



Deliverable 2.4 (V1.0)

Sustainability Maturity Model

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

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Abbreviations

AI	Artificial Intelligence
AM	ADMIRAL Marketplace
BAU	Business as Usual
BN	Bayesian Network
CERTH	Centre for Research and Technology - Hellas
CPT	Conditional Probability Tables
CW	Convergent Weights
DAG	Directed Acyclic Graph
DNSH	Do Not Significant Harm
EC	European Commission
EVs	Electric Vehicles
DTLF	Digital Transport & Logistics Forum
eFTI	Electronic Freight Transport Information
EGDC	European Green Digital Coalition
ERDF	European Regional Development Fund
ESRS	European Sustainability Reporting Standards
EU ETS	European Union's Emissions Trading System
FESTA	Field Operational Test Support Action
GA	Grant Agreement
GHG	Greenhouse gases
GRI	Global Reporting Initiative
HC	Horizontal Collaboration
ICT	Information and Communication Technologies
IoT	Internet of Things
KPI	Key Performance Indicator
LCA	Life-Cycle Analysis
LL	Living Lab
LNEC	National Laboratory for Civil Engineering - Portugal
LMI	Logistics Maturity Index
LPI	Logistics Performance Index
LSI	Logistics Sustainability Index
LTI	Logistics Transferability Index
LSPs	Logistics Services Providers
MP	Marketplace

PAEI	Port Authority Environmental Index
PEI	Port Environmental Index
PS	Pilot Site
R&D	Research and Development
SC	Supply Chain
SCOR	Supply Chain Operations Reference
SDG	Sustainable Development Goals
SEI	Ship Environmental Index
SFA	Sustainability Framework Architecture
SL	Severity Level
SP	Sustainability Performance
TEI	Terminal Environmental Index
TEN-T	Trans-European Transport Network
TIC4.0	Terminal Industry Committee 4.0
T&L	Transport & Logistics
VC	Vertical Collaboration
WP	Work Package
WPL	Work Package Leader

Publishable Executive Summary

ADMIRAL seeks to develop and pilot AI-driven solutions for managing logistics supply chains to reduce transport and logistics emissions and to increase transparency, resilience, and stakeholder cooperation. This deliverable reports the results of the Task 2.4 - Development of factors and KPIs to measure sustainability - carried out in the project's Work Package 2 - Sustainable Development of logistics & transport.

The primary aim of Deliverable 2.4 is to propose a sustainability maturity model by identifying and proposing reference Key Performance Indicators (KPIs) to measure sustainability, adapting the STAR model to estimate the overall sustainability rating of logistics solutions, and determining the probability of sustainability noncompliance risks in various activities. In addition, Deliverable 2.4 analyses the requirements and proposes the specifications for the validation of a green port certification.

To achieve its aims, the report elaborates a multifaceted approach by mixing methodological tools and analyses, such as desk research, expert validation (workshops, online consultation, questionnaires), the STAR model methodology for evaluating the sustainability of ADMIRAL logistics solutions and the Bayesian Network analysis for the sustainability risk noncompliance of the AM. It also deploys an in-depth analysis of the regulatory framework, to correlate selected KPIs with EU regulations. This ensures that the ADMIRAL project complies with policies that enhance efficiency, safety, and environmental impact.

The main study conclusions and suggestions can be summarised as follows:

- The ADMIRAL Sustainability Maturity Model integrates environmental, economic, social, and governance aspects using various methodological tools and analyses.
- A pool of over 400 logistics KPIs was identified, leading to the ADMIRAL KPI core and extended list.
- The Bayesian Network model provides a clear view of the system's strengths and vulnerabilities, identifying key areas for improvement and offering valuable guidance for strategic decisions to enhance sustainability and reduce non-compliance risks.
- The Global Sustainability Model provides a holistic evaluation tool for assessing and improving the sustainability of logistics operations within the ADMIRAL project.
- Finally, the deliverable proposeσ a Green Port Certification Framework, integrating the PIXEL project's Port Environmental Index with ADMIRAL framework and TIC4.0 standards to enhance environmental performance of ports.

1 Introduction

1.1 Purpose of the report

ADMIRAL seeks to develop and pilot AI-driven (Artificial Intelligence-driven) solutions for managing logistics supply chains, including related missions to reduce transport and logistics emissions and increase transparency, resilience of logistics supply chains, and stakeholder cooperation. One key vision - and an expected result - of the ADMIRAL project is to develop a digital marketplace that enables emissions-aware logistics services planning and purchasing. The marketplace, called the ADMIRAL Marketplace (ADMIRAL MP), aims to connect all relevant logistics value chain actors from shippers to consumer deliveries, especially adding emissions data sharing services. Additionally, the ADMIRAL marketplace works as a channel for solution developers to distribute their innovative and sustainability-focused solutions to the market.

WP2 aims to address key sustainability issues in the transport and logistics sector related to the work programme topic, such as zero (low) emissions logistics, reducing energy consumption from fossil fuels in transport, and enhancing collaborative logistics to achieve common sustainability goals in the project pilots. The objectives are to establish a common and collaborative reference sustainability framework, develop a roadmap outlining current trends, barriers, and common solutions to address identified emissions, energy consumption, and other specific goals—including social aspects—and define key performance indicators to measure each sustainability dimension. These indicators will be aligned with digital, green, and intermodal/multimodal/collaborative targets.

This deliverable reports the results of Task 2.4 – ‘Development of factors and KPIs to measure sustainability’. It builds on the work performed in Task 2.2 – ‘Different transport modes and their sustainability now and in the future’ (D2.2) and receives input from Task 2.1 – ‘Sustainability Framework for Collaborative, Digital and Green Logistics’ (D2.1), to feed the work that is undergoing in WP6, Task 6.1 – ‘Impact assessment framework, KPIs definition and prioritization’ (D6.1).

The primary aim of Deliverable 2.4 is to propose a sustainability maturity model by identifying and proposing reference Key Performance Indicators (KPIs) to measure sustainability, adapting the STAR model to estimate the overall sustainability rating of logistics solutions, and determining the probability of sustainability noncompliance risks in various activities. In addition, Deliverable 2.4 analyses the requirements and proposes the specifications for the validation of a green port certification.

1.2 Methodology of the report

To achieve its aims, the report elaborates a multifaceted approach by mixing the following methodological tools and analyses:

- Review of recent literature and practice (EU-funded projects) (desk research)
- Expert validation in the context of the ADMIRAL pilot requirements (workshops, online consultation, questionnaires)
- Analysis of the sustainability noncompliance risk using Bayesian Network Risk analysis (questionnaire surveys, Mentimeter on site survey, statistical interpretation)

- Regulation compliance analysis (EU regulations analysis, schematic correlation)
- STAR model adaptation (models & weights adjustment, multi-criteria decision analysis).

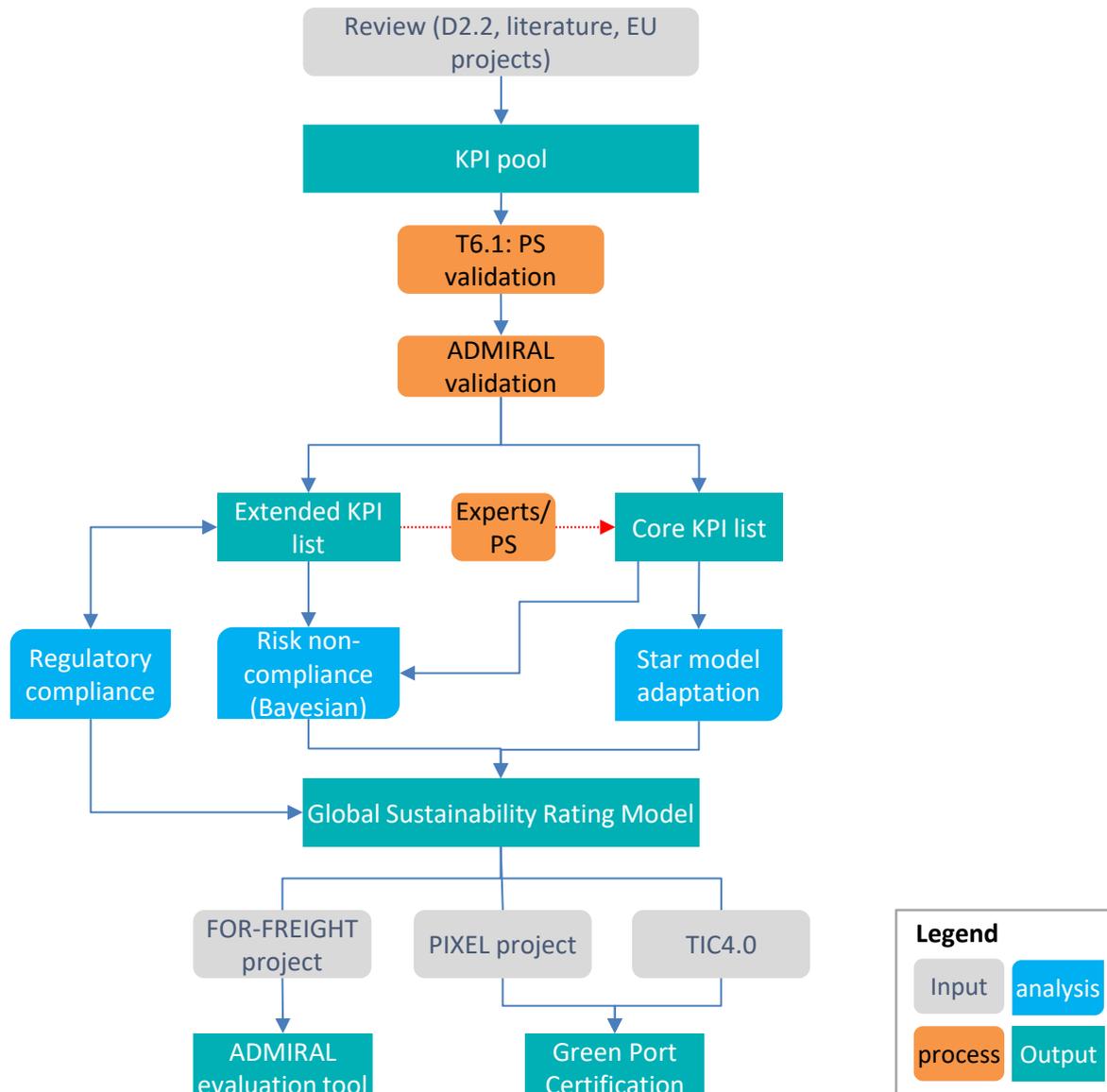


Figure 1: Overview of the report methodology

The starting methodological point is the identification of a wide pool of KPIs, by reviewing recent EU projects, the extant literature, as well as relevant outcomes of the ADMIRAL project (e.g., Deliverable 2.2), to create the basis for the subsequent analyses. This pool has been discussed with the project partners undertaking Task 6.1 and narrowed down through project site validation. Further validation with ADMIRAL’s description of work takes place within Task 2.4, ensuring alignment between the identified KPIs and the project’s objectives; the outcomes of this process formulate the ADMIRAL impact categories that are then validated by ADMIRAL’s pilot sites, ensuring both relevance and feasibility for stakeholders.

As a result, two KPI lists are formed in ADMIRAL: (a) an extended and (b) a core list of KPIs. The extended list is applied for the regulatory compliance and risk non-compliance analyses, while the core list supports risk non-compliance analysis, the adaptation of the STAR model and feeds WP6 for the operational evaluation. Based on this groundwork and the findings related to ADMIRAL KPIs, Bayesian risk analysis, and the STAR sustainability rating model adaptation, the project formulates a Global Sustainability Rating Model aligned with the regulatory framework. Finally, ADMIRAL builds upon this work and insights from other EU projects to develop an evaluation tool and propose the specifications for a Port Green Certification. Figure 1 above illustrates the overall methodology of this report.

1.3 Structure of the report

Deliverable 2.4 is structured as follows: Section 1 introduces the deliverable scope, and methodologies used. Section 2 provides a detailed analysis of the extant literature and practice in the measurement of logistics sustainability, including gaps and future directions, logistics KPIs and the identification of the applicable regulatory framework in the EU. Section 3 presents the detailed analysis of Section 2 findings under the scope and requirements of the ADMIRAL project and formulates the ADMIRAL KPI lists. Section 4 explores the risk of non-compliance by implementing a Bayesian Network analysis and a regulation compliance analysis, while Section 5 adjusts the STAR model for application in the ADMIRAL project. Section 6 outlines the ADMIRAL global sustainability rating model and proposes an evaluation tool to be used under WP6. Section 7 analyses the requirements and proposes specifications to set a Port Certification Framework. Finally, key findings of Deliverable 2.4 are summarized in Section 8 to guide further work in the project.

2 Measuring Logistics Sustainability

This section aims to provide a holistic view of the efforts and strategies necessary to achieve sustainable logistics. It emphasizes the importance of leveraging advanced technologies, aligning with regulatory frameworks, and implementing comprehensive performance evaluation to drive sustainability in the logistics sector. It is structured into three main sections: Logistics Sustainability Measurement, Regulatory Framework Analysis and Performance Evaluation Criteria Definition.

Section 2.1 provides an overview of the sustainability levels within the logistics sector, highlighting the challenges and opportunities that exist. Key gaps in sustainable logistics are identified, including data reliability, regulatory compliance, cost pressures, and technological integration. In addition, the role of key supply chain actors and stakeholders in greening logistics operations and attaining sustainable outcomes is analysed. Section 2.2 provides an in-depth analysis of the regulatory landscape that governs sustainable logistics. It discusses key legislative acts and policies aimed at reducing greenhouse gas emissions, promoting the use of renewable energy, and enhancing the overall sustainability of transport and logistics operations. Finally, Section 2.3 reviews previous work in logistics performance measurement to create an inclusive pool of KPIs.

2.1 Logistics Sector Sustainability Level

2.1.1 Challenges for Sustainable Logistics

Sustainable logistics is an essential component of modern supply chain management, aiming to minimize environmental impact, enhance social responsibility, and ensure economic viability (Nicoletti & Appoloni, 2024). However, despite significant advancements several gaps remain that hinder the full realization of sustainable logistics (Chatzoudes et al., 2023). These challenges are further shaped by the EU sustainability strategies and technological factors (ADMIRAL Del.2.2, 2024). To support those arguments, the following literature review examines key gaps and future directions in sustainable logistics, along with a summary of the main conclusions on the influence of EU strategies and technology, as outlined in ADMIRAL Deliverable 2.2.

2.1.1.1 Key Gaps in Sustainable Logistics

One of the primary challenges in sustainable logistics is the reliability and transparency of data. Inconsistent and unreliable data on environmental and social impacts across supply chains make it difficult to accurately assess and report sustainability metrics (Di Nardo et al., 2025). To overcome this challenge, advanced technologies like blockchain can be implemented to ensure data integrity and transparency (Sun et al., 2022). Blockchain provides a decentralized and immutable ledger that can track and verify every transaction and process within the supply chain, ensuring that the data is accurate and trustworthy (Saberli et al., 2019).

Another significant gap is regulatory compliance. The regulatory landscape for sustainable logistics is complex and constantly evolving, making it challenging for companies to stay compliant (Roshid et al., 2024). Navigating these regulations increases compliance costs and operational complexities (MIT, 2024). Developing adaptive compliance strategies and leveraging digital tools for real-time regulatory updates can provide automated alerts and updates on new regulations, helping companies quickly adapt their practices to remain compliant (Raj et al., 2020; Bäckström, 2024).

Cost pressures also pose a significant challenge to sustainable logistics, as the high costs associated with implementing sustainable practices can discourage companies from investing in them (Solari et al., 2025). Public-private partnerships and subsidies can make it more economically viable for companies to adopt these practices; they can also facilitate the sharing of resources and knowledge, reducing the overall cost burden on individual companies (Kumar et al., 2025).

Technological integration is another area where gaps exist. The slow adoption of innovative technologies limits the efficiency and sustainability improvements that can be achieved in logistics (Sun et al., 2022). Promoting common standards and incentives for technological adoption can accelerate the integration of new technologies, enhancing both operational efficiency and sustainability outcomes (Roshid et al., 2024). Table 1 summarizes the above key gaps in implementing sustainable logistics practices.

Table 1: Key Gaps in Sustainable Logistics

	Data Reliability and Transparency	Regulatory Compliance	Cost Pressures	Technological Integration
Challenge	Inconsistent and unreliable data on environmental and social impacts across supply chains	Navigating complex and evolving regulatory landscapes	High costs associated with sustainable practices	Slow adoption of innovative technologies
Impact	Hinders accurate assessment and reporting of sustainability metrics	Increases compliance costs and operational complexities	Discourages investment in sustainable logistics	Limits efficiency and sustainability improvements
Solution	Implementing advanced technologies like blockchain to ensure data integrity and transparency	Developing adaptive compliance strategies and leveraging digital tools for real-time regulatory updates	Encouraging public-private partnerships and subsidies to offset initial costs	Promoting industry-wide standards and incentives for technology adoption

2.1.1.2 Future Directions for Sustainable Logistics

To address these gaps, several directions can be pursued. Enhanced traceability and transparency are critical for sustainable logistics. Utilizing blockchain and the Internet of Things (IoT) can significantly improve traceability and transparency within supply chains. Blockchain can provide a secure and transparent record of every transaction, while IoT devices can collect real-time data on various aspects of the supply chain. This combination ensures ethical sourcing and compliance with sustainability standards, as every step of the supply chain can be monitored and verified (Moreno et al., 2025; Li, 2024).

Adopting circular economy models is another promising direction. Companies can design products and packaging with end-of-life considerations in mind, ensuring that materials can be easily recycled or repurposed. Implementing circular economy models can reduce the environmental impact of logistics and create new business opportunities through the recovery and reuse of materials (Loza Aduai et al., 2025; Nikolaou et al., 2024).

Collaborative networks among supply chain stakeholders, including suppliers, customers, and regulators, are essential for advancing sustainable logistics. Fostering collaboration can enhance knowledge sharing, innovation, and collective problem-solving. Collaboration can also extend to sharing logistics infrastructure, such as warehouses and transportation networks, to optimize resource use and reduce environmental impact (Aloui et al, 2023). In line of this, the ADMIRAL Marketplace aims to connect logistics actors of multiple levels (vertical and horizontal), serving as a management tool for the whole supply chain infrastructure and related emissions and will work as a channel for developers to distribute their innovative and sustainability-focused solutions to other parts of Europe; improving the visibility of the whole supply chain emissions, and thus assist companies organize their logistics and transportation services based on emissions rate and comply with the incoming regulation requirements (ADMIRAL Del.3.2, 2024).

Investing in sustainable transportation solutions is another critical direction for sustainable logistics. Green transportation technologies, such as electric and hydrogen-powered vehicles, can significantly reduce carbon emissions and dependency on fossil fuels. Companies can invest in these technologies for their fleets and advocate for the development of supporting infrastructure, such as charging stations and hydrogen refuelling stations. Additionally, optimizing transportation routes and modes can further enhance sustainability by reducing fuel consumption and emissions (Sobczuk & Borucka, 2024). Table 2 summarizes the key future directions for sustainable logistics practices and their respective benefits.

Table 2: Future Directions for Sustainable Logistics

	Enhanced Traceability and Transparency	Circular Economy Models	Collaborative Networks	Sustainable Transportation Solutions
Direction	Utilizing blockchain and IoT to improve traceability and transparency	Adopting circular economy principles to reduce waste and enhance resource efficiency	Fostering collaboration among stakeholders, including suppliers, customers, and regulators; improve visibility of the whole supply chain emissions	Investing in green transportation technologies such as electric and hydrogen-powered vehicles
Benefit	Ensures ethical sourcing and compliance with sustainability standards	Promotes recycling, reuse, and sustainable resource management	Enhances knowledge sharing, innovation, and collective problem-solving; T&L services based on emissions rate; comply with regulation requirements	Reduces carbon emissions and dependency on fossil fuels

2.1.1.3 European Strategies

ADMIRAL Del. 2.2 (2024), reviewed the sustainability challenges related to greening supply chains across transport modes, focusing on European strategies that emphasize sustainability.

The EU's Green Deal strategy aims to transform the EU into the first climate-neutral economy by 2050, with transport as a key sector. The European Green Deal, presented in December 2019, is a comprehensive strategy to make the EU's economy more sustainable and resilient, targeting climate neutrality by 2050. It covers all sectors, including energy and transport, and sets out actions to reduce greenhouse gas emissions, enhance the circular economy, promote innovation and green finance, and protect natural resources. The Green Deal is part of the EU's strategy to achieve the SDGs of the United Nations 2030 Agenda. It identifies eight policy areas: raising climate ambition, providing clean energy, mobilizing industry for a circular economy, building energy-efficient infrastructure, accelerating sustainable mobility, designing an environmentally friendly food system, preserving ecosystems, and adopting a zero-pollution ambition.

Key Targets by 2050: Achieve Net Zero greenhouse gases emissions; 90% reduction in greenhouse gas emissions from transport; Economic growth is decoupled from resource use.

The EU's commitment to climate neutrality through the Green Deal and the mid-term goal of reducing net greenhouse gas emissions by at least 55% by 2030 (relative to 1990 levels) are made legally binding by the European Climate Law (Regulation (EU) 2021/119).

The European Sustainable and Smart Mobility Strategy, presented in December 2020, aims to transform the EU transport sector and align it with the Green Deal. The strategy sets out the ambition for a green, digital, and resilient transport system, with GHG emissions reduced by 90% by 2050. It identifies 10 key areas for action and 82 initiatives to guide the Commission's work for the next four years, aiming to create an irreversible shift to zero-emission mobility.

By 2030, the EU aims to have 30 million zero-emission vehicles, 100 climate-neutral cities, doubled high-speed rail traffic, carbon-neutral collective travel under 500 km, large-scale automated mobility, and market-ready zero-emission vessels. By 2050, nearly all vehicles will be zero-emission, rail freight traffic will double, high-speed rail traffic will triple, and the multimodal Trans-European Transport Network (TEN-T) will be operational with sustainable and smart transport connectivity.

Following the Communication from the Commission on "Greening Freight Transport" presented in July 2023, freight transport accounts for over 30% of transport CO₂ emissions and is a significant source of air pollutants. Freight transport volumes are projected to increase by around 25% by 2030 and 50% by 2050, making greening transport a key sustainability challenge.

