its effective life and minimizing the impact of repair op Some moderations.**

ICEBURNER (2015-2018)	High performance in efficiency, availability and versatility of **Railpoint Heating Systems**. ICEBURNER represented a great leap in the performance of point heaters, improving them in the following areas: a) **Improved availability of modular power electronics** with two parallel solutions that allow fault tolerance; possibility of connection of external batteries that allow maintenance of the functions for at least 4h in a reduced working regime; configuration of hot spots on rail or slab with the possibility of redundancy for fault tolerance; b) **Improving efficiency**: use of induction heaters with rail or plate heating by induced currents, which allows efficiency to increase in from 20% to more than 80%; power regulation that allows the adaptation of the power consumed to external environmental conditions; c) **Improved versatility**: self-diagnosis function of the installation; communication with checkpoints for monitoring and remote control; design of inductors with multiple configurations for the same power electronics; and a single inductor installation-uninstall solution to facilitate substructure maintenance.
Transport and Communications Architecture 2030 and 2050 2016	**Transport and Communications Architecture 2030 and 2050.** In autumn 2016, the Finnish Ministry of Transport and Communications appointed a group of rapporteurs to draw up a vision of the state of the transport and communications system in the years 2030 and 2050, and to investigate ways of reaching the desired state. The objective was to create a vision of how developments of the transport and communication system can create a favourable environment for Finnish well-being, competitiveness and the economy. International and national emissions reduction targets concerning climate and environmental issues have been set such as they are as boundary conditions for this work. The following vision has been defined in the work for 2030 and 2050: 1. New revolutionary technological breakthroughs that will transform the current transport and communication systems are about to happen globally. 2. Traditional traffic and digital solutions will merge. 3. Data will become the primary factor of production and competition. 4. Finland's greatest opportunities lie in quickly and comprehensively utilising the technological solutions being created globally. 5. These opportunities must be seized, as this would allow Finland's particular challenges in internal and external accessibility to be overcome in a sustainable manner. 6. Finland must make radical changes to its existing structures, operating models and decision making. 7. The objective must be to make Finland the global leader of intelligent transport ecosystems. 8. This requires investment, readiness for change, risk-taking, new skills and a culture of experimentation. 9. Succeeding in this would bring sustainable economic growth, create new business and enable high-quality transport and communications services for citizens.

	10. This change must be brought about in a way that benefits every Finnish citizen. The report describes the dynamics and components of a functional transport and communications architecture: technology and knowledge, skills, infrastructure, pricing and taxation, regulation, safety, accessibility, open interfaces, risk-taking and market pioneering, public-private-people partnerships, and decision-making.
AXIS **(2016-2018)**	**High reliability advanced technologies to maximize the life, safety and availability of railway vehicles in service.** Development of damage tolerance methodologies and inspection technologies to monitor the structural integrity of railway axles in service that would improve the safety of these components and reduce vehicle LCC costs increasing their availability.
BEA **(2016-2018)**	**Intelligent Monitoring System for Predictive Maintenance of Bogies based on Acoustic Emission.** Technologies to allow the detection, location and diagnosis, in incipient states of cracks of critical elements of the bogie, such as the axles, as well as the evolution of these cracks, to make a prediction of the fracture of the component once the presence of a crack is detected.
GNSS Signal Quality Evaluation in Finland **(2016-2017)**	Satellite navigation together with wireless data transformation and geographic information enables many applications enhancing safer, more cost-effective and more environmentally friendly transportation. This preliminary study refers to an information service about the usability of satellite navigation. The service will be giving information about the current and forecasted quality, availability and other information of satellite navigation systems and signals over Finland. **The service is meant to be a useful tool for all industries and individual actors using satellite navigation** in their work or other activities, benefiting therefore numerous market segments such as surveying, **transportation,** banking, agriculture, energy distribution**, and location-based services**.
ALIS **(2015-2017)**	**Modeling based on Intelligent Algorithms for the integration of electrification, safety and energy efficiency in railway systems.** This Project was proposed by Inabensa, Universidad Politécnica de Madrid (Partner in ADMIRAL) and Universidad de Málaga. The innovative solution developed was a **simulation tool** divided into modules. The concepts included were related to concepts of optimal location of substations, behaviour of pantographs within the interaction with catenary, development of modules associated with safety in the vicinity of railway systems, both for workers, travellers and passers-by in general, and the effects on the rail system. In addition, the project dedicated attention to the analysis of the energy re-use of regenerative braking with its corresponding systems of storage, use of renewable energy and efficient driving.
EDINPF **(2015-2018)**	**Dynamic assessment of railway bridges; Safety and interoperability of existing, upgraded and new structures.** Development of new computational models and the improvement of existing models, adjusted and updated through experimental measurements, and applied to the Spanish railway network. Two experimental tests were carried out on railway

	bridges on the Spanish railway network to evaluate their dynamic behaviour by measuring their modal properties (Eigen frequencies, modal shapes and damping).
REGUTRAIN (2014-2016)	Design of an effective regulation for the opening of Spanish passenger railway transport to competition.
WARMED (2014-2016)	**Wheel and Rail Modelling for Enhanced Durability**. Development of models to reduce the wear of wheels and rail tracks**.**
TOOLTRAIN (2016-2018)	A complete and detailed model of the operation of trains equipped with the **CBTC and ERTMS signalling systems** would be obtained, which would allow the accurate calculation of transport capacity, including models of the dynamics of the train, operation of the signalling and ATP protection systems (both trackside and onboard), and operation of the ATO (Automatic Train operation) systems (including the new "ATO over ERTMS" system, under development).
The train is always faster 2014	Croatian Railways (HZ Infrastructure) implemented the educational campaign "The train is always faster", as part of the International Awareness Day on level crossings.
SOLBAN (2014-2016)	Development of an advanced welding procedure of new carbide free bainitic steels for rail. An experimental quality rail was developed and the welding parameters for crackling and aluminothermic welding were defined. A **robotic welding head was designed to automate the process and achieve a low level of defects**. In addition, sensors with wireless communication systems for specific maintenance were developed and installed on the ArcelorMittal rail network.
SORDITO (2014-2016)	The system for **route optimization in dynamic transportation environment**. A web-based application for speed profile presentation was developed. Prior to the application development the speed profiles were calculated for all Croatian roads and streets. Speed profiles were calculated based on many GPS records which were collected by Mireo d.d. The application uses digital map for presentation of the speed profiles. The map was also provided by the project partner Mireo d.d. The application offers a wide range of functionalities for the speed profile presentation depending on the time of the day, week or a year (winter or summer period).
SoilBrRail (2016-2019)	Numerical analysis and experimental validation of soil structure interaction effects on the dynamic response of railway bridges. Fundamental tendencies on the structural properties and dynamic response of the evolution of soil properties were derived for an ensemble of representative bridges, assuming simplified substructure geometries. Experimental campaigns were performed to characterise the soil and identify the bridge dynamic properties and its response under railway traffic, both under resonant and not resonant conditions.
PYRKAST (2016-2018)	**Premium brake discs for high-speed trains.** These brake discs would present greater braking capacity and have a longer service life, and be safer and more reliable than conventional ones, with zero defect. Through its development, the **reliability of high-speed brake systems** will be increased.

SENSEROD (2016-2017)	**Monitoring and diagnosis solutions for the advanced management of main rolling stock components.** Development of technologies for data acquisition, and monitoring and diagnosis solutions, that would enable an optimization of rolling stock management, lowering vehicle's LCC and improving train availability. The developed technologies are intended to improve the competitiveness of the Spanish railway industry in international tenders, through vehicles and services of higher performance.
SIMIT (2014-2015)	**Intelligent monitoring system for slopes and obstacle detection on track**. Pro-active slope maintenance. A demonstrator was achieved with each type of system (all of them were deployed at a specific point on the Madrid-Valencia HSL and the Madrid-Barcelona HSL). The results of this project allowed for further tests that have finally led to the practical implementation of all of them.
SAREMSIG_1 (2014-2016)	For a Dependable Railway Operation: Evaluation of the Effect of the **Electromagnetic Interferences in Railway Signalling Systems**.
ESFUCON (2014-2016)	Estimation of wheel/rail contact forces in vehicles instrumented with **inertial and optic sensors using advances computational models.** It developed a railway vehicle dynamic model specially adapted for the estimation of wheel/rail contact forces, using multibody system dynamics.
SAREMSIG_2 (2015-2016)	For a **Reliable Railway Operation**: Evaluation of the effect of **Electromagnetic Interferences in Railway Signalling Systems**. The main objective of this project was to establish the link between the threats caused by electromagnetic interference and the quality of service (QoS) or key performance indicators (KPI) of a Railway Control and Signalling System (RCSS).
Projects in Lithuania	Lithuania | TRIMIS (europa.eu) https://trimis.ec.europa.eu/country-profile/lithuania

3 Combined Analysis of Patents and Scientific Articles

This section reports a systematic analysis of data that investigated patenting technology trends and its connection with the evolution of the scientific paper contents around sustainable and intelligent logistics from 2013 to 2024. Comparing patents and scientific papers provides a comprehensive view of technological development and research trends. The works developed in this chapter resulted into a scientific paper designated as "Co-evolution of green freight logistics across industry and academia" (Aparicio, J., Arsenio, E., Henriques, R.).

3.1 Data collection and processing

Data was gathered from both academic papers and patents to ensure a comprehensive coverage of the emerging research trends and patented solutions in the field of intelligent and sustainable logistics operations. It was used the PATENTSCOPE database of the World Intellectual Property Organization (WIPO). It contains 118.6 million patent documents including 4.9 million published international patent applications. The PATENTSCOPE database provides access to international Patent Cooperation Treaty (PCT) applications in full text format on the day of publication, as well as to patent documents of participating national and regional patent offices. Patent information is all the data contained in patent applications and granted patents. It may include bibliographic data about the inventor, a description of the claimed invention, newest developments in a particular field of technology, or a list of claims indicating the scope of patent protection sought by the applicant. It uses the International Patent Classification (IPC) to classify patents and utility models according to the different areas of technology to which they relate. The search query used in the previous chapter was optimized to target a larger sample of papers on intelligent supply chain solutions to improve the sustainability of operations, comparable in size to the dataset of patents. Table 11 shows the number of records used for analysis.

Table 11: PATENTSCOPE and Scopus Databases search query and number of records for analysis

Database	Search query	Number of records
Scopus	(("intelligent supply chain" OR "logistic" OR resilien*) AND ("sustainable transport operation" OR "intermodal freight transport")) AND PUBYEAR > 2013 AND PUBYEAR < 2024	1911
PATENTSCOPE	EN_ALLTXT: ((intelligent supply chain OR logistic OR resilien*) AND (sustainable transport operation OR intermodal freight transport)) AND AD: ([01.01.2014 TO 06.05.2024])	2138

To create a unified textual representation, the title and abstract of each document were concatenated. For the extraction of keywords, we employed a transformer-based model, specifically the T5 (Text-To-Text Transfer Transformer) model. This model, pre-trained on a diverse range of NLP tasks, is adept at handling various text generation tasks. The variant used in this study, *Voicelab/vlt5-base-keywords* (Pęzik et al., 2023) is fine-tuned for keyword extraction, making it particularly effective for identifying significant terms within texts. The T5 model works on the principle of converting all NLP tasks into a text-to-text format, treating both input and output as text strings (Raffel et al., 2020).

The suitability of the *Voicelab/vlt5-base-keywords* model for our task is reinforced by its training on the Polish Open Science Metadata Corpus (POSMAC) platform. It includes a comprehensive collection comprising 216,214 abstracts of scientific publications across various domains and a total of 203,865 documents across various fields, with a majority containing keywords. Specifically, it includes 58,974 documents in engineering and technical sciences (57,165 with keywords), 58,166 in social sciences (41,799 with keywords), and 29,811 in agricultural sciences (15,492 with keywords). Additionally, it covers 22,755 documents in humanities (11,497 with keywords), 13,579 in exact and natural sciences (9,185 with keywords), 12,809 in humanities and social sciences (7,063 with keywords), 6,030 in medical and health sciences (3,913 with keywords), and smaller subsets in interdisciplinary fields. This extensive and diverse corpus ensures the model's effectiveness in extracting relevant keywords from a wide range of scientific texts. The keyword extraction process involves passing the concatenated textual representations through the model, which then generates keywords that capture the core themes and topics of the document.

Figure 25 in the next section shows, for the case of Patents (left) and Paper networks (right), the evolution of connected components.

3.2 Paper and Patent Semantic Similarity Network Construction

To evaluate the semantic relationships between keywords, embeddings were generated using the SentenceTransformer model. The cosine similarity between pairs of keyword embeddings was calculated as follows:

$$\cos \operatorname{sim}(A, B) = \frac{A.B}{||A||\ ||B||}$$

where *A* and *B* are embedding vectors. Using these similarity measures, a graph *G* = (*V*,*E*) was constructed, with *V* representing keywords and *E* representing edges based on a similarity threshold.

The similarity threshold for edge construction was determined by analysing topological changes in the network. Metrics such as the number of connected components, graph density, and clustering coefficients were observed at various thresholds. The optimal threshold balanced community granularity and network connectivity is shown in Figure 25.

The process of selecting an optimal similarity threshold for community detection in network analysis is critical, as it determines how edges are formed between nodes and ultimately affects the structure of the communities identified. In the context of Figure 25 this threshold selection is guided by observing changes in key network metrics such as the number of connected components and clustering coefficients across different similarity thresholds.

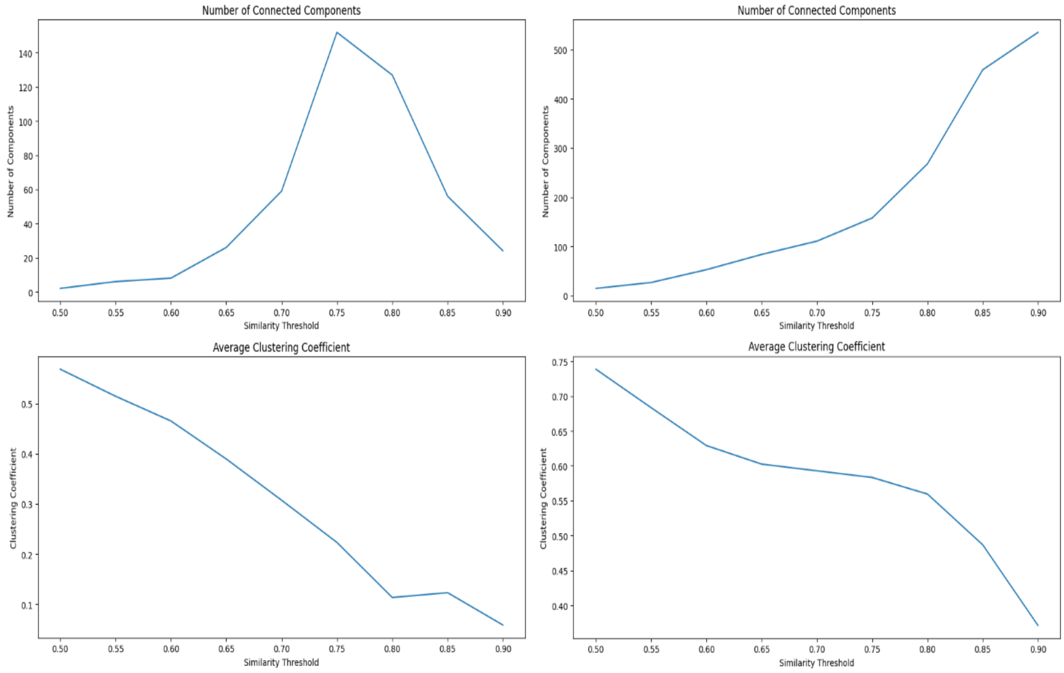


Figure 25: Evolution of the number of connected components, clustering coefficient across similarity thresholds (Left – Paper networks; Right – Patents network)

Based on the observed patterns in Figure 25, a threshold of 0.75 was chosen, as it represents the point where the network begins to show a significant number of distinct clusters (connected components) while still retaining some internal clustering. This threshold balances granularity and connectivity, providing a clear delineation of communities without excessive fragmentation or loss of structure. Besides the relevance of the image in a methodological perspective we can also do a comparative analysis of the evolution of connected components and clustering coefficients across varying similarity thresholds for two datasets (Figure 25): scientific papers (left) and patents (right), revealing structural differences and commonalities. For scientific papers, the number of connected components increases sharply around a threshold of 0.75, peaking before declining, indicating initial fragmentation into distinct clusters, followed by consolidation as the threshold rises. In contrast, the number of components in the patent network grows steadily with increasing thresholds, reflecting continuous fragmentation and less cohesive connectivity, suggesting more independent technological development paths. Regarding clustering coefficients, the paper network shows a steady decline as the similarity threshold increases, indicating that at lower thresholds, papers are more interconnected, but become less clustered as similarity increases. The patent network exhibits a similar decline, but less pronounced, maintaining relatively higher local clustering even at higher thresholds, implying that technological innovations form tighter groups within domains despite network fragmentation. This comparison shows that scientific papers form more cohesive networks at lower thresholds, while patents are more fragmented and less interconnected, reflecting the isolated nature of technological innovations.

The Louvain method was employed for community detection within the constructed graph (Blondet et al., 2008). This choice was made based on the benchmarked result from the previous ADMIRAL

Deliverable 2.2[6] where the Louvain method outperformed in tasks of community finding with paper networks using semantic relationships. This method identifies clusters of keywords that frequently co-occur, revealing thematic structures within the data (Tantipathananandh et al., 2011). We also extended this method by using the temporal variant of this algorithm for the snapshots of each year.

We analysed keyword co-occurrence across papers and patents to understand the propagation of ideas between research and practical applications. The transitions and directions of keywords were assessed to identify trends in technology transfer and innovation diffusion.

3.3 Concept similarity network construction

To analyse the relationship between papers and patents, we constructed a bipartite multilayer network. Each layer corresponds to a document type (either papers or patents). Nodes in each layer represent keywords extracted from the documents, and edges are established based on the semantic similarity between these keywords.

We performed topological clustering on the constructed network, inspired by hierarchical clustering techniques. This involved connecting the keywords that had the highest semantic similarity in pairs, forming hierarchical chains of keywords.

Layers were joined based on threshold similarity stated prior, ensuring that only the most relevant connections between keywords from different document types were preserved. This threshold was determined dynamically by analysing the network's topological changes.

We mapped the interlayer flow and lag of keywords to understand the propagation of ideas between academic research and practical applications. This involved tracking the movement and influence of keywords across layers over time.

3.4 Data analysis of Papers and Patent records

3.4.1 Review of Keywords Co-occurrence Networks

The VOS Viewer (version 1.6.20) visualizations provide an exhaustive examination of the keyword co-occurrence networks for academic papers, revealing key thematic clusters and the interconnections among various research topics (Figure 26). These visualizations were developed using previously indexed keywords from both the papers and patents, including those without attributed keywords in the source.

[6] Deliverable 2.2 submitted in 26.04.2024.