Europe's Fit for 55 Package aims to reduce net GHG emissions by at least 55% by 2030 to combat climate change and achieve carbon neutrality by 2050. It includes actions to make each transport mode more sustainable, using sustainable fuels and providing the necessary recharging and refuelling infrastructure. The package also includes legislation to transition to renewable and low-carbon fuels across modes, including maritime transport.

The European Green Digital Coalition (EGDC) is an initiative supported by the European Commission and the European Parliament, aiming to harness the emission-reducing potential of digital solutions.

ADMIRAL's task 2.2 focuses on "low emission and low energy transportation," encompassing a cross-modal/multimodal perspective and CO2 emissions (scope 1, 2, and 3) along the entire logistics supply chains.

2.1.1.4 *The role of technology in sustainability transitions*

Technology is crucial for implementing sustainable logistics practices. ADMIRAL Del. 2.2 (2024), presented a survey conducted by LNEC, examining the role of technological versus non-technological factors in sustainability transitions toward Net Zero across different transport modes. The survey targeted global companies and stakeholders involved in the ADMIRAL pilots.

The key findings of the survey can be summarised as follows:

- Most companies address sustainability issues and aim to reduce GHG emissions, with some already estimating CO2 emissions using tools like EcoTransIT.
- Common challenges include scope 3 emissions, data sharing, and lack of primary data.
- Shipping companies prioritize IoT, blockchain, and optimization tools for collaborative logistics.
- Optimization tools are important but often prioritize efficiency over environmental criteria. There is a need for transparent tools to calculate CO2 emissions.
- Reducing "empty miles" is crucial for road and rail modes.
- Digital technologies and platforms can enhance service productivity.
- Companies are uncertain about alternative fuels like hydrogen and biofuels, needing governmental incentives and regulations.
- Interest in renewable energy and electrification is growing, with electric trucks expected by 2030, requiring more charging stations and intermodal transport.
- Shifting freight from road to rail is seen as effective for reducing CO2 emissions but is complex.
- High infrastructure investments are unlikely before 2030; digital tools are considered more relevant.
- Economic implications of technology and port tariffs are significant concerns, indicating the need for complementary measures to promote the shift to Net Zero.

2.1.2 **Case Network and Actor analysis**

The ADMIRAL project aims to minimize greenhouse gas emissions in the logistics and supply chain while supporting socio-economic development. To achieve this, ADMIRAL project has designed the Sustainability Framework Architecture (SFA) aims to provide ADMIRAL pilots with tools/components to identify the main sustainability objectives per pilot and the KPIs that are related to their targets. The core element of the SFA is the identification and engagement of key stakeholders for each pilot project.

To that end, case network and actor analysis were conducted to understand the stakeholders involved and their interactions. At the end, the ADMIRAL pilots were tasked with mapping different stakeholders who might be interested in the progress of the project or potential customers or users of the marketplace to be tested in each pilot.

Below the case network and actor analysis for sustainable logistics and supply chain is included for each of the main ADMIRAL stakeholders' categories perspectives.

Cargo Owners (Shippers). They are companies that produce, or own goods being transported (e.g., manufacturers, retailers, etc.). Cargo owners have a great influence in deciding the type of mode to be used to move their goods to the final customers. They face several challenges in achieving sustainability goals:

- **Carbon emissions reduction.** Due to the high reliance on fossil fuels for freight transportation. There are difficulties in measuring and reducing Scope 3 emissions (indirect emissions from logistics).
- **Cost of green logistics.** Since sustainable practices (e.g., the use of electric vehicles, biofuels) often come with higher upfront costs.
- **Lack of transparency.** Due to the difficulties in tracking sustainability metrics across complex supply chains.
- **Regulatory compliance.** Sustainability regulation at European level and across regions.
- **Supplier alignment.** Suppliers should be ensured adhering to sustainability standards.
- **Consumer needs.** There is an increasing demand for eco-friendly and ethically sourced products.

By the part, cargo owners could adopt different strategies to improve sustainability such as: green procurement based on partnering with suppliers and logistics services providers (LSPs) that prioritize sustainability; investment in carbon offset program to neutralize emissions; use IoT, AI, and blockchain for supply chain transparency and efficiency; collaborative logistics by sharing transportation resources with other companies to reduce empty miles; implement recycling and reuse programs for packaging and materials; educate staff on sustainable practices and compliance; work with regulators or customers to align sustainability goals.

Transport Operators. They are companies providing freight transportation services (e.g. trucking companies, rail freight operators, etc.) and are responsible for the movement of goods (trucking, shipping, rail, air). They have a high interest in expanding their freight market share and proving sustainable freight transport. Transport operators face several challenges when trying to achieve sustainability, such as:

- **High carbon emissions.** Road transport is a major contributor to GHG emissions which is reliance on fossil fuels. Rail, while more efficient, still relies on non-renewable energy in some regions and its use is very limited.

- **Cost of transition.** High-upfront costs for adopting green technologies (e.g., electric trucks, hydrogen trains, etc.).
- **Infrastructure limitations.** Lack of charging stations for electric vehicles or electrified rail networks.
- **Regulatory pressure and uncertainty.** Different regulations across regions and lack of harmonized standards.
- **Competition and market demand.** Pressure to remain competitive while investing in sustainability. On its part, there is limited consumer willingness to pay higher prices for sustainably delivered goods.

By its part, Transport Operators can implement several strategies to improve sustainability such as: fleet optimization (transition to electric, hybrid, or low-emission vehicles, etc.), efficient route management (based on smart logistics, AI-powered route planning, etc.), carbon offsetting (invest in carbon offset programs to mitigate environmental impacts), collaboration (work with shippers and 3PLs to consolidate shipments and reduce empty miles), green certification and reporting (adopt sustainability certifications and publish transparency reports to improve credibility and accountability).

Freight forwarded and custom brokers. They are companies that arrange transportation, handle documentation, and ensure compliance for cargo owners. They act as intermediaries in the logistics and supply chain sector, coordinating the movement of goods and ensuring compliance with regulations. They face some challenges in achieving sustainability goals:

- **Complex Supply Chain.** Coordinating multiple transport modes and stakeholders makes it difficult to track and reduce emissions.
- **Regulatory compliance.** Difficulty in following different sustainability and customs regulations in different regions.
- **Cost of transition.** Initial costs for adopting green technologies, like electric trucks or carbon tracking software, can be high.
- **Lack of transparency.** Difficulty in tracking and reporting emissions and sustainability metrics across the supply chain.
- **Customer demands.** Freight forwarders and brokers may face resistance from clients who are unwilling to pay a premium for sustainable solutions, despite the long-term benefits.
- **Technological integration.** Adopting and integrating new technologies for sustainability tracking and optimization.

Freight forwards and customs brokers can interact with various stakeholders and apply the following strategies to achieve sustainability goals: route optimization (use AI-driven route planning tools to reduce fuel consumption, optimize loads, and minimize environmental impact), carbon offset programs (partnerships with offset providers to compensate for carbon emissions related to freight transport), green freight solutions (choose eco-friendly transport operators, use alternative fuels and consolidate shipments to reduce emissions), sustainable customs clearance (ensure compliance with environmental regulations and certification to help cargo owners move sustainable goods through

international borders efficiently), blockchain for transparency (use of blockchain technology to create transparent and traceable supply chains that showcase sustainability efforts).

Infrastructure managers or operators. They are responsible for maintaining and optimizing transport networks (roads, railways, ports, airports, intermodal terminals and storage warehouses) to support efficient and sustainable transport. They are interested in reducing operational costs, minimizing environmental impacts and ensuring long-term infrastructure viability. Infrastructure managers have a high influence on sustainable transport, as they control the physical network that logistics companies rely on. Nevertheless, they face the following challenges for integrating sustainability:

- **High initial costs.** Developing sustainable infrastructure (i.e., renewable energy facilities, electrified transport networks, etc.) requires significant upfront investment.
- **Regulatory complexity.** Different countries and regions may have different sustainability standards, creating challenges for global infrastructure operators.
- **Technological integration.** Incorporating advanced technologies (i.e., IoT, smart grids, automation systems, etc.) can be complex and require careful planning.
- **Maintenance.** Managing and maintaining sustainable infrastructure requires continuous effort, especially to keep up with technological advancements and environmental regulations.
- **Scalability and flexibility.** Ensuring that infrastructure can be expanded and adapted to meet future sustainability demands, such as a shift to electric vehicles or renewable energy integration, can be challenging.

To face those challenges, they can implement different strategies to enhance sustainability such as: energy efficiency measures (incorporate renewable energy into logistics hubs, ports, airports, etc.), green infrastructure design, smart infrastructure solutions (i.e. IoT sensors for real-time monitoring of energy use, waste management, etc.), electrification of transport networks, sustainable mobility integration (encourage the use of sustainable transport modes like rail or electric trucks through infrastructure upgrades that facilitate their operation).

Energy Suppliers. They provide energy solutions (e.g. electricity, hydrogen, biofuels, etc.) to power freight transport. Their main interests are expanding market share, meeting regulatory requirements, and supporting sustainable goals. They have a high influence as they enable the transition to low-emission transport. They face some challenges in driving sustainability to logistics:

- **Cost and infrastructure.** High initial investment in renewable energy infrastructure (e.g. solar farms, wind turbines, etc.) and energy storage systems.
- **Grid stability.** Management of energy storage solutions and smart grid system to ensure stable energy supply.
- **Regulation uncertainty.** Government regulations, such as carbon taxes and energy subsidies, can vary by region and may create barriers to renewable energy adoption.

- **Stakeholders' priorities.** Fragmented stakeholders' interests and priorities.
- **Balancing** short-term profitability with long-term sustainability goals.

To meet these challenges, energy providers can implement different strategies such as: green energy tariffs (offer green energy tariffs to logistics companies and shippers), implement energy storage systems, invest in smart grid technology and advanced energy management systems to optimize energy use, and provide carbon offset programs to logistics companies. In conclusion, their ability to provide renewable energy, optimize energy consumption, and support the transition to low-carbon transport and infrastructure is crucial for decarbonizing the sector. By embracing renewable energy sources, energy storage technologies, and energy management systems, they can help logistics operators meet their sustainability goals while contributing to the broader global energy transition.

IT and Technology providers. They develop and deploy digital solutions (i.e. IoT, AI, blockchain, big data analytics) to optimize logistics and supply chain operations for sustainability. They aim to foster innovation, business and partnerships with logistics companies and governments. They have high influence towards sustainable logistics and freight transport as they enable the digital transformation of logistics and supply chains. Nevertheless, they face some challenges in fostering sustainability in logistics:

- **High cost.** High investment costs for implementing advanced technologies.
- **Stakeholders' priorities.** Fragmented stakeholders' interests and priorities.
- **Regulatory complexity**
- **Balancing** short-term profitability with long-term sustainability goals.

On the other hand, IT and technology providers play an essential role in enabling sustainable logistics. Some of the key technologies that are contributing to sustainability in logistics are: cloud-based platforms and big data analytics; Internet of Things (IoT), Artificial Intelligence (AI) and Machine Learning, Blockchain, automation and robotics, software, etc.

Government and regulation bodies. They develop and implement policies, regulations and incentives related to sustainability. They influence sustainability by developing policies, enforcing laws, setting standards, infrastructure development, collaboration and partnerships, and fostering incentives that encourage business to adopt green practices. By contrast, they face the following challenges:

- **Coordination** across various levels of government (local, national, international). Inconsistent policies across regions can complicate compliance.
- **High costs.** Transitioning to sustainable practices often requires significant investment.
- **Stakeholders' involvement.** Industry stakeholders may resist stringent regulations due to perceived operational disruptions and their diverse needs.
- **Balancing socio-economic development** with environmental protection.
- **Enforcement of regulations** due to global supply chains.

Government and regulation bodies could overcome such barriers by harmonizing regulations (aligning sustainability standards to reduce complexity), providing financial support (grants, subsidies, tax incentives, etc.), and foster collaboration (public-private partnership), using data and technology. The government and regulatory perspective are central to achieving sustainability in logistics and supply chains. By developing robust policies, enforcing compliance, and fostering collaboration, governments can drive the transition to a more sustainable future.

Associations. Associations (transport, logistics, cargo owners or customers) represent various stakeholders involved in logistics and supply chain management. They help to shape industry practices, provide a unified voice to policymakers, and foster collaboration between different actors. These groups can be highly influential in promoting sustainability by:

- **Setting sustainability standards.** Many associations establish guidelines, certification programs, and industry standards to improve sustainability across logistics and supply chains.
- **Influencing legislation.** Associations often lobby for regulation or incentives that favour sustainable practices. They represent the collective voice of industry stakeholders to influence government policies.
- **Collaboration and innovation.** These associations foster collaboration among industry players to develop innovative solutions for sustainability. This includes the promotion of shared infrastructure, green technologies, and new business models.
- **Education and training.** Associations often educate their members about sustainability best practices and provide training on how to implement sustainable logistics solutions (i.e., through webinars, courses and certifications).

Associations are facing challenges due to the different goals of their members (varying priorities, creating difficulties in reaching consensus on sustainability goals), the cost of adopting sustainable practices (it often requires significant investment in new technologies and infrastructure, which may not be easily achievable for smaller companies of associations) and the complexity of global supply chains, where regulatory standards and practices can vary widely across countries.

Research and Academia. Academic institutions and research bodies drive innovation, knowledge dissemination, and evidence-based solutions for sustainability challenges in logistics and supply chains. Their key areas of influence towards sustainable logistics and supply chain are:

- **Innovation and technology development.** Academia creates new technologies, methodologies, and sustainable practices (i.e., research into electric trucks and drones, development of biodegradable packing materials, etc.)
- **Modelling and data analytics.** They provide the analytical tools necessary for the assessment of environmental, social and economic impacts of logistics and supply chain practices. Advanced modelling can predict carbon footprints, resource usage, or efficiency improvements throughout their life cycle (LCA).
- **Policy and regulatory insights.** Research bodies help decision-makers by providing evidence to guide policy makers in creating regulations for sustainable supply chain practices.

- **Education and knowledge dissemination.** Academia plays a significant role in training the next generation of supply chain professionals with the skills and knowledge to drive sustainability. Also, they serve as hubs for disseminating research findings through conferences, publications, and collaborations with industry.

The main challenges that academic institutions and research bodies are facing relate with the lack of the necessary funding and resources since research in sustainability often requires significant investment, the difficulty of adopting the research innovations by the industry (especially if solutions are costly or require significant changes in operations), and the complexity of global supply chains, as regulations and best practices differ across regions and industries.

Research and academia play a foundational role in advancing sustainability in logistics and supply chains. Through technological innovation, data analysis, policy recommendations, and education, academic institutions provide the knowledge and frameworks that drive sustainable practices. Their work helps industry actors, policymakers, and other stakeholders make informed decisions and take evidence-based actions toward reducing the environmental impact of logistics and supply chains. Although challenges exist—such as securing funding and overcoming slow industry adoption—academia's potential to influence change and shape the future of sustainable supply chains is immense. By continuing to collaborate with industry and governments, academic research can lead the way toward a more sustainable and efficient global supply chain ecosystem.

Stakeholder challenges and opportunities

In conclusion, sustainability in logistics and supply chains is increasingly critical due to environmental, social, and economic challenges. Table 3 examines challenges and opportunities of ADMIRAL key stakeholders in shaping sustainable logistics and freight transport.

Table 3: Challenges and Opportunities of ADMIRAL key stakeholders towards sustainable logistics

Stakeholders' category	Challenges	Opportunities
Cargo owners (Shippers)	Carbon emissions reduction. Due to the high reliance on fossil fuels for freight transportation. There are difficulties in measuring and reducing Scope 3 emissions (indirect emissions from logistics).	Green procurement based on partnering with suppliers and logistics services providers (LSPs) that prioritize sustainability
	Cost of green logistics. Since sustainable practices (e.g., the use of electric vehicles, biofuels...) often come with higher upfront costs.	Investment in carbon offset program to neutralize emissions
	Lack of transparency. Due to the difficulties in tracking sustainability metrics across complex supply chains.	Use IoT, AI, and blockchain for supply chain transparency and efficiency
	Regulatory compliance. Sustainability regulation at European level and across regions.	Collaborative logistics by sharing transportation resources with other companies to reduce empty miles

Stakeholders' category	Challenges	Opportunities
	Supplier alignment. Suppliers should be ensured adhering to sustainability standards.	Implement recycling and reuse programs for packaging and materials
	Consumer needs. There is an increasing demand for eco-friendly and ethically sourced products.	Educate staff on sustainable practices and compliance
Transport Operators	High carbon emissions. Road transport is a major contributor to GHG emissions which is reliance on fossil fuels. Rail, while more efficient, still relies on non-renewable energy in some regions and its use is very limited.	Green financing. Access funding opportunities to upgrade fleets or invest in green technologies
	Cost of transition. High-upfront costs for adopting green technologies (e.g., electric trucks, hydrogen trains, etc.)	Collaboration. Collaborate with government and private actors to enhance infrastructure for sustainable transport (i.e. public-private partnerships).
	Infrastructure limitations. Lack of charging stations for electric vehicles or electrified rail networks.	Technological advancements. Adopt new technologies to further optimize fuel usage, reduce emissions, and improve operational efficiency.
	Regulatory pressure and uncertainty. Different regulations across regions and lack of harmonized standards.	Consumer preferences. Tap into the growing demand for sustainable products and services.
	Competition and market demand. Pressure to remain competitive while investing in sustainability. By its part, limited consumer willingness to pay higher prices for sustainably delivered goods.	
Freight forwarded and custom brokers	Complex Supply Chain. Coordinating multiple transport modes and stakeholders makes it difficult to track and reduce emissions.	Green logistics certification. Pursue certification (ISO 14001) or eco-label to demonstrate commitment to sustainability
	Regulatory compliance. Difficulty in following different sustainability and customs regulations in different regions.	Collaboration. Strengthen relationships with sustainable transport operators to offer comprehensive eco-friendly supply chain solutions.
	Cost of transition. Initial costs for adopting green technologies, like electric trucks or carbon tracking software, can be high.	Technology integration. Embrace new technologies such as IoT, AI, and blockchain for better data management, real-time tracking, or sustainability reporting.

Stakeholders' category	Challenges	Opportunities
	Lack of transparency. Difficulty in tracking and reporting emissions and sustainability metrics across the supply chain.	Consumer demand. Positioning as a sustainable logistics provider.
	Customer demands. Freight forwarders and brokers may face resistance from clients who are unwilling to pay a premium for sustainable solutions, despite the long-term benefits.	
	Technological integration. Adopting and integrating new technologies for sustainability tracking and optimization.	
Infrastructure managers or operators	High initial costs. Developing sustainable infrastructure (i.e. renewable energy facilities, electrified transport networks, etc.) requires significant upfront investment.	Green financing. Leverage green bonds or green financing mechanisms to fund the development of sustainable infrastructure projects.
	Regulatory complexity. Different countries and regions may have different sustainability standards, creating challenges for global infrastructure operators.	Collaboration. Collaborate with government to co-finance and develop green infrastructure that aligns with both public sustainability goals and private sector interests.
	Technological integration. Incorporating advanced technologies (i.e. IoT, smart grids, automation systems..) can be complex and require careful planning.	Sustainability certifications. Seek environmental certification to build credibility and attract eco-conscious business and consumers.
	Maintenance. Managing and maintaining sustainable infrastructure requires continuous effort, especially to keep up with technological advancements and environmental regulations.	Government incentives. Take advantage of government subsidies, grants, and tax incentives for building sustainable infrastructure and transitioning to green technologies.
	Scalability and flexibility. Ensuring that infrastructure can be expanded and adapted to meet future sustainability demand, such as a shift to electric vehicles or renewable energy integration, can be challenging.	
Energy suppliers	Cost and infrastructure. High initial investment in renewable energy infrastructure (e.g. solar farms, wind	Government incentives. Take advantages of subsidies, tax credits, and other financial incentives offered by governments to support

Stakeholders' category	Challenges	Opportunities
	turbines...) and energy storage systems.	the development of renewable energy infrastructure.
	Grid stability. Management of energy storage solutions and smart grid system to ensure stable energy supply.	Collaboration. Partnerships with logistics operators to design integrated solutions.
	Regulation uncertainty. Government regulations, such as carbon taxes and energy subsidies, can vary by region and may create barriers to renewable energy adoption.	Green certification. Compliance with certification that demonstrate commitment to sustainability and attract environmental conscious customers.
	Stakeholders' priorities. Fragmented stakeholders' interests and priorities.	Energy-as-a-Service. Transition from a traditional energy supply model to an "energy-as-a-service" model, offering logistics companies bundled solutions that include energy supply, storage, and management.
	Balancing short-term profitability with long-term sustainability goals.	
IT & Technologies providers	High cost. High investment costs for implementing advanced technologies.	Implementation of digital solutions to optimize logistics and reduce emissions
	Stakeholders' priorities. Fragmented stakeholders' interests and priorities.	Collaboration. Collaborating with stakeholders to create shared value and align incentives.
	Regulatory complexity. For instance, data privacy regulation	Government incentives. Accessing government grants or incentives for technology-driven sustainability projects.
	Balancing short-term profitability with long-term sustainability goals.	Consumer demand. Meeting growing consumer demand for sustainable practices.
Government and regulation bodies	Coordination across various levels of government (local, national, international). Inconsistent policies across regions can complicate compliance.	Innovation and technology. Regulation can drive innovation in green technologies (i.e. autonomous vehicles, blockchain for transparency)
	High costs. Transitioning to sustainable practices often requires significant investment.	Socio-economic development. Sustainable logistics can create new and qualified jobs and industries.
	Stakeholders' involvement. Industry stakeholders may resist stringent regulations due to perceived operational disruptions and their diverse needs.	Improved reputation. Companies complying with regulations can enhance their brand image and customer loyalty.