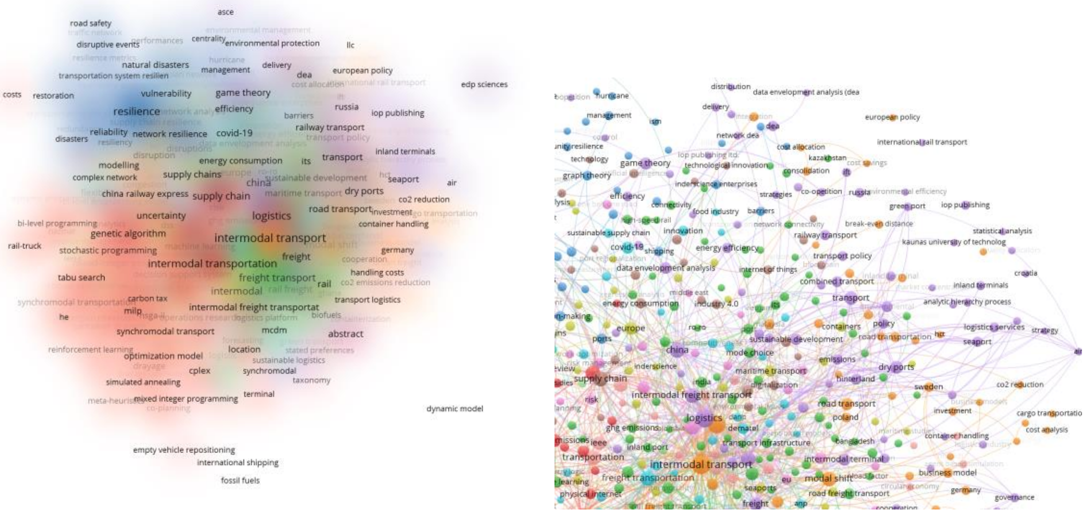


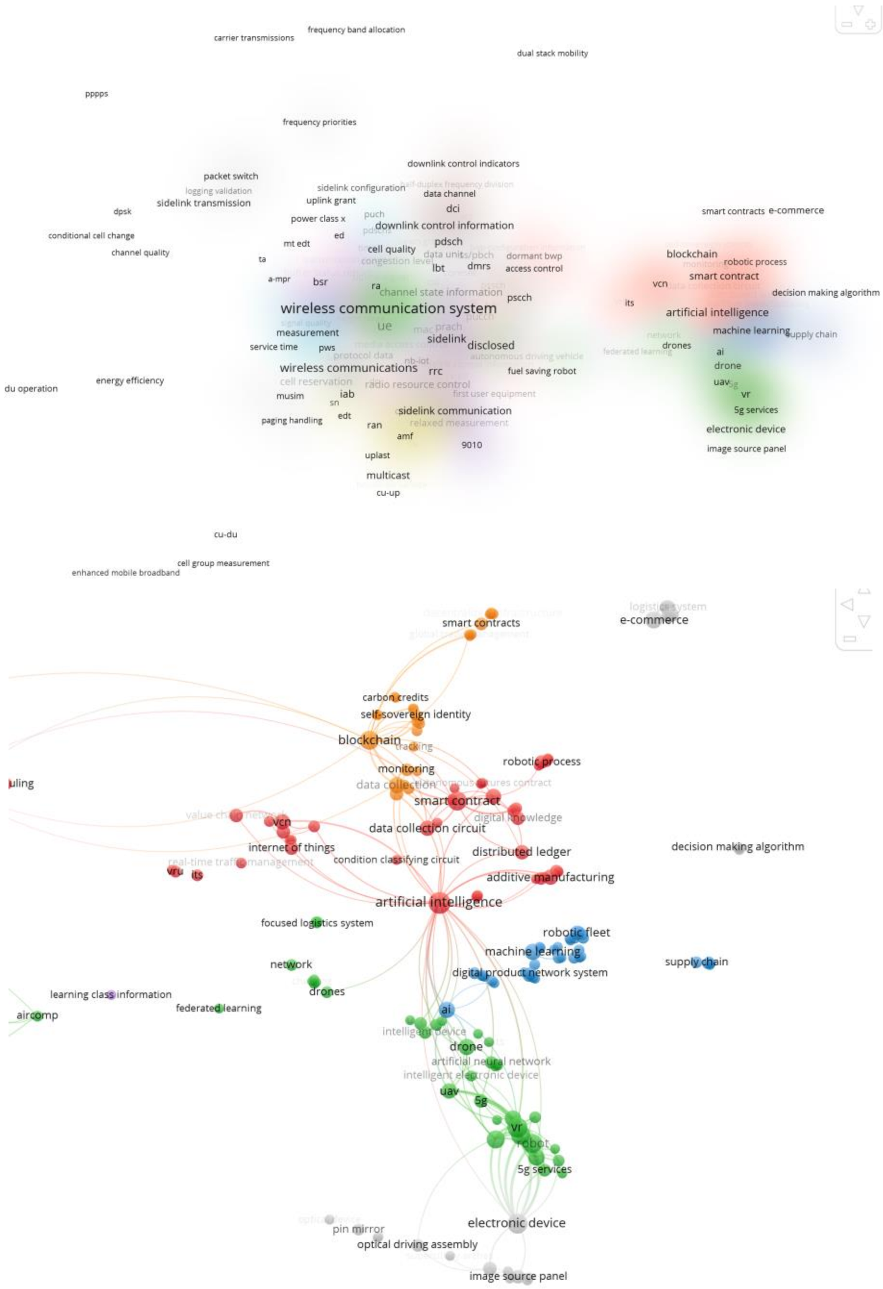
Figure 26: Network Diagram of Keyword Co-occurrence in academic papers

Figure 26 reveals several insights from the network visualization, underscoring the multidisciplinary nature of transport and logistics research. The density of connections around the central keywords ”intermodal transport” or “Intermodal freight transportation” highlights their widespread relevance, while more peripheral terms suggest specialized research niches with narrower focus areas. Terms such “Intermodal transport”, “logistics”, “freight transport” and “supply chains” represent somehow “hubs” in the literature, indicating their core relevance across numerous research studies. Emerging topics like “COVID-19”, ”energy efficiency,” and ”sustainability” have gained prominence, highlighting their increasing importance in current research. The incorporation of advanced technologies is evident from keywords like “machine learning”, ”genetic algorithm” and ”blockchain” highlighting a trend towards digital transformation and innovation within the logistics and transport sector.

Intermodal transport and logistics form the foundation of academic discourse in this field, encompassing research focused on optimizing transport modes, enhancing logistics efficiency, and integrating supply chain processes. The emphasis on terms such as “energy efficiency”, ”CO_2 reduction” and ”sustainability” reflects a growing focus on sustainable practices within the transport sector. Studies in this cluster are likely to include methods to minimize the carbon footprint of transport activities, implement energy-efficient technologies, and promote sustainable logistics practices. Highlighted clusters connected by several bridging terms, such as ”energy efficiency”, linking environmental studies with broader logistics research, indicate an integrated approach to sustainability.

Technological advancements are a significant focus, with keywords like ”machine learning”, ”genetic algorithm”, ”blockchain” and ”IoT” highlighting the sector’s ongoing adoption of advanced technologies to improve logistics and transport operations. The inclusion of ”COVID-19” alongside terms like ”resilience” and ”transport policy” illustrates substantial research interest in understanding the pandemic’s impact on transport systems, with a focus on building resilience against future disruptions.

Turning to the keyword co-occurrence **network for patents**, using the keywords extracted by the model described earlier, the VOS Viewer visualizations in Figure 27 highlight some thematic clusters (a) and the interconnections among various technological advancements (b). This offers insights into the evolving landscape of technological innovation in the logistics and transport sector. “**Wireless communication systems**”, “**artificial intelligence**”, ”**blockchain**” and ”**machine learning**” are examples of central themes with significant role in the patent literature. These terms are highly interconnected, suggesting their core importance in advancing technologies within the sector.



(a)

(b)

Figure 27: Network Diagram of Keyword Co-occurrence in Patents

The presence of keywords ”**smart contracts**”, ”**drones**”, ”**5G services**”, and ”**robotic process**” points to the integration of advanced technologies aimed at enhancing existing systems. Emerging technologies such as ”**virtual reality** (VR)”, ”**electronic device**” and ”federated learning[7]” highlight ongoing research and development efforts to incorporate these innovations into practical applications. Wireless communication systems, AI and ML, and emerging technologies are central themes in patents, indicating a strong focus on advancements and their integration into various domains.

A comparison of the keyword co-occurrence networks of patents and academic papers reveals several key differences and similarities. Both networks highlight the importance of themes such as ”logistics”, ”supply chain” and ”artificial intelligence.” However, **patents place a stronger emphasis on the technical aspects of wireless communication and emerging technologies like ”5G**” and ”**drones**”, while academic papers focus more on the theoretical and applied research aspects. The technological integration is a shared focus, with academic papers exploring the integration of advanced technologies into logistics and transport, and patents emphasizing practical implementation and innovation.

Both networks exhibit an interest in sustainability and efficiency, with emerging topics like ”energy efficiency” in academic papers and ”fuel saving robot” in patents. The impact of COVID-19 is prominently featured in academic research, highlighting a focus on resilience and adaptation, whereas patents do not emphasize this aspect as much.

From a network science perspective, the co-occurrence networks can be analysed using graph theory metrics. Central keywords with high degree centrality, i.e. connected to many keywords via paper co-occurrence (Rodrigues, 2019), such as ”artificial intelligence” have numerous direct connections, indicating their broad applicability and central role in research and innovation. Keywords acting as bridges between clusters like ”blockchain” and ”machine learning,” have high betweenness centrality, i.e. importance as a bridge, which counts the fraction of shortest paths going through a given node (Barthelemy, 2004), signifying their role in connecting different research areas and technological domains.

3.4.2 Analysis of Trends in Keywords of Papers and Patents

The cumulative trends of papers and patents over the years reveal the growth dynamics in these domains. Figure 28 shows the cumulative count of papers and patents from 2014 to 2024.

[7] Federated learning is a sub-field of machine learning (ML). Multiple entities collaboratively train a model while keeping data decentralized.

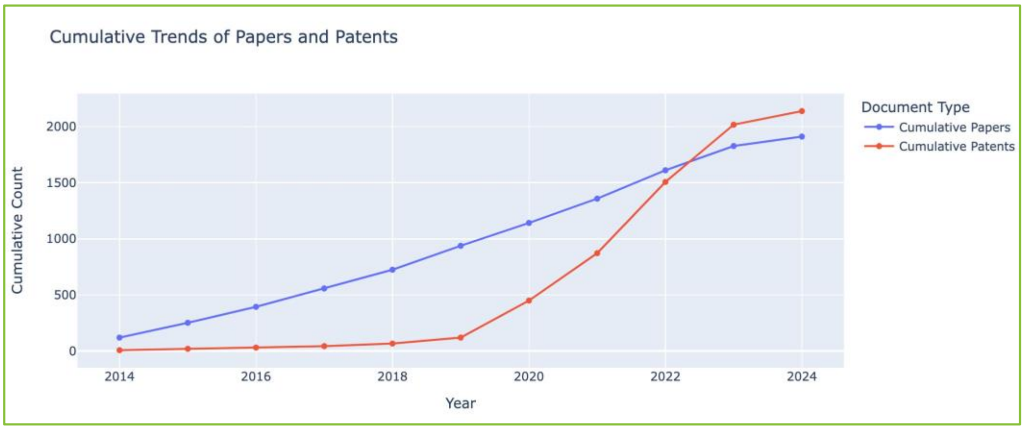


Figure 28: Cumulative Trends of Papers and Patents

It can be observed in Figure 28 that the number of papers has consistently increased over the last ten years, reflecting ongoing research in the field. **The patent filings, however, show a significant increase starting around 2018, which suggests a rise in technological innovations and their formal protection through patents.** The convergence of these trends around 2023 seems to indicate a robust interaction between academic research and practical innovations.

Figure 29 shows the yearly growth rate of papers and patents, highlighting the percentage growth year-over-year.

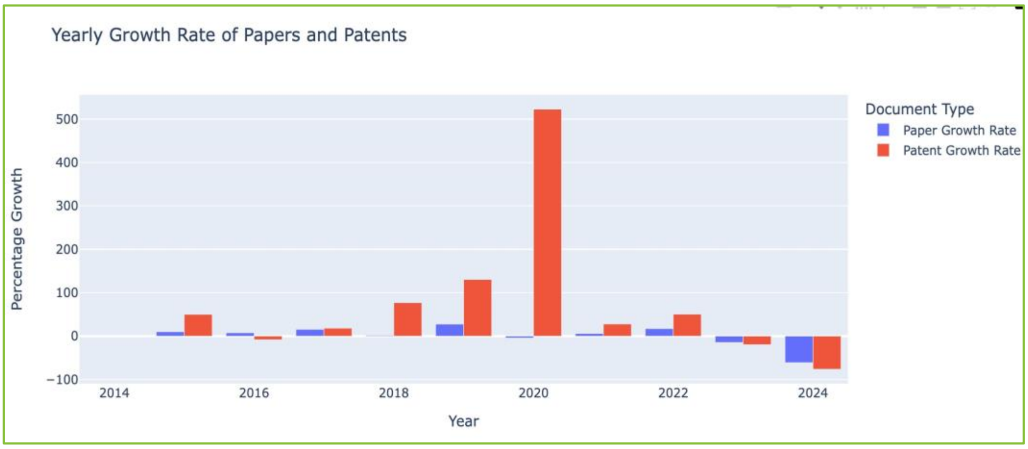


Figure 29: Yearly Growth Rate of Papers and Patents

The growth rate of patents shows significant spikes in certain years, notably around 2020 (Figure 29), which might correspond to heightened innovation activities, possibly driven by the adaptation of companies to the challenges posed by the COVID-19 pandemic. The relatively stable growth of papers indicates a steady progression of academic contributions, while the more volatile patent growth highlights the bursts of innovative outputs. The substantial increase in patent filings in 2020 could be attributed to industries diversifying their departments of innovation and increased funding for technological advancements in this sector. This might also be a way to justify keeping smaller companies operating independently (Merges, 2020).

3.4.3 Analysis of top keywords in Papers and Patents

Figure 30 displays the top 20 keywords in papers (right) and patents (left), respectively.

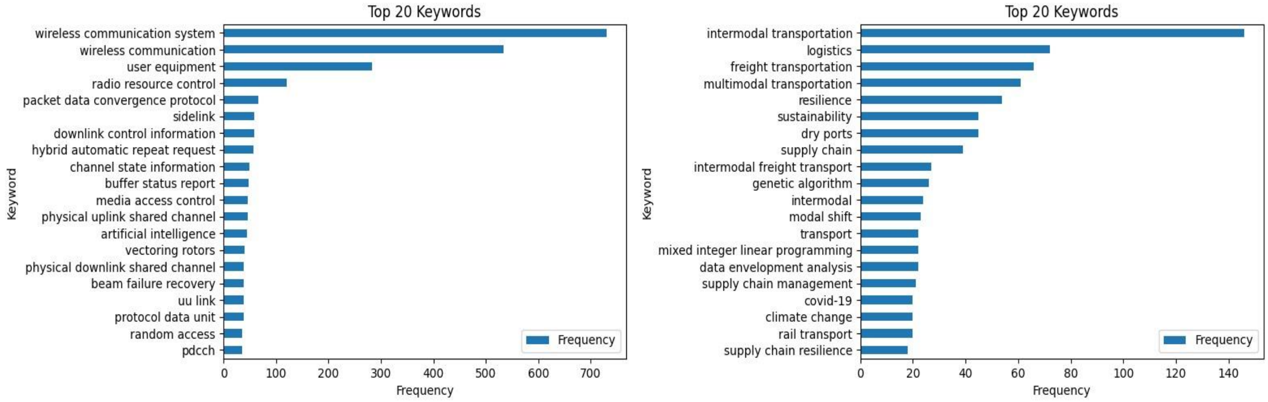


Figure 30: Top 20 Keywords in Papers (right) and Patents (left)

In academic papers, terms like ”intermodal transportation”, ”logistics” and ”freight transportation” dominate, reflecting the primary focus areas of research. **In patents, keywords such as ”wireless communication system”, ”user equipment,” and ”radio resource control” are prevalent, indicating a strong emphasis on communication technologies and their applications in logistics and supply chain management.**

3.4.4 Analysis of top IPC codes in Patents

The top 20 International Patent Classification (IPC) codes for patents are shown in Figure 31. The most frequent IPC codes such as **H04L 5/00 and H04W 72/04** pertain to **wireless communication systems**, focusing on efficient transmission path usage and various network aspects including resource allocation, scheduling, and optimization. The presence of **G06N 20/00 highlights the application of AI and machine learning in these technologies**, emphasizing the importance of advanced computational models in modern communication systems.

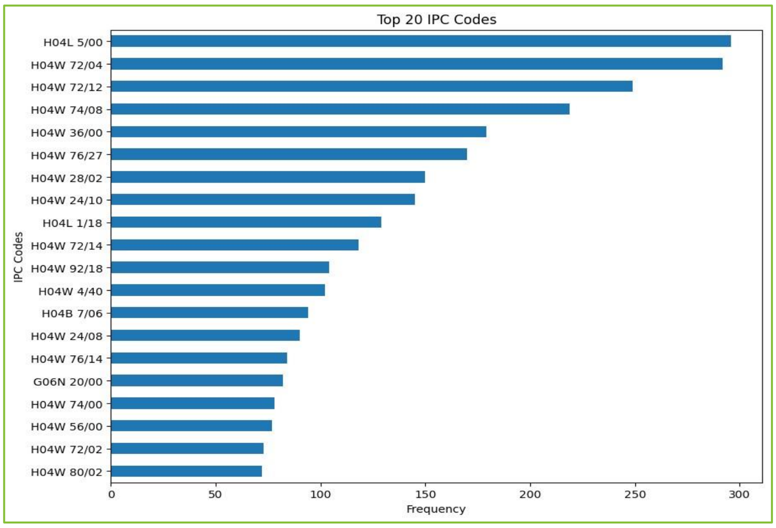


Figure 31: Top 20 IPC codes in Patents

The top 20 IPC codes are described as follows:

- H04L 5/00: Focuses on techniques for efficient use of transmission paths in communication systems.
- H04W 72/04, 72/12, 74/08, 36/00, 76/27, 28/02, 24/10, 72/14, 92/18, 4/40, 24/08, 76/14, 74/00, 56/00, 72/02, 80/02: these codes relate to various aspects of wireless communication networks, including resource allocation, scheduling, network planning, optimization, and specific techniques like TDMA (Time Division Multiple Access, a communication protocol), power management, self-organizing networks, emergency communication, and ad hoc networks.
- H04L 1/18: Pertains to error detection and prevention in communication systems.
- H04B 7/06: Involves multi-channel transmission systems, often used in wireless communication.
- G06N 20/00: Covers computer systems based on models like neural networks, indicating AI and machine learning applications.

3.4.5 Evolution of G06Q Patents by Top Countries

The yearly evolution of G06Q patents, which cover data processing systems or methods specifically adapted for administrative, commercial, financial, managerial, supervisory, or forecasting purposes, is shown in Figure 32.

G06Q 10/00	**Administration; Management** [2012.01]
G06Q 10/02	• Reservations, e.g. for tickets, services or events **[2012.01]**
G06Q 10/04	• Forecasting or optimisation, e.g. linear programming, "travelling salesman problem" or "cutting stock problem" **[2012.01]**
G06Q 10/06	• Resources, workflows, human or project management, e.g. organising, planning, scheduling or allocating time, human or machine resources; Enterprise planning; Organisational models **[2012.01]**
G06Q 10/08	• Logistics, e.g. warehousing, loading, distribution or shipping; Inventory or stock management, e.g. order filling, procurement or balancing against orders **[2012.01]**
G06Q 10/10	• Office automation, e.g. computer aided management of electronic mail or groupware (electronic mail network systems H04L 12/58; electronic mail protocols H04L 29/06); Time management, e.g. calendars, reminders, meetings or time accounting **[2012.01]**

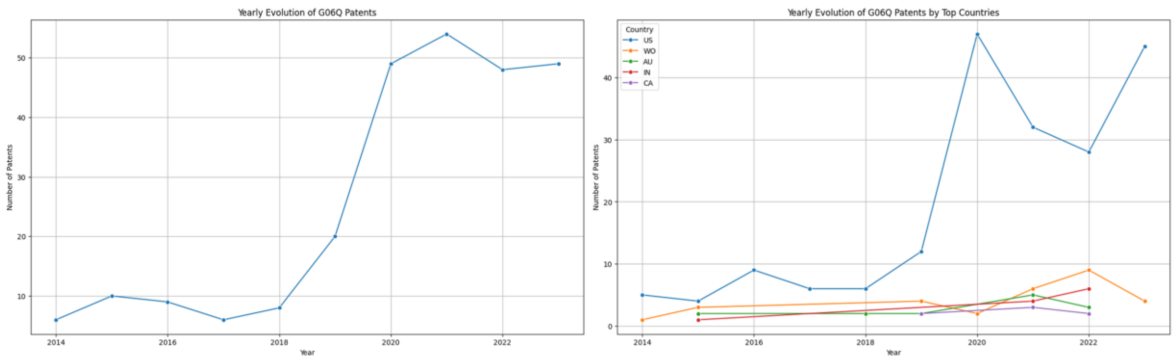


Figure 32: Yearly evolution of G06Q Patents: annual trend (left) and yearly evolution considering the top contributing countries (right)

In Figure 32, the graphic on the left shows the overall yearly trend, while the one in the right breaks down the data by top contributing countries: USA (blue), WO[8] (orange), Australia (green), India (red) and Canada (violet). The significant increase around 2019/2020 reflects the growing importance of advanced data processing in various sectors, probably driven by the need for better decision-making tools and efficiency improvements in logistics and supply chain management.

[8] WO: World Intellectual Property Organization (WIPO)

3.4.6 Percentage Distribution of Patents in Sub-Categories of B60

The analysis of patents within the sub-categories of **B60 - Vehicles in general**, reveals significant trends in automotive and vehicle technologies. Figure 33 illustrates the percentage distribution of patents across various B60 sub-categories. It can be shown that the highest percentage of patents fall within subcategories B60L and B60W, which are "**Propulsion of electrically-propelled vehicles**" and "**Vehicle suspension arrangements**" respectively. This indicates a strong focus on the **development of electric vehicle technologies and advanced suspension systems, reflecting the industry's shift towards sustainability and improved vehicle performance**. The sub-categories B60J and B60K, that cover "Windows, windscreens, non-fixed roofs, doors, or similar devices for vehicles" and "Arrangement or mounting of propulsion units or of transmissions in vehicles," also show a considerable number of patents. This suggests ongoing innovations in vehicle design and propulsion unit arrangements to enhance safety, efficiency, and user experience. Sub-categories like B60H (arrangements of heating, cooling, ventilating, or other air-treating devices) and B60T (vehicle connections, including components of brake systems) have a lower percentage of patents. However, their presence indicates continuous improvements in vehicle comfort and safety features.

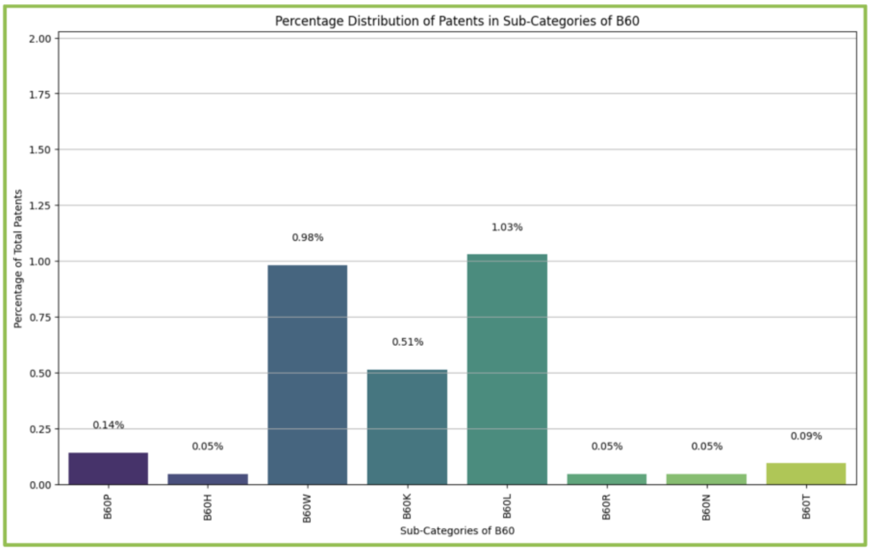


Figure 33: Percentage distribution of Patents in sub-categories of B60

Figure 33 highlights the importance of the following:

- B60L: **Propulsion of Electrically-Propelled Vehicles**: This sub-category has the highest percentage of patents, highlighting the automotive industry's focus on electric propulsion technologies. Innovations in this area are crucial for developing more efficient, sustainable, and environmentally friendly vehicles.
- B60W: **Vehicle Suspension Arrangements**: The significant number of patents in this category reflects advancements in suspension technologies aimed at improving vehicle stability, safety, and passenger comfort.
- B60K: **Arrangement or Mounting of Propulsion Units or of Transmissions in Vehicles**: Patents in this category indicate continuous innovation in vehicle powertrain configurations, aiming for better performance and fuel efficiency.
- B60H: **Arrangements of Heating, Cooling, Ventilating, or Other Air-Treating Devices**: This

category, though with a smaller percentage, highlights the importance of climate control systems in enhancing vehicle comfort and usability.

The distribution of patents across the above sub-categories suggests a balanced approach to vehicle innovation, addressing various aspects of vehicle design, propulsion, and user experience. **A multi-faceted innovation is essential in the context of sustainability and advanced vehicle technologies**.

The highest percentage of patents falls within sub-categories B60L and B60W, indicates a strong focus on electric vehicle technologies and advanced suspension systems. This **trend aligns with the industry's shift towards sustainability and the pursuit of improved vehicle performance, to improve energy efficiency and reduce CO_2 emissions**. Additionally, sub-categories such as B60J and B60K, which cover vehicle design elements and propulsion unit arrangements, exhibit considerable patent activity. This suggests ongoing innovations aimed at enhancing safety, efficiency, and user experience in vehicle design. These insights reflect the industry's commitment to advancing technology and sustainability in automotive engineering.

3.4.7 Analysis of Yearly Percentage Evolution of Top 5 IPC codes by category

Figure 34 presents the yearly percentage evolution of each IPC first letter (2014-2024). The first letter in the International Patent Classification (IPC) system that is used by the World Intellectual Property Organization (WIPO) refers to the section of technology to which the patent belongs. The main sections are: A: Human Necessities; B: Performing Operations; Transporting; C: Chemistry; Metallurgy; D: Textiles; Paper; E: Fixed Constructions; F: Mechanical Engineering; Lighting; Heating; Weapons; Blasting; G: Physics; H: Electricity

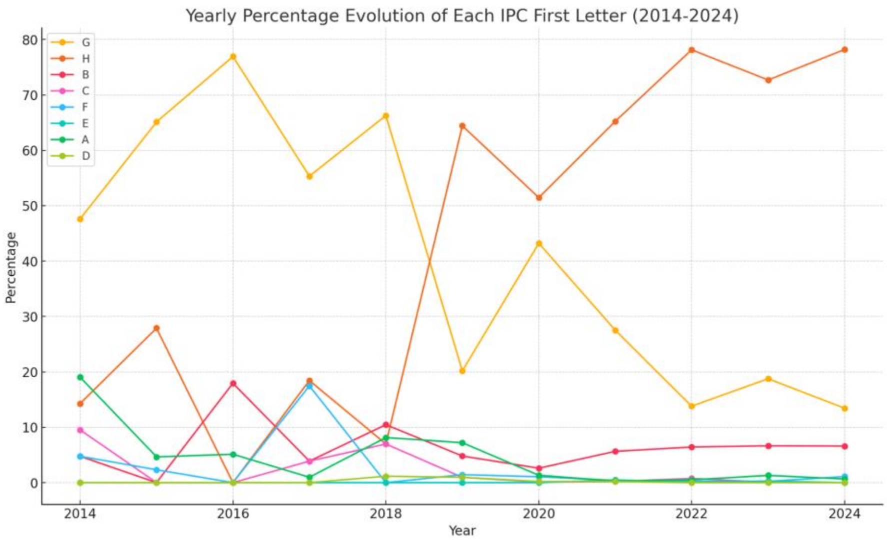


Figure 34: Yearly Percentage Evolution of Each IPC category/first letter (2014-2024)

The yearly percentage evolution of the top 5 IPC codes across different categories from 2014 to 2024 (Figure 34) seems to reveal dynamic patterns of innovation:

- In the **Electricity (H) category**, codes such as H04W 00/0402 and H04L 29/08 demonstrate sustained interest and periodic peaks, indicating ongoing advancements in electric communication techniques. These trends suggest a continuous push towards **enhancing digital communication infrastructures, critical for the logistic transport sector's need for real-time tracking and efficient data transmission**.

- In the **Performing Operations; Transporting (B) category**, codes like B65B 3/06 show an initial high level of activity in 2014, with subsequent declines, reflecting early but diminished focus on specific packaging technologies (Like for instance machines for sealing semi-automated packaging in pipelines). Meanwhile, codes such as B64C 39/02 and B61L 23/04 exhibit fluctuating interest, suggesting episodic innovation bursts in aeronautical and railway logistics, respectively. These patterns highlight the sector's evolving priorities, with a growing emphasis on integrating advanced materials and aerodynamics to optimize transport efficiency.
- The Chemistry; Metallurgy (C) category showcases significant spikes in codes like C09J 7/38 around 2020, pointing to **innovations in adhesives and coatings critical for enhancing the durability and efficiency of transport vehicles**. Such advancements are vital for reducing maintenance costs and improving the longevity of logistics infrastructure.
- In **Mechanical Engineering; Lighting; Heating; Weapons; Blasting** (F), the dominant activity in codes such as F25D 1/100 and F03G 7/08 around 2014 and 2020, respectively, indicates a focus on **refrigeration technologies and wind energy systems**. For the logistics sector, these innovations are crucial for developing more efficient cold chain logistics and integrating renewable energy sources into transport systems, thereby reducing operational costs and environmental impact.
- The **Fixed Constructions** (E) category, with codes like E01B 7/00 showing late and significant peaks in 2022, suggests recent advancements in **railway construction technologies**. These developments are instrumental for enhancing the efficiency and safety of rail logistics, a backbone of intermodal freight transport systems.
- In the Human Necessities (A) category, significant spikes in codes such as A61K 38/00 and A23L 33/418 in 2016 and 2018, respectively, reflect innovations in pharmaceuticals and food technology. **For logistics, this implies improvements in the transportation and storage of perishable and sensitive goods**, ensuring quality and compliance with regulatory standards.
- Lastly, the Textiles; Paper (D) category, with peaks in codes like D02G 3/08 around 2018, highlights innovations in textile technologies. This is relevant for the logistics sector concerning the packaging materials that protect goods during transit, enhancing the overall reliability of supply chains while accounting for the inclusion of circular economy models.

The analysis of the yearly percentage evolution of each IPC first letter (Figure 34) reveals critical insights into the technological focus areas in logistics and transportation. The dominance of categories such as B60 (Vehicles in General) and B60L (Electric Vehicle Technologies) highlights the sector's emphasis on developing advanced vehicle technologies and electric propulsion systems. This shift is consistent with the global push towards sustainable transport solutions and reducing carbon footprints. Furthermore, the significant presence of categories like H (Electricity) highlights the integration of electrical and electronic innovations in enhancing vehicle performance and operational efficiency.

Figure 35 shows the top keywords trends in patents over the period 2014-2024. It can be shown a substantial rise after 2018 in terms related to "wireless communication systems","AI" and "blockchain". This trend signifies the growing importance of digital technologies in logistics operations. Additionally, "**wireless communication systems" reflect advancements in connectivity solutions crucial for real-time data transmission and vehicle to-everything (V2X) communication (e.g.**

connected freight vehicles). Concurrently**, the rise in AI-related keywords indicates the deployment of machine learning algorithms for optimizing logistics and transportation processes**, **enhancing decision-making, and predictive analytics.**

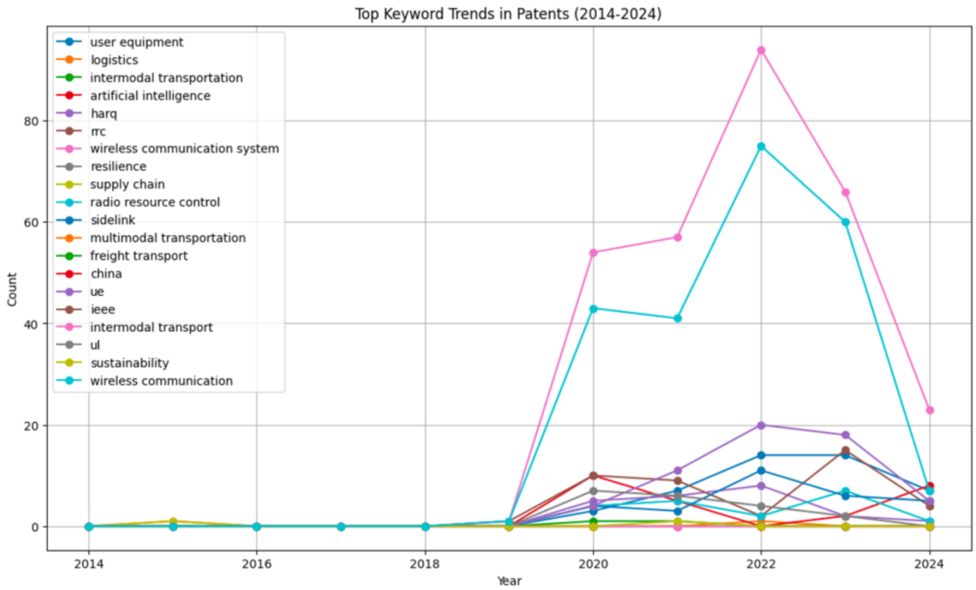


Figure 35: Top Keyword trends in Patents (2014-2024)

3.4.8 Practical Implications for the Transport and Logistics Sector

The analysis highlights a shift towards an increase in the integration of advanced communication technologies in the transport and logistics sector, accounting for the weight of the Electricity (H) category of patents as well. The sustained and growing interest in electric communication techniques, as evidenced by the activity in codes such as H04W 00/0402, is indicative of a broader trend towards digitalization. For logistics, this translates to improved real-time tracking, enhanced data analytics capabilities, and more efficient supply chain management systems.

In the "**Performing Operations; Transporting**" (B) category, the **innovation bursts in aeronautical and railway logistics** reflect the sector's response to the growing demand for faster and more efficient transportation solutions. Innovations in these areas are essential for developing intermodal transport systems that can seamlessly integrate various modes of transport, thereby enhancing the overall efficiency and reliability of supply chains.

From 2020 onwards, there has been a notable increase in patented technologies, especially within the domain of electricity and data transmission. **The fact that the number of patents in certain communities has surpassed the number of academic papers in recent years indicates a strong drive towards protecting intellectual property and commercializing innovations**. This trend is critical for the logistics sector, where technological advancements in AI and machine learning are central for optimizing route planning, predictive maintenance, and automating warehouse operations.

3.4.9 Distribution of Papers and Patents between 2014 and 2024

The distribution of papers and patents per year highlights the temporal evolution of academic research and technological innovation within the studied domain. Figure 36 shows the number of papers and patents published annually, between 2014 to 2024.

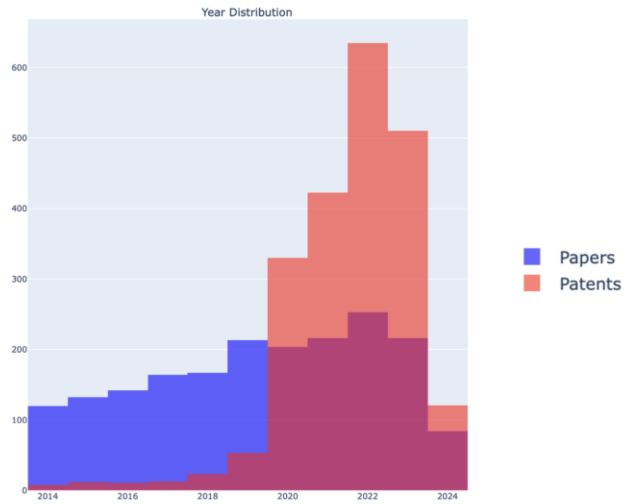


Figure 36: Distribution of Patents and Papers (2014-2024)

The analysis of distribution trends further highlights the symbiotic relationship between academic research and practical application. The overlapping regions of the graph (Figure 36) indicate periods where academic research directly contributed to, or was inspired by, technological advancements, leading to the filing of patents. This co-evolution of papers and patents reflects the dynamic interplay between theoretical research and its practical implementation.

The analysis reveals interesting trends. Firstly, **there has been a notable increase in patent filings starting around 2018, with a peak observed in 2022**. This trend suggests a surge in innovation and the development of new technologies, possibly driven by increased investment in research and development within these sectors. Additionally, **the number of academic papers published each year shows a steady increase**, indicating ongoing interest and research activities in the field of intelligent logistics and sustainable transport operations. The overlap between the increase in papers and patents around 2020-2022 seems to suggest a **close interaction between research outputs and technological innovations**. **The spike in both papers and patents during 2020-2022 could be associated with the global response to the COVID-19 pandemic, which boosted rapid innovation and adaptation in logistics, supply chain management, and transportation technologies**. This period saw significant advancements aimed at addressing the challenges posed by the pandemic, highlighting the critical role of innovation in crisis response.

Moreover, the distribution pattern suggests that while research activities have been consistently growing, the practical application of these research findings, as evidenced by patent filings, saw a more dramatic increase in recent years. This can be attributed to the maturation of research ideas into market-ready innovations, facilitated by advancements in technology and increased funding.