Stakeholders' category	Challenges	Opportunities
	Balancing socio-economic development with environmental protection.	Collaboration. Building public-private partnerships to develop sustainable infrastructure.
	Enforcement of regulations due to global supply chains.	Creating incentives. For businesses to adopt greener practices
Associations (transport, logistics, shippers, customers)	Different goals. Different sectors (e.g., transport, logistics, retail) may have varying priorities, creating difficulties in reaching consensus on sustainability goals.	Driving Change. Associations can unite fragmented sectors and drive collective action toward sustainability through shared goals, industry standards, and collaboration.
	Costs. Adoption of sustainable practices often requires significant investment in new technologies and infrastructure, which may not be easily achievable for smaller companies of associations	Access to Resources and Innovation. By providing members with access to research, technology, and sustainability frameworks, associations can help companies innovate and stay competitive while reducing their environmental impact.
	Complexity of Global Supply Chains. Sustainability initiatives often face challenges in global supply chains, where regulatory standards and practices can vary widely across countries.	Consumer Demand. Increasing consumer interest in sustainability offers associations the opportunity to help their members capitalize on the growing demand for green and ethical products.
Research and Academia	Funding and resources. Research in sustainability often requires significant investment, and securing funding can be difficult.	Influence on Industry Transformation. Research can provide innovative solutions that enable the transformation of the logistics industry, such as more energy-efficient technologies or new business models.
	Industry adoption. While academic research can provide innovative solutions, the adoption of these ideas by industry players may be slow, especially if solutions are costly or require significant changes in operations	Policy Shaping. Research institutions have the opportunity to play a major role in shaping global and national policies for sustainable logistics.
	Complexity of Global Supply Chains. Analysing and improving sustainability in global supply chains is complex, as regulations and best practices differ across regions and industries	Global Collaboration. Research offers the chance for global collaboration between academics, industries, and governments, accelerating the adoption of sustainable supply chain practices.

2.2 Regulatory Framework and Future Requirements

This section presents the regulatory framework for transport and logistics in Europe, focusing on the set of legislative acts that drive transport and logistics into low emissions, energy transition, and technology advancements towards collaborative, digital and greener supply chains. The main legislative acts are analysed and correlated with the KPIs that compound the ADMIRAL framework. The documents were extracted from the EUR-Lex, which is an official online gateway to EU Law, and include Regulations, Directives, and important Communications directly applicable in all European Union Member States. A Directive is a legal act addressed to the EU Member States and the national authorities of each country determine the form and the methods they use to incorporate the Directive into their national Law. Communications are also policy evaluations, commentaries, explanations of action programs, or brief outlines of future policies and arrangements concerning current policy details.

For the documentation research in the EUR-Lex database, a time frame of six years (2019-2024) was established in themes regarding freight and logistics in different modes (e.g., road, rail, maritime) and their ramification in environment, technology, and governance. A total of seventeen documents were retrieved to compose this regulatory framework, of which nine documents are Regulations, four are Directives, and four are Communication (two are proposals for future regulations).

2.2.1 The European Climate Law as the framework for the EU climate policy

The European Climate Law (Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 the Framework for Achieving Climate Neutrality and Amending Regulations (EC)No 401/2009 and (EU) 2018/1999) represents the reference framework across transport and logistics and has a direct focus on CO₂ emissions across transport modes. This Law is the foundation for other European Regulations concerning environmental targets for 2030 and 2050, and it establishes the framework for the European Union's climate policy to achieve climate neutrality by 2050. In addition to this long-term target, the regulation sets an intermediate target for GHG emission reduction of at least 55% by 2030, compared to 1990 levels. Moreover, the European Climate Law requires that each Member State prepare and update climate strategies in all economic sectors, including transport, to contribute to the overall EU targets. Table 4 synthesizes the environmental targets proposed by the European Climate Law.

Table 4: Synthesis of the European Climate Law targets

European legislation	Targets	Enforcement year*	Main sustainability dimensions**
EU Regulation 2021/1119 The European Climate Law	2030 - To reduce net greenhouse gas emissions by at least 55% by 2030 (compared with 1990) 2050 - Climate neutrality	2021	Environment Governance

*Year when the referred legislation enters into force

**According to the dimensions for the KPIs of the ADMIRAL project

2.2.2 EU Strategies and Regulatory framework applied to all modes of transport and logistics

The European Commission issued **The Sustainable and Smart Mobility Strategy** (COM (2020) 789 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Sustainable and Smart Mobility Strategy – Putting European Transport on Track for the Future) (Table 5) which outlines the EU’s vision for transforming its transport sector to achieve a more sustainable, efficient, and innovative system by 2030 and beyond. The strategy sets the ambitious goal to reduce 90% of transport-related emissions by 2050, focusing on decarbonising all modes of transport, which will enhance mobility, and improve the environmental performance of vehicles. It also envisions a shift towards cleaner, more digitalized, and more connected transport systems, prioritizing green technologies, such as electric vehicles, sustainable fuels, and smart mobility solutions like autonomous and shared transport. The strategy still requires the improvement of infrastructure, digitalization, and the integration of innovative technologies to increase the efficiency and safety of the transport system across Europe.

On the environmental measures to accelerate CO₂ emissions reduction in the EU in the logistics sector, **The Greening Freight Transport** (COM (2023) 440 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Greening Freight Transport) **and the creation of the Fit for 55 Package** (Table 5) outline a series of measures aimed at the decarbonization of the freight transport sector within the European Union. These initiatives seek to reduce greenhouse gas emissions by at least 55% by 2030 and achieve net-zero emissions by 2050. Achieving the proposed goals will be possible through the implementation of strategies that include the acceleration in the adoption of clean technologies and low-emission fuels in freight transport, such as electric and hydrogen-powered vehicles, as well as the enhancement of the efficiency of logistics operations. Some key measures include expanding the use of digitalization and smart technologies to optimize transport routes and the reduction of fuel consumption. The package also includes the EU Emissions Trading System, a social climate fund to address the social and distributional impact of the new emissions trading system for buildings and road transport, a carbon border adjustment mechanism, and progressive decarbonized fuels in shipping.

Table 5: Synthesis of the Sustainable and Smart Mobility Strategy of the European Commission

European legislation	Targets	Enforcement year*	Main sustainability dimensions**
COM(2020)789 The Sustainable and Smart Mobility Strategy	2030 - Intermodal transport (rail and waterborne) is expected to be competitive with road transport within the EU (in terms of the share of external costs internalized) 2050 - All external costs of transport within the EU will be covered by the transport users	-	Governance
COM(2023)440 Greening Freight	2030 - Acceleration of the reduction of GHG emissions, with a target of	2025	Environment Governance

European legislation	Targets	Enforcement year*	Main sustainability dimensions**
Transport and EPRS 2024 Fit for 55 Package	55% reduction (compared with 1990 levels) 2050 - Climate Neutrality		

*Year when the referred legislation enters into force

**According to the dimensions for the KPIs of the ADMIRAL project

In consonance with COM (2020) 789 and COM (2023) 440, the **EU Regulation on Electronic Freight Transport Information (eFTI)** (Regulation (EU) 2020/1056 of the European Parliament and of the Council of 15 July 2020 on Electronic Freight Transport Information) (Table 6) aims to integrate and digitalize the freight transport sector within the European Union by creating a common framework for the use of electronic transport documents and data. This regulation intends to improve the efficiency, transparency, and sustainability of freight operations by facilitating the seamless exchange of data across borders and between transport operators, customs authorities, and other relevant stakeholders. Some specific measures proposed by this regulation are the standardization of formats for electronic freight information, such as transport orders and consignment notes, which reduces administrative burdens, minimizes the risk of errors, and accelerates customs procedures. For companies, the implementation of the eFTI will enable fewer unexpected stops and shorter delays caused by inspection, as well as an instant sharing of data with partners through eFTI platforms that can lead to more efficient logistics planning, vehicle loading, and routing. The implementation of the eFTI is expected to promote EUR 1 billion in administrative cost savings for the European transport and logistics sector (European Commission, 2020).

The implementation of the **EU Directive on Corporate Sustainability Reporting** (Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 Amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive/34/EU, as Regards Corporate Sustainability Reporting) (Table 6) aims to promote the enhancement of transparency and accountability in corporate environmental, social, and governance performance by expanding and standardizing sustainability reporting requirements for businesses operating in the European Union, which includes the accounting of emissions scope 1 (i.e., emissions from the sources the companies' own or control directly), scope 2 (i.e., indirect emissions deriving from the companies' purchase of electricity, fuel, etc.), and scope 3 (i.e., emissions that arise across the value chain, such as transports carried out by third parties). It requires the companies to provide information aligned with internationally recognized standards such as the Global Reporting Initiative (GRI) and the European Sustainability Reporting Standards (ESRS) for companies subject to the CSRD. The costs derived from the application of this directive will be reduced for companies over the medium to long term by harmonizing the information to be provided. Therefore, in May 2024 [guidance on corporate sustainability reporting](#) was issued (European Commission, 2024a), and in August 2024 a [FAQ](#) was circulated to cover aspects of the reporting, such as the information to be reported.

To complement the EU Directive 2022/2464, the **EU Regulation on Sustainability Reporting Standards** (Regulation (EU) 2023/2772 of 31 July 2023 Supplementing Directive 2013/34/EU of the European Parliament and of the Council as Regards Sustainability Reporting Standards) (Table 6) establishes a

comprehensive framework aimed at guiding the way businesses report on sustainability issues. The regulation introduces a set of detailed, EU-wide reporting standards to ensure consistency, comparability, and reliability in sustainability reports, facilitating informed decision-making by investors, consumers, and other stakeholders. The regulation also establishes the adoption of standardized metrics for reporting on a range of ESG factors, including climate-related risks, resource usage, and social impacts.

To allow the good reception and understanding of the digital information provided by companies, Regulation (EU) 2024/1942 of 5 July 2024 Laying down Common Procedures and Detailed Rules for Accessing and Processing Electronic Freight Transport Information by Competent Authorities in Accordance with Regulation (EU) 2020/1056 of the European Parliament and of the Council (Text with EEA Relevance) (Table 6) establishes a unified framework to enhance the efficiency and transparency of **cross-border freight operations within the European Union**. The regulation aims to consolidate the exchange of electronic transportation data among competent authorities, ensuring that critical information about the movement of goods is accessible, processed, and managed in a standardized manner across Member States. Additionally, it supports the digitization of freight logistics, allowing for smoother, more secure, and quicker data flows between authorities, transport operators, and other stakeholders. For authorities, access to eFTI will improve efficiency due to more streamlined compliance checks, lower enforcement costs since it will require fewer physical inspections, and the quality of data will be higher, which allows better monitoring of policy implementation. For this, by 2025 the European Commission plans to adopt the remaining eFTI implementing specifications, providing detailed functional and technical requirements for IT systems and services used by businesses, as well as rules for their implementation. In 2026, eFTI platforms and service providers can begin operations, and Member State authorities may start accepting data stored on certified eFTI platforms for inspection.

Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 Amending Directive 2003/87/EC Establishing a System for Greenhouse Gas Emission Allowance Trading within the Union and Decision (EU) 2015/1814 Concerning the Establishment and Operation of a Market Stability Reserve for the Union Greenhouse Gas Emission Trading System (Text with EEA Relevance) (Table 6) was established to strengthen the European Union's Emissions Trading System (EU ETS) by introducing a more robust framework for the allocation and trading of greenhouse gas allowances. The directive sets out provisions for the expansion of the EU ETS to cover additional sectors, including maritime transport and certain industrial processes, thereby broadening the scope of carbon pricing (Figure 2). It introduces stricter emission reduction targets and further enhances the carbon market by ensuring that emissions are progressively capped, while also promoting the use of low-carbon technologies.



Figure 2: Introduction of new sectors in the ETS (Adapted from (European Council, 2023))

In addition, the **EU Regulation Energy Efficiency** (Regulation (EU) 2023/955 of the European Parliament and of the Council of 10 May 2023 Establishing a Social Climate Fund and Amending Regulation (EU) 2021/1060) (Table 6) aims to accelerate the EU's transition to a low-carbon economy by setting stricter measures to improve energy efficiency across various sectors. The regulation establishes a comprehensive framework that includes mandatory energy-saving targets for Member States, enhancing efforts to reduce overall energy consumption and optimize energy use. A key component of the regulation is the priority of energy efficiency in some areas, such as buildings, industry, and transport, promoting the adoption of energy-efficient technologies and practices. This regulation was amended by Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on Energy Efficiency and Amending Regulation (EU) 2023/955 (Recast) (Text with EEA Relevance), which focuses on binding a target to reduce EU final energy consumption by at least 11.7% by 2030 (compared with 2020), the establishment of indicative national energy efficiency contributions from Member States, an annual energy savings obligation of 1.3% in 2024-2025 to 1.9% in 2028-2030, the reduction of energy consumption of at least 11.7% across the EU by 2030. These objectives can be achieved by the encouragement of the transition to more energy-efficient modes of transport and the use of renewable energy in transport.

Concerning the adoption of low-emission fuels, Regulation (EU) 2024/1789 of the European Parliament and of the Council of 13 June 2024 on the Internal Markets for Renewable Gas, Natural Gas and Hydrogen, Amending Regulations (EU) No 1227/2011, (EU) 2017/1938, (EU) 2019/942 and (EU) 2022/869 and Decision (EU) 2017/684 and Repealing Regulation (EC) No 715/2009 (Recast) (Text with EEA Relevance (Table 6) aims to facilitate the integration of renewable gases, natural gas, and hydrogen into the European energy market by establishing a robust regulatory framework for their production, trade, and consumption. The regulation promotes the development of a competitive and transparent market for these gases, with a focus on ensuring that they contribute to the EU's climate and energy objectives, including the provision of stricter standards for vehicle emissions due to the priority to low-emission fuels.

Besides the regulation for energy efficiency, **The Promotion of Energy from Renewable Sources was proposed by** Directive (EU) 2023/2413 of The European Parliament and of The Council of 18 October 2023 Amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as Regards The Promotion of Energy from Renewable Sources, and Repealing Council Directive (EU) 2015/652 (Table 6) seeking the acceleration of the transition to renewable energy within the European

Union, contributing to the EU’s ambitious climate and energy objective to achieve net-zero emissions by 2050. The directive establishes clear and restraining targets for increasing the share of renewable energy in the EU’s energy mix, with a focus on enhancing the deployment of renewable technologies such as wind, solar, and bioenergy. The directive also aims to support the increase of renewable energy in key sectors such as heating and cooling, transport, and industry, with specific measures to encourage the use of renewable fuels and technologies in these areas.

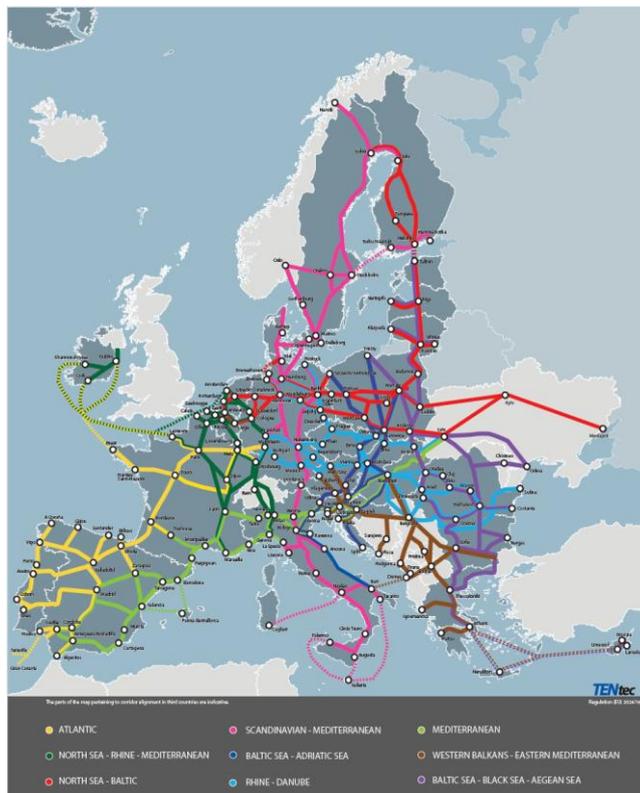


Figure 3: Schematic map of the European Transport Corridors (European Commission, 2024b)

The decrease in GHG emissions is also due to the promotion of a modal shift established by Regulation (EU) 2024/1679 of the European Parliament and of the Council of 13 June 2024 on Union Guidelines for the Development of the Trans-European Transport Network, Amending Regulations (EU) 2021/1153 and (EU) No 913/2010 and Repealing Regulation (EU) No 1315/2013 Text with EEA Relevance (Table 6). This regulation provides a strategic framework for the development and modernization of Europe’s transport infrastructure, aiming to enhance connectivity, sustainability, and efficiency across the EU. It also outlines guidelines for the planning, implementation, and management of the TEN-T (Figure 3), a network of roads, railways, ports, and airports designed to facilitate the seamless movement of goods and people across Member States. The regulation emphasizes that the passenger railway lines on the core and extended core network must support trains travelling at speeds of 160 km/h or faster, the number and capacity of transshipment terminals will be expanded to meet traffic demand, including the accommodation of 740-meter-long train in freight terminals to promote the shift to sustainable transport modes. This regulation is also relevant for the ADMIRAL Pilots in Portugal-Spain (Atlantic corridor section) and Finland (Baltic Sea corridor section).

Taking into consideration all the aspects regarding the procedures to achieve the EU climate goals in 2030 and 2050, some trends on the matter are of extreme relevance for logistics studies. COM (2023) 441 Proposal for a Regulation of the European Parliament and of the Council on the Accounting of Greenhouse Gas Emissions of Transport Services (Table 6), for example, outlines a framework for improving the transparency and accuracy of GHG emissions reporting within the transport sector. The proposal seeks to establish standardized methodologies for calculating (ISO 14083:2023) and reporting the carbon footprint of various transport services, including freight, passenger, and logistics operations, across the European Union. By introducing clear and consistent accounting practices, the proposal aims to support the reduction of emissions from the transport sector. The proposal includes measures to ensure that companies and transport operators report emissions comparably, enabling better monitoring, data-driven decision-making, and the identification of emission reduction opportunities. It includes the GHG transparency clauses in transport contracts that require parties to provide information on the GHG emissions associated with specific transport services, the Climate-related Criteria for Green Procurement that supports the integration of climate-related criteria procedures and green transport programs to incentivize the adoption of low-emission technologies and practices in the transport sector.

Table 6: Synthesis of the European Regulations for the transport sector

European legislation	Targets	Enforcement year*	Main sustainability dimensions**
EU Regulation 2020/1056 Electronic freight transport information	2030 - Enforcement of rules to use electronic exchange of regulatory freight (eFTIs)	2024	Technology
EU Directive 2022/2464 Corporate sustainability reporting	2050 - Large public-interest entities and companies must disclose their sustainability strategies, performance metrics, and progress towards climate goals, including GHG emissions, and energy usage following the EU's climate neutrality objectives	2024	Governance Environment
EU Regulation 2023/2772 Sustainability reporting standards	2050 - The establishment of sustainability reporting in companies with disclosure of the climate-related targets that are consistent with the EU's climate neutrality objectives (definition of details on how the report must be done, standardization of the information to be disclosed)	2024 (the first reports from companies are expected in 2025)	Environment Governance
EU Regulation 2024/1942	2050 - The modernization of the freight transport sector by promoting the use of electronic	2026	Technology Governance

European legislation	Targets	Enforcement year*	Main sustainability dimensions**
The common procedures and detailed rules for accessing and processing electronic freight transportation information by competent authorities	data exchange, which improves the efficiency of transport operations, and contributes to the EU's climate and digital transformation goals		
EU Directive 2023/959 The establishment of a system for greenhouse gas emission allowance trading	2030 - The establishment of the Emissions Trading System (ETS) to cover CO ₂ emissions. A reduction of 42% in CO ₂ emissions from buildings, road transport, and small industries must be achieved (compared with 2005 levels) 2050 - Climate neutrality	2026	Governance Environment
EU Regulation 2023/955 Energy efficiency	2030 - The reduction of 11.7% in energy consumption	2024	Environment
EU Directive 2023/1791 Energy efficiency and amending EU Regulation 2023/955	2030 - The reduction of 11.7% in energy consumption in specific sectors, including transport (compared with 2020)	2024	Environment
EU Regulation 2024/1789 The international markets for renewable gas, natural gas, and hydrogen	2030 - Stricter standards for vehicle emissions, fuel efficiency, and the use of sustainable materials in vehicle manufacturing 2050 - Climate neutrality	2024	Environment
EU Directive 2023/2413 The promotion of energy from renewable sources	2030 - The share of at least 29% of renewable fuels and renewable electricity within the final consumption of energy in the transport sector	2024	Environment
EU Regulation 2024/1679	2030 - The increase of 50% in rail freight transport. Transport by	2024	Environment Governance

European legislation	Targets	Enforcement year*	Main sustainability dimensions**
Guidelines for the development of the trans-European transport network	<p>inland waterways and short-sea shipping should increase its market share by 25%. At least 80,000 zero-emission trucks should be in operation</p> <p>2050 - Rail freight should double. Transport by inland waterways and short-sea shipping should increase its market share by 50%. Nearly all new heavy-duty vehicles should be zero-emissions</p>		
<p>Proposal COM(2023)441</p> <p>The accounting of greenhouse gas emissions of transport services</p>	<p>2050 - The harmonization of the methodology for GHG emissions accounting across the transport sector to allow customers to make informed choices regarding the environmental impact of their transport options.</p>		Environment

*Year when the referred legislation enters into force

**According to the dimensions for the KPIs of the ADMIRAL project

2.2.3 Regulatory framework applied to road transport

Regarding the specific regulations for road transport, Regulation (EU) 2019/1242 of the European Parliament and of the Council of 20 June 2019 on **Setting CO₂ Emission Performance Standards for New Heavy-Duty Vehicles** and Amending Regulations (EC) No 595/2009 and (EU) 2018/956 of the European Parliament and of the Council and Council Directive 96/53/EC (Table 7) sets emission reduction targets for 2030, intending to achieve a 30% reduction in CO₂ emissions from new heavy-duty vehicles compared to 2019 levels. The regulation also introduces a system of performance standards for different vehicle categories, such as trucks, buses, and coaches, and provides incentives for zero- and low-emission vehicles. For this, manufacturers are required to monitor and report the CO₂ emissions and fuel consumption of their heavy-duty vehicles, and this data must be submitted to the European Commission. Nevertheless, to accommodate the diverse range of heavy-duty vehicles and their applications, the regulation includes flexibility mechanisms to allow manufacturers to meet the standards through various means, such as pooling arrangements or credits for early deployment of low-emission technologies.