Interestingly, the decline in both papers and patents in 2024 may indicate a lag in reporting or a potential stabilization phase following the intense period of innovation driven by the pandemic. This stabilization could represent a period of consolidation, where existing innovations are refined and integrated into mainstream practices, as well as due to the mid-year break in analysis.

The focus on humanitarian logistics has also been a relevant area of development from 2014 to 2023. The need for efficient delivery of essential goods during emergencies, such as natural disasters, conflicts, and pandemics, has driven innovations in real-time tracking, blockchain for transparency, and AI for resource allocation. These advancements have significantly enhanced the capabilities of **humanitarian logistics**, ensuring timely access to essential goods and improving overall response effectiveness (Kamat et al., 2023; Rodríguez-Espíndola et al., 2023), yet only papers referred to this concept directly.

Table 12 presents the resulting communities of papers and patents, where "Pp" and "Pt" denote the number of papers and patents respectively within each one of the mixed communities. These communities are formed through methods for the extraction of keywords using T5 trained in scientific literature keywords and then applying a threshold of semantic similarity between the sets of keywords between papers and patents. By mapping these connections, we aim to trace the flow and evolution of ideas across academia and industry, providing insights into their collaborative dynamics over time. The date of the analysis is limited to queries dated the 6th of May of 2024.

The dates mentioned alongside each community (e.g., 2014 to 2024, 2015 to 2024) reflect the active period during which the papers and patents within that community were published. These date ranges indicate the time frame of technological relevance and intellectual activity within each community, shedding light on the temporal distribution of innovation efforts.

Table 12: Research-industry communities of Papers (Pp) and Patents (Pt) obtained with a focus on Transport and Logistics Innovations.

Research-industry community designation (period covered)	Top keywords	Main Emerging technologies	Pp/Pt	Size (Pp+Pt)
Advanced Automation in Intermodal Transport and Cognitive Supply Chains (2014-2024)	**Papers:** automation, intermodal transport, logistics, maritime freight, supply chain management, system dynamics **Patents**: automation, smart contract, artificial intelligence, cognitive insights, customization, solar photovoltaic array, wireless communications	Automation, AI, Cognitive Insights, Solar Photovoltaic Array, Wireless Communications	0.6	152
Advanced Systems and Resource Allocation in	**Papers:** advanced systems, AI, automated systems, resource allocation, carbon emissions, reliability,	Advanced Systems, Resource Allocation,	0.398	186

Carbon Emissions Reduction (2014-2024)	supply chain, logistics, heavy-duty trucks, hydrogen fuel cell. **Patents:** advanced systems, AI, automated systems, resource allocation, carbon emissions, reliability, supply chain, logistics, heavy-duty trucks, hydrogen fuel cell	Heavy-Duty Trucks, Hydrogen Fuel Cell		
Artificial Intelligence and Automated Systems in Sustainable Logistics (2015-2024)	**Papers:** AI, artificial intelligence, automated systems, freight transport, energy efficiency, climate change, logistics **Patents:** AI, artificial intelligence, waste management system, VR, fleet value chain network automation, wireless communication system, beam failure recovery	AI, Automated Systems, Waste Management System, VR, Fleet Value Chain Network Automation, Wireless Communication System, Beam Failure Recovery	0.318	145
Autonomous Electric Vehicles and Smart Charging Infrastructure in Green Logistics (2015-2024)	**Papers**: electric vehicles, dynamic load/truck control system, autonomous vehicles, ITS, collaboration mechanism, deep learning, convolution, BRT **Patents**: electric vehicles, data transfer disturbance, smart washing machine, artificial neural network, wireless communication system, IoT, charging stations, energy optimization engine	Autonomous Vehicles, Smart Charging, Deep Learning, Convolution, Charging Stations, Energy Optimization Engine	0.423	74
Blockchain and e-commerce integration in green logistics (2014-2024)	**Papers**: blockchain, e-commerce, supply chain, logistics, sustainability, physical internet, decentralized leadership **Patents**: blockchain, smart contract, data collection, IoT, logistics, manufacturing, wireless communication	Blockchain, Smart Contract, Data Collection, IoT, Wireless Communication	0.625	26
CO_2 Reduction and Hydrogen Fuel Cell Innovations in Logistics (2016-2024)	**Papers**: CO2 reduction, heavy-duty trucks, logistics, intermodal transport, resource allocation **Patents**: CO2 reduction, hydrogen fuel cell, IoT, waste management system,	Hydrogen Fuel Cell, IoT, Waste Management System, Wireless Communication System	0.25	20

	wireless communication system, social disruptive events, logistics warnings			
Dynamic Load Control and Multi-device Management in Logistics (2014-2024)	**Papers**: supply chain, dynamic load/truck control system, logistics management, carbon emissions, hazardous materials, optimization techniques **Patents**: dynamic load/truck control system, supply chain, value chain network automation, environment, waste management system, v3, multi-device ref, machine learning	Dynamic Load/Truck Control System, Value Chain Network Automation, Waste Management System, Machine Learning	0.375	121
Energy Efficiency, Real-time Tracking in Supply Chain Management (2014-2024)	**Papers**: logistics, supply chain management, carbon emissions reduction, intermodal transport, quantitative methods, freight transport, renewable energy, optimization techniques **Patents**: logistics, engineering, manufacturing, self-sovereign identity, real-time tracking, computer program, mechanical engineering, dynamic vision system	Real-time Tracking, Self-Sovereign Identity, Dynamic Vision System, Optimization Techniques	2.222	58
Fairness and Equity in ITS and Railway Transport (2014-2023)	**Papers**: heterogeneous information, ITS, railway transport, co-planning, dynamic load/truck control system, SAM, traffic control, resilience, equity **Patents**: utility resource asset management, IoT, digital user-controlled environment, data transfer disturbance, resource allocation, CO_2 reduction, hydrogen fuel cell, fairness, traffic control	Fairness, Railway Transport, Dynamic Load/Truck Control System, Hydrogen Fuel Cell, IoT, Digital User-Controlled Environment	2.591	79
Hazardous Transport and Real-Time Big Data (2014-2024)	**Papers**: hazardous materials, cargo transportation, big data, public transit, electric vehicles, supply chain resilience, resource management **Patents**: hazardous materials, real-time tracking, failure detection, recovery,	Hazardous Transport, Big Data, Supply Chain Resilience, Real Time Tracking, Failure Detection, Temperature	1.833	51

	electric vehicles, aemp, intelligent transport system, temperature monitoring, random access	Monitoring, Random Access		
High-Speed Rail Systems and Integrated Green Logistics (2017-2023)	**Papers**: ITS, IoT, intermodal transport, green logistics, Indian manufacturing enterprises, reliability, high-speed trains, pricing, container transport **Patents**: IoT, real-time traffic management, LNG regasification, energy saving, wireless communication system, reliability, highspeed railway, insurance, memory devices, secondary cell group	High-Speed Rail Systems, Real Time Traffic Management, LNG Regasification, Secondary Cell Group	2.7	37
Intelligent Transport Systems and Heterogeneous Information Management (2015-2023)	**Papers**: intelligent transport systems, collaboration mechanism, heterogeneous information, machine learning, ITS, freight transport, energy efficiency, fairness, resilience, co-planning **Patents**: intelligent transport systems, ship scheduling, weather, event generator, hazard, dynamic vision system, public land mobile network, accessibility, electronic platform	Intelligent Transport Systems, Machine Learning, Freight Transport, Ship Scheduling, Dynamic Vision System, Public Land Mobile Network, Electronic Platform	0.760	169
Intelligent Transport System and Deep Learning in Hub-and-Spoke (H&S) Network (2017-2023)	**Papers**: network optimization, LVCT, genetic algorithm, deep learning, intelligent transport system, electric vehicles, Hub-and-Spoke (H&S) network **Patents**: network optimization, logging validation, wireless communication, intelligent transport system, smart washing machine, artificial neural network, mobility, temperature monitoring unit	Intelligent Transport System, Deep Learning, H&S Network, Smart Washing Machine, Artificial Neural Network, Mobility, Temperature Monitoring Unit	0.459	270
Intermodal Transport Economics and European Infrastructure (2016-2023)	**Papers**: traffic control, Critical Infrastructure, electric vehicles, transport economics, logistics, performance analysis, European infrastructure	Intermodal Transport Economics, Traffic Control, Electric Vehicles, Vehicle Coupling Units, Heat	2.579	433

	Patents: traffic control, Critical Infrastructure, vehicle coupling units, heat exchange module, wireless communication system, air vehicles, small data transmission, 3D environment	Exchange Module, Air Vehicles		
Intermodal Transport and Progressive Augmentation in Green Logistics (2015-2023)	**Papers**: intermodal transport, DSS, electric vehicles, autonomous vehicles, AI, green logistics, SAM, progressive augmentation algorithm, renewable energy, performance analysis **Patents**: intermodal transport, IoT, electric vehicles, autonomous vehicles, AI, green logistics, SAM, renewable energy, performance analysis	Intermodal Transport, Electric Vehicles, Autonomous Vehicles, Progressive Augmentation Algorithm, Green Logistics	15.077	209
IoT and Autonomous Vehicles in Intelligent Transport Systems (2015-2014)	**Papers**: IoT, intelligent transport systems, GPS, electric vehicles, autonomous vehicles, logistics management, energy efficiency **Patents**: IoT, AI, autonomous vehicles, V2X, GPS, electric vehicles, smart contracts, supply chain, logistics services, quality indicators	IoT, Autonomous Vehicles, V2X, Electric Vehicles, Smart Contracts, GPS	0.778	32
Machine Learning and Dynamic Systems in Regional Transportation (2014-2022)	**Papers**: machine learning, traffic patterns, regional highway transportation system, supply chain, cargo consolidation, intermodal transport, passenger transportation **Patents**: machine learning, dynamic vision system, real-time tracking, cargo consolidation, congestion, wireless communication system, device	Machine Learning, Traffic Patterns, Regional Highway Transportation System, Cargo Consolidation, Congestion, Dynamic Vision System, Real-Time Tracking	0.538	283
Machine Learning and Predictive Models in Renewable Energy Logistics (2014-2024)	**Papers**: machine learning, renewable energy, carbon dioxide gas, transport logistics, inspection records, BRT, IoT, lean manufacturing, covid-19 **Patents**: machine learning, dynamic vision system, predictive model, electronic engineering, wireless	Machine Learning, Predictive Model, Dynamic Vision System, BRT, RFID	1.333	63

	communication system, CO_2, AI, BRT, RFID, NAC, side link			
Mobility Systems and Hub-and-Spoke (H&S) Networking Vehicle Procurement (2014-2022)	**Papers**: mobility systems, H&S network, logistic organization, evaluation, analytic network processes, vehicle procurement, time delay **Patents**: mobility systems, wireless communication system, evaluation, sidelink communication, Radio Access Technology (RAT), UE	Mobility Systems, Vehicle Procurement, Sidelink Communication, RAT	0.394	92
Network Optimization and Genetic Algorithms in Resilient Logistics (2014-2023)	**Papers**: network optimization, LVCT (Line Voltage Communicating Thermostats), genetic algorithm, progressive augmentation algorithm, intermodal transport, real-time co-planning, resilient optimization, performance analysis **Patents**: network optimization, logging validation, wireless communication, resource allocation, multi-risk assessment systems, electronic platform, buffer status report	Network Optimization, Genetic Algorithm, Progressive Augmentation Algorithm, Resilient Optimization, Multi-Risk Assessment Systems	0.843	94
Network Optimization and AI-driven Traffic Management in Logistics (2014-2024)	**Papers**: network optimization, logistics, supply chain management, CO2 reduction, traffic patterns, regional highway transportation system, blockchain, physical internet, congestion, public carrier **Patents**: network optimization, blockchain, IoT, artificial intelligence, smart contract, resource allocation, social disruptive events, genetic algorithm, mobile tracking	Network Optimization, IoT, Artificial Intelligence, Smart Contract, Genetic Algorithm, Mobile Tracking	1.554	143
Network Optimization and Critical infrastructure in Cargo Transport and Recovery (2014-2023)	**Papers**: network optimization, LVCT (Line Voltage Communicating Thermostats), genetic algorithm, dynamic load/truck control system, resilient optimization, critical	Network Optimization, Genetic Algorithm, Dynamic Load/Truck Control System, Real-Time Tracking, Cargo Transportation,	3.12	103

	infrastructure, pricing, recovery, vulnerability **Patents**: network optimization, logging validation, wireless communication, real-time tracking, cargo transportation, insurance, memory devices, intelligent shipping agent	Insurance, Intelligent Shipping Agent		
Operational Models and Route Sequencing in Intermodal Terminals (2014-2023)	**Papers**: intermodal terminals, network optimization, heterogeneous information, Indian manufacturing enterprises, roadways, European infrastructure, layered analysis **Patents**: robot fleet management, wireless communication, energy saving, hazard, beam failure recovery, governance, route sequencing	Operational Models, Route Sequencing, Robot Fleet Management, Beam Failure Recovery, Governance	2.109	143
Quantitative Methods and Strategic Freight Transport Models (2014-2024)	**Papers**: transportation systems, traffic assignment model, intermodal transport, quantitative methods, AI, agricultural production, strategic freight transport model **Patents**: transportation systems, AI, strategic freight transport model, fleet management, drone, public land mobile network, tokens, accessibility, security, IoT, order management, 3D environment	Strategic Freight Transport Model, Fleet Management, Drone, Public Land Mobile Network, IoT,3D Environment	5.909	76
Resiliency and Redundancy in Carbon Emission Reduction (2014-2024)	**Papers**: resiliency, redundancy, energy efficiency, carbon emissions, intermodal transport, supply chains, performance analysis, uncertainty **Patents**: energy efficiency, mechanical engineering, order management, transportation systems, value chain network automation, carbon credits, tokens, supply chain, traffic control, logistics	Energy Efficiency, Value Chain Network Automation, Carbon Credits, Order management, Traffic Control	0.522	140
Resilient Optimization and Multifactor	**Papers**: resilient optimization, progressive, heterogeneous	Resilient Optimization,	0.357	308

Supporting Road Networks (2014-2023)	information, pricing, road networks, transport economics, reliability, vulnerability, multifactor **Patents**: resilient optimization, resource allocation, utility resource asset management, insurance, intelligent shipping agent, heat exchange module, thermoelectric cooler, reliability, dashboard visualization	Intelligent Shipping Agent, Thermoelectric Cooler, Dashboard Visualization		
Supply Chain Resilience and Multifactor Support in Mixed Logical Dynamical Systems (2014-2023)	**Papers**: supply chain resilience, traffic control, freight transport, collaboration mechanism, GPS, mobile tracking, multifactor support, mixed logical dynamical **Patents**: supply chain resilience, real-time tracking, LNG regasification, GPS, derivatives contracts, dashboard visualization, wireless communication, user equipment	SC Resilience, Multifactor Support, Mixed Logical Dynamical, Derivatives Contracts, User Equipment	0.972	140
Sustainability and Risk Management in Self-Sovereign Logistics (2014-2014)	**Papers**: sustainability, risk management, cost savings, carbon emissions reduction, environment, logistics management, transportation system **Patents**: self-sovereign identity, wireless communication system, carbon credits, vehicle routing, GPS, shipment ref (shipment reference is a unique identifier)	Self-Sovereign Identity, Wireless Communication System, Carbon Credits, Vehicle Routing, GPS	1.882	98
Traffic Patterns, Beam Failure Recovery and Highway Systems (2014-2021)	**Papers**: traffic patterns, layered analysis, regional highway transportation system, container transport, utilization function, mobility, logistic organization **Patents**: traffic patterns, beam failure recovery, congestion, wireless communication system, BFR, device support, time, Transport Stream (TS)	Beam Failure Recovery, Device Support, Transport Stream (TS) States	0.172	68

	states (regarding telecommunications protocols)			
Urban Consolidation Centres and Cyber Security in Logistics (2014-2024)	**Papers**: urban consolidation centres, energy efficiency, renewable energy, AI, IoT, cyber security, big data, co-planning, real-time, optimization techniques **Patents**: urban consolidation centres, energy efficiency, renewable energy, AI, IoT, cyber security, big data, co-planning, real-time, optimization techniques	Urban Consolidation Centres, Cyber Security, Big Data, Co-Planning, Optimization Techniques	0.326	232

3.4.10 Interest and Significance of the industry-research communities/clusters

The concept of industry-research communities is of particular interest in this analysis as it demonstrates the interconnectedness of research outputs and patented technologies. Identifying these communities, as shown in Table 12. It helps to understanding how academic findings influence industry practices and innovation trends, and vice versa. It also highlights areas where research is rapidly translating into practical applications, or where gaps might exist between research outputs and their commercial exploitation.

The joint community designation in Table 2 not only serves as a methodological innovation indicator but also as a strategic tool for policymakers, researchers, and business leaders. The designation is characterized by the most common keywords but also the most distinct ones by a specific community (even if the number of papers regarding that may be slightly lower). The main goal with this naming strategy was to not ignore smaller or emerging distinct trends that semantically are distinguished within two communities that in general are quite similar. This idea was derived by information extraction TF-IDF that calculates the term frequency of a keyword based on the inverse document frequency of that seme keyword, i.e. it calculates how important a certain keyword is within a document divided by how popular it is in the remaining dataset. By examining the composition and characteristics of these communities, stakeholders can better strategize their R&D investments, foster collaborations between academia and industry, and enhance the overall impact of technological advancements.

The application of network analysis and selection of sets of keywords of common themes within the sets of papers and patents led to the identification of the clusters (joint communities of Patents and Papers) previously described in Table 12.

The research-industry clusters (mixed communities) in Table 11 offer insights into the interconnections between research and patents around central themes. **Higher Pp/Pt ratios indicate larger gaps between research and industry, suggesting that more time may be needed to bring the patented work to market until full implementation.** To further understand each community, a paper and a patent from each community were chosen based on highest semantic similarity to the other papers and patents of the community.

At the core of advancements in the research communities lies the synergy between automation, AI, and sustainable practices. The **Advanced Automation in Intermodal Transport and Cognitive Supply Chains** community emphasizes the integration of advanced automation into intermodal transportation and cognitive supply chains. By incorporating automation technologies, this approach enhances efficiency and optimizes supply chain processes. Automation reduces environmental impact by promoting energy efficiency and minimizing emissions through better resource management and route optimization. For instance, Bartulovic et al. (2023) examine the strategic integration of dry ports into major port operations, highlighting the potential to alleviate congestion and reduce emissions through efficient cargo handling and reduced truck hauls. Additionally, the patent titled *"Operation Method of Relay UE Related to Relay Device"* explores innovative techniques in transportation, focusing on enhancing communication and operational efficiency within transport systems.

Interconnected with this is the **Artificial Intelligence and Automated Systems in Sustainable Logistics** community, which highlights how AI and automation optimize route planning, resource utilization, and operational efficiency. These technologies significantly reduce energy consumption and carbon emissions. Smith et al. (2022) discuss how AI algorithms optimize delivery routes in urban environments, directly contributing to lower fuel consumption and emissions by reducing idle times and unnecessary travel. Complementing this, the patent *"AI-Enhanced Systems for Efficient Warehouse Operations"* presents methods for improving warehouse operations through AI, increasing speed and accuracy, and reducing energy use.

The **Advanced Systems and Resource Allocation in Carbon Emissions Reduction** community focuses on optimizing resource allocation to reduce carbon emissions. Ghanem et al. (2021) explore AI applications in enhancing critical infrastructures' resilience, methodologies adaptable for carbon management. The interconnection with AI communities underscores the role of intelligent systems in emissions reduction strategies. The recurring mention of the patent *"Operation Method of Relay UE Related to Relay Device"* across multiple communities suggests a cross-functional technology that enhances communication efficiency, indirectly aiding in carbon emission reduction.

Similarly, the **CO_2 Reduction and Hydrogen Fuel Cell Innovations in Logistics** community contributes by advocating for hydrogen fuel cells as cleaner alternatives to fossil fuels. Kim and Park (2024) discuss hydrogen fuel cells' potential to lower CO_2 emissions in logistics. The patent *"Advanced Hydrogen Fuel Cell Systems for Sustainable Logistics"* offers technological solutions that enhance eco-efficiency, showing a direct link between innovative energy sources and emissions reduction. This community's work is complemented by the **Energy Efficiency, Real-time Tracking in Supply Chain Management** community, which uses real-time tracking to optimize energy consumption (Anderson & Lee, 2022), highlighting the interconnected nature of energy optimization efforts.

The integration of autonomous vehicles and IoT technologies creates a nexus between several communities. The **Autonomous Electric Vehicles and Smart Charging Infrastructure in Green Logistics** community focuses on deploying autonomous EVs and smart charging infrastructure to reduce greenhouse gas emissions. Chen et al. (2023) emphasizes potential reductions in traffic congestion and emissions through autonomous EVs. The patent *"Smart Charging System for Autonomous Electric Vehicles"* describes an innovative charging system designed to optimize energy consumption of autonomous EVs, ensuring they operate at maximum efficiency with minimal environmental impact.

Complementing this, the **IoT and Autonomous Vehicles in Intelligent Transport Systems** community leverages IoT for real-time monitoring and control. Foster and Nguyen (2023) explore how IoT and autonomous vehicles transform urban transport, reducing congestion and enhancing fuel efficiency. The patent *"Autonomous Vehicle Coordination System for Optimized Traffic Flow"* illustrates how these technologies work together to optimize traffic patterns. These communities collectively demonstrate the symbiotic relationship between vehicle technology advancements and intelligent systems in promoting sustainability.

Supply chain resilience is a theme that connects multiple communities. The **Supply Chain Resilience and Multifactor Support in Mixed Logical Dynamical Systems** community integrates resilience into supply chains using advanced systems. Wang and Chen (2023) show how data-driven models optimize operations and reduce environmental impacts. This is closely related to the **Network Optimization and AI-driven Traffic Management in Logistics** community, which focuses on improving logistics networks through AI and analytics, reducing travel times and emissions (Taylor & Singh, 2023). The patent *"Intelligent Traffic Management System Using Real-Time Data Analysis"* supports this by providing technological solutions for efficient traffic management.

Additionally, the **Resiliency and Redundancy in Carbon Emission Reduction** community ensures that emission reduction systems withstand challenges. Roberts and Lee (2023) implement resilient strategies for continuous emission reduction despite disruptions. The patent *"Redundant Systems for Carbon Emission Control in Transportation"* outlines designs for incorporating redundancy in emission control systems, ensuring consistent environmental performance.

Data management and security are crucial for modern logistics, creating intersections between technology and operational integrity. The **Blockchain and E-commerce Integration in Green Logistics** community enhances transparency and efficiency through blockchain technology. Johnson and Lee (2022) investigate blockchain applications in streamlining supply chain processes while ensuring environmental compliance. The patent *"Integrated Blockchain System for Sustainable E-commerce Operations"* introduces methods to verify sustainable practices throughout the supply chain.

The **Urban Consolidation Centres and Cyber Security in Logistics** community addresses the need for robust cyber security in urban logistics systems. Lee and Thompson (2023) integrate cyber security technologies to protect logistics operations, ensuring operational integrity while reducing congestion and emissions. The emphasis on security in both communities highlights the interconnectedness of data integrity and sustainable logistics operations.

Infrastructure optimization is a key concern for sustainable logistics, bringing together communities focused on transport efficiency. The **Intermodal Transport Economics and European Infrastructure** community works on optimizing intermodal transport systems, enhancing efficiency and sustainability. Schneider and Müller (2023) analyse environmental benefits of enhanced intermodal transport, demonstrating significant reductions in emissions. The patent *"Advanced Routing and Scheduling System for European Intermodal Transport"* supports this by optimizing route planning across different transport modes.

The **Intermodal Transport and Progressive Augmentation in Green Logistics** community integrates advanced technologies in intermodal logistics to improve performance (Martin & Thompson, 2023). The patent *"System for Optimized Intermodal Transport Using Real-Time Data"* illustrates how real-time data enhances intermodal transport networks. These efforts are interconnected with the **Operational Models and Route Sequencing in Intermodal Terminals** community, where Wang and Zhao (2023) implement sophisticated routing algorithms for efficient goods management, showing a holistic approach to infrastructure and operational optimization.

Machine learning applications span several communities, contributing to optimization and sustainability. The **Machine Learning and Dynamic Systems in Regional Transportation** community promotes traffic flow optimization using machine learning. Gupta and Choi (2023) investigate algorithms analysing traffic patterns, reducing emissions. The patent *"Machine Learning-Based System for Dynamic Traffic Control"* demonstrates practical applications of these algorithms.

In renewable energy logistics, the **Machine Learning and Predictive Models in Renewable Energy Logistics** community enhances efficiency by integrating renewable sources (Lee & Patel, 2023). The patent *"Advanced Predictive System for Solar Energy Allocation in Logistics"* outlines systems employing machine learning for efficient energy resource allocation. The overlap between these communities signifies the broad applicability of machine learning in enhancing sustainability across logistics sectors.

Resilience and risk management are essential for sustainable logistics, linking communities focused on robust operational strategies. The **Sustainability and Risk Management in Self-Sovereign Logistics** community enhances autonomy and efficiency while ensuring environmental resilience (Kim & Park, 2023). The patent *"System for Risk Management in Logistics Using Blockchain-Based Self-Sovereign Identity"* employs blockchain technology for enhanced risk management, indicating an intersection between data security and operational resilience.

The **Network Optimization and Critical Infrastructure in Cargo Transport and Recovery** community focuses on enhancing cargo transport networks' resilience and efficiency through infrastructure optimization (Morales & Kim, 2023). The patent *"System for Rapid Recovery in Cargo Transport Using Network Optimization"* provides technological solutions for minimizing disruptions, highlighting the interdependence of network optimization and resilience.

Addressing social aspects in green logistics, the **Fairness and Equity in ITS and Railway Transport** community ensures technologies promote accessibility and equitable resource distribution. Wang and Kumar (2023) discuss integrating equity factors into transportation planning, ensuring advanced technologies benefit all populations. The patent *"Equitable Resource Allocation in Railway Transport Systems"* presents systems prioritizing fairness, linking social responsibility with technological advancement.

Communities with **higher Pp/Pt ratios** in Table 12 such as in **Intermodal Transport and Progressive Augmentation in Green Logistics** (with a ratio Pp/Pt equal to 15.077) and **Quantitative Methods and Strategic Freight Transport Models** (Pp/Pt equal to 5.909) indicate a **strong academic focus**. These are research-heavy fields where theoretical advancements or new methodologies are being explored more intensively in academia rather than being immediately translated into industrial applications. This could signal future areas of innovation, where research is preparing the groundwork for potential applications, particularly in logistics and green transport. On the other hand, communities with low Pp/Pt ratios such as **Traffic Patterns, Beam Failure Recovery**, **and Highway Systems** (Pp/Pt equal to 0.172) and **CO_2 Reduction and Hydrogen Fuel Cell Innovations in Logistics** (Pp/pt equal to 0.25) reflect a **more industry-focused community**, with a **heavier emphasis on patents**, showing that the knowledge generated is being quickly applied in real-world systems and technologies. For example, the low ratio in Traffic Patterns and Beam Failure Recovery suggests active industrial engagement, likely tied to modern wireless and telecommunications needs for logistics optimization and highway infrastructure.

Further analysis was developed to understand the dynamics of the communities over time. Figure 37 shows how the total number of papers published by each community evolves over time. Some key takeaways include the continued dominance of Intermodal Transport and Green Logistics, with growing interest in AI, automation, and sustainable technologies. The diversification within these communities, shown by the spread of smaller communities starting to contribute, reflects how interdisciplinary fields are influencing logistics and transport research.

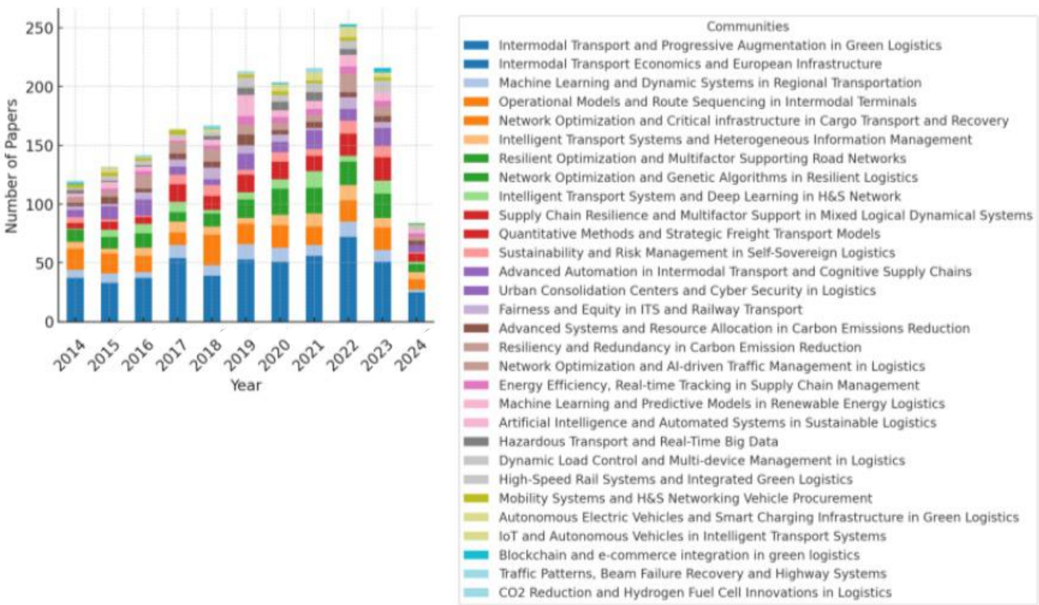


Figure 37: Community Growth over time by Community (Sorted)

Figure 37 shows how closely related topics within each research community have been across different years. A declining trend in similarity suggests an increased diversification within communities, meaning more interdisciplinary or broader research areas are being pursued. This could imply that fields like green logistics and supply chain resilience are becoming more open to integrating new technologies, such as AI or IoT.

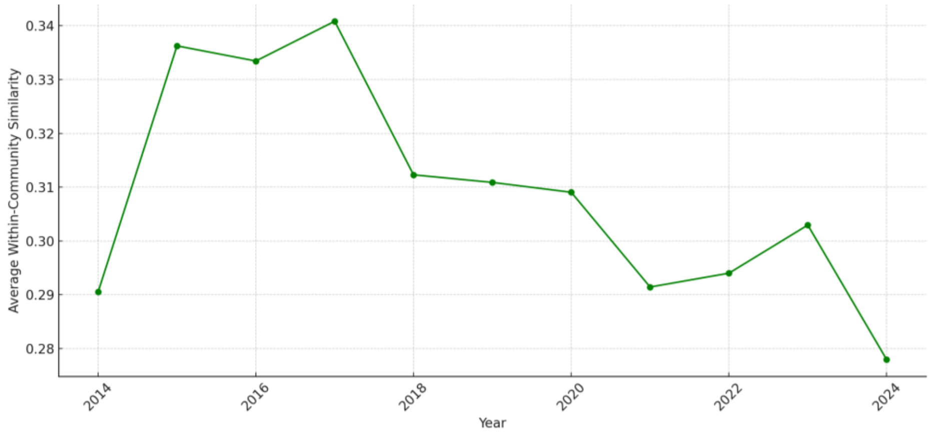


Figure 38: Average Within Community Similarity over time

3.4.11 Implications and Relationships between Communities

The interconnections between these communities highlight a multidisciplinary approach to green logistics (See Figure 37). The integration of AI and machine learning across various communities underscores the importance of intelligent systems in optimizing logistics operations and reducing environmental impacts. For instance, the **Advanced Automation in Intermodal Transport** and **Artificial Intelligence and Automated Systems in Sustainable Logistics** communities share a goal of efficiency and sustainability through technology.

The focus on data management and security in the **Blockchain and E-commerce Integration** and **Urban Consolidation Centres and Cyber Security** communities reflects the need for secure, transparent operations in an increasingly digitalized environment. These communities demonstrate how technological advancements must be paired with robust security measures to ensure sustainable progress.

Moreover, the emphasis on resilience in communities like **Supply Chain Resilience** and **Resiliency and Redundancy in Carbon Emission Reduction** shows the importance of robust systems capable of maintaining sustainability goals despite disruptions. This highlights a shared understanding that sustainability is not just about efficiency but also about adaptability and continuity.

The overlapping interests in infrastructure optimization among communities focusing on intermodal transport and high-speed rail systems indicate a collaborative effort to improve transportation efficiency on multiple fronts. These relationships suggest that advancements in green logistics are not isolated efforts but part of an integrated framework where innovations in one area support and enhance developments in others.

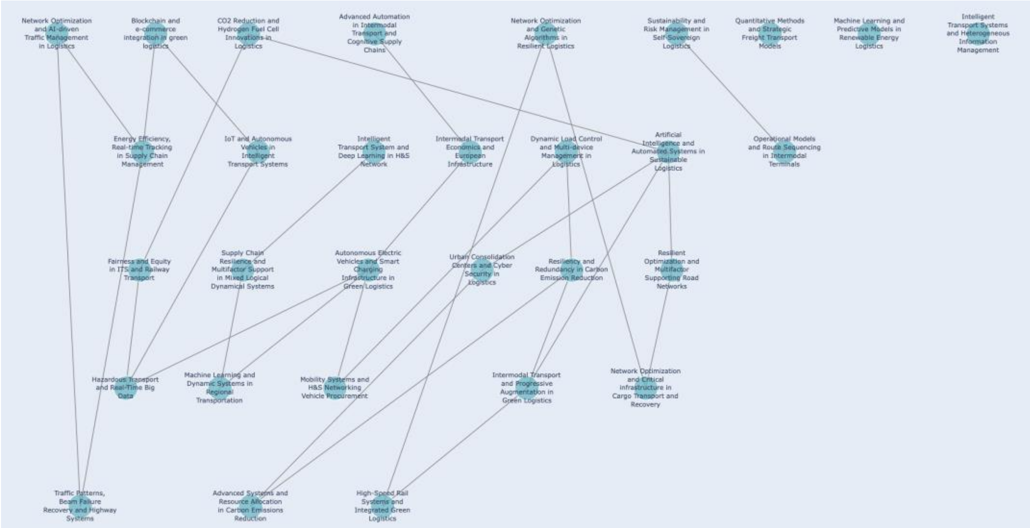


Figure 17: Average Similarity between communities

3.5 Industry-research mega trends in intelligent logistics and transportation

The logistics and transportation sectors are undergoing transformative changes driven by emergent technologies and enhanced methodologies targeting operational efficacy, promote environmental sustainability, and tackle diverse social issues.

As shown in the analysis in the previous sections, a relevant area of development characterized by a significant number of papers and patents and a relatively low level of industry development, as indicated by the high paper-to-patent ratio, is the domain of "Intermodal Transport and Progressive Augmentation in Green Logistics". This field effectively integrates sustainable methodologies aimed at minimizing carbon emissions. It showcases extensive academic contributions such as those from Szaruga et al. (2023), who explore the convergence of energy intensity in rail transport exports within EU countries, demonstrating a significant rate of spatial convergence in energy intensity reductions. Furthermore, Aditjandra (2018) analyse the evolution of Europe's freight transport policy, highlighting shifts towards "smart," "green," and "integrated" themes aimed at decarbonizing road haulage. The sector also capitalizes on advancements in electric vehicles, emphasized by Islam et al. (2016), who discuss strategies for increasing rail's market share to achieve modal shift targets set by the EU. Additionally, the field benefits from AI-driven route optimization innovations, with Oudani (2021) developing a simulated annealing algorithm for optimizing intermodal transportation on incomplete networks. Moreover, Tang et al. (2021) studied multi-disruption resilience assessments of rail transit systems, optimizing commuter flows to enhance system resilience against multiple disruptions. Collectively, the scholarly works underscore a **shift towards environmentally sustainable logistics operations facilitated by strategic application of AI and advances in electric vehicle technologies**.

The literature highlights an emerging role of renewable energy and progressive augmentation algorithms establishing robust, efficient logistics networks (Wang et al., 2016). **Progressive Augmentation** refers to an optimization algorithm used to solve complex mathematical models, particularly in logistics, transportation, and other network-based systems. The algorithm starts with a simplified version of a large optimization problem, solving it iteratively by adding more variables and constraints over time. In each iteration, the model is "augmented" with additional elements, progressing toward an optimal solution (Wang et al., 2016). These innovations converge to a paradigm shift towards environmentally sustainable logistics operations, significantly curtailing carbon footprints through the strategic application of AI and electric vehicle technologies.

Considering the cluster “Blockchain and E-commerce Integration in Green Logistics” (see Table 12), blockchain technology is instrumental in validating sustainable practices across supply chains, ensuring transparency and accountability in sourcing and distribution. The implementation of smart contracts and IoT enhances data acquisition and real-time traffic management, fostering a green logistics framework (Lahkani et al, 2020; Khan et al, 2021; Zarrin et al., 2021; Costa, 2023). This integration heralds a new era of logistics models that are both sustainable and efficient, exemplifying the **synergistic relationship between blockchain technology and environmental sustainability.**

The cluster “CO_2 Reduction and Hydrogen Fuel Cell Innovations in Logistics” spotlight the deployment of electric heavy-duty trucks and hydrogen fuel cells, particularly within intermodal terminals. This community focus is on reducing CO2 emissions through the adoption of clean energy vehicles and sophisticated waste management systems. Research papers (Sadeghi, 2019; Ghisolfi et al., 2022) and patents (LLC, 2014; Camacho, 2022; Patel et al., 2022) highlight innovations in wireless communication systems and disruption management, further reinforcing sustainable logistics practices. The confluence of theoretical research and practical application in this field showcases **the transformative potential of hydrogen fuel cells and advanced waste management in mitigating logistics-related carbon emissions**.