Table 7: Synthesis of the European Regulations for Road Transport

European legislation	Targets	Enforcement year*	Main sustainability dimensions**
EU Regulation 2019/1242 CO₂ emission performance standards for new heavy-duty vehicles	2030 – The reduction of 30% in CO ₂ emissions from new trucks (compared with 2019) 2050 – Zero-emission fleet	2021	Environment

*Year when the referred legislation enters into force

**According to the dimensions for the KPIs of the ADMIRAL project

2.2.4 Regulatory framework applied to rail transport

In addition to the general targets proposed by **The Sustainable and Smart Mobility Strategy (COM 789, 2020)**, it also outlines specific objectives for rail freight transport to drive decarbonization and efficiency (Table 8). By 2030, the strategy sets a target to increase the rail freight market share in the EU, aiming for a significant shift from road to rail transport for freight, thus reducing emissions and congestion. This is supported by efforts to improve rail infrastructure, digitalization, and interoperability across borders, represented by the aforementioned **(TEN-T program)**. For 2050, the strategy envisions doubling the rail freight traffic and decarbonizing the sector, with rail transport playing a central role in achieving the EU’s overall goal of net-zero emissions. The strategy outlines the need for investments in green technologies, including electrification, automation, and the development of innovative solutions to increase rail freight efficiency, making it a key element in the EU's sustainability framework.

Following the trends in rail transport, a recent proposal was outlined regarding the provision of technical specifications for telematics applications in rail transport, which is crucial for achieving interoperability in the European rail system (Table 8). The proposal focuses on the role of data sharing among stakeholders to improve efficiency in rail freight transport. It emphasizes the importance of increasing rail freight's competitiveness by fostering digitalization and intermodal connectivity, particularly through real-time data sharing on train movements and freight status.

Table 8: Synthesis of the European Regulations for Rail Transport

European legislation	Targets	Enforcement year*	Main sustainability dimensions*
COM(2020)789 The Sustainable and Smart Mobility Strategy	2050 - To double the rail freight traffic (compared with 2015)	-	Governance

European legislation	Targets	Enforcement year*	Main sustainability dimensions*
Proposal*	2050 - Implementation of data sharing for rail passenger and freight services to ensure interoperability within the EU's transport network. The regulation aims to update and merge previous regulations (EU 454/2011 and EU 1305/2014) for better integration of digital systems, open data architecture, and multimodal travel	-	Governance Technology

*Year when the referred legislation enters into force

**According to the dimensions for the KPIs of the ADMIRAL project

2.2.5 Regulatory framework applied to maritime transport

The Sustainable and Smart Mobility Strategy (COM 789, 2020) (Table 9) also sets a comprehensive approach to decarbonizing maritime transport. By 2030, the strategy seeks to reduce the carbon intensity of maritime transport through the adoption of alternative fuels, enhanced energy efficiency, and digitalization, to improve the sustainability of both short-sea and deep-sea shipping with an increase in inland waterways and short-sea shipping by 25% by 2030. A key target for 2050 is the full decarbonization of the maritime sector, including the widespread deployment of zero-emission vessels, the expansion of green ports, and the integration of sustainable maritime logistics within the broader transport network, alongside an increase of 50% in inland waterways and short-sea shipping.

Alongside the strategy, Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the Use of Renewable and Low-Carbon Fuels in Maritime Transport and Amending Directive 2009/16/EC (Text with EEA Relevance) (Table 9) addresses the use of renewable and low-carbon fuels in maritime transport, aiming to significantly reduce the sector's greenhouse gas emissions. By 2030, the regulation targets the deployment of renewable and low-carbon fuels in maritime freight transport, with a focus on enhancing the uptake of alternative fuels such as biofuels, synthetic fuels, and hydrogen. Also, container ships calling at EU ports will be required to use OPS or equivalent technologies during berthing to reduce emissions from auxiliary engines while at ports. These efforts are intended to reduce the carbon intensity of shipping, facilitating the transition towards a more sustainable maritime sector. For 2050, the regulation targets the full decarbonization of maritime transport, positioning renewable and low-carbon fuels as a central element in achieving net-zero emissions. These measures are supported by the establishment of fuel-specific sustainability criteria, the creation of infrastructure to support alternative fuel adoption, and financial mechanisms to incentivize innovation in clean maritime technologies.

Furthermore, (Directive (EU) 2023/2413 of The European Parliament and of The Council of 18 October 2023 Amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as

Regards the Promotion of Energy from Renewable Sources, and Repealing Council Directive (EU) 2015/652, 2023) (Table 9) focuses on promoting energy from renewable sources, with specific implications for maritime freight transport. The directive sets a framework for increasing the share of renewable energy in the transport sector, including the maritime industry, by 2030, with targets to significantly boost the use of renewable fuels, such as biofuels, synthetic fuels, and hydrogen, in shipping. By 2050, the directive envisions a fully decarbonized transport sector, with maritime freight playing a key role in the transition through the widespread adoption of renewable and low-carbon fuels. It also emphasizes the need for infrastructure investments, regulatory support, and technological innovation to enable the maritime sector to meet these targets. The application of this Directive is expected to require 800,000 seafarers to be trained to handle alternative fuels (EEA & EMSA, 2025).

Table 9: Synthesis of the European Regulations for Maritime Transport

European legislation	Targets	Enforcement year*	Main sustainability dimensions**
COM(2020)789 The Sustainable and Smart Mobility Strategy	2030 - To increase the transport by inland waterways and short-sea shipping by 25% by 2030 2050 - To increase the transport by inland waterways and short-sea shipping by 50% by 2050	-	Governance
EU Regulation 2023/1805 The use of renewable and low-carbon fuels in maritime transport	2030 - The reduction of 6% in the GHG intensity of the energy used onboard ships (compared with 2020) 2050 - The reduction of 80% in the GHG intensity of the energy used onboard ships (compared with 2020)	2025	Environment
EU Directive 2023/2413 The promotion of energy from renewable sources	2030 - The share of at least 1.2% of renewable fuels of non-biological origin in the total energy supply to maritime transport	2024	Environment

*Year when the referred legislation enters into force

**According to the dimensions for the KPIs of the ADMIRAL project

In short, the European Union has been developing a set of measures to reach the targets of reducing 55% of GHG emissions by 2030 and reaching climate neutrality by 2050. Among the Regulations, Directives, and Communications available on the matter, several apply to transport and logistics, aiming for changes in environment, governance, and technology aspects. Thus, the pathway to the decarbonization of the transport sector involves the active participation of stakeholders to apply mechanisms that improve the digitalization of processes, the shift to more efficient and less polluting

modes of transport, vehicles and fuels, as well as improving the sustainability information reporting throughout the entire supply chain allowing customers to take more appropriate choices, aligned with the twin transition.

2.3 Performance Evaluation Criteria

2.3.1 Evaluation frameworks analysis

This section provides an overview of selected evaluation frameworks that have recently been developed and applied in significant EU-funded projects focusing on transport and logistics research and innovation. Only EU-funded projects that have similar sustainability, and operational efficiency objectives are considered. Some preliminary work is presented on Deliverable 6.1 (projects NOVELOG, SULPITER, SHOW), and is being enhanced in the current report (projects FENIX, FOR-FREIGHT, URBANE, PLANET, PIXEL, and e-Ferry).

By examining these projects, ADMIRAL is able to establish a broad pool of relevant logistics sustainability KPIs (Section 2.3.3), working closely with Task 2.2 (as reported in Del. 2.2) to support Task 6.1 (as reported in Del. 6.1) in adapting and refining KPIs based on proven approaches and lessons learned.

2.3.1.1 NOVELOG

The NOVELOG project (2025) focused on optimizing city logistics and reducing emissions in urban freight transport. Key KPIs from NOVELOG included CO₂ emissions per ton-kilometre, modal shift percentage, and transport efficiency (ton-kilometres per unit of energy). These KPIs were adapted into ADMIRAL's framework to track emissions reductions and energy use across multimodal networks (ADMIRAL Del. 6.1, 2024).

2.3.1.2 SULPITER

The SULPITER project (2025) integrated sustainable logistics practices and efficient energy use in supply chains. KPIs from SULPITER, such as energy consumption per ton-kilometre and emissions reduction potential of low-emission vehicles, were incorporated into ADMIRAL's KPI set to assess the effectiveness of technologies like electric vehicles (EVs) and autonomous systems (ADMIRAL Del. 6.1, 2024).

2.3.1.3 SHOW

The SHOW project (2025) tested autonomous vehicle technology in logistics and public transport. KPIs such as autonomous vehicle adoption rate, energy efficiency of autonomous systems, and CO₂ savings from autonomous transport were identified and integrated into ADMIRAL's methodology to assess technological integration and emissions reductions from advanced logistics solutions (ADMIRAL Del. 6.1, 2024).

2.3.1.4 FENIX

The FENIX project (2025) aimed to develop the first European federated architecture for data sharing serving the European logistics community of shippers, logistics service providers, mobility

infrastructure providers, cities, and authorities to offer interoperability between any individual existing and future platforms. The idea of FENIX comes from the work and recommendations of the European Commission's Digital Transport and Logistic Forum (DTLF) to create a viable and valid federative network of platforms as enabler for Business to Administration (B2A) and Business to Business (B2B) data exchange and sharing by transport and logistics operators.

The FENIX Evaluation Framework was designed to assess the readiness and benefits of this federated network, ensuring interoperability between existing and future platforms. The evaluation methodology is based on the FESTA methodology for field testing and piloting and follows a six-step approach. These steps include identifying expected impacts and impact categories, identifying Key Performance Indicators (KPIs) and measurements, defining baseline scenarios and target values, collecting pilot data and quantifying KPIs, determining evaluation outcomes, and finally, reporting and analysing pilot site results.

2.3.1.5 FOR-FREIGHT

The FOR-FREIGHT project (2025) aims to maximize the utilization of multimodal freight transport capacity, achieve competitive sustainability with higher levels of efficiency, and reduce the average cost of freight transport through the development of novel solutions and their integration with legacy logistics systems. This will enable more effective and sustainable management of goods and freight flows in airports, ports, inland terminals and various logistics nodes, considering the requirements of all involved stakeholders, and accounting for economic, environmental and social aspects.

FOR-FREIGHT developed a framework that provides a replicable and scalable model for assessing the benefits of digital transformation initiatives, addressing critical aspects such as operational efficiency, interoperability, and sustainability. The framework consists of sequential steps that define intended impacts for specified multimodal logistics operations, establish relevant KPIs and their metrics, and determine outcomes through comparative analysis of baseline (pre-digitalization) and post-implementation scenarios. It highlights measurable improvements, including enhanced data accuracy, streamlined processes, and informed decision-making capabilities. Furthermore, the alignment with FENIX's established methodology ensures consistency and comparability, facilitating broader application across the T&L sector.

2.3.1.6 URBANE

The URBANE project (2025) aims to support the transition path towards effective, resilient, safe and sustainable last-mile transport, through four Lighthouse Living Labs (LL) in Helsinki, Bologna, Valladolid and Thessaloniki. For the evaluation process, URBANE develops an impact assessment methodology that aims at verifying the compliance of new delivery business models demonstrated in the project with European Sustainable Development Goals (SDGs), the Do Not Significant Harm (DNSH) principle as well as adopt indicators able to monitor energy efficiency gains obtainable from delivery models based on collaboration and sharing of assets by Logistics Service Providers (LSPs). To this end, where 'classic' KPIs (i.e., traditionally used in European projects) were insufficient to describe the pursuit of these objectives, specific KPIs were defined and then discussed and agreed.

2.3.1.7 PLANET

The PLANET project addressed the challenges of assessing the impact of emerging global trade corridors on the TEN-T network and ensuring effective integration of the European to the Global Network by focusing in two key R&D (research and development) pillars: (1) A Geo-economics approach, modelling and specifying the dynamics of new trade routes and their impacts on logistics infrastructure & operations, with specific reference to TEN-T; (2) An EU-Global network enablement through disruptive concepts and technologies which can shape its future and address its shortcomings, aligned to the DTLF concept of a federated network of T&L platforms.

The methodological approach adopted to develop the impact assessment framework includes defining the expected impact categories, identifying indicators and targets, collecting data and evaluating the impacts. The impact assessment approach is bottom-up, using a scoring system to assign numerical values to each indicator based on their performance in Baseline and TO-BE scenarios. The data collected includes measurements for 30 indicators, and indicator weights derived through a questionnaire addressed to relevant stakeholders. In total, 27 indicators had targets assigned to them, out of which 24 achieved them.

2.3.1.8 PIXEL

The PIXEL project (2025) enabled a two-way collaboration of ports, multimodal transport agents and cities for optimal use of internal and external resources, sustainable economic growth and environmental impact mitigation, towards the Ports of the Future. PIXEL will leverage technological enablers to voluntary exchange data among ports and stakeholders, thus ensuring a measurable benefit in this process. The main outcome of this technology will be efficient use of resources in ports, sustainable development and green growth of ports and surrounding cities/regions.

PIXEL formulated a concrete methodology for the evaluation of the Project in terms of the technical functioning and interoperability of all components of PIXEL, in terms of usability and finally regarding its results. More specifically, the evaluation plan aims to provide guidelines for the evaluation of the PIXEL enabling IT infrastructure and the PIXEL use cases ICT (Information and Communication Technologies) solutions. This evaluation strategy is structured around three main pillars: (a) The Technical Impact Assessment; (b) The Business and Economic Impact Assessment; and (c) The PIXEL Proof of Concept and future R&D potential. The approach followed for the evaluation of each one of the above pillars is based on a common rationale, which has taken into consideration the FESTA (Field opErational teSt support Action) Methodology for assessing Field Operational Tests.

2.3.1.9 e-Ferry

The E-ferry project (2025) addressed the urgent need for reducing European CO₂ emissions and air pollution from waterborne transportation by demonstrating the feasibility of a 100% electrically powered, emission free, medium sized ferry for passengers and cars, trucks and cargo relevant to island communities, coastal zones and inland waterways. E-ferry built on the Danish ERDF funded project Green Ferry Vision proving feasibility of the concept to be demonstrated and indicating significant potential impacts compared to conventionally fuelled ferries operating on the same

medium range routes; energy savings of up to 50%, annual emission reductions of approx. 2,000 tonnes CO₂, 41,500 kg NO_x, 1,350 kg SO₂ and 2,500 kg particulates.

2.3.1.10 LEAD

The LEAD project (2025) created Digital Twins of urban logistics networks in six TEN-T urban to support experimentation and decision making with on-demand logistics operations in a public-private urban setting. City logistics solutions represent a set of value case scenarios that address the requirements of the on-demand economy and the pressures caused by the increase of parcel deliveries while aligning competing interests and creating value for all different stakeholders. Each value case combines a number of measures coined as LEAD Strategies to cover the complete dynamics and complexity of a city’s logistics challenges. The LEAD project uses the STAR Logistics Methodology, which is an adaptation of the STAR Methodology, for the sustainability assessment of LEAD strategies, highly relative to the AM solutions. This close relation, as well as the highly transferability of the STAR methodology, sets the ground to adapt it to the ADMIRAL, as presented in detail in Section 5.

2.3.1.11 TIC4.0

In addition, TIC4.0 (2025) standardisation efforts were reviewed. The TIC 4.0 (Terminal Industry Committee 4.0) initiative aims to bring together representative companies from both the Terminal Operators industry and Port Equipment Manufacturers and Suppliers to collectively work on adopting commonly agreed industry standards, equipment/systems specifications and defining the format and protocols for electronic data exchanges.

Table 10 summarizes the key KPIs identified in the above projects that are related to the ADMIRAL scope and therefore could be used to feed the ADMIRAL KPI pool.

Table 10: Reference KPIs for ADMIRAL in EU projects

Project	Short description (focus)	Reference KPIs for ADMIRAL
NOVELOG	optimizing city logistics and reducing emissions in urban freight transport	sustainability and digitalization, energy consumption, emissions, optimization, emissions reduction
SULPITER	sustainable logistics practices and efficient energy use in supply chains	Sustainability, energy consumption, emissions reduction
SHOW	autonomous vehicle technology in logistics and public transport	sustainability and digitalization, adoption rate of autonomous vehicles, energy efficiency, CO ₂ savings
FENIX	federated architecture for data sharing serving the European logistics community	emissions, operational costs, collaboration, organizational, modal shift, optimization, administration, safety
FOR-FREIGHT	maximise the utilisation of multimodal freight transport capacity and achieve competitive sustainability	emissions, fuel consumption, energy sources, collaboration, productivity, safety
URBANE	support the transition path towards effective, resilient, safe and sustainable last-mile transport	emissions, air pollution, noise level, waste production, sustainability adoption rate, investments, fuel cost, optimization, productivity, employment, safety, society adoption, IT adoption

Project	Short description (focus)	Reference KPIs for ADMIRAL
PLANET	assessing the impact of emerging global trade corridors on the TEN-T network	emissions, operational costs, modal shift, productivity, accessibility, collaboration
PIXEL	sustainable economic growth and environmental impact mitigation towards the Ports of the Future	Air pollution, emissions, noise level, operating costs, organizational, productivity, community impact
e-Ferry	reducing European CO2 emissions and air pollution from waterborne transportation	emissions, noise level, oil pollution, energy reduction, energy cost, employment
LEAD	Digital Twins of urban logistics networks in six TEN-T urban	Emissions, employment, energy consumption, noise level, operational costs, productivity
TIC4.0	Port Terminal Operators industry standardization	Productivity, technology

2.3.2 Selected studies on transport and logistics systems performance measurement

The review of EU-funded research and innovation projects is followed by a comprehensive review of selected studies on transport and logistics systems performance measurement. The studies cover a range of performance indicators, categorized into operational performance, financial performance, service quality, environmental performance, social sustainability, infrastructural sufficiency, and market growth.

Gunasekaran et al. (2001, 2004, 2007) focus on supply chain performance measures and metrics. They identify indicators such as capacity utilization, inventory costs, on-time delivery, customer service, and information sharing. Psaraftis and Panagakos (2012) examine green corridors in European surface freight logistics, highlighting indicators like transport times, reliability, emissions, traffic safety, and congestion. Clausen et al. (2012) explore ICT applications in green corridors, with indicators including loading factor, transport times, greenhouse gases, and bottlenecks. Bosona and Gebresenbet (2013) investigate food traceability in logistics management, focusing on expected output, profit, lead time, waste elimination, and service effectiveness. Debelic et al. (2015) analyse transport corridor logistics and port competitiveness, emphasizing productivity, tariffs, turnaround times, and operator efficiency. McKinnon (2015) studies performance measurements in freight transport for public policy, with indicators such as loading factors, transit times, emissions, and market diversity.

Piotrowicz and Cuthbertson (2015) examine the supply chain performance metrics, identifying distribution costs, on-time delivery, emissions, and health and safety as key indicators. Prause and Schroder (2015) focus on green transport corridor implementation, highlighting throughput, service frequency, energy use, and cooperation intensity. The International Transport Forum (2016) examines the logistics observatory for Chile, with indicators like throughput, costs, reliability, and sectorial data. Morales-Fusco et al. (2017) assesses intermodal freight terminals, focusing on throughput, revenues, cargo security, emissions, and maintenance. The SCOR (Supply Chain Operations Reference) v12 Framework (2017) provides a supply chain operations reference model, with indicators such as cost measures, asset management efficiency, order fulfilment, and market adaptability. Nathanail et al. (2018) develop a sustainability framework for urban freight transportation, emphasizing load factors, planning costs, punctuality, energy consumption, and safety.

Kazancoglu et al. (2018) propose a holistic framework for green supply chain management, with indicators including green manufacturing, logistics performance, environmental costs, and customer satisfaction. Radovic et al. (2018) measure performance in transportation companies in developing countries, focusing on time utilization, fuel cost, damaged vehicle coefficient, and load capacity. The LPI (Logistics Performance Index) 2018 report evaluates trade logistics at the country level, with indicators such as customs efficiency, logistics service quality, timeliness, and infrastructure quality. Rashidi and Cullinane (2019) assess the sustainability of national logistics performance, highlighting goods transport, greenhouse gas emissions, energy use, and job creation. Persdotter Isaksson et al. (2019) examine sustainable logistics performance management, focusing on loading factors, emissions, congestion, and coordination. Karaman et al. (2020) analyse green logistics performance and sustainability reporting, with indicators such as utilization, on-time consignment, emissions, and service frequency. Finally, Islam et al. (2021) review environmental concerns in logistics, emphasizing efficiency, waste reduction, carbon emissions, and resource consumption.

Arabelen and Kaya (2021) assess logistics service quality dimensions, identifying key factors and dimensions through systematic literature analysis and semi-structured interviews. Feng et al. (2025) presents a risk-aware stochastic vehicle trajectory prediction model, focusing on spatial-temporal interaction modelling for improved logistics performance. Additionally, Zhao et al. (2024) evaluates air traffic network resilience, providing insights into operational efficiency and service quality in the logistics sector. Focusing on sustainability issues in logistics Solari et al. (2025), explore sustainable logistics and supply chain management in the post-COVID-19 era, addressing challenges such as the international energy crisis and climate change. Shee Weng (2025) investigates green logistics innovations, examining sustainable transportation and distribution strategies like electric and hydrogen-powered freight transport, sustainable warehousing, and AI-driven routing. Finally, Lee et al. (2023) evaluates the impact of green logistics practices on supply chain performance, emphasizing the role of alternative fuels and circular economy principles.

In summary, these studies (Table 11) collectively highlight the importance of various performance indicators in assessing the efficiency, effectiveness, and sustainability of transport and logistics systems. Key areas of focus include operational efficiency, financial performance, service quality, environmental impact, social sustainability, and infrastructural sufficiency. These indicators help in monitoring and improving logistics processes, ensuring better service delivery, cost management, and environmental stewardship.