Communities focused on “Intelligent Transport Systems (ITS) and Deep Learning in H&S Networks”, and “Fairness and Equity in ITS and Railway Transport”, are addressing social issues in transportation. The former advances connectivity and system performance in urban transport networks, enhancing accessibility and inclusivity (Yadav et al., 2018; Johnson and Wang, 2019; Shee et al., 2021; Garg and Kaur, 2023). The Intelligent Transportation using Deep Learning (ITDL) system by Yadav et al (2018) leverages deep learning methods to ensure equitable logistics practices, while other patents emphasize fairness in wireless communication systems to guarantee fair service delivery and improved accessibility (Huang et al, 2006; Mulley et al., 2017; Guevara, 2020; R.Inc., 2022; Whitmore et al., 2022). These **initiatives highlight the increasing importance of social equity in technological advancements, ensuring a fair distribution of costs and benefits across society/stakeholders**.

Operational efficiency is challenged in the cluster “Mobility Systems and H&S Networks in Vehicle Procurement”, that focus on cutting-edge technologies and strategic frameworks to enhance service flexibility and efficiency. Particularly we find Cella et al., (2024) that was filled both at US and World level (WO) regarding advanced value chain network (VCN) that integrates **AI-based learning models and IoT for intelligent procurement**. The system optimizes procurement processes through automated data collection, analysis, and decision-making algorithms. It is specifically designed to improve efficiency in vehicle procurement by using AI to forecast demand and optimize supply chain operations. “Network Optimization and AI-driven Traffic Management in Logistics” emphasize the use of IoT for logistics optimization, fostering highly connected, real-time data-driven systems that improve operational efficiency and reduce costs (Paiva et al.,2021; Xu and Chpara, 2023; Shi et al.,2024). This fusion of IoT and AI highlights the profound **impact of real-time data analytics on logistics efficiency**.

The spatio-temporal analysis of patents and scholarly publications conducted in the previous sections reveals a dual focus on efficiency and sustainability. The temporal distribution of intellectual property and research articles in communities such as “CO_2 Reduction and Hydrogen Fuel Cell Innovations in Logistics” and “Mobility Systems and H&S Networks in Vehicle Procurement” highlights the **progressive integration of advanced technologies to decarbonise transport and supply chains centred in electric vehicles and AI in recent years.** This reflects somehow a global commitment trend across regions including Europe, Asia, and North America (Karaman et al, 2020; Chung, 2021; Yang and Zhang, 2022). The patterns found in the analysis of research-industry clusters demonstrate a burgeoning international effort towards environmental stewardship and technological innovation.

Emerging technologies for intermodal logistics optimization encompass IoT for smart tracking, AI and machine learning for decision support, blockchain and smart contracts for enhanced security and transparency, and autonomous vehicles for efficient cargo handling. “Intermodal Transport and Progressive Augmentation in Green Logistics” highlight the growing corpus of research in the field. “Network Optimization and Genetic Algorithms in Resilient Logistics” explore cost-effective strategies for intermodal freight transport, emphasizing economic and algorithmic optimization of logistics performance. “Quantitative Methods and Strategic Freight Transport Models” focus on optimizing the transportation of agricultural products using geographic information systems (GIS) and location-based technologies to enhance logistical precision and efficiency (Kubáč, 2016; Oliveira and Silva, 2019; Woschank et al., 2020; Xu et al., 2021). These technologies not only enhance logistical efficiency but also contribute to reductions in GHG emissions, underscoring the central role of innovation in achieving sustainability goals.

4 Analysis of companies' practices

This section provides an in-depth analysis of the innovative companies' practices with worldwide logistics businesses in the field of logistics and transportation through the implementation of semi-structured interviews. A sample of companies were selected in close articulation with the ADMIRAL Collaborative Stakeholder Forum (task 2.1) and the ADMIRAL Pilots. Additionally, the corporate sustainability reports of the companies are considered in the analysis.

The analysis in this chapter will contribute to assess how intelligent technologies will impact sustainability performance in each Pilot context, providing insights into transport and logistics decisions until 2030 and beyond, focusing on stated choices to move towards multimodal/intermodal operations and greener supply chains until 2030 or beyond.

4.1 Semi-structured survey model

Semi-structured interviews are a qualitative research method that allow the interviewer to explore a topic in depth with each interviewee/company. It follows a flexible and adaptable guide, while the set of questions accounts for the characteristics of the company business and listening/conversation flow.

The first survey model developed was tested in a former interview conducted in 14th June 2024 to a Finnish company - METSÄ Group, following a contact promoted by the Pilot leader STEVECO. The model was afterwards optimized to enable an interview time of around 60 minutes.

The survey model adopted is presented in Table 13, considering the scope of the analysis, goals and main dimensions for the analysis directly related with the research questions. The issues were investigated at present (current practice of companies) and gathered their intentions for future practice following each company business strategy.

Table 13: The Semi-structured survey model structure

<table>
<tr><th colspan="4">Scope of the analysis:
Sustainability Performance of Operations (SPO)</th></tr>
<tr><td colspan="4">Specific goal:
To identify, analyse and assess innovative solutions to improve the sustainability performance of the company operations</td></tr>
<tr><td colspan="4">Main dimensions for the analysis now and in the future</td></tr>
<tr><td>Technologies</td><td>Sustainability and Resilience criteria</td><td>Use of intelligent systems</td><td>Governance practices</td></tr>
<tr><td>To identify how companies are dealing with:
• Technologies to address sustainability and efficiency in supply chains
• Identified technologies to address energy</td><td>• To identify how the requirements for resilience and sustainability are considered in the company current operations
• To identify the weight that each company</td><td>To identify how intelligent systems are being used/planned to:
• Integrate all logistic stakeholders (producers, suppliers,</td><td>To identify actual governance practices
To identify how and which types of governance practices:</td></tr>
</table>

efficiency and reduction of CO_2 emissions • Adapting systems to the digital economy • Adapting systems to automation • New services (IoT, autonomous delivery, robotics, circular supply chains, etc.	gives to the resilience and sustainability in their operations • To identify the perceived influence that the consideration of the requirements of resilience and sustainability have for the future operations of the company	shipowners, transport operators, support services, etc.) • Integrate sustainability performance indicators (SPIs)	• Connect all suppliers and service providers • Consider codes of conduct and corporate sustainability reports to meet sustainability targets • Consider circular supply chains in their business strategy

The set of questions and main topics for the analysis are described in Table 14.

Table 14: Questions and topics for the analysis

Sustainability in Logistics Operations and Governance practice	Companies' technologies & sustainability performance of operations, including resilience and intermodal transport	Impacts on sustainability performance of Intelligent solutions/technologies and new services
Current State • Introduce yourself and your role in the company? • Considering your company's operations now, please tell us the three expressions/words that come first to mind when you think of sustainability? • Does your company publish annual sustainability reports? • Is your company implementing supply chains? If so, could you describe how? • How do you rate your current logistics operations in a scale of 0 (very poor) to 10 (excellent) in terms of: Energy efficiency, Sustainability, Reduction of CO_2 emissions along supply chains, Social Responsibility, Ethics and transparency, Intermodality? **Future** • Thinking about your company's operations in the future, please tell us the three expressions	**Current State** • What technologies or systems are currently in place to manage your company's operations? • How do you rate your current logistics operations in a scale of 0 (very poor) to 10 (excellent) in terms of: Sustainability: Intermodality? • What measures/actions did your company implemented to improve energy efficiency, the resilience and sustainability performance of its logistics operations? **Future** • What are the main efficiency criteria and respective targets that you have set (or plan to achieve) by 2030? • What measures/actions did your company plans to	**Current state** • Does your company's logistics operations are supported by intelligent solutions? • What type of intelligent solutions are currently being used in your company? (e.g., IoT, autonomous delivery, robotics, collaborative platform). • How have these solutions impacted your operations so far in terms of sustainability performance? **Future** • Does your company plan any change in the technologies or systems until 2030? • Is your company exploring (or plans to explore) the development of new services in response to

that come to your mind when you think of sustainability • Do you foresee any challenges in implementing the European Corporate Sustainability Reporting Directive that entered in force in January 2023? • What challenges do you foresee, particularly regarding scope 3 emissions? • Which are the three main barriers that you consider that will hinder the implementation of the ECSR Directive? • Do you have any suggestions on how to overcome the stated barriers?	implement to improve energy efficiency, the resilience and sustainability performance of its logistics operations? • As part of the green and digital transition in logistics, how does your company consider or plans to consider intermodal transport until 2030?	technological advancements? If so, could you provide some examples? • How do you see those mentioned new services impacting your company's sustainability performance? • Does your company plan to implement any technological measure to reduce carbon emissions and/or improve energy efficiency? (Yes or No) * If the answer is Yes: Which measures? For each measure given as answer, for example: How is your company planning to adapt its operating systems for digitization? How is your company planning to adapt its operating systems for automation (…) * If the answer is No: Would you mind to state the main reasons? • How is your company considering (or planning to consider) intelligent solutions to improve the sustainability performance of logistics operations?

4.2 Sample target for in-depth analysis

The sample selection target of interviewees/companies aimed to cover two (minimum) key companies considered of relevance in logistics operations in each Pilot country. As already mentioned, **the analysis aims to contribute to assess how intelligent technologies are being used (or planned to be used) along with other requirements, and how these will impact in each Pilot context**. This will provide insights into transport and logistics decisions until 2030 and beyond, based on the stated intentions of companies to move towards sustainable supply chains, including the enhancement of intermodal operations in the applicable cases.

Table 15 describes the sample of the interviewed companies in each country, their activity scope and market size geography, interviewees position and the date of the Teams interview. In one case, the name of the company is kept as confidential due to their request and, hence, only the country is mentioned. The interviews are organized by date (day/month of 2024) in ascending order. However, answers in the subsequent tables are kept as random to enable confidentiality.

Table 15: Sample of interviewed companies and respondent roles

Interview Reference (Country code)	Company name	Activity scope of the company & market	Interviewee position	Teams interview Date (start time)
I-1 (FI)	METSÄ Group	Industry group (forest related products), including wood trade and forest services; represents 1/3 of forest owners; market at the global scale.	Head of Sustainability	14.06.2024 (10: 00 CET)
I-2 (LT)	Lietuvos Paštas AB	Postal services; 9 logistic centres at the national level	Strategic Coordinator and Data Analytics Group Manager	17.07.2024 (11:00 CET)
I-3 (PT)	RANGEL Logistics Solutions	Logistics operator offering global/World solutions, present in 3 Continents	IT and Sustainability Directors	18.07.2024 (12:00 CET)
I-4 (LT)	GIRTEKA EUROPA West	Logistics operators in EU, International transportation, with temperature-controlled goods, own fleet (EU market and Norway)	Head of Sustainability	23.07.204 (14:30 CET)
I-5 (PT) (ES)	Repsol Polímeros	Chemical company manufacturer /energy provider; it operates the Sines industrial complex and exports products via rail, road and sea; EU market, inc. Portugal and Spain	Business Manager	30.07.2024 (10:30 CET)
I-6 (PT) (ES)	MEDWAY – Transportes e Logística	Leading Railways/Intermodal transport and Logistics Operator in Portugal and Spain	Business Manager	3.09.2024 (17h30 CET)
I-7 (PT) (ES)	LOGIFRIO	Leading operator in controlled temperature logistics services in Portugal and Spain; member of the European Food Network	CEO & President of the Portuguese Association of Logistics	28.08.2024 (10h30 CET)

I-9 (SI) (HR)	POSTA SLOVENIJE DOO	Universal postal services ensured by the state, and other market services/biggest logistics provider in Slovenia	Pilot Leader & Sustainability manager	16.09.2024 (12:00 CET)
I-9 (SI) (HR)	Slovenian Railways	National rail transport operator	Director	17.09.2024 (10:00 CET)
I-10 (FI)	Finnish manufacturer with a global market*	Global manufacturer product leader; present in more than 50 countries, and with suppliers/distribution in more than 100 countries	Global category manager, air &sea Logistics procurement	18.09.2024 (14:00 CET)

(*) This company asked to be kept anonymous.

The set of companies described in Table 15 were selected due to its global market geography or extensive market size covering more than one country, which may be useful to leverage the positive impacts of the Teams interaction on sustainability and innovation beyond the pilots.

4.3 Engaging companies and conduction of the semi-structured interviews

The ADMIRAL Pilot leaders (APS, TIA, PS, STEVECO) and supporting partners (Marlo, NORM, UL, UPM, VTT) made initial phone contacts with the selected companies to engage them in the proposed works. After their cooperation was confirmed, LNEC sent formal e-mails to each company contact for arranging a suitable day/time for the Teams meeting. Each interview took place at the preferred day/time of the interviewee/company. The ten semi-structured interviews were conducted by LNEC through Teams and each had an average duration of 1 hour. However, it shall be noted that time was kept flexible to make sure that the interviewee has a free-flow conversation.

At the beginning of each interview (Figure 39), the consent of the company/interviewee was asked to record and/or take notes of the interview. Only one interviewee requested the anonymous state of the company due to its market size and competitors. All companies agreed that notes could be taken.

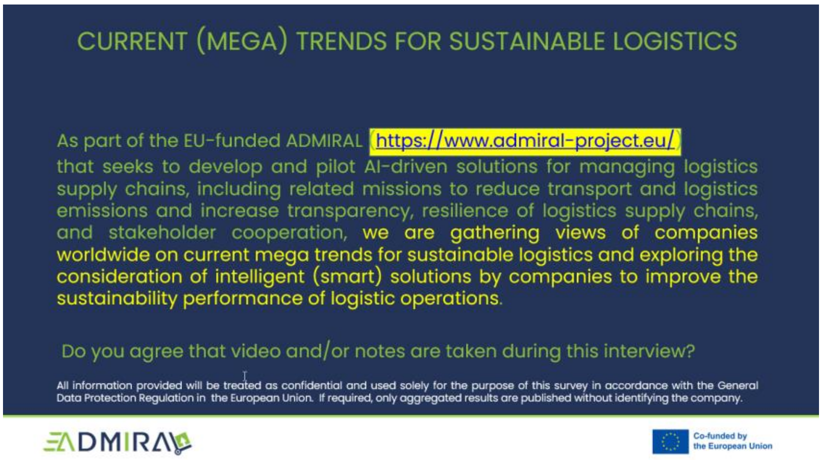


Figure 39: Presentation of the semi-structured survey model (screen 1)

4.4 Analysis of results

The data gathered through the Teams interviews was organized into themes and contents were grouped and interpreted based on specific quotes, common patterns and distinct features, accounting for the sample features in terms of markets geography, main activity area and role/expertise of the respondent in the company. The results are presented in this chapter as aggregated due to the agreement made with the interviewees/companies.

After the presentation of the company and of the interview role, she/he was asked to consider the company's operations now, and in the future, and to state the first three expressions/words that came first to her/his mind when thinking about sustainability. The sequence of questions are based on the method of free association of expressions and words, where the interviewee is asked to refer the three terms in response to a stimulus that his presented, in this case – the sustainability of logistics operations at present and, also, in the future (Figure 40).

Figure 40: Sustainability of company operations now (left) and in the future (right) questions

The expressions/words related to sustainability in the context of the logistic operations of the company at present are summarized in Table 16. Each line corresponds to the answers given by one interviewee/company.

Table 16: Sustainability expressions in the context of the company operations at present

Interviewee/ company*	Expression/word 1	Expression/word 2	Expression/word 3
	Area for improvement	Efficiency /operational efficiency	Energy efficiency
	Future	Commitment	Complexity
	Reduction of CO_2 emissions	Future	e-mobility /electric vehicles
	Intermodal transport	Alternative fuels	e-mobility
	Environmental sustainability/shift to zero carbon emissions	Safety of operations	Food safety / FSSC 22000 certification
	Opportunity (to establish a business difference)	Structuring / Organizing and prioritizing sustainability actions	Sharing / Sharing with companies and customers covering the whole value chain
	Decarbonisation	CO_2 emissions	Railways
	Fleet electrification	Clear goals	Data

	Environment	Digitalisation	Green transition
	CO_2 emissions	Fair transport (equity)	-

(*) Answers are treated as aggregated and are not individually specific.

The expressions/words related to sustainability in the context of the logistic operations of the company in the future (2030 and beyond) are summarized in Table 17. Each line corresponds to the answers given by each interviewee/company.

Table 17: Sustainability expressions in the context of the company operations in the future

Interviewee/ company*	Expression/word 1	Expression/word 2	Expression/word 3
	Operational efficiency	Automation	Integration / (adaptative management of processes)
	Decarbonization	Mobility and Net Zero	Sustainability reporting
	Disruptive attitudes	-	-
	Scalability to implement main transport solutions	Accurate data /Clear reporting systems	Data analytics – sustainability driven purchasing
	Efficiency/Logistics integration	Environmental sustainability	Modal transfer/shifting to more sustainable transport options
	Carbon neutrality	Collaboration	Energy transition
	Integrated logistics	Integrated solutions	-
	Intelligence of data in processes	Electrification	Data transparency
	Environment/National transport policy to shift from road to rail	Digitalization	Increase rail modal share
	CO2 emissions	Network optimization	Smart transport

(*) Answers are treated as aggregated and are not individually specific.

The analysis of the data gather (Table 16 and Table 17) considers Abric (1987) that states the "central nucleus" of the social representations as the one that represents most of the stated contents , whereas expressions or words more distant from this "central nucleus" are considered as peripheric, though with content relevance. In this research, the following criteria was considered:

1) Central nuclei: the anchor of social representations of the sustainability of logistics operations are represented by the contents (expressions/words) that were stated by more than 50% of the interviewees/companies.
2) Peripheric contents – the contents (expressions/words) that were stated by at least 20% and less that 50% of the interviewees/companies.
3) Residual contents – the content (expressions/words) that were stated by less than 20% of the interviewees/companies.

Table 18 shows the analysis of expressions linked to the sustainability of logistics operations at present. It shall be note that several stated expressions belong to the same thematic categoric.

Table 18: Analysis of sustainability expressions in the context of the company operations: present versus future

Sustainability of logistic operations – at present		
Core expressions	Peripheral expressions	Residual expressions
Decarbonisation & Alternative mode/energy	Future Efficiency Digitalization	Clear goals Commitment Complexity Fair transport (equity) Structuring / Organizing and prioritizing sustainability actions
Sustainability of logistic operations – in the future		
Core expressions	Peripheral expressions	Residual expressions
Decarbonisation & Alternative mode/energy	Optimization/Integrated solutions Efficiency Data /Digitalization	Automation Disruptive attitude Operational efficiency

Table 18 shows that companies consider sustainability of logistic supply chains both in the present and in the future with a focus on decarbonisation and using alternative/mode energy (core expression category that aggregates all the mentioned technologies). The analysis seems to reveal that social and governance related quotes such as "fair transport" and "organizing and prioritizing sustainability actions" are still residual.

Regarding the questions on what technologies are currently in place to manage the company's operations, the following were mentioned: Transport Management Systems (TMS), Warehouse Management System (WMS), automation (parcel lockers), digital automatic coupling, electronic ticketing, traffic management system, Power BI, IoT to control temperatures, GPS tracking of vehicles, electrification technology in reefer truck cargo to replace diesel, electric vehicles, optimization tools.

In question 2.4 the interviewee/company was asked to rate their logistics operations in the company at present considering overall sustainability performance and other sub-indicators, using a scale of 0 (very poor) to 10 (excellent). Table 19 presents the scores given by the interviewees. One of the interviewees/companies did not state scores but mentioned sustainability and ESG reporting as advanced. The company's sustainability reports and code of conducts have been considered in the analysis.

Table 19: Scores for the logistics operations considering overall sustainability performance at present (scale: 0 to 10)

Energy efficiency	Sustainability	Reduction of CO_2 emissions along the supply chains	Social responsibility	Ethics and transparency	Intermodal transport
n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
6	5	5	9	10	n.a.
8	6	8	7	10	9 or 10
8	7	7	7	7	7
5	8	5	8	9	4
8	7	6	9	9	6
8 or 9	8	7 or 8	10	10	9
8	6	6	8	8	6 or 7
5	5	4	8	9	3
8	5	3	8	8	6

n.s.: no score was given; n.a.: not applicable to the company business.

Considering the scores given by the interviewees/companies, shown in Table 19, the reduction of CO_2 emissions along the supply chains is the item with lower scores in relative terms, followed by the intermodal transport and the overall sustainability performance indicator. Overall, **companies mentioned that collaboration with other companies (e.g., subcontractors) is needed to address the reduction of CO_2 emissions along the supply chains**, hence this depends on the various parties involved and "*it's not entirely in the hands of the company*". The "ethics and transparency" was highly rated by most companies, mainly due to the **existence of code of conducts and complaints channel**. The scores given to social responsibility performance are relatively high, but there are two companies that were distinguished in this category, in one of the these the results from surveys show that employees consider themselves happy to work in the company. Nevertheless, some interviewees recognised that there exists room to improve to achieve the highest score. Scores with some strategic bias may have been given for marketing purposes.

Figure 41 introduces the interviewee/company questions related to logistics operations, future plans and new services, aiming to understand the extent efficiency, resilience and sustainability performance are considered (or planned to be considered).

Figure 41: Logistic operations, future plans and new services

Table 20 presents a synthesis of key data gathered for questions 3.3 and 3.4 (Figure 41).

Table 20: Efficiency, resilience and sustainability in logistics operations

Efficiency focus		Targets		Measures		
Energy	Other	Qualitative	Quantitative	Efficiency	Resilience	Sustainability
yes*	yes -Reduce resources (water) - Reduce waste delivered - Zero accidents at work	yes	yes All ESG have metrics and targets	yes	yes **Regenerative forestry creates business resilience to impacts related to legislation, the markets and climate change.** Mixed forests increase forest biodiversity and **forest resilience against storm** and insect damage, for example. The company offers forest owners a forest regeneration service, in which both spruce and pine are planted on the same site.	yes
no	yes Operational (maximize capacity use)	yes	yes -Reduced CO_2 emissions,% in 2023 (change compared to 2020)	yes -Last-mile delivery parcel lockers network - 9 logistics centres -Vehicle use optimization by route	no	Network of 430 parcel lockers implemented in the country/ enabling to reduce CO_2 emissions reductions from less km driven by road vehicles (last-mile) -124 old cars were replaced with 84 new cars, where of 2 are electric
no	Zero waste	yes (CO_2 emissions)	no	no	no	Plan for the sustainable certification of buildings and platforms
yes	Reduction of CO_2 emissions	yes	yes -20% reduction of carbon footprint in 5 years	yes -HVO 100 dedicated fleet -Renewable energy	No	-Double materiality assessment report -Intermodal transport -e-mobility
yes	-	yes	yes	Solar energy and wind	no	- Net Zero Plan - Electrification

yes	Optimization of operations	yes	no	-Technology replacement and retrofitting of warehouses and equipment -Photovoltaic panels installed - Energy monitoring system	no	yes - Four pillars: People, Planet, Product, and Process - Lean and Green Program -Mental health program for the employees - Alternative fuels (HBO) - Plug-in electric technology - 3 electric vehicles purchased
yes	-	yes (CO_2 emissions)	no	yes - Shift cargo from road trucks to rail	yes -shift of road trucks moving dangerous goods to rail	yes -Operation Clean Sweep - Certificate of sustainable transport customers**
yes	Operational (processes optimization)	yes	yes -Zero CO_2 emissions by 2050	yes - Reduce fuel consumption of transport by 12% relative to 2018 -Reduce overall energy consumption per building surface area by 6.4% relative to 2018	no***	yes -Increase the proportion of electric vehicles to 45%, until 2030
yes	yes operational (capacity, speed, timetable integration with other modes, etc.)	yes	no	yes -Increase rail modal cargo share for cargo/build 2nd railway track at the Port of Koper and also passengers - New/renovate rail	no	yes -Digital automatic coupling (DAC) Electrification

				infrastructures and fleet wagons - Railway interoperability		
yes	operational	yes	yes -Reduction of CO_2 emissions (scope 3) by 40% until 2030 (2018 as base) -Reduction of the company own emissions (scope 1 and 2) by 50%) until 2030	yes -renewable energy use at facilities - Select fuel-efficient vehicles - Use of more eco-efficient transportation equipment - Driving performance and route optimization	yes -Plan to work on climate resilience of the logistics network and solution design	yes -Carbon neutral manufacturin g units**** -fleet of lower emission vehicles - Waterway and railway transportatio n prioritized over air freight

(*) Fossil free energy accounts for 91% of total energy consumption. The company uses the energy efficiency index, base year 2018 and has quantitative targets set until 2030. Energy efficiency work is managed by an energy efficiency coordinator, supported by the ISO 50001-compliant energy management system. (**) In 2022 it was avoided 102194 tons of CO_{2e} that were transported by rail instead of road (the effort of 38 clients of the company were awarded with the certificate for sustainable transport). (***) Dealing with resilience in under the responsibility of the subcontracted parties of the company. (****) The sustainability report sent by the company refers that it was the first in the industry to achieve carbon neutral manufacturing units globally.

Table 20 above shows that progress is required by most companies to tackle issues on the resilience of supply chains, as this represents at present a residual dimension. Most companies implemented energy efficient measures and are concerned to improve operational efficiency or its optimization. Regarding sustainability and efficiency targets to achieve by 2030, progress needs to be done to their quantification and assessment.

Figure 42 shows the interviewee/company questions related to the green and digital transition and intermodal transport in the logistics operations of the company, aiming to understand how companies are planning to adapt foreseen technologies into their businesses.

Figure 42: Logistic operations, future plans and new services – green transition and intermodal transport.

Table 21 presents a synthesis of key data gathered from questions 3.5 to 3.7.1 (Figure 42), with quotes confirmed in the company's sustainability reports.

Table 21:Plans on Intermodal transport, adapting to technologies and new services

Intermodal transport		Plans to explore any change in technologies or systems	Development of new services in response to technology advances	New Services Expected Impact on sustainability performance
Yes	no			
yes*	-	yes - High levels of automation, best available technology and economies of scale - Abandon fossil-based fuels by 2030	yes -R&D to exploit new applications for wood fibre and by-products from production (demonstration) - Test new technologies/digital solutions - Carbon capture	High or very high
-	no -Business is centred on using road transport	yes -AI solutions (to be identified)**	yes -New services based on the network of parcel lockers	High
-	no	yes -Robotic Process Automation	n.s.	n.s.
-	no	yes -Implement 2 external platforms, one to calculate CO_2 emissions based on GLEC and another for external certification	yes -New solutions based on data -Solutions for lower fuel consumption	Very high
-	no	yes	no	Don't know

		-Digital tools, e.g. to optimize information flows -Automated Guided Vehicles (AGVs) for moving cargo		
yes	-	yes -Transportation Management System, to manage fleet operation - Alternative energy fuels such as HBO, to replace diesel	- Use AI tools for customization of services	Moderate / High in the supply chain
yes	-	no***	-app for new services	Moderate
yes (Main Business Group)	-	yes -Digitalization of processes and data	yes -Offer Zero emission delivery services - Optimization of processes	Very high
yes	-	yes - Digital automatic coupling - ETCS level 2 rail track	yes -Participation in R&I actions -Electronic timetable/train scheduling	n.s.
yes (EU-Asia)	-	yes -"Ongoing big IT project"	yes -Smart tracking of containers - Global events/incidents platform	Low to moderate

n.s.: not directly stated by the interviewee/company. **(*)** Collaboration was the keyword stated by the interviewee, and the focus is rail – maritime/inland waterways. **(**)** The interviewee referred that there exists plans to adapt not only to the new technology, but also to be able to connect with different clients, different partners, and different countries' requirements; AI to provide services and run business as efficiently as possible. **(***)** The interviewee mentioned that the company implemented the SAP system for supply chain management (SCM). The aim of the system is vast, including the management of the maintenance activity, monitoring the real performance of the rolling stock in commercial service and also establishing contacts with customers, remotely, maximizing the efficiency of service and the reliability of the transacted data.

Table 21 shows that most companies are adapting/planning to adapt their systems to a wide range of emerging technologies. The focus is around digital and AI-based tools, automation/robotic process automation/automated guided vehicles, and also on alternative fuels to replace diesel. Intermodal transport is considered at the strategic business level, in cases of companies that move cargo or ship products across regions and continents.

Figure 43 shows questions addressing intelligent logistic solutions and its foreseen impact by companies.

Figure 43: Intelligent Logistic operations and impact in the company

Table 22 presents a synthesis of key data gathered from interviewees/companies for the set of questions in Figure 43, and information from their sustainability reports.

Table 22: Impact on sustainability performance of intelligent logistics solutions

Does your company's logistics operations are supported by intelligent solutions? No	 Yes	Intelligent Solutions	Impact of intelligent solutions on sustainability performance
-	Yes	-Application that uses **AI and satellite data** to help identify insect damage in owner-members' forests -**Industrial symbioses** and **clean process technologies***	High to Very High
-	Yes	-**Digitalization, process automation and robotization**, e.g. automation of the processing of export consignments - Explore AI solutions (in the near future)**	n.s.
No	-	-	-
-	Yes	"This is confidential information". "All our solutions based on data" (quotes from the interviewee)	Very high
-	Yes	Systems, applications and products in data processing; Deal CMR solution for customer management; and	Very high

		ongoing ElioT initiative in Spain***	
-	Yes	Real-time fleet management; IoT for controlling temperatures and synchronization, including in warehouses	High to Very high
-	Yes	At present, use of the analytical tool Power BI for data-driven decisions across the various markets (PT, Spain, France…); Single Logistic Window Investment in smart wagons is planned for future	n.s.
No	-	-	-
No	-	-	-
-	Yes	Marketing intelligence platforms for benchmarking; TMS is in place; automatic monitoring shipment system.	Low to Moderate

n.s.: not stated or known. (*) Described in the Sustainability Report sent by the Interviewee/company. (**) The company is open to develop AI solutions in the future, e.g. to improve the label quality certification system. (***) ElioT aims at enhancing operational efficiency and sustainability using advanced technologies like IoT, AI and big data.

Overall, Table 22 shows that the perceived impact on sustainability performance is high. Existing AI based tools in the market seem to be actionable in several companies, which seems to indicate the increasing role of prescriptive decision-making. Table 22 shows that 3 (30% or 3 out of 10) companies do not use any intelligent solution for their operations at present. In this case a set of follow-up questions were posed to these interviewees/companies as shown in Figure 44 and Figure 45.

Table 23 summarizes the answers obtained. It is interesting to note that the three companies have distinct market sizes: global, national, and cross-border involving two EU Member States.

Figure 44: Plans to implement Intelligent Logistics solutions

Figure 45: Intelligent Logistics plans and sustainability performance

Table 23: Plan to apply intelligent logistics solutions

Main reason to apply intelligent logistics solutions in the future	Reduce Carbon Emissions	Improve Energy Efficiency	Improve Resilience	Improve Sustainability Performance	Plans for 2030: Min logistics solutions
Company with global footprint	-	-	"AI to predict when products break down and/or need repair"	n.s.	**Smart products or connected products*** "All company products to become connected (smart)"
Company with national footprint	"We started a project on carbon footprint"	-	-	Yes (Users/clients satisfaction, CO_2 emissions)	Focus on improving operational criteria to increase modal share; reduce CO_2 emissions
Company with cross-border footprint (2 EU Member States)	-	Robotization; autonomous delivery	-	Yes (Collaboration with last-mile providers; procurement of electric deliveries)	**Automation Digitalization** "The Innovation Department is developing a plan to do more on digitalization"

n.s.: not stated or known. (*) For example, they can communicate and integrate with other products.

It's interesting to note from Table 23 that digitalization, automation and smart products are the trends. One of the companies mentioned that smart products can provide intelligence on the status or location of a specific good and anticipate service needs, align with customer needs and preferences, opening opportunities to create new business models. Regarding the improvement of sustainability performance, the social dimension and satisfaction is mentioned by one company. Following the study made by the Cognizant Technology Solutions Corporation (2019) in the United States, involving the analysis of 14 companies across several industries (manufacturing, travel and hospitality, healthcare and life sciences, retail and consumer goods), IoT applications were mostly oriented to improve efficiency and productivity (e.g., reduction of production time by 50% per machine), increase market share, and to improve customer experience.

Figure 46 and Figure 47 show the indicative questions on **sustainability and governance practice** posed to each interviewee/company. The analysis was complemented by corporate reports, including sustainability reports and codes of conduct. Table 24 summarizes the answers obtained.

Figure 46: Sustainability and Governance Practice: Sustainability Reporting

Figure 47: Sustainability and Governance Practice: the ECSR Directive

Table 24: Sustainability and Governance aspects: summary of answers

No/Yes	Does your company's publish annual sustainability reports?	CO2 emissions from supply chains?	Circular supply chains?	Aware of the ECSR Directive?	ECSR and scope 3 emission challenges	Foreseen barriers in the implementation of the ECRS Directive / Suggestions to overcome the stated barriers
-	yes	yes*	no** "We work on circularity on our own company"	yes	• Challenges/Barriers - Calculation of scope 3 emissions can be very time consuming, including the data collection from suppliers - Data is scarce and emission factors are not known - How to ensure that emissions from different suppliers are comparable? • Suggestions of solutions to overcome barriers -**Work together with the suppliers to find solutions** **- Have a common platform to store data**	
-	yes	yes***	no "Not yet identified as core area in the company"	yes	• Challenges/Barriers - The main barriers are the bureaucracy around the process, technology and how to develop plans to reduce emissions along supply chains • Suggestions of solutions to overcome barriers - **Guidance with examples for companies is required**	
-	yes	no	no	yes	• Challenges/Barriers - The ECSR Directive was not transposed ye to our national law - Difficult to implement by small and medium enterprise - Supply chains are long and have many subcontractors - The amount data needed is a problem. • Suggestions of solutions to overcome barriers - **Software for companies to use**	
No	-	-	no	yes	• Challenges/Barriers -No accurate data -Not enough data analytics internally, higher expenses to implement -Not yet auditing process • Suggestions of solutions to overcome barriers - **"Education internal and external"**	
	yes	no	no	yes, "I've heard about it but not in detail"	n.s.	n.s.
	yes	no	no	yes	• Challenges/Barriers	

					“*We cannot build a house starting from the roof*” - Data is not available along supply chains - How to integrate the data and time to do it - There’s no culture to work considering the whole supply chain • Suggestions of solutions to overcome barriers - **Tool to enable companies to implement the ECSR Directive** **- Use a common standard**	
No	-	no	no	no “It’s interesting for us to get information on this Directive”	n.s.	n.s.
	yes	TBCF; the company reports scope 1 and 2	TBCF	yes	• Challenges/Barriers - “*Complexity of the EU Directive without clear and unified rules for all stakeholders in the same industry, so that everyone seems to create their own methodology, although to achieve the same objectives*” -Lack of data to apply it; “we do not have all data, for example from the GHG emissions of commuting travel of our employees” - Low level of digitalization of the subcontractors - The application of ISO standards require time - Lack of incentives for subcontractors • Suggestions of solutions to overcome barriers -**Incentives** to report GHG emissions of scope 3, besides 1 and 2 **-More training** **-Standardization of rules** for everybody in the chain (for example: between countries, between large, medium and small companies, and subcontractors)	
	yes	no; only direct GHG emissions and energy indirect emissions	no; the strategic policy plan considers circular economy though	yes	• Challenges/Barriers - Large amount of data is needed for the calculation of GHG emissions along the value chain, and it’s not easy; it will be particularly challenging to smaller companies - Knowledge about the whole value chain is required - Reports are complex • Suggestions of solutions to overcome barriers - A **transition period** to enable all requirements to be met in a specific ESRS standard. In the reporting more reliance should be given on the sector specific standards – but these are not	

					ready yet for all the sectors. Need longer phase-in for value chain reporting.
	yes	yes****	yes	yes	*"CSRD reporting is already well underway. There are challenges but not the ones we cannot live with."*

n.s.: not stated or known; TBCF: the interviewee said it will be considered in the future, until 2030 (*) The sustainability report refers that the value chain generated 5,891,347 tonnes of greenhouse gas emissions to air (Scope 3). (**) "We have bioproduct mills"; the circular economy is promoted by making efficient use of side streams and producing recyclable products. (***) Indirect GHG emissions (scope 3) are estimated in the company sustainability report. (****) The company set a 40% reduction target until 2030 in emissions related to its products' materials and lifetime energy consumption (scope 3), compared to a 2018 baseline; in 2023 the company became the first in the industry to achieve carbon neutral manufacturing units globally (in "Sustainability report 2023").

Corporate reports from other organizations such as the VR Group, Finnlines, and Transfennica, highlight the **critical role of governance in sustainability compliance**. These reports highlight strategic initiatives such as the International Maritime Organization's (IMO) 2050 targets that drive the adoption of energy efficiency programs, renewable energy sources, and comprehensive training programs.

Governance practices within these organizations ensure that sustainability goals are integrated at every level of the supply chain. For instance, the focus on renewable energy transition in Finnlines' corporate strategy reflects a multi-tiered approach, where governance not only mandates compliance but sets forward-thinking frameworks for continuous improvement in environmental performance. This alignment is not just limited to internal practices but extends outward to suppliers and service providers who are expected to follow the same governance models. By requiring suppliers and service providers to adhere to the same sustainability goals set out in corporate governance reports, companies can ensure that sustainability is a shared responsibility across the entire logistics network. This includes setting stringent energy efficiency benchmarks for transport operators and encouraging renewable energy adoption throughout the supply chain (VR Sustainability Report).

Regarding CO2 emissions, one company's scope 3 emissions can account for between 70 to 90% of its total carbon footprint. Therefore, collaboration with suppliers who can evaluate their emissions (and implement actions to lower them) is of utmost importance in the future. One of the interviewed companies mentioned that "*…no collaboration also means losing a business opportunity the future*".

The quotes of the companies are summarized and used to build the framework represented in Figure 48.