Table 11: Selected studies on transport and logistics systems performance measurement

Authors	Impacts/Orientations/Perspectives						
	Operational Performance	Operational Costs & Returns	Service Quality (Level of Service)	Environmental performance	Social Sustainability, Risks & Safety	Infrastructural sufficiency and Maintenance	Market, Cooperation & Growth
APICS Dictionary (2015)	Indicators that enable monitoring the impact of physical and digital services on logistics processes in operational terms	Indicators that enable monitoring the impact of physical and digital services on logistics processes in financial terms	A measure (usually expressed as a percentage) of satisfying demand through inventory or by the current production schedule in time to satisfy the customers' requested delivery days and quantities	Indicators that enable monitoring the impact of physical and digital services on logistics processes in environmental terms	Indicators that enable monitoring the impact of physical and digital services on logistics processes in social terms	Indicators that enable monitoring the impact of physical and digital services on existing infrastructure	Indicators that enable monitoring the impact of physical and digital services on the transport and logistics sector in general
International Transport Forum, 2016	Operational data e.g., Throughput; Productivity; Optimization (i.e., routing)	Financial data e.g., Costs; Rates; Taxes	Duration data e.g., Reliability/Delays; Transit/Delivery times; Dwell time				Sectorial data e.g., Companies; Fleet; GDP Contribution; Labour
Morales-Fusco et al., 2017	Operational performance e.g., Throughput; Productivity; Utilization; Capacity	Financial performance e.g., Revenues and costs; ROI	Service quality e.g., Cargo security/safety; Waiting times; Reliability/Delays; Round trip/turnaround	Environmental performance e.g., Emissions; Footprint; Noise; Alternative fuels use; Dangerous goods	Socio-economic: Safety: e.g., Accidents, Dangerous goods related accidents	Maintenance (vehicles, equipment, infrastructure) e.g., Failures; Faults; Maintenance costs; Corrosion rates	Market e.g., Trading balance; Competition
SCOR v12 Framework also Girjatovičs et al., 2018	Cost measures e.g., SC management costs; Cost of goods Asset Management Efficiency e.g., Cash-to-Cash Cycle Time; Returns on Assets/Working capital		Reliability: e.g., Perfect Order Fulfilment Responsiveness: e.g., Order Fulfilment Cycle Time				

Authors	Impacts/Orientations/Perspectives						
	Operational Performance	Operational Costs & Returns	Service Quality (Level of Service)	Environmental performance	Social Sustainability, Risks & Safety	Infrastructural sufficiency and Maintenance	Market, Cooperation & Growth
			Agility/Flexibility: e.g., Market adaptability				
Nathanail et al., 2018	Vehicles e.g., Load factor; Vehicle utilization	Costs e.g., Planning and managerial; Investment; Wages; Warehousing; Personnel	Level of service e.g., Punctuality; Quantity; Quality; Visibility	Energy: e.g., Energy consumption Environment: e.g., Air quality (CO ₂ , CH ₄ , N ₂ O); Noise level	Safety and security e.g., Accidents (Fatalities, Injuries)		
Kazancoglu et al., 2018	Operational performance e.g., Efficiency; Green manufacturing, Green packaging; Green/eco design Logistics performance e.g., Green logistics; Reverse logistics; Green purchasing	Economic/financial performance e.g., Cost oriented; Revenue oriented	Operational performance e.g., Quality	Environmental performance e.g., Emissions; Energy consumption; Business waste; Environmental cost; (Increasing) environmental revenues			Marketing performance e.g., Customer satisfaction; Cooperation/collaboration with customers; Marketing measures Organizational performance e.g., Green image; Environmental management; Green information systems

Authors	Impacts/Orientations/Perspectives						
	Operational Performance	Operational Costs & Returns	Service Quality (Level of Service)	Environmental performance	Social Sustainability, Risks & Safety	Infrastructural sufficiency and Maintenance	Market, Cooperation & Growth
Radovic et al., 2018	Operational performance e.g., Coefficient of time utilization; Number of km per vehicle; Number of routes per vehicle; Number of routes per driver; Number of tours per vehicle; Coefficient of working vehicle utilization; Average number of routes per day; Number of tours per driver; Number of tours per route; Coefficient of weight utilization; Load capacity per month; Number of routes per employer; Coefficient of utilization in pallets; Coefficient of parked vehicle; Average number of tours per day	Operational performance e.g., Costs per driver; Fuel cost per total km; Cost per realized route; Cost per km; Costs per driver				Operational performance e.g., Coefficient of damaged vehicle	

Authors	Impacts/Orientations/Perspectives						
	Operational Performance	Operational Costs & Returns	Service Quality (Level of Service)	Environmental performance	Social Sustainability, Risks & Safety	Infrastructural sufficiency and Maintenance	Market, Cooperation & Growth
LPI 2018	Policy regulation e.g., efficiency of customs and border management Supply chain performance e.g., Ease of arranging competitively priced international shipments (cost)		Policy regulation: e.g., Competence and quality of logistics services Supply chain performance: e.g., Timeliness (time); Tracking and tracing (reliability)			Policy regulation e.g., quality of trade- and transport-related infrastructure	
Rashidi & Cullinane, 2019	Logistics production criterion e.g., Goods transport			Environmental criterion: e.g., Greenhouse gas emissions GHGE) Logistics production criterion: e.g., Energy use	Logistics production criterion e.g., rate of job creation		
Persdotter Isaksson et al., 2019	Efficiency variables* e.g., Loading factor; Optimization (i.e., routing); Coordination		Service variables* e.g., Fill rate	Environmental variables* e.g., Emissions; Pollution; Energy consumption; Fuel types; Transport modes		Infrastructural metrics* e.g., Congestion	
Karaman et al., 2020	Efficiency* e.g., Utilization; Optimization (i.e., routing)		Quality of logistics services* e.g., On-time consignment; Lead times; Waiting times; Service frequency; Visibility	Environmental aspects* e.g., Emissions; Energy and fuel consumption		Infrastructural aspects* e.g., Quality; Efficiency; Congestion	

Authors	Impacts/Orientations/Perspectives						
	Operational Performance	Operational Costs & Returns	Service Quality (Level of Service)	Environmental performance	Social Sustainability, Risks & Safety	Infrastructural sufficiency and Maintenance	Market, Cooperation & Growth
Islam et al., 2021	Operational performance e.g., efficiency, effectiveness	Costs		Environmental performance e.g., Reduce waste; Carbon emissions (CO2, greenhouse gas GHG); Resource consumption (fossil fuel energy)			
Arabelen and Kaya (2021)	Efficiency, effectiveness		Customer satisfaction, Service reliability, Responsiveness				
Feng et al. (2025)	Vehicle trajectory prediction accuracy; Route optimization	Cost savings from optimized routes	Improved delivery times; Reliability	Reduced fuel consumption; Lower emissions	Enhanced safety through risk-aware modelling		
Zhao et al. (2024)	Network resilience; Operational efficiency	Cost efficiency	Service reliability; Timeliness				
Solari et al. (2025)	Efficiency in logistics operations	Cost management	Service quality improvements	Emissions reduction; Energy efficiency	Addressing social sustainability challenges		Growth in sustainable logistics practices
Shee Weng (2025)	Innovations in transportation and distribution	Cost savings from sustainable practices	Enhanced service quality	Reduced emissions; Use of alternative fuels	Improved safety standards		Growth in green logistics market
Lee et al. (2023)	Efficiency improvements	Cost reductions	Improved delivery performance	Emissions reduction; Adoption of circular economy principles			Market competitiveness

2.3.3 Pool & Categorization of Sustainability KPIs

Following the review of the EU-funded projects, the extant literature and the previous work performed in ADMIRAL (e.g., Deliverable 2.2), Deliverable 2.4 reports a comprehensive list of 428 logistics KPIs (including metrics), as presented in Annex I. The KPIs are divided into the ADMIRAL impact categories (based on the analysis on ADMIRAL impact categories that follows in section 3), assigned additional subcategory labels for further potential interpretation.

This pool of KPIs is used to feed the undergoing work of Task 6.1 and WP6, to identify the KPIs that are more related to ADMIRAL (1st level filtering through pilot site validation) and then create the extended list of KPIs (2nd level filtering based on the mapping of ADMIRAL requirements in section 3.1) (see section 3.2) that will feed the social and environmental risk analysis (see section 4.1), the regulatory compliance analysis (see section 4.2) and the definition of the Green Port Certification specifications (see section 7). Further filtering of the extended list creates the core list of the ADMIRAL KPIs (3rd level) to be used in the Bayesian analysis and the STAR model adaptation (see section 5) during this work and provide input for Del. 6.1’s milestones.

Figure 4 presents the above process highlighting the methodological steps adopted for defining the ADMIRAL KPIs and the analyses that they feed.

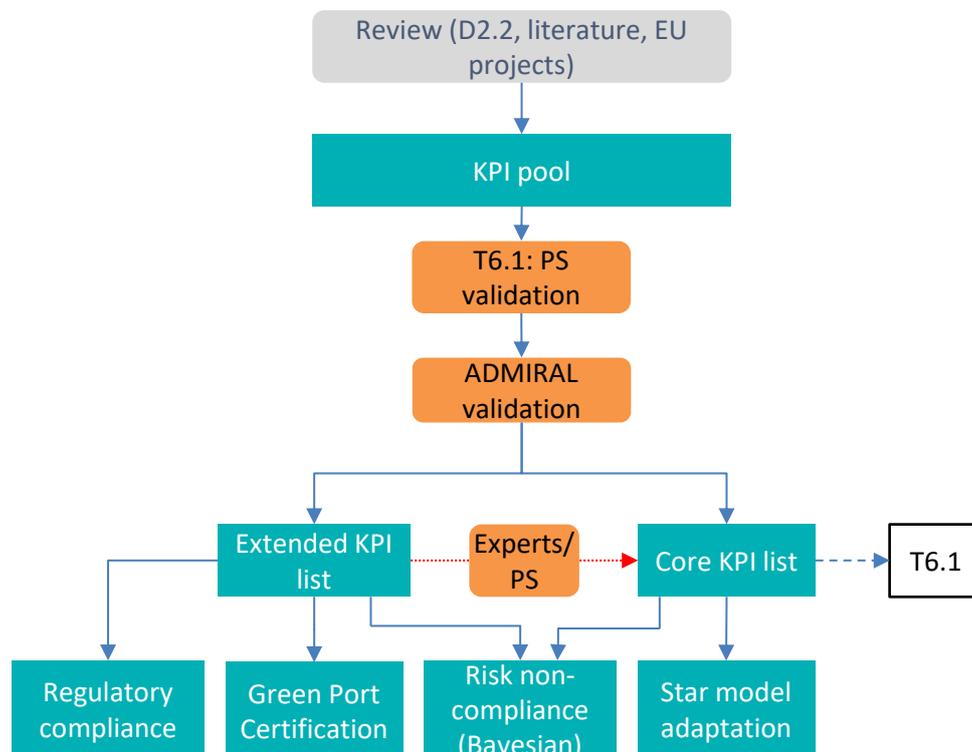


Figure 4: ADMIRAL KPIs identification and selection

2.4 Key point in logistics sustainability requirements

Chapter 3 has provided a comprehensive examination of the current state, challenges, and future directions for sustainable logistics. This analysis assisted in identifying the performance measurement criteria (KPIs) and examine the regulatory aspects within the EU context. The key takeaways from this chapter can be summarized as follows:

- **Sustainability Levels and Gaps:** Despite significant advancements in sustainable logistics, several gaps remain, including data reliability, regulatory compliance, cost pressures, and technological integration.
- **European Strategies:** The EU's Green Deal and Sustainable and Smart Mobility Strategy set ambitious targets for reducing greenhouse gas emissions and promoting sustainable practices across all transport modes. These strategies are essential for guiding the logistics sector towards climate neutrality by 2050.
- **Role of Technology:** Technology plays a pivotal role in sustainability transitions. Digital solutions such as blockchain, IoT, and optimization tools are critical for enhancing traceability, transparency, and efficiency in logistics operations. However, the slow adoption of these technologies remains a challenge.
- **Regulatory Framework:** The regulatory landscape is complex and evolving, with numerous legislative acts aimed at promoting sustainability in logistics. Key regulations include the European Climate Law, the Fit for 55 Package, and the Sustainable and Smart Mobility Strategy. Understanding and navigating these regulations is essential for companies striving to achieve sustainability goals.
- **Performance Evaluation Criteria:** The chapter introduces a comprehensive framework for evaluating logistics sustainability, including key performance indicators (KPIs) that cover various dimensions such as environmental, economic, social, and technological aspects. 428 KPIs were identified as pool for creating the ADMIRAL KPIs to be used in the following analyses, as Figure 5 shows.

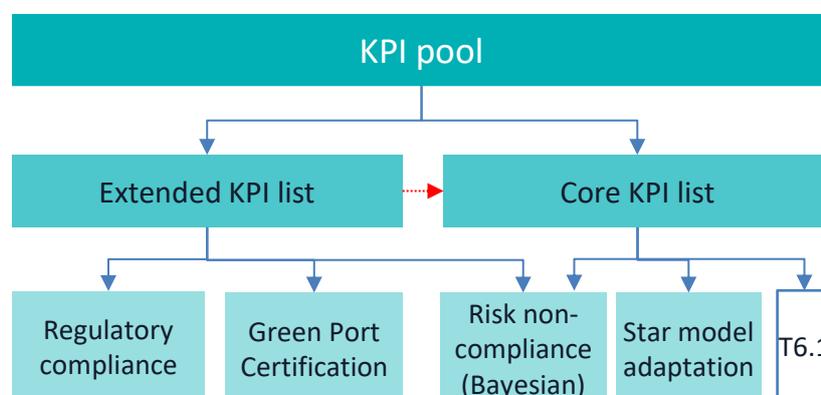


Figure 5: ADMIRAL KPIs framework

3 Expected Sustainability Impacts in ADMIRAL

This section maps the expected sustainability impacts within the ADMIRAL project, focusing on the alignment of ADMIRAL's impact categories with its sustainability requirements. It explores the relationship between these categories and the project's goals, ensuring consistency with the Grant Agreement and the proposed KPIs. The identified categories assist in the update of the KPI pool list (Annex I). The pool of KPIs through a two-level filtering (pilot site validation, ADMIRAL impact categories) produces the extended and the core list of the ADMIRAL KPIs to be used in the following analyses (Sections 4, 5, 6 and 7).

3.1 Mapping of ADMIRAL Sustainability Requirements

This section investigates the relationship between the ADMIRAL impact categories and the ADMIRAL sustainability requirements to ensure the consistency of the analysis with the project Grant Agreement and the alignment of the proposed KPIs with the project aims. It additionally explores the relation with Task 6.1's findings to cross-check for any necessary adjustments. The steps followed for the current analysis are:

- STEP 1.** Identify ADMIRAL impact requirements in the description of work (Grant Agreement description).
- STEP 2.** Categorize the impact requirements in impact categories.
- STEP 3.** Finalize the ADMIRAL Impact Categories.
- STEP 4.** Communicate and cross-check the results with Deliverable 6.1.

Table 12 summarizes the results of following those steps.

Table 12: ADMIRAL Impact Categories identification

ADMIRAL IMPACTS IDENTIFICATION (GA)	ADMIRAL Impact categories		Impact categories (D6.1)
	GA	D2.4	
<p>Various</p> <ul style="list-style-type: none"> • SO4: Develop and pilot solutions that have altogether energy and emission reduction potential higher than 30% • SO2: Develop solutions that enable better utilization of current assets and existing infrastructure to decrease energy use and emissions without significant investments needs • In addition, because the marketplace brings the users and applications together into one place it increases societal resilience, e.g., if one user or application fails a replacement is easier found through the marketplace. • Societal benefit: A significant decrease in CO2 emissions and increased supply chain operational efficiency. New type of collaboration and process optimization can be achieved globally, leading up to 40% reduction in emissions and roughly 20-40% reduced cost of transport • From a technological perspective, the workforce qualification is essential • This includes the analysis of industry 5.0 issues, namely on how companies and stakeholders are dealing with technological changes and adapting their operating systems for digitization, automation and the creation of new services • Objective is enabling multimodal marketplace trading transactions for logistics buyers and sellers <p>Impact pathway for a multimodal & green digital corridor between Sines and Madrid</p> <ul style="list-style-type: none"> • Positive consequences in terms of synchronization and collaboration, greater agility, digital alignment with the authorities and reduction of administrative tasks • Significant impact in Sines Fit for 55 strategies, towards reaching 55% carbon footprint reduction by 2030 <p>Impact pathway for Slovenian-Croatian pilot</p> <ul style="list-style-type: none"> • Informed procurement of logistics services by end users • Redistribution of peak demand onto external stakeholders • Improved overall planning and cargo occupancy <p>The impact pathway for Lithuanian pilot</p> <ul style="list-style-type: none"> • CO2 emission is reduced by at least 20 % at a network level <p>Impact pathway for AI-based cargo planning tool (Finnish pilot)</p> <ul style="list-style-type: none"> • not only reduce the resource requirements of port cargo handling operations by 20%, but correspondingly increase the port throughput capacity and reduce the unloading times of trains and trucks at the Hamina Kotka pilot port • a productivity increase of 20% directly leads to a 15% reduction in port emissions per handled ton of cargo 	<p>Environmental</p> <ul style="list-style-type: none"> • emission reduction • multimodal transport adoption <p>Energy</p> <p>Economic</p> <ul style="list-style-type: none"> • cost of transport • Investment needs <p>Business & Governance</p> <ul style="list-style-type: none"> • Collaboration • Administration • New business and governance models • marketplace usage • multimodal transport adoption <p>Operational & productivity</p> <ul style="list-style-type: none"> • Societal resilience • Planning • Informed procurement • Peak demand redistribution • Resource requirements (port) 	<p>Environmental</p> <ul style="list-style-type: none"> • Emissions • Waste • Awareness • Green strategies <p>Energy</p> <ul style="list-style-type: none"> • Consumption • Optimization • Systems/materials • Adoption • Economic <p>Economic</p> <ul style="list-style-type: none"> • Operating cost • Energy cost • Fees & charges • Financial • Services <p>Business & Governance</p> <ul style="list-style-type: none"> • New models & collaboration • Administration • Service level <p>Operational & productivity</p> <ul style="list-style-type: none"> • Optimization 	<p>Logistics Sustainability Index (LSI)</p> <ul style="list-style-type: none"> • Emissions Reduction • Energy Consumption • Multimodal Transport Adoption <p>Logistics Maturity Index (LMI)</p> <ul style="list-style-type: none"> • Technology Readiness • Adoption Rate of Low-Emission Solutions • Level of Integration in Supply Chains <p>Logistics Transferability Index (LTI)</p> <ul style="list-style-type: none"> • Regional Policy Alignment • Infrastructure Compatibility • Readiness of Local Stakeholders

ADMIRAL IMPACTS IDENTIFICATION (GA)	ADMIRAL Impact categories		Impact categories (D6.1)
	GA	D2.4	
<ul style="list-style-type: none"> A significant decrease in CO2 emissions (app. 15-25%) and increased supply chain operational efficiency depending on the tool adoption rate <p>The impact pathway for the marketplace</p> <ul style="list-style-type: none"> 400 logistic chains starting to use the marketplace leading up to 40% reduction in emissions and roughly 20-40% reduced cost of transport Unique contribution of the project is enabling the reduction of about 775 Million Tons of CO2 from the logistic chains. for every ton CO2 reduced, 157€ is saved Cost of implementation: - 39,5 € / metric tons CO2 reduced Significant potential to reduce emissions. With multimodal marketplace focusing on low emission transportation, new type of collaboration and process optimization can be achieved globally, leading up to 40% reduction in emissions and roughly 20-40% reduced cost of transport (percentages depending on the part of the logistics chain naturally). <p>Impact pathway for business and governance models</p> <p>Scale and significance of the project's contribution</p> <ul style="list-style-type: none"> we expect to have 20-30% decrease in CO2 emissions additional 20% savings of CO2 emissions <p>Task 6.4</p> <p>A set of appropriate KPI will be associated with impacts due to increased connectivity level, increased operational status, job loss, land use, urban space consumption, space cost changes, etc. Subsequently, with the support of training programs, various scenarios for further adaptation approaches will be developed. The future adaptation scenarios will also support existing professions and occupations (respecting the development of skills, capabilities, competencies, etc.) to transform these jobs/professions into new concepts and improve job opportunities in the freight transport and logistics sectors. This task will correspondingly deal with the assessment of equity issues that might be increased by digital solutions (operational aspects, connectivity, and optimization) for users of freight transport services by UPM and NORM. Various methods (such as workshops, focus groups, interviews, etc.) are used to analyse the digital capabilities of users and possible barriers, in particular vulnerable user groups that would find it difficult to use such digital solutions.</p>	<ul style="list-style-type: none"> Port throughput capacity <p>Societal</p> <ul style="list-style-type: none"> Societal resilience job creation & loss professions and occupations (skills & competencies) equity (digital solutions adoption) land use urban space consumption space cost changes <p>Technological</p> <ul style="list-style-type: none"> Digital alignment workforce qualification (skills & competencies) operating systems adaptation 	<ul style="list-style-type: none"> Capacity optimization Routing optimization Port operations optimization Delivery efficiency Time efficiency Modal share Administration Tracking & tracing Service level Systems/methods <p>Societal</p> <ul style="list-style-type: none"> Employment Health & safety Inclusiveness Societal resilience Competence building Service perception <p>Technological</p> <ul style="list-style-type: none"> Technology adaptation Services Security Innovation Technology readiness 	

Figure 6 points out graphically the alignment achieved on impact categories identification with the project GA description and aims.

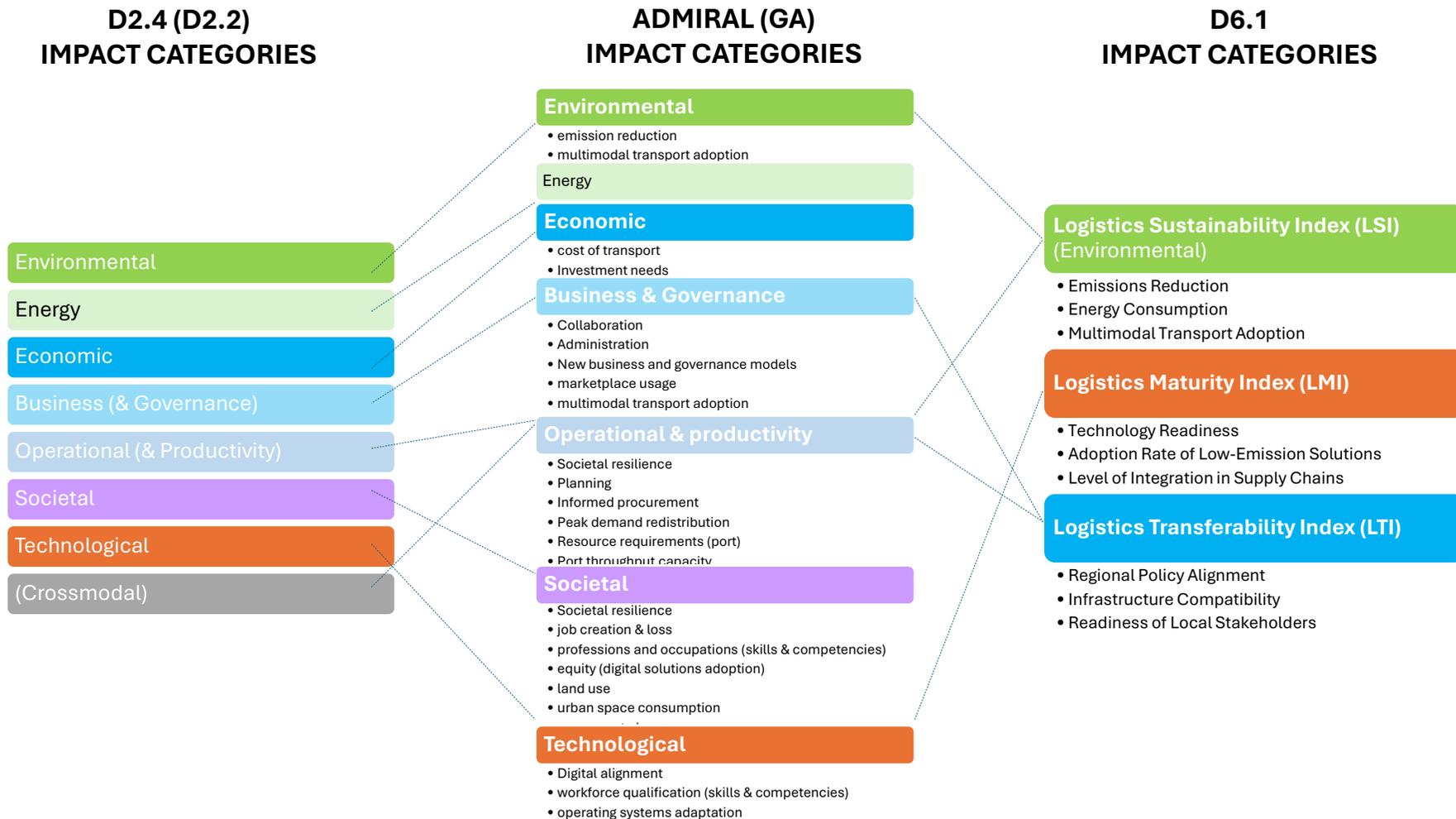


Figure 6: ADMIRAL Impact Categories alignment

The impact categories were also reviewed in relation to the categories used in Deliverable 2.2, to maintain consistency across the project. These categories were slightly adjusted to include and better label the additional KPIs. Moreover, additional sub-categories were introduced to facilitate potential further analysis, as part of the WP6 analysis. The pool of KPIs as presented in Annex I incorporates this categorization. The number of KPIs identified in each one is presented in Table 13.

Table 13: ADMIRAL impact categories

ADMIRAL impact categories	Sub-categories	No of KPIs
Business & Governance (27 KPIs)	New models & collaboration	14
	Administration	6
	Service level	7
Economic (33 KPIs)	Energy cost	8
	Fees & charges	6
	Operating cost	12
	Financial	2
	Services	5
Energy (80 KPIs)	Consumption	13
	Optimization	7
	Systems/materials	14
	Adoption	24
	Resources	19
	Economic	3
Environmental (48 KPIs)	Emissions	22
	Waste	7
	Awareness	8
	Green Strategies	11
Operational & Productivity (127 KPIs)	Modal share	9
	Optimization	13
	Capacity optimization	16
	Routing optimization	6
	Delivery efficiency	20
	Systems/methods	4
	Administration	4
	Tracking & tracing	2
	Time efficiency	24
	Service level	10
Port operations optimization	19	
Societal (59 KPIs)	Employment	10
	Health & safety	11
	Inclusiveness	11
	Societal resilience	17
	Competence building	5
	Service perception	5
Technological (54 KPIs)	Technology adaptation	27
	Services	16
	Security	2
	Innovation	5
	Technology readiness	4

3.2 Sustainability KPIs and Metrics validation with pilot sites

Task 2.4 provided a comprehensive list of over 400 logistics KPIs, categorized into seven main groups: Business & Governance, Economic, Environmental, Energy, Operational & Productivity, Societal, and Technological. These KPIs were identified from EU-funded projects and existing literature. They are specifically selected to directly address the impacts of the ADMIRAL project (Annex I).

Specifically, a list of 428 KPIs has been developed, divided into the following impact categories and subcategories (Table 14):

Table 14: ADMIRAL impact categories

Environmental	Energy	Economic	Business & Governance
<ul style="list-style-type: none"> • Emissions • Waste • Awareness • Green strategies 	<ul style="list-style-type: none"> Consumption Optimization Systems/materials Adoption Economic 	<ul style="list-style-type: none"> Operating cost Energy cost Fees & charges Financial Services 	<ul style="list-style-type: none"> New models & collaboration Administration Service level
Societal	Technological	Operational & productivity	
<ul style="list-style-type: none"> • Employment • Health & safety • Inclusiveness • Societal resilience • Competence building • Service perception 	<ul style="list-style-type: none"> • Technology adaptation • Services • Security • Innovation • Technology readiness 	<ul style="list-style-type: none"> • Optimization • Capacity optimization • Routing optimization • Port operations optimization • Delivery efficiency • Time efficiency • Modal share • Administration • Tracking & tracing • Service level • Systems/methods 	

This pool of KPIs supports the ongoing work of Task 6.1 and WP6 by identifying the KPIs most relevant to ADMIRAL. The first level of filtering is conducted through pilot site validation, followed by the creation of an extended KPI list through a second-level filtering process based on the mapping of ADMIRAL requirements (see Sections 3.1-3.2). The extended KPI list is then used for the social and environmental risk analysis (Section 4.1), regulatory compliance analysis (Section 4.2), and the definition of Green Port Certification specifications (Section 7). A further filtering process refines this extended list into the core set of the ADMIRAL KPIs (third level), which is applied in Bayesian analysis and STAR model adaptation (Section 5). This final selection also serves as input for the milestones of Deliverable 6.1. Sections 3.2.1-3.2.3 present and analyse this process in detail.

3.2.1 Pilot Site validation (1st level filtering)

According to Deliverable 6.1, the KPIs were prioritized through a collaborative process involving stakeholders from the ADMIRAL consortium. During a dedicated workshop held in Vilnius, Lithuania, on May 30, 2024, participants from the project pilot sites and technical teams assessed the KPIs' alignment with the project's impact areas and validated the feasibility of data collection across pilot sites. This prioritization ensured that the most important and impactful metrics were emphasized and

would be used to track the ADMIRAL project’s success. By combining a literature review, best practices from EU-funded projects, and a collaborative prioritization process, ADMIRAL has developed a robust and comprehensive set of KPIs. These KPIs effectively measure the project's contributions to logistics sustainability, emissions reductions, and technological advancements.

The Task 6.1 KPI list (Annex II) has been defined based on ADMIRAL’s core objectives: reducing emissions, improving logistics efficiency, increasing transparency in data sharing, and promoting technological integration across multimodal logistics operations. The KPIs have been categorized into three groups (Indexes): Logistics Sustainability Index (LSI), Logistics Maturity Index (LMI), and Logistics Transferability Index (LTI) (for more details please advise Deliverable 6.1).

3.2.2 ADMIRAL validation through identified impact categories (2nd level filtering)

After consultation with the ADMIRAL partners and other industry experts, the list in Annex II was further narrowed down based on the criterion of higher measurability by the ADMIRAL pilot stakeholders. In addition, some KPIs’ titles were refined, and a short description was added along with measurement units to assist understanding among partners and ensure a common perception of what each KPI means and measures. Table 15 presents the result of this process, which also feeds directly the Bayesian Network Analysis (Section 4.1).

Table 15: Extended ADMIRAL KPIs list (Task 6.1)

#	KPI	Short description	Measurement unit
1	Technology Readiness	Readiness of ADMIRAL solutions and industry stakeholders for broader implementation across the logistics industry.	TRL 1-9
2	Cost per shipment	The unit cost of shipments with the use of AM services.	Euro/shipment
3	GHG emissions per shipment	The environmental impact of transport operations per shipment.	t CO2e/shipment
4	Willingness to pay for green logistics	Share of users willing to pay for green logistics.	% of users willing to pay for green logistics services
5	Solution integration	The ratio between the number of integrated and total systems.	systems integrated/per total systems across a supply chain (%)
6	Professions and occupations	Number of new jobs opportunities in the freight transport and logistics sector.	New jobs/month
7	Collaboration among stakeholders	Number of new collaborations among stakeholders that occur after the use of the marketplace.	New collaborations/month
8	Number of Accidents	Measures on-site security and safety.	Accidents/month
9	Customer satisfaction	Level of customers’ satisfaction by the use of the ADMIRAL Marketplace (AM) - Significant or optimal usefulness with current and potential services.	% (satisfied/total)

#	KPI	Short description	Measurement unit
10	Shipment turnaround time	Overall time from shipment order to delivery to the end-user.	Time (hours or days)
11	Shipment load factor	Shipment capacity utilization.	Used/available capacity (%)
12	Shipment total costs	Total Managerial and Operational costs associated to the use of AM services.	Euro
13	Market Penetration	The number of companies or logistics providers integrating the AM solutions along their supply chains.	Market share
14	Fulfilled shipments	Shipments planned and fulfilled at a specified timeframe.	Number of shipments/month
15	Shipment delivery reliability	The share of shipments that were successfully delivered on-time.	Actual/planned deliveries (%)
16	Public acceptance	Public/society perception on the importance of AM towards green logistics (behavioural change).	% people willing to adopt green services
17	Stakeholder acceptance	Number of companies using AM or collaborating within the platform.	% of supply chain stakeholders willing to adopt green logistics services
18	Vehicle type	The type of vehicle used in transport operations.	EURO
19	Empty running	Amount of truck kilometres travelling empty.	empty km/total km
20	Shipment visibility	Share of disruptions or inefficiencies in the transmission of data within users and the AM.	Tracked/total shipments (%)
21	Lack of knowledge about stakeholders' requirements	Supply chain awareness - Perception of stakeholders for the level that the AM responds to their technological requirements.	share of supply chain stakeholders claiming to not understand what AM services offer (%)
22	Changes in legislation (national or EU level)	Changes in legislation that considerably alter the way the transport and logistics industry operates (e.g., eFTI, Scope 3).	Yes/No

3.2.3 Final filtering (3rd level)

Finally, the findings from the KPI prioritization workshop held in Vilnius on May 30, 2024, provided valuable insights into ADMIRAL's most critical performance metrics. During the session, participants engaged in detailed discussions and assessments to prioritize the KPIs based on their alignment with ADMIRAL's core objectives, and pilot site feasibility/data availability. The outcomes of the workshop established a clear and actionable set of KPIs that will guide the project's performance evaluation in terms of emissions reductions, operational efficiency, and technological integration across the pilot sites (ADMIRAL Del. 6.1, 2024). The prioritized KPIs will serve as the foundation for measuring ADMIRAL's progress and impact, ensuring that the project delivers measurable sustainability and

innovation outcomes. Further discussion within ADMIRAL, with logistics experts and the pilot leaders, during tactical WP meetings, narrowed down the scope of the KPIs to sustainability, while also exploring the social dimension of the ADMIRAL Marketplace.

The following KPIs have been selected as core measurements of the successful implementation of the project ADMIRAL and the successful application of the ADMIRAL Marketplace. Each selected KPI is designed to provide measurable and actionable insights into ADMIRAL's progress toward its objectives, ensuring that data collected is relevant and directly aligned with the project's vision of a greener, more efficient, and technologically integrated logistics network.

KPI.1: Unit Emission of Delivery. This KPI measures the emissions generated per unit of cargo delivered, expressed as kg of CO₂ per ton of cargo or kg of CO₂ per kilometre-travelled. This KPI is central to ADMIRAL's mission of reducing emissions in logistics operations. It provides a direct measure of the environmental impact of transport operations, helping to evaluate the effectiveness of ADMIRAL's strategies in reducing emissions through multimodal logistics solutions, including the adoption of low-emission vehicles and optimized routing.

KPI.2: Unit Cost of Delivery. This KPI tracks the total cost incurred per unit of cargo delivered, considering key factors such as fuel consumption, labour costs, and operational efficiencies. This KPI allows ADMIRAL to assess the financial viability and cost-effectiveness of its logistics solutions. By monitoring the unit cost of delivery, ADMIRAL can identify opportunities for improving cost efficiencies through better logistics coordination, more efficient transport modes, and optimized use of resources, thereby supporting its goal of providing sustainable, cost-effective logistics solutions.

KPI.3: Willingness to Pay for Green Urban Logistics. This KPI measures the extent to which customers (both businesses and consumers) are willing to pay a premium for logistics services that prioritize environmental sustainability and green logistics practices. This KPI reflects the growing market demand for environmentally friendly logistics solutions. It is critical for assessing the market acceptance and potential for ADMIRAL's green logistics marketplace. The willingness to pay a premium for sustainable logistics services is a strong indicator of the project's potential to drive the adoption of eco-friendly logistics practices across Europe.

KPI.4: Professions and occupations. This KPIs measures the number of new jobs opportunities in the freight transport and logistics sector. It is based on the needs of development of skills, capabilities, competencies, etc. to transforms jobs/professions into new jobs opportunities.

KPI.5: Collaboration among stakeholders. This KPI measures the number of new collaborations among stakeholders that that occur after the use of the marketplace.

KPI.6: Technology Readiness (Start-to-End TRL). This KPI tracks the TRL progression of logistics and transportation technologies, from initial concept and development stages to full deployment and operational use. The TRL KPI is essential for evaluating ADMIRAL's role in advancing the maturity of logistics technologies. By assessing the progression of technologies such as green logistics vehicles, autonomous systems, and digital platforms, this KPI provides a clear indication of how well ADMIRAL is driving innovation and technology adoption. It also highlights the readiness of these solutions for

broader implementation across the logistics industry, contributing to their long-term integration into European logistics networks.

KPI.7: Solution Integration and Standardization. This KPI measures the degree to which the new logistics solutions developed within ADMIRAL are integrated into existing logistics systems and standardized across the industry. It also assesses the level of interoperability between different systems and technologies within the logistics sector. For ADMIRAL’s solutions to have lasting impact, they must not only be innovative but also practical and widely implementable. This KPI ensures that the solutions developed—such as multimodal coordination tools, low-emission vehicle technologies, and digital platforms—are adaptable to existing logistics operations and can be easily integrated into broader industry practices. The focus on standardization and interoperability is crucial for ensuring the scalability of ADMIRAL’s solutions, enabling their adoption by a range of logistics providers across EU.

These core KPIs (Table 16) are designed to track and measure ADMIRAL’s contributions to achieving its sustainability goals and explore social implication. Through careful monitoring of these indicators, ADMIRAL will gain valuable insights into the impact of its innovative logistics solutions, including emissions reduction, cost efficiency, consumer demand for green logistics, technological advancement, and integration within the logistics industry. The ongoing evaluation of these KPIs will allow ADMIRAL to adapt its strategies and ensure that it delivers tangible, measurable outcomes that contribute to a more sustainable and efficient logistics ecosystem across Europe.

Table 16: ADMIRAL KPIs core list

#	KPI	Sustainability Dimension	Measurement
KPI.1	Unit Emission of Delivery	Environmental	Unit Emission of Delivery = Total Emissions (kg of CO2) / Total Delivery Units (e.g., tons of cargo or km travelled)
KPI.2	Unit Cost of Delivery	Economic	Unit Cost of Delivery = Total Delivery Cost / Total Delivery Units (e.g., tons of cargo or km travelled)
KPI.3	Willingness to Pay for Green Urban Logistics	Economic	[Average amount consumers are willing to pay for green services / Average amount consumers are willing to pay for standard services] x 100
KPI.4	Professions and occupations	Social	New jobs opportunities (Survey based)
KPI.5	Collaboration among stakeholders	Governance	Number of new collaborations among stakeholders (Survey addressing stakeholders/users)
KPI.6	Technology Readiness	Technology maturity	End TRL - Start TRL
KPI.7	Solution Integration and Standardization	Technology transferability	Some of scores for each criterion / total number of criteria

3.3 Summarizing ADMIRAL framework key points

The ADMIRAL project aims to establish a robust framework for measuring and evaluating logistics sustainability. By aligning impact categories with sustainability requirements and developing a comprehensive KPI framework the project is well-positioned to achieve its sustainability goals.

The key points of this section can be briefly summarized as follows:

- **Alignment with Sustainability Requirements:** The ADMIRAL project has successfully aligned its impact categories with its sustainability requirements, ensuring consistency with the project Grant Agreement and the proposed KPIs.
- **Comprehensive KPI Framework:** A comprehensive list of over 400 logistics KPIs was developed, categorized into seven main areas: Business & Governance, Economic, Environmental, Energy, Operational & Productivity, Societal, and Technological.
- **Stakeholder Consultation and Validation:** The KPIs were refined through consultations with ADMIRAL and experts and pilot sites, ensuring higher measurability and relevance.
- **Performance Evaluation:** The final set of KPIs (core) was prioritized through a collaborative process involving stakeholders from the ADMIRAL consortium. This prioritization ensures that the most important and impactful metrics are emphasized for tracking the project's success.

4 ADMIRAL Compliance Analysis

This section provides a holistic approach to ADMIRAL Marketplace compliance by identifying potential risks related to critical dimensions of social/environmental, and regulatory factors. It begins with employing a Bayesian Network analysis for the first dimension and continues with Regulation Compliance analysis for the second. Both analyses use the ADMIRAL KPI lists produced in Section 3.2, and their outcomes will contribute to the development of the Global Sustainability Rating model in Section 6.1.

4.1 Social and Environmental Risks analysis

Bayesian Network (BN) risk analysis is a robust probabilistic modelling technique widely applied across various domains such as finance, healthcare, cybersecurity, and engineering. Named after Reverend Thomas Bayes, this method utilizes Bayes' theorem to update the probability of an event based on new evidence. Bayesian Networks, as graphical models, represent a set of variables and their conditional dependencies through a Directed Acyclic Graph (DAG), enabling detailed risk assessment and decision-making in complex systems (Fenton & Neil, 2018).

Bayesian Network risk analysis is instrumental in modelling complex systems and integrating both qualitative and quantitative data. Key applications include:

- **Risk Identification and Assessment:** BNs are effective tools for identifying potential risks and evaluating their likelihood and impact. By modelling the relationships among various risk factors, BNs provide a comprehensive understanding of the risk landscape. This can include assessing the risks of adopting new technologies, the uncertainty around emission reductions, or the potential impacts of regulatory changes.
- **Decision Support:** BNs aid in decision-making by quantifying the probabilities of different outcomes and evaluating the effectiveness of various mitigation strategies. This enables decision-makers to prioritize actions and allocate resources efficiently. For example, a company may use a BN to decide which sustainable transport solutions to invest in based on the risk of failure or inefficiency, enabling more informed decisions that align with long-term sustainability goals.
- **Scenario Analysis:** BNs support scenario analysis by simulating the effects of different risk factors and interventions. This helps organizations understand the potential consequences of various decisions and develop robust risk management strategies. Through scenario analysis, businesses can explore different strategies, assess the likelihood of achieving specific outcomes, and develop effective risk management strategies tailored to specific operational or environmental objectives.
- **Dynamic Risk Management:** BNs are especially useful for managing risks in dynamic environments, where risks and their interdependencies evolve over time. By continually updating the network with new data, organizations can maintain an up-to-date risk profile and respond proactively to emerging threats. This dynamic approach is vital in rapidly changing industries, ensuring that organizations remain agile and capable of adapting to new challenges in real time.

Bayesian Networks as a Tool for Risk Assessment

BNs are a probabilistic modelling approach based on Bayes' Theorem, enabling a structured assessment of risks by integrating conditional probabilities. This methodology is particularly relevant for evaluating complex risk landscapes, such as those addressed in sustainability-focused projects. By capturing dependencies between various risk factors, BNs provide a systematic framework for analysing uncertainties and their potential impact.

Advantages of Bayesian Networks

BNs are a widely used method for risk analysis and decision-making in complex systems for the provide a wide set of key advantages in various applications.

Flexibility: BNs can model a wide range of risk factors and their interdependencies, making them suitable for complex systems.

Integration of Data: BNs can incorporate both qualitative expert judgments and quantitative data, providing a holistic view of risks.

Transparency: The graphical representation of BNs makes it easy to understand and communicate the relationships between different risk factors.

Probabilistic Reasoning: BNs provide a rigorous framework for probabilistic reasoning, allowing for more accurate and reliable risk assessments.

Significance in ADMIRAL

In the ADMIRAL project, Bayesian Networks (BNs) provide a structured approach to modelling complex interdependencies among key sustainability, operational, and technological factors. By leveraging BNs, ADMIRAL enables data-driven risk assessment, visualizing probabilistic relationships and quantifying sustainability noncompliance risks in multimodal low-emission transport chains. This methodology supports the project's systemic socio-technical approach, guiding decision-making for emission reduction, efficiency improvements, and regulatory compliance.

4.1.1 Structure of Bayesian Networks:

To effectively understand Bayesian Networks, it is essential to grasp a few key concepts that form the foundation of their structure and functionality. These concepts are central to how Bayesian Networks model relationships and assess risks in complex systems. Below are the key elements that define the structure and operations of Bayesian Networks.

- **Nodes and Edges:** In a Bayesian Network, nodes represent random variables that can be either discrete or continuous. The edges (arrows) connecting the nodes signify conditional dependencies. If there is an edge from node A to node B, node A is the parent of node B, and B is conditionally dependent on A.
- **Conditional Probability Tables (CPTs):** Each node in the network is associated with a Conditional Probability Table, which quantifies the influence of parent nodes on the node itself. The CPT specifies the probability of each state of a node, given the states of its parent nodes.

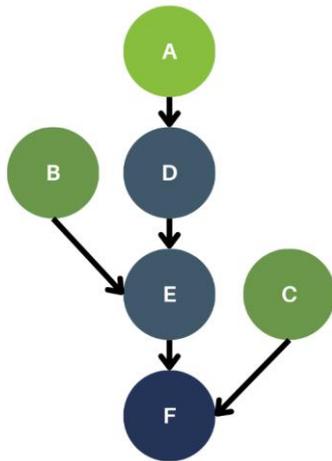
- **Inference:** Bayesian Networks allow for probabilistic inference, which involves computing the posterior probabilities of certain variables given observed evidence. This is particularly useful for risk analysis, as it enables the updating of risk assessments as new information becomes available.

BNs are represented as **Directed Acyclic Graphs (DAGs)**, where:

- Nodes** correspond to variables or uncertain events.
- Edges** illustrate probabilistic dependencies or causal relationships.

Each edge is quantified through **conditional probabilities**, making it possible to model how risks interact and propagate.

Illustrative Example of a Bayesian Network:



Consider a BN comprising a set of nodes $N=\{A,B,C,D,E,F\}$.

Root nodes (A,B,C) have no parents and are associated with **prior probabilities** $P(A),P(B),P(C)$.

Conditional dependencies are established as follows:

- $P(D|A)$ (edge from A to D),
- $P(E|B,D)$ (edges from B and D to E), and
- $P(F|E,C)$ (edges from E and C to F).

Joint Probability Distribution:

The entire BN's behaviour is captured by the **joint probability distribution**, defined as the product of the prior probabilities and conditional probabilities:

$$P(A,B,C,D,E,F)=P(A)P(D|A)P(B)P(E|B,D)P(C)P(F|E,C)P(A, B, C, D, E, F)$$

In many practical applications, rather than computing the joint probability of all variables, we are often interested in the marginal probability of a specific variable—such as $P(F)$, which represents the overall probability of event F occurring regardless of the values of other variables. This is done by summing over all possible values of the other variables in the network:

$$P(F) = \sum_E \sum_C P(F | E, C)P(C) \sum_B \sum_D P(E | B, D)P(B) \sum_A P(D | A)P(A)$$

4.1.2 Bayesian methodology

4.1.2.1 Identification of Risks

The initial step in implementing a Bayesian Network (BN) for risk assessment involves identifying the relevant risks and variables that will form the foundation of the model. Key Performance Indicators (KPIs) are selected based on their capacity to represent important aspects of the system, such as environmental impact, operational performance, and economic efficiency. These KPIs are typically determined through expert input, literature review, or consultation with stakeholders. The selected KPIs must be measurable and capable of providing insights into the factors influencing system performance.

4.1.2.2 Identification of Key Variables

Following the identification of risks, the next step is to define the key variables for the Bayesian Network model. These variables may be associated with various domains, including environmental, operational, economic, social, and regulatory factors. The process involves selecting variables that are crucial for assessing system performance and risks, ensuring the inclusion of a broad range of factors that impact the overall sustainability. Each variable is clearly defined and accompanied by relevant measurement units to facilitate the practical application of the model.

4.1.2.3 Data Collection and Quantification

Data collection is a critical step in developing a Bayesian Network model, involving the gathering of both qualitative and quantitative data from various sources such as historical records, expert assessments, real-time data, and existing research. This data is aligned with the selected Key Performance Indicators (KPIs) to ensure consistency and relevance. Experts help identify the relationships and interdependencies between KPIs, which are then mapped to understand how changes in one variable affect others. These relationships are quantified using methods such as probability distributions, regression analysis, or machine learning, depending on the available data and the model's complexity, enabling the representation of variable dependencies in the network.

4.1.2.4 Structuring the Bayesian Network

The next phase involves constructing the Bayesian Network model, which is generally represented as a DAG. In this graph:

- Nodes represent the KPIs and relevant variables.
- Edges represent the conditional dependencies between the nodes, with the direction of the edges indicating the flow of influence.

The dependencies between variables are quantified through CPTs, and the structure of the network is refined to ensure it accurately represents the real-world relationships between the identified KPIs. The model incorporates uncertainty, enabling the simulation of different scenarios and the assessment of how variations in one part of the system affect overall outcomes.

4.1.2.5 Model Construction

The construction of the Bayesian Network follows from the structured relationships identified in the previous step. The selected KPIs are integrated into the DAG, where each node represents a KPI and the edges represent their probabilistic dependencies. CPTs are used to quantify the relationships, defining the likelihood of one KPI based on the values of its parent nodes. To account for uncertainty, each KPI is assigned a probability distribution, enabling the simulation of various scenarios and the evaluation of potential outcomes. This approach allows the model to assess the impacts of changes, such as policy or operational adjustments, on system performance, providing valuable insights for data-driven decision-making.

4.1.2.6 Sensitivity Analysis

Once the Bayesian Network model has been constructed, sensitivity analysis is conducted to evaluate the influence of each KPI on the final risk outcome. This analysis involves varying the values of individual KPIs while holding other variables constant to isolate their individual effects. Sensitivity analysis identifies the KPIs that have the most significant impact on the risk outcomes. These KPIs are then prioritized for further analysis or intervention, ensuring that efforts are focused on the most critical factors for risk mitigation.

In a nutshell, Bayesian risk assessment identifies key risks and performance indicators, structures them into a DAG, and quantifies relationships using conditional probability tables. Sensitivity analysis highlights influential KPIs for targeted intervention, while continuous expert review and model refinement ensure its accuracy and adaptability, supporting data-driven, sustainable decision-making.

4.1.3 Bayesian methodology Implementation and Results

4.1.3.1 Identification of Risks and Variables

The KPIs derived from the analysis in section **Error! Reference source not found.** have also been used for the BN risk analysis. These KPIs, which were prioritized through a collaborative workshop with pilot sites, focus on key aspects such as emissions reductions, operational efficiency, and the adoption of low-emission transport systems. The selected KPIs provide measurable insights that will be integrated into the Bayesian Network to assess risks and evaluate the ADMIRAL project's progress in achieving its sustainability and technological goals.

4.1.3.2 Identification of Key Variables

In this step, we identify and select the KPIs that will serve as the foundation for the BN model in the ADMIRAL project. These KPIs are critical for assessing various factors influencing the sustainability, efficiency, and stakeholder engagement within the logistics system. The selected variables cover a range of operational, environmental, economic, social, technological, and regulatory aspects. By evaluating these KPIs, we aim to gain a comprehensive understanding of the dynamics at play in the logistics network and the potential risks involved. Table 15 (section 3.2.2) presents the selected KPIs, their short descriptions, and the corresponding measurement units.

4.1.3.3 Data Collection and Quantification

The data collection and quantification process for constructing the BN model in the ADMIRAL project followed a systematic approach to capture both qualitative and quantitative insights into the complex interdependencies among various KPIs. The primary objective was to create a comprehensive model that accurately reflects these relationships, with a particular focus on assessing sustainability risks and ensuring compliance.

Phase 1: Expert Questionnaire for Mapping Interrelationships

The first phase involved administering an expert questionnaire designed to identify and quantify the relationships among the KPIs. Experts were tasked with:

- **Identifying Influences:** For each KPI, experts identified other KPIs that it most significantly influenced, along with the direction of these relationships.
- **Assessing Strength of Influence:** Experts rated the strength of influence between KPIs using qualitative categories—high, moderate, and low—which were subsequently quantified as 5, 3, and 1, respectively. These numerical values were then used to reflect the intensity of the relationships between the KPIs.

This structured approach provided the foundation for constructing the DAG of the Bayesian Network. In this graph, nodes represent the KPIs, and edges reflect the directional influences between them. The data collected during this phase was instrumental in shaping the structure of the model and in understanding how both internal and external factors influence the project's sustainability risks.

Phase 2: Follow-Up Questionnaire for Probability Distributions and Intensity Ratings

The second phase of data collection aimed to refine the Bayesian Network further by establishing the probability distributions for the root nodes and quantifying the influence of KPIs on sustainability risks. This was accomplished through a live Mentimeter session with project experts during the Kotka GA, where experts engaged in two key activities:

- **Expected Level Assignment for Root Nodes:** Experts rated each root KPI (representing external influences) on a scale of High, Moderate, or Low, which corresponded to specific probability ranges (e.g., High = 80–100%, Low = 0–20%).
- **Rating Influence Levels:** Experts evaluated the strength of each KPI's influence on sustainability noncompliance risk, using a scale from 1 (Very Low) to 5 (Very High).

These expert ratings were then used to construct the CPTs, which are central to quantifying the strength of relationships between KPIs and assessing how changes in one KPI affect overall sustainability risks.

- **Quantification Process Overview**

The entire quantification process unfolded in a logical sequence of four key steps:

1. **Expert Input:** The first questionnaire identified the interrelationships among KPIs, while the follow-up questionnaire gathered the necessary data for assigning probability distributions and quantifying influence levels.
2. **Conditional Probability Tables (CPTs):** The expert feedback was systematically integrated into the CPTs, which served to quantify the dependencies between KPIs and illustrate how the state of one KPI can influence others. The complete set of CPTs is provided in ANNEX III.
3. **Model Calibration and Simulation:** The Bayesian Network model was calibrated and tested by simulating a range of risk scenarios. This ensured that the model accurately reflected expert judgments and captured the dynamics of the system.
4. **Data-Driven Decision-Making:** Ultimately, the refined Bayesian Network model allowed for the simulation of various risk scenarios, providing valuable insights that support data-driven decision-making for managing sustainability risks within the project.

Through this multi-phase process, the project successfully developed a robust Bayesian Network model that not only quantifies the complex relationships among KPIs but also facilitates informed, strategic decision-making in the context of sustainability and compliance risks.

4.1.3.4 Key Findings and Impact on the Bayesian Network

The combined results from both expert questionnaires provided essential data for shaping the Bayesian Network. Key findings included significant variations in probability distributions for root nodes, such as "Shipment Visibility" at 86% and a 90% reduction in Empty Running, highlighting their importance in logistics optimization and emissions reduction. While the intensity of KPI influence on sustainability risks revealed that KPIs like "GHG Emissions per Shipment" (4.62) and "Collaboration Among Stakeholders" (4.56) were strong drivers of sustainability outcomes, emphasizing their role in achieving the project's goals.

These insights were critical in developing a Bayesian Network that accurately reflects the complexity of the ADMIRAL project, supporting effective management of sustainability risks within multimodal low-emission transport chains.

4.1.3.5 Structuring the Bayesian Network

The Bayesian Network is structured by categorizing the nodes into Root Nodes, Intermediate Nodes, and Outcome Nodes, with probabilistic dependencies established between them to reflect the complex relationships between various factors.

Node Categorization:

- **Root Nodes:** These represent key variables influencing the system:
 - *Safety & Accidents:* 68% foresee no change, 32% a decrease.
 - *Shipment Turnaround Time:* 47% expect a reduction.

- *Shipment Load Factor*: 63% predict an increase.
- *Total Shipment Costs*: 41% foresee no change, 41% expect reductions.
- *Empty Running*: 90% expect a decrease.
- *Shipment Delivery Reliability*: 69% expect improvements.
- *Vehicle Type Shift*: 68% anticipate a shift to sustainable vehicles.
- *Shipment Visibility*: 86% foresee enhanced transparency.
- *Customer Satisfaction*: 77% expect high satisfaction.
- *Market Penetration*: 55% foresee significant adoption.
- *Public & Stakeholder Acceptance*: 77% and 71% of experts foresee approval.
- *Lack of Knowledge about Stakeholder Requirements*: 67% see this as a challenge.
- *Regulatory Changes*: 93% expect shifts in legislation.
- **Intermediate Nodes**: These are influenced by root nodes and affect other variables:
 - *GHG Emissions per Shipment*: Critical for sustainability.
 - *Collaboration Among Stakeholders*: Key for successful logistics.
 - *Solution Integration*: Vital for seamless operations.
 - *Cost per Shipment*: A crucial economic factor.
 - *Technology Readiness*: Reflects infrastructure preparedness.
 - *Willingness to Pay for Green Logistics*: Indicates market adoption potential.
- **Outcome Node**:
 - *Sustainability Non-Compliance Risk*: Represents the risk of not meeting sustainability objectives, such as regulatory compliance and environmental goals.

These nodes and their probabilistic relationships are outlined in detail in the Conditional Probability Tables in **Error! Reference source not found.**

Defining Relationships: Probabilistic dependencies between various KPIs are established based on expert input and data, outlining the interrelations among key factors. For instance, **Technology Readiness** influences both **Solution Integration** (intensity = 68) and **Collaboration Among Stakeholders** (intensity = 36). In turn, **Cost per Shipment** is related to **GHG Emissions per Shipment** (intensity = 26) and **Willingness to Pay for Green Logistics** (intensity = 54). Similarly, **GHG Emissions per Shipment** impacts **Cost per Shipment** (intensity = 26) and **Willingness to Pay for Green Logistics** (intensity = 37), demonstrating a bidirectional influence between cost-related factors and

environmental performance. Additionally, **Solution Integration** plays a crucial role in shaping **Technology Readiness** (intensity = 47) and **Collaboration Among Stakeholders** (intensity = 43), emphasizing the interconnectedness of system components. **Professions and Occupations**, in turn, are significantly influenced by **Technology Readiness** (intensity = 40) and **Solution Integration** (intensity = 35), reflecting how technological advances and integration impact workforce dynamics. Furthermore, **Collaboration Among Stakeholders** directly affects both **Technology Readiness** (intensity = 43) and **Solution Integration** (intensity = 54), highlighting the importance of stakeholder engagement in enhancing technological capabilities and integration across the system.

Extending to broader KPIs, **Technology Readiness** also influences **Market Penetration** (intensity = 24) and **Stakeholder Acceptance** (intensity = 37), reinforcing the role of technological advancements in fostering market growth and acceptance among stakeholders. **Cost per Shipment** is connected to operational performance, particularly impacting **Shipment Turnaround Time** (intensity = 7) and **Shipment Load Factor** (intensity = 28), which in turn affects efficiency and overall delivery performance. **GHG Emissions per Shipment** plays a pivotal role in influencing **Shipment Load Factor** (intensity = 32) and **Public Acceptance** (intensity = 40), demonstrating the significance of environmental considerations in shaping public perceptions of logistics operations. **Willingness to Pay for Green Logistics** is a key determinant of **Customer Satisfaction** (intensity = 27) and **Shipment Delivery Reliability** (intensity = 31), linking consumer preferences for sustainability with overall satisfaction and delivery performance. **Solution Integration** is similarly tied to operational outcomes, affecting both **Fulfilled Shipments** (intensity = 10) and **Shipment Delivery Reliability** (intensity = 12). Lastly, **Collaboration Among Stakeholders** impacts **Public Acceptance** (intensity = 32) and **Changes in Legislation** (intensity = 25), underscoring the critical role of collaboration in responding to public and regulatory demands.

These relationships, as outlined in the CPTs in Annex IV, comprehensively illustrate how each KPI influences others, ultimately driving the system's behaviour. Additionally, the relationship between **Regulatory Changes** and **Sustainability Non-Compliance Risk** is modelled to reflect how evolving regulations can impact compliance with sustainability goals, highlighting the broader regulatory context in which these interdependencies exist.

4.1.3.6 Model Construction

The construction of the model follows a structured process that integrates key performance indicators (KPIs) and their interdependencies to accurately represent the relationships within the logistics and sustainability system. Initially, critical KPIs such as Technology Readiness, Cost per Shipment, GHG Emissions per Shipment, Willingness to Pay for Green Logistics, Solution Integration, and Collaboration Among Stakeholders are identified based on expert input and historical data. These KPIs serve as the foundation of the model and are connected through probabilistic dependencies that capture how the value of one KPI influences the others.

The model is represented as a DAG, where each KPI is depicted as a node, and the directed edges between nodes represent conditional dependencies. These edges reflect the intensity of influence between the KPIs, which is quantified using degrees of intensity based on expert judgment and data

analysis. The strength of each relationship is formalized through CPTs, which specify the probability distribution of one KPI given the values of its parent nodes.

Uncertainty is incorporated into the model by assigning probability distributions to each KPI, acknowledging the inherent variability of real-world data. This probabilistic approach enables the model to simulate different scenarios and assess the impact of changes across the system. Through this method, the model can predict the outcomes of various interventions, such as policy changes or strategic adjustments, and provide insights into the effects of these changes on key metrics like cost, emissions, and stakeholder satisfaction.

By capturing these interdependencies in a DAG structure, the model facilitates the identification of potential areas for improvement, highlights the impact of different variables on system behaviour, and supports data-driven decision-making. The DAG representation of the model (Figure 7) provides a transparent and intuitive way to visualize the interactions between KPIs and their influence on sustainability and logistics performance.

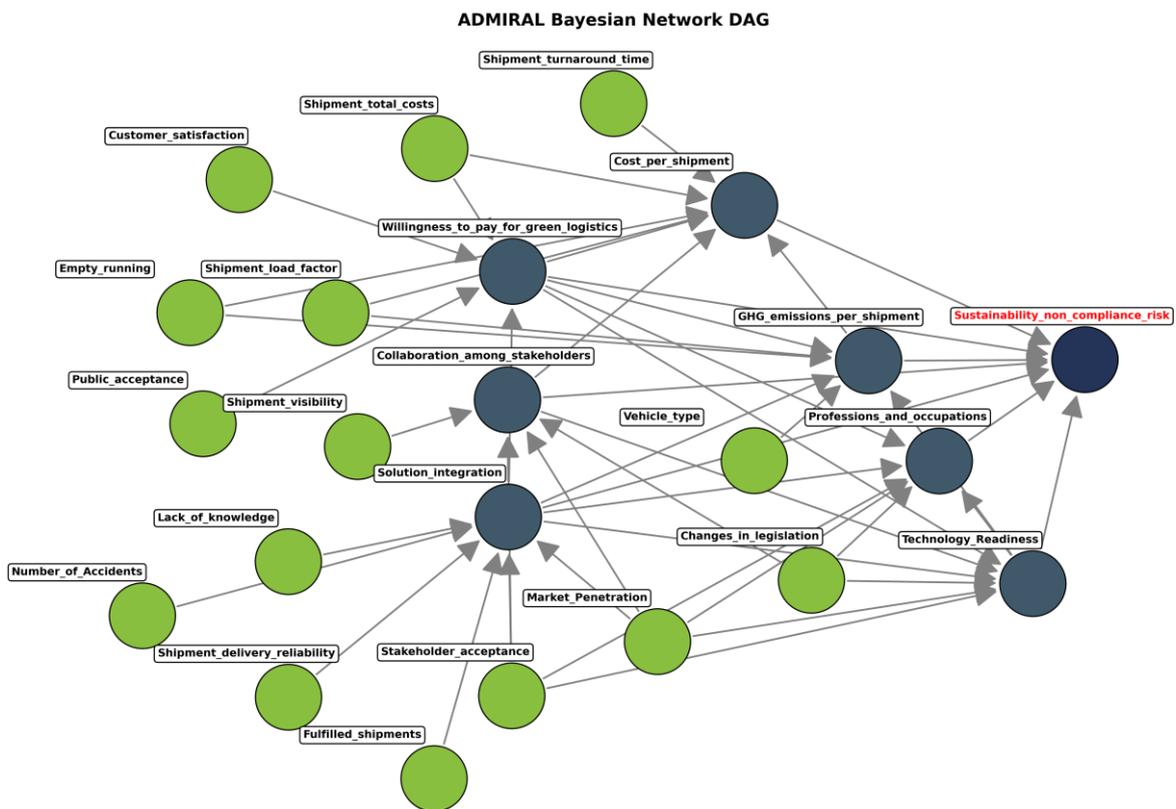


Figure 7: Sustainability non-compliance Directed Acyclic Graph

The model construction yields results derived from the BN, represented by the DAG, which provides valuable insights into the relationships among KPIs related to logistics and sustainability. These results, grounded in probabilistic dependencies, offer a comprehensive understanding of the system's performance and associated risks.

Table 17 presents the final core KPI values for Sustainability Non-Compliance Risk. The key performance indicators and their mapped values are as follows:

Table 17: Final Core KPI values for Sustainability Non-Compliance Risk

KPI	Impact direction on Non-Compliance	Mapped Value	Eqv. Number	Influence Rating	Product
Technology Readiness	Decreases Risk	High	0,11	3,97	0,44
Cost per Shipment	Increases Risk	Moderate	0,33	4,13	1,36
GHG Emissions per Shipment	Increases Risk	Moderate	0,33	4,62	1,52
Willingness to Pay for Green Logistics	Decreases Risk	High	0,11	3,61	0,40
Solution Integration	Decreases Risk	Moderate	0,33	4,29	1,41
Professions and Occupations	Decreases Risk	Low	0,99	3,12	3,08
Collaboration Among Stakeholders	Decrease Risk	Moderate	0,33	4,56	1,50

Technology Readiness is assigned a high value of 0.11, reflecting strong technological support for sustainable logistics practices. Cost per Shipment, GHG Emissions per Shipment, Solution Integration, and Collaboration Among Stakeholders each receive moderate values of 0.33, suggesting intermediate contributions to sustainability outcomes. Willingness to Pay for Green Logistics is also high (0.11), indicating strong consumer demand for green logistics. Professions and Occupations has a low value of 0.99, indicating minimal direct impact on sustainability outcomes in this model.

The weighted sum for Sustainability Non-Compliance Risk is calculated by multiplying the final core KPI values by their respective influence ratings, reflecting the relative importance of each KPI in determining the overall risk. The resulting weighted sum of 9.72, out of a maximum possible value of 28.30, indicates a moderate alignment with sustainability objectives. This value represents the cumulative effect of factors such as technology readiness, cost per shipment, GHG emissions, willingness to pay for green logistics, and others. Based on this weighted sum, the Sustainability Non-Compliance Risk probability is calculated, with a 34.38% probability for high-risk non-compliance (Table 18). This suggests that, despite efforts toward sustainability, the system is moderately vulnerable to non-compliance, with key areas like technological integration and emissions reduction presenting challenges that may hinder full compliance with sustainability goals.

Table 18: Final Probability Distribution for Sustainability Non-Compliance Risk

Sustainability Non-Compliance Risk	Probability
High	34.38%
Low	65.62%

The Sustainability Non-Compliance Risk has a balanced probability distribution, with a higher likelihood of low-risk (65.62%) versus high-risk (34.38%). While compliance is more probable, this distribution highlights the system's vulnerability to risks, particularly due to technological and logistical constraints that could hinder full sustainability adoption.

Overall, the Bayesian Network model provides a clear view of the system's strengths and vulnerabilities, identifying key areas for improvement and offering valuable guidance for strategic decisions to enhance sustainability and reduce non-compliance risks.

4.1.3.7 Sensitivity Analysis

To analyse the sensitivity of each KPI on sustainability non-compliance within the framework of a Bayesian Network, we examine how individual changes in each KPI independently affect the final risk outcome, while holding all other variables at a neutral baseline. This approach isolates the influence of each KPI, enabling the determination of its relative impact on sustainability non-compliance. The thresholds set within the analysis (0.3 and 0.7) define critical points at which the sustainability non-compliance risk is considered low (<30%) or high (>70%). These thresholds, derived from curve intersections, represent key decision points where notable shifts in risk occur.

The factors most influential to sustainability non-compliance are those with the highest potential to exacerbate risk when their values exceed the High-Risk Threshold. These factors have significant ramifications for both operational and environmental performance, making them critical in maintaining sustainability compliance. Among the most dangerous factors are the cost per shipment, which, when exceeding the High-Risk Threshold of 0.6, becomes a substantial financial burden, exacerbating operational inefficiencies and hindering sustainability efforts. Similarly, GHG emissions per shipment, exceeding the threshold of 0.55, directly contravene environmental goals, accelerating the risk of non-compliance. Vehicle type is another significant factor; exceeding the threshold of 0.6 increases fuel inefficiency and emissions, escalating the risk of non-compliance. Empty running, the inefficient return of vehicles without cargo, also becomes increasingly detrimental when surpassing the 0.6 threshold, contributing to resource waste and increased emissions. Finally, shipment turnaround time exceeding 0.6 contributes to operational inefficiencies and delays, further undermining sustainability efforts and operational performance.

Most sensitive factors are those that exhibit a narrow margin between their High-Risk and Low-Risk Thresholds, indicating that even slight changes in their values can lead to substantial shifts in sustainability outcomes. These factors are particularly vulnerable to fluctuations, where even small deviations can result in significant risks of non-compliance. For example, the number of accidents in logistics operations is highly sensitive, with a narrow range between the High-Risk (0.65) and Low-Risk (0.35) thresholds. An increase in accidents can disrupt both safety and sustainability, highlighting the

need for constant monitoring. Similarly, a lack of knowledge about stakeholder requirements, also exhibiting a narrow threshold range, can lead to operational misalignment and inefficient resource use. Shipment delivery reliability and shipment visibility, both characterized by narrow gaps between thresholds (0.6 and 0.4), are similarly sensitive to performance changes, as disruptions in these areas can significantly impact sustainability compliance.

The highest risk factors combine both high levels of influence on sustainability outcomes and high sensitivity to changes, making them the most critical areas for proactive risk management. GHG emissions per shipment and cost per shipment are identified as the highest risk factors due to their dual nature of being both dangerous and sensitive. Small increases in GHG emissions can significantly breach environmental sustainability targets, while fluctuations in cost per shipment can disrupt the economic sustainability of logistics operations. Similarly, the number of accidents, empty running, and vehicle type each combine dangerous and sensitive characteristics, making them highly responsive to changes and requiring focused attention for risk mitigation.

In conclusion, the most influential (dangerous) factors, such as cost per shipment, GHG emissions per shipment, vehicle type, empty running, and shipment turnaround time, represent critical areas of concern for sustainability compliance. Their potential to escalate the risk of non-compliance, should they exceed their High-Risk Thresholds, necessitate focused and proactive management. The most sensitive factors, including the number of accidents, lack of knowledge about stakeholder requirements, shipment delivery reliability, and shipment visibility, are vulnerable to small performance changes and must be precisely managed to prevent non-compliance. Finally, the highest risk factors, which merge both dangerous and sensitive characteristics, such as GHG emissions per shipment, cost per shipment, number of accidents, empty running, and vehicle type, should be rigorously monitored and mitigated to ensure compliance with sustainability objectives.

The detailed results of the sensitivity analysis, including the curves that display risk sensitivity, can be found in ANNEX IV. A summary of the sensitivity analysis results is provided in the Table 19 below.

Table 19: Sensitivity analysis results

Node	High-Risk Threshold	Low-Risk Threshold	Explanation
Technology Readiness	0.3	0.7	Technology Readiness exhibits low sensitivity due to its wide threshold range; higher values contribute positively by supporting risk mitigation and reducing non-compliance risk.
Cost per Shipment	0.6	0.4	Cost per Shipment is highly sensitive. When values exceed 0.6, financial inefficiencies intensify, significantly increasing the risk of non-compliance and negatively affecting both operational and environmental sustainability.
GHG Emissions per Shipment	0.55	0.45	GHG Emissions per Shipment is highly sensitive with a narrow threshold; slight increases beyond 0.55 sharply elevate non-compliance risk, directly undermining environmental sustainability.

Node	High-Risk Threshold	Low-Risk Threshold	Explanation
Willingness to Pay for Green Logistics	0.3	0.7	This KPI exhibits low sensitivity; higher values foster positive sustainability outcomes by promoting green logistics, thereby reducing non-compliance risk.
Solution Integration	0.3	0.7	Solution Integration has low sensitivity; improved integration contributes to risk reduction by enhancing system cohesion, though its overall impact is moderate.
Professions and Occupations	0.3	0.7	This KPI shows low sensitivity; while higher values can indirectly improve operational efficiency, its direct impact on sustainability compliance is limited.
Collaboration Among Stakeholders	0.3	0.7	Collaboration Among Stakeholders is low-sensitive; stronger collaboration supports efficient resource use and alignment with sustainability goals, thereby reducing risk.
Number of Accidents	0.65	0.35	The Number of Accidents is highly sensitive, with a narrow threshold. Increases above 0.65 significantly disrupt operations and safety, markedly elevating non-compliance risk.
Customer Satisfaction	0.3	0.7	Customer Satisfaction has low sensitivity; higher satisfaction levels indirectly support operational efficiency and reduce risk, although its direct influence on sustainability outcomes is modest.
Shipment Turnaround Time	0.6	0.4	Shipment Turnaround Time is highly sensitive; values exceeding 0.6 lead to delays and bottlenecks, substantially increasing non-compliance risk and negatively impacting sustainability performance.
Shipment Load Factor	0.6	0.4	Shipment Load Factor is moderately sensitive; low values (below 0.6) result in inefficient resource utilization and higher emissions, thereby undermining sustainability outcomes.
Shipment Total Costs	0.6	0.4	Shipment Total Costs are highly sensitive; when costs exceed 0.6, financial pressures intensify, adversely impacting both operational and environmental sustainability.
Market Penetration	0.5	0.5	Market Penetration exhibits neutral sensitivity, as its fixed threshold indicates that moderate fluctuations do not substantially affect sustainability compliance.
Fulfilled Shipments	0.5	0.5	Fulfilled Shipments are neutrally sensitive; stable fulfilment rates support operational efficiency but have limited direct impact on non-compliance risk unless significant disruptions occur.
Shipment Delivery Reliability	0.6	0.4	Shipment Delivery Reliability is highly sensitive; reliability issues (values above 0.6) can sharply increase non-compliance risk by disrupting operational performance.

Node	High-Risk Threshold	Low-Risk Threshold	Explanation
Public Acceptance	0.7	0.3	Public Acceptance exhibits low sensitivity; its wide threshold range means that high levels generally stabilize system performance, thereby reducing risk.
Stakeholder Acceptance	0.7	0.3	Stakeholder Acceptance is similarly low-sensitive; high acceptance levels help align practices with sustainability goals, reducing overall risk.
Vehicle Type	0.6	0.4	Vehicle Type is highly sensitive; deviations beyond 0.6, such as using less efficient vehicles, markedly increase fuel consumption and emissions, elevating non-compliance risk.
Empty Running	0.6	0.4	Empty Running is highly sensitive; values above 0.6 result in significant resource waste and increased emissions, representing a critical risk factor for sustainability non-compliance.
Shipment Visibility	0.6	0.4	Shipment Visibility is highly sensitive; poor visibility (values above 0.6) leads to operational delays and disruptions, thereby significantly increasing non-compliance risk.
Lack of Knowledge About Stakeholders' Requirements	0.65	0.35	This KPI is highly sensitive; a narrow threshold indicates that even minor deficiencies in understanding stakeholder needs can lead to operational misalignments and heightened sustainability risk.
Changes in Legislation	0.7	0.3	Changes in Legislation exhibit low sensitivity; unless there are significant regulatory shifts, they have minimal direct impact on non-compliance risk.

4.2 Regulation Compliance analysis

The transport and logistics sectors are experiencing rapid changes due to digitalization, sustainability goals, and regulatory frameworks that shape their operations. The ADMIRAL project selected 22 KPIs to measure the effectiveness of these transformations in the ADMIRAL Marketplace, ensuring compliance with policies that enhance efficiency, safety, and environmental impact. The correlation between the selected KPIs and the EU regulation provides guidelines for sustainable growth, digital technology adoption, and emissions reduction. The following analysis presents the correlations between each KPI, and the EU regulations presented in Section 2.3. A synthesis of these correlations is presented in Table 20.

Technology readiness is crucial for adopting digital solutions and ensuring operational efficiency in transport and logistics. COM (2023) 440 emphasizes the **uptake of digital technology by train drivers**, facilitating smoother operations and improved safety. Additionally, EU Regulation 2023/1805 highlights the **importance of technology maturity in the maritime sector, ensuring the availability of renewable and low-carbon fuels**. Regulations such as EU Directive 2023/959 promote the **development of emissions-reducing technologies**, while EU Directive 2023/1791 supports the cogeneration of engine structures to accommodate sustainable fuels. Moreover, EU Regulation

2024/1679 focuses on enhancing information and communication technology systems to improve connectivity and efficiency in transport networks.

The use of specific **vehicle type** is also critical to achieve sustainability goals. EU Regulation 2019/1242 mandates a cost-efficient deployment of renewable energy, reducing dependence on imported fuels while fostering innovation and economic growth. COM (2023) 440 supports the introduction of EURO 7 standards in new freight vehicles, and EU Regulation 2023/955 stands for the provision of zero- and low-emission vehicles for logistics.

Sustainability measures are increasingly affecting financial structures within the transport industry (**Cost per shipment**). The European Union Emissions Trading System (EU ETS) has been extended to CO₂ emissions from all large ships (of 5000 gross tonnages or above) and road transport ensuring that companies surrender allowances for a portion of their emissions (i.e., 40% of emissions by 2025, 70% of emissions by 2026, and 100% of emissions by 2027). Moreover, EU Regulation 2023/955 mandates a review of cost increases related to the use of sustainable fuels, ensuring that market competitiveness is not compromised. EU Directive 2023/959 highlights the risks of additional sustainability costs leading to increased operational expenses, necessitating strategic cost management.

Taking into consideration the **greenhouse gas emissions per shipment**, the TEN-T network should be sufficiently equipped with alternative fuel infrastructure to support the transition to zero and low-emission mobility, as mandated by COM (2023) 441. This regulation ensures that charging and refuelling infrastructure for alternative fuels is widely available, promoting a sustainable and well-integrated transport network. In addition, COM (2023) 441 also establishes standardized greenhouse gas (GHG) emissions calculations using ISO 14083:2023, making sustainability reporting more transparent and comparable across transport networks.

The success of sustainability initiatives depends on a skilled workforce (**professions and occupations**). EU Directive 2022/2464 mandates continued professional education to support sustainability reporting, ensuring that industry professionals are equipped with the necessary expertise. Similarly, EU Directive 2023/1791 promotes training programs for energy-related professionals, ensuring the workforce is prepared for advancements in clean energy technologies.

Collaboration among stakeholders is crucial for achieving sustainability goals. COM (2023) 441 supports stakeholder cooperation in emissions measurement and standardization, ensuring consistency across the transport sector. Additionally, EU Regulation 2023/2772 requires organizations to report on stakeholder contributions and collaborative sustainability initiatives, reinforcing the importance of collective action.

Transport safety is a critical KPI measured by the **number of accidents**, with EU documents such as COM (2023) 440 promoting improvements in train punctuality and reliability to increase railway usage and decrease road accidents. Additionally, EU Regulation 2024/1679 ensures that the TEN-T network prioritizes the reduction of congestion and accidents, reinforcing safety in freight and passenger transport.

Market dynamics are influenced by regulatory transparency, which leads to increased **public acceptance** of services. COM (2023) 441 states that better emissions data transparency allows

customers to make informed choices, promoting sustainable transport solutions. And EU Directive 2022/2464 highlights that the sustainability reports from freight companies need to be made accessible, free of charge to the public so customers can make more assertive choices. This legislation inter-charged with EU Directive 2022/2464 mandating that the sustainability information reported should not place a disproportionate burden on efforts and costs on companies would increase the **willingness to pay for green logistics**.

Digital solutions play a key role in cost-efficient logistics operations to reduce the **shipment total cost**. EU Regulation 2024/1942 mandates the implementation of eFTI (Electronic Freight Transport Information) systems, reducing administrative burdens and improving operational efficiency. Similarly, EU Regulation 2020/1056 promotes the digitization of freight information systems, ensuring faster and more efficient logistics processes.

Sustainability in transport is reinforced through market-based measures to reduce greenhouse gas emissions, as outlined in EU Regulation 2023/959. Additionally, EU Directive 2023/1791 encourages Member States to support market development for energy-efficient solutions, ensuring balanced growth in sustainable transport technologies to facilitate **market penetration**.

Shipment delivery reliability is a key KPI for logistics companies. COM (2023) 440 highlights the need for improving the reliability of rail services, reducing delays and ensuring seamless freight movement.

In addition, the EU Regulation 2021/1119 requires that all new legislation or **changes in legislation** align with the EU’s climate-neutrality objectives, ensuring policy consistency across transport and energy sectors.

Table 20: Correlation between the EU legislation and the ADMIRAL KPIs

KPI*	Correlated legislation	Correlation
Technology readiness	COM (2023) 440	Uptake of digital technology by train drivers
		Deployment of digital automatic couplings (DAC) to support faster and heavier trains
	EU Regulation 2023/1805	Technology maturity or availability in the maritime sector may affect the uptake of renewable and low carbon
		Expected technology development and increased production of renewable and low-carbon fuels
		Obligation to use onshore power supply (OPS) or zero-emission technology in ports
		Types of technology to be developed: fuel cell, on-board electrical energy storage, on-board power generation from wind and solar energy
	EU Directive 2023/959	Development of technology that reduces the emission of ships
	EU Directive 2023/1791	Cogeneration of technologies involving the structure of the engines to accommodate sustainable fuels
EU Regulation 2024/1679	Information and communication technology systems for transport are necessary to provide the basis for	

KPI*	Correlated legislation	Correlation
		optimizing traffic safety and improving related services
		Deployment of innovative transport services (e.g., automatic train operations, advanced traffic management, digital connectivity for passengers based on ERTMS and digital automatic coupling, connectivity based on 5G and satellite units)
	EU Regulation 2023/2772	Reporting on technology: e.g., the substitution of products or services by products or services with a lower impact on water, marine sources, and the general biodiversity, as well as the transition to more efficient and clean technologies and monitoring of technologies
	EU Regulation 2019/1242	In the case of vehicle combinations including alternatively fuelled or zero-emission vehicles, the maximum weights shall be increased by the additional weight of the alternative fuels or zero-emission technology
Cost per shipment	COM (2023) 440	ETS to maritime and road transport will ensure that the cost of CO2 is reflected in the final cost of these services DAC is expected to lower costs
	EU Regulation 2023/1805	The increase in cost from the use of sustainable fuels needs to be evaluated by the Commission in order not to reduce the competitiveness of the maritime sector
	EU Regulation 2023/955	Possible increase in costs as fuel suppliers are subject to obligations under the emission trading system
	EU Directive 2023/959	The internalization of sustainability costs can lead to additional costs and extra distance travelled to evade the requirements of the Commission
	EU Regulation 2023/2772	Reporting information about current and anticipated financial effects of the reduction in the use of natural resources in the supply chain and the strategic responses to mitigate such impacts or risks
	EU Directive 2023/2413	The use of renewable energy should be deployed in a cost-efficient way (i.e., improvement of energy diversification in the transport sector, while promoting innovation, economic growth, and jobs while the reliance on energy imports is reduced)
	EU Regulation 2019/1242	Average specific CO2 emissions, specific CO2 emission targets, and excess CO2 emissions differ according to the vehicle group (Annex 1)
Greenhouse emissions per shipment	COM (2023) 440	Introduction of zero-emission HDV
	EU Regulation 2023/1805	Different emission factors need to be used according to the fuels used in ships
	EU Regulation 2024/1679	TEN-T should be sufficiently equipped with alternative fuel infrastructure to ensure that it effectively

KPI*	Correlated legislation	Correlation
		supports the transition to zero and low-emission mobility
		Stimulate resource efficiency and zero and low-emission operation
	COM (2023) 441	Use of ISO 14083:2023 to calculate greenhouse gas emissions from the transport sector to standardize the methodology
Willingness to pay for green logistics	EU Directive 2022/2464	The information reported with the sustainability reporting should not place a disproportionate burden on efforts and costs on companies, the sustainability reporting standards should take account of existing standards and frameworks for sustainability reporting and accounting where appropriate
		The exploitation of information more efficiently holds the potential for significant cost savings
Solutions integration	EU Regulation 2023/955	Funds to State Members to support their policies to address the social impacts of the introduction of emission trading system for road transport
	EU Regulation 2023/2772	Reporting on the integration of sustainability-related performance in incentive schemes
	EU Directive 2023/2413	The cost-efficient deployment of renewable energy supported by joint programs contributes to market integration
	COM (2023) 441	The provision of better transparency on the performance of transport services creates incentives for more sustainable solutions integration
	EU Regulation 2024/1942	To reduce costs and the time taken to set up the eFTI gates and ICT components, it is possible to rely on reusable solutions
Professions and occupations	COM (2023) 440	Certification of train drivers to better use of capacity by rail freight
	EU Directive 2022/2464	Sustainability reporting needs to be supported by continued professional education
	EU Directive 2023/1791	Promotion of suitable training programs for energy-related professionals
	EU Regulation 2024/1679	Guarantee access to adequate resting facilities for professional drivers on the entire trans-European transport network
	EU Directive 2023/2413	Ensure enough trained and qualified workers to work with renewable energy
Collaboration among stakeholders	EU Directive 2022/2464	Creation of standardized natural capital through stakeholder collaboration
	EU Regulation 2024/1789	Smart grid solutions or connection to other network operators including the direct connection of production facilities of renewable gas and low-carbon gas should be transmitted among operators

KPI*	Correlated legislation	Correlation
	EU Regulation 2024/1679	Improvement of cooperation of the stakeholders of the supply chain
		TEN-T should be used to promote cooperation between all relevant stakeholders. They should strengthen the complementarity with action by Member States and infrastructure managers and in particular set indicative milestones
	EU Regulation 2023/2772	Reporting the description of the organization of the collaboration or initiative, including the specific contribution of the undertaking and the roles of the different stakeholders in the project
	COM (2023) 441	Stakeholders recognize that harmonized measurement and calculation for emissions is needed as GHG accounting becomes increasingly embedded in the broader policy ecosystem and the decision-making processes of transport service users
	COM (2023) 440	Improvement of train punctuality and reliability to increase its usage and decrease road accidents
	EU Regulation 2023/2772	Reporting the number and rate of recordable work-related accidents
Number of accidents	EU Regulation 2024/1679	TEN-T aims to reduce negative externalities from transport, including congestion and accidents
	COM (2023) 441	Better transparency in emissions data allows customers to make more assertive choices and influences business decisions of entities organizing and providing these services on the market
Customer satisfaction	COM (2023) 440	Better management and coordination of international rail traffic
		Implementation of DAC can reduce terminals' turnaround time
Shipment turnaround time	EU Directive 2023/959	If the costs of sustainability are passed on to the entity operating the ship, the incentives to implement operational measures for fuel efficiency would be limited
	EU Directive 2023/1791	Member States can reduce the costs and enhance the benefits of the internal market by creating business opportunities for suppliers and energy service providers
	EU Regulation 2024/1679	Environmental impact assessment must be carried out and should integrate the costs of greenhouse gas emissions and the positive effects of climate mitigation measures in the cost-benefit analysis
European transport corridors should not create additional administrative burdens or costs		
Shipment total cost		The promotion of short-sea shipping links concentrated in freight can reduce negative external costs such as emissions and congestion from road transport

KPI*	Correlated legislation	Correlation
	EU Regulation 2024/1942	The costs associated with the establishment and maintenance of ICT components and eFTI exchange should be mediated by the Member States
	EU Regulation 2020/1056	Implementation of eFTI to reduce administrative costs and enhance the efficiency and sustainability of transport
Market penetration	EU Directive 2022/2464	Progressive development of the assurance market for sustainability information and undertaking reporting practices
	EU Directive 2023/959	Market-based measures to reduce greenhouse gas emissions from maritime transport
	EU Directive 2023/1791	Member States should stimulate market development on the demand and supply sides, they should identify and support setting up potential facilitators or one-stop shops for energy, as well as promote potential entrepreneurs to fill the gap in the market and to promote innovative ways to enhance energy efficiency
	EU Regulation 2024/1679	Ensure non-discriminatory access to all market participants on the TEN-T network
		Member States should conduct a market and prospective analysis on multimodal freight terminals by July 2027 to examine the current and future traffic flows of freight per transport mode, identify the existing multimodal freight terminals to assess the need for new multimodal freight terminals or additional transshipment capacity in existing terminals, and analyse how to ensure adequate distribution of multimodal freight terminals with adequate transshipment capacity to meet the needs in multimodal freight
		Periodically updates on the transport market in the corridor should be performed including the necessary socio-economic costs and benefits associated
Shipment delivery reliability	COM (2023) 440	Improvement of the reliability of rail services
Public acceptance	EU Directive 2022/2464	Sustainability reporting needs to be made accessible, free of charge to the public
	EU Regulation 2023/955	Public consultations should be done in Member States to establish social climate plans
	EU Directive 2023/1791	Decarbonization plans should receive feedback on policies to improve their acceptance by the public
	COM (2023) 441	The improvements in the comparability of GHG emissions data are projected to result in increased transparency, credibility, positive effects on reputation and public image
Stakeholder acceptance	EU Directive 2022/2464	Improvement of constructive dialogue with all stakeholders

KPI*	Correlated legislation	Correlation
	EU Regulation 2023/1805	Consultations between the managing body of ports, port users and other relevant stakeholders should take place to coordinate the availability of alternative fuel supply
	EU Regulation 2023/2772	Reporting on how stakeholders' interests and views inform the undertaking's strategy and business model
Vehicle type	COM (2023) 440	Implementation of EURO 7 standards in new freight vehicles
	EU Regulation 2023/955	Provision of access to zero- and low-emission vehicles
	EU Regulation 2024/1679	Prioritization of low- and zero-emission vehicles on the TEN-T. For the trans-European transport network to keep up with innovative technological developments and deployments, the Member States and the Commission should encourage projects of common interest which aim to promote and deploy sustainable emerging technologies that enhance and ease the transport and mobility of freight, such as automated train operations, and autonomous vehicles
	EU Regulation 2023/2772	Reporting on the action plan for the supply of e-vehicles, which might lead to stranded assets to produce supply parts for conventional vehicles
	EU Directive 2023/2413	Facilitating the integration and operation of electric vehicles, complementing the provisions on access to battery data related to facilitating the repurposing of batteries
	EU Regulation 2019/1242	Zero-emission vehicles: The maximum authorised weight of 18 tonnes is increased by the additional weight of the zero-emission technology with a maximum of 2 tonnes Three-axle zero-emission vehicles: the maximum