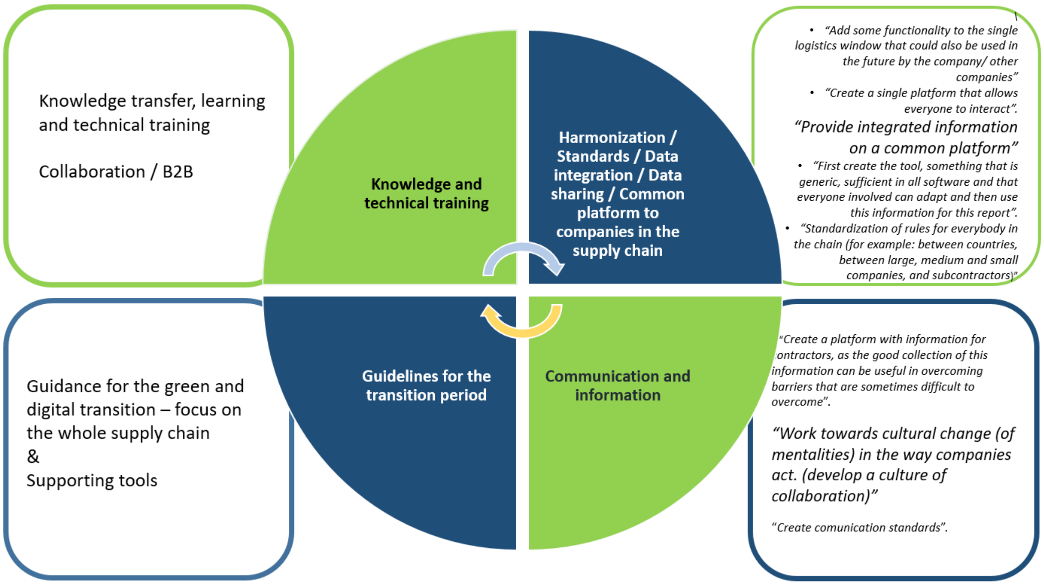


Figure 48: Requirements to address the ECSR according to company views

5 Conclusion

The ongoing global transformation of logistic supply chains and transport is aligned with the twin transition (digital and green) in Europe. Several smart technologies are already well positioned to impact positively in the logistic industry and transport systems. Chung (2021) defines smart technologies as applications of artificial intelligence and data science technologies, such as machine learning, big data, aiming to create cognitive awareness /autonomy of an object with the support of information and communication technologies such as IoT and Blockchain[9]. Estimates indicate that logistics technologies could cut shipping and customs processing times by 16 to 28% (Lehmacher, 2021).

To achieve the research goals, the following tasks were undertaken: i) analysis of global trends in innovative solutions to enhance the sustainability performance of logistics operations through a comprehensive literature review, which included scientific papers, EU-funded projects, national projects, and corporate reports; ii) an integrated systematic data analysis of academic publications and patents on intelligent supply chains and sustainable transport operations, including intermodal transport, covering the period from 2013 to 2024, using the PATENTSCOPE database of the WIPO; iii) conducting semi-structured interviews via Teams with globally relevant companies for each Pilot. The engagement of companies was facilitated by all Pilot leaders (in alphabetical order): APS, STEVECO, TIA, PS, and supporting partners. Although the answers to each research goal are detailed in each chapter, we provide hereafter some of the key findings.

The research in the domain of reverse logistics and closed-loop supply chains (circular supply chains) is in a growing phase, and in recent years, a lot of attention has been given by researchers across the globe. European regulations and strategies such as the Circular Economy Action Plan, push industries beyond compliance, fostering the development of zero-waste manufacturing models. This is particularly critical for urban logistics, where the rise of urban consolidation centres offers a tangible application of lean principles to optimize the last-mile delivery of goods.

Autonomous trucks are expected to respond to the shortage of truck drivers which is one of the most pressing issues facing road freight companies across the world. However, the deployment of freight autonomous trains and technology enablers show that the rail industry is also moving towards more connected and cooperative systems with increasing grades of automation of train operations, to be further explored for moving cargo, also in the context of the ADMIRAL Pilots.

The integration of enabling technologies like IoT, AI, big data, and cyber-physical production systems transforms traditional production processes by increasing real-time visibility, traceability, and adaptability across the entire supply chain. Digital twins are particularly useful in symbiotic logistics, where multiple stakeholders share logistics hubs and resources. Hence, agile logistics results from the fusion of cutting-edge technology like AI, IoT, and predictive analytics, enabling to improve companies'

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[9] Spector (2024) refers as technologies shaping the future of logistics operations: automation, IoT, cloud computing, AI, digital twins, blockchain, advanced data analytics, robotics, augmented reality, and advanced geolocation technologies.

performance. Advancements in robotic systems represents a promising way and includes to adapt automated guided vehicles to move cargo, drones, parcel lockers and functional robots to improve efficiency and contactless delivery. Intelligent automation is the combination of robotic process automation, AI and soft computing such as cognitive computing (Ng et al., 2021).

Insights from case studies enabled to get insights on a several of key issues:

a) How companies/stakeholders are dealing with identified technological changes and adapting systems for digitalisation, automation and the creation of new services?

As an example, companies in the retail/postal industry aim to leverage emerging transport modes to balance economic benefits with environmental externalities such as CO2 emissions by freight activities, through the implementation of electric vehicles, modular e-vehicles, cargo bike, delivery drones, public transit system, robotic vehicles, taxi, inland waterway, parcel lockers, mobile depots and delivery robots.

b) How intelligent systems are being used or planned to integrate all logistics stakeholders?

Intelligent systems are revolutionizing the logistics sector by fostering the integration among diverse stakeholders such as producers, suppliers, ship owners, transport operators, and support services. These systems, enabled by advancements in IoT, AI, blockchain, and automation, not only enhance operational efficiency but also focus on improving sustainability performance through real-time data tracking, energy optimization, and emissions reduction. For example, the use of blockchain technology applications for smart contracts is used by several worldwide companies such as Blockshipping, CargoSmart, COSCO, DP World HNA Group, Maersk, MSC, PSA, PIL, SIPG. Smart contracts automatically execute functions such as receiving orders, tracking shipments, and updating logistics information, thus ensuring continuous feedback loops between stakeholders. From a sustainability standpoint, blockchain's ability to provide immutable records enhances accountability, particularly in terms of adhering to corporate codes of conduct and reporting frameworks. IoT-based systems play a critical role in enhancing data acquisition and processing across intermodal supply chains. By integrating container tracking, rail management, and inland navigation, IoT systems enable seamless data sharing between shippers, port operators, and inland terminals. For example, the technology, operational at the Port of Seville, provides real-time updates on container movement, ensuring that decisions made by transport operators and shipowners are synchronized, reducing idle times and energy consumption.

Collaborative logistics is still a challenge. For example, there are many actors involved in the planning, control, and execution of container logistic operations, such as suppliers (representing any production or storage system connected to a terminal by road, rail, or inland waterways), freight forwarders (the operators in charge of organising door-to-door shipping), logistic agents (e.g. barge operators), conveyance operators (e.g., barge owners), terminal operators (they perform loading and unloading of handling units at the terminal), and consumers (they receive the goods at the end of the transport operation). Another key challenge is data integration across inland rail and maritime ports, which can be mitigated by standardized data protocols and blockchain-based documentation systems to ensure seamless cargo handoffs.

c) How the requirements for improving resilience and sustainability are considered?

The integration of resilience and sustainability in logistics and infrastructure systems is becoming increasingly crucial, especially given the rising frequency of disruptions caused by natural disasters, climate change, and operational uncertainties. For example, charging infrastructure resilience is found a critical issue. During power outages or natural disasters, EV networks could become non-operational, compromising the mobility of entire cities. Therefore, integrating renewable energy sources such as solar-powered charging stations or smart grid technologies into the EV network can provide energy autonomy, ensuring continuity during disruptions. Future transportation systems must incorporate renewable energy-powered EV charging stations to enhance both resilience and sustainability. Therefore, prioritization of investment in distributed energy systems that provide grid-independence for critical transportation infrastructure during crises.

d) How does governance practice connect all levels of supplies and service providers to achieve sustainability goals?

The integration of governance practices within supply chains and service providers is key for achieving sustainability goals, particularly when considering the growing complexity of logistics networks, use of advanced technological systems, stringent and evolving environmental regulation landscapes, mixed with increasing levels of uncertainty. Chen et al. (2023) developed an inspiring governance framework for a green and smart port that considers six dimensions (of several levels each) obtained from the industry and academic works. The dimension themes are greenness, agility, personalisation, cooperation, intelligence and liberalization. The governance framework begins by defining objectives for various hierarchies, ensuring that sustainability goals such as carbon reduction and energy efficiency are aligned across all levels of operation. This includes producers, suppliers, ship owners, transport operators, and support services, who are connected by the governance system, ensuring their roles are in sync with sustainability practices. Step 1 identifies critical factors affecting systematic problems, like emissions from port production and transportation, which disproportionately affect the environment (notably around 60-90% during ship berthing periods). Step 2 focuses on stakeholder collaboration and the mutual impact between these factors, such as the joint promotion of green and smart ports between shipping departments and ports. This foster improved transparency and cooperation in sustainability practices. Step 3 to 5 involve building and analysing hierarchical models that identify the interactions between these factors, which, in the context of governance, ensure all supply chain actors follow a unified code of conduct. This facilitates mutual accountability in sustainability reporting, particularly in monitoring carbon emissions and energy consumption.

Governance practices also involve corporate strategies for green servitisation, which align product and service offerings with sustainability goals. Kumar et al. (2024) note that industries are embedding sustainability into governance practices through the adoption of green servitisation, ensuring that both products and services are developed with sustainability in mind. This involves the integration of sustainability performance indicators into product life cycle assessments (LCAs), ensuring that suppliers and service providers adhere to the same sustainability standards.

Governance practices that incorporate employee welfare into the decision-making process are increasingly seen as essential for achieving long-term sustainability (Gultekin et al., 2022).

The review of EU-funded projects and national actions showed a trend on the decarbonization of the road freight vehicle fleets and the development/demonstration of a wide range of solution to boost operational efficiency and improve performance of transport operations, including minimizing delays at intermodal nodes and enable seamless freight flows. Ongoing research addresses more complex challenges related to resilience, digitalization and sustainability of logistics supply chains.

The systematic analysis of data that investigated patenting technology trends and its connection with the evolution of the scientific paper contents around sustainable and intelligent logistics from 2013 to 2024, provided a global and comprehensive industry-research overview of technological development and research trends. AI and data science methods were used for the analysis of 2138 records of patents and 1911 research papers. The number of papers in the field has consistently increased over the last ten years. The patent filings, however, show a significant increase starting around 2018, which suggests a rise in technological innovations and their formal protection through patents. The convergence of these trends around 2023 seems to indicate a robust interaction between academic research and practical innovations. The growth rate of patents shows significant spikes in certain years, notably around 2020, which might correspond to heightened innovation activities, possibly driven by the adaptation of companies to the global challenges posed by the COVID-19 pandemic.

Terms like "intermodal transportation", "logistics" and "freight transportation" dominate in academic papers, reflecting the primary focus areas of research. In patents, keywords such as "wireless communication system", "user equipment," and "radio resource control" are prevalent, indicating a strong emphasis on communication technologies and their applications in logistics and supply chain management. The analysis of patents within the sub-categories of B60 - Vehicles in general, reveals significant trends in automotive and vehicle technologies. The highest percentage of patents fall within subcategories "Propulsion of electrically-propelled vehicles" and "Vehicle suspension arrangements" respectively. This indicates a strong focus on the development of electric vehicle technologies and advanced suspension systems, reflecting the industry's shift towards sustainability and improved vehicle performance.

In the patents records, over the period 2014-2024, it was found a substantial rise after 2018 in terms related to "wireless communication systems","AI" and "blockchain". This trend signifies the growing importance of the digital technologies in logistics operations. Additionally, "wireless communication systems" reflect advancements in connectivity solutions crucial for real-time data transmission and vehicle to-everything (V2X) communication (e.g. connected freight vehicles). Concurrently, the rise in AI-related keywords indicates the deployment of machine learning algorithms for optimizing logistics and transportation processes, enhancing decision-making, and predictive analytics.

In the "Performing Operations; Transporting" category of patents, the innovation bursts in aeronautical and railway logistics reflect the sector's response to the growing demand for faster and more efficient transportation solutions. From 2020 onwards, there has been a notable increase in patented technologies, especially within the domain of electricity and data transmission. The fact that the number of patents in certain communities has surpassed the number of academic papers in recent years indicates a strong drive towards protecting intellectual property and commercializing innovations. This trend is critical for the logistics sector, where technological advancements in AI and machine learning are central for optimizing route planning, predictive maintenance, and automating warehouse operations.

The research-industry clusters analysis provided novel insights into the interconnections between research and patents around central themes. Higher Pp/Pt ratios indicate larger gaps between research and industry, suggesting that more time may be needed to bring the patented work to market until full implementation. Communities with higher Pp/Pt ratios such as in Intermodal Transport and Progressive Augmentation in Green Logistics (with a ratio Pp/Pt equal to 15.077) and Quantitative Methods and Strategic Freight Transport Models (Pp/Pt equal to 5.909) indicate a strong academic focus. These are research-heavy fields where theoretical advancements or new methodologies are being explored more intensively in academia rather than being immediately translated into industrial applications. On the other hand, communities with low Pp/Pt ratios such as Traffic Patterns, Beam Failure Recovery, and Highway Systems (Pp/Pt equal to 0.172) and CO2 Reduction and Hydrogen Fuel Cell Innovations in Logistics (Pp/pt equal to 0.25) reflect a more industry-focused community, with a heavier emphasis on patents, showing that the knowledge generated is being quickly applied in real-world systems. The interconnections between these communities highlight a multidisciplinary approach to green logistics. The integration of AI and machine learning across various communities underscores the importance of intelligent systems in optimizing logistics operations and reducing environmental impacts. For instance, the Advanced Automation in Intermodal Transport and Artificial Intelligence and Automated Systems in Sustainable Logistics communities share a goal of efficiency and sustainability through technology.

The spatio-temporal analysis of patents and scholarly publications conducted reveals a dual focus on efficiency and sustainability (environmental focus). The temporal distribution of intellectual property and research articles in communities such as "CO2 Reduction and Hydrogen Fuel Cell Innovations in Logistics" and "Mobility Systems and H&S Networks in Vehicle Procurement" highlights the progressive integration of advanced technologies to decarbonise transport and supply chains centred in electric vehicles and AI in recent years. This reflects somehow a global commitment trend across regions including Europe, Asia, and North America. Collectively, the scholarly works underscore a shift towards environmentally sustainable logistics operations facilitated by strategic application of AI and advances in electric vehicle technologies.

Emerging technologies for intermodal logistics optimization encompass IoT for smart tracking, AI and machine learning for decision support, blockchain and smart contracts for enhanced security and transparency, and autonomous vehicles for efficient cargo handling. "Intermodal Transport and Progressive Augmentation in Green Logistics" highlight the growing corpus of research in the field. "Network Optimization and Genetic Algorithms in Resilient Logistics" explore cost-effective strategies for intermodal freight transport, emphasizing economic and algorithmic optimization of logistics performance. "Quantitative Methods and Strategic Freight Transport Models" focus on optimizing the transportation of agricultural products using geographic information systems (GIS) and location-based technologies to enhance logistical precision and efficiency.

The conduction of semi-structured interviews with ten companies with global and EU footprints enabled to collect valuable insights to all the research goals, namely to assess how intelligent technologies are being used (or planned to be used) along with other requirements, and how these will impact in each Pilot context to improve the sustainability performance of operations. Some of the findings are hereafter summarized:

Interviewed companies consider that sustainability of logistic supply chains both in the present and in the future (2030 horizon) are decarbonisation and using alternative/mode energy (core expression category that aggregated all the mentioned technologies). The analysis reveals that social and governance related quotes such as "fair transport" and "organizing and prioritizing sustainability actions" are still residual. This contradicts the scores given to social responsibility performance which are relatively high, denoting a possible strategic bias in the ratings.

Most companies mentioned that collaboration with other companies (e.g., subcontractors) is needed to address the reduction of CO_2 emissions along the supply chains, making this to depend on the various parties involved, using quotes such as: "*it's not entirely in the hands of the company*". The "ethics and transparency" was highly rated by most companies, mainly due to the existence of code of conducts and complaints channel.

At present companies use several technologies to manage operations, and the following were mentioned: Transport Management Systems (TMS), Warehouse Management System (WMS), automation (parcel lockers), digital automatic coupling, electronic ticketing, traffic management system, Power BI, IoT to control temperatures, GPS tracking of vehicles, electrification technology in reefer truck cargo to replace diesel, electric vehicles, optimization tools. Three out of ten companies (30%) do not use any intelligent solution for their operations at present. However, the perceived impact on sustainability performance of a possible use is high. AI based tools in the market seem to be actionable in several companies through their stated plans, which seems to indicate the increasing role of data-driven and prescriptive decision-making.

Digitalization, automation and smart products seem to be amongst the main trends. One of the companies mentioned that smart products can provide intelligence on the status or location of a specific good and anticipate service needs, align with customer needs and preferences, opening opportunities to create new business models. Regarding the improvement of sustainability performance, the social dimension and satisfaction of clients was mentioned by one company.

Company's scope 3 emissions can account for between 70 to 90% of its total carbon footprint. Therefore, collaboration with suppliers who can evaluate their emissions (and implement actions to lower them) is of utmost importance in the future for more advanced companies in reporting sustainability. One of the interviewed companies mentioned that "…no collaboration also means losing a business opportunity the future".

Progress is required by most companies to tackle issues on the resilience of supply chains, as this represents a residual dimension at present. Most companies implemented energy efficient measures and are concerned to improve operational efficiency or its optimization. Regarding sustainability and efficiency targets to achieve by 2030, progress needs to be done to their quantification and assessment, to complement qualitative targets.

Most companies are adapting/planning to adapt their systems to a wide range of emerging technologies identified through this research. The stated focus is around digital and AI-based tools, automation/robotic process automation/automated guided vehicles, and also on alternative fuels to replace diesel. Intermodal transport was mentioned to be considered at the strategic business level, in cases of companies that move cargo or ship products across regions and continents.

Overall, companies perceive the twin transition challenge as complex in the evolving regulatory landscape (e.g., eFTI and ECSR). Logistics covers all the processes a business has in place to get their goods from the point of origin to the customer – including procurement, inventory management, distribution, warehousing, transportation, packaging and risk management. Therefore, addressing the entire supply chain involves managing a network of interconnected human, mechanical, activity, resource, and technical nodes in the creation and distribution of a product. One of the interviewees/company mentioned about the need to foster collaboration by devising the appropriate tools to act and change the prevailing culture first. Nevertheless, the digital exchange of information by the competent authorities and the companies involved in freight transport and logistics is expected to transform the way businesses operate until 2030, enabling each company to comply with regulations and improve transparency, data security and efficiency of cross-border logistics. Overall, a systemic and collaborative logistics approach is essential to make progress towards sustainability.

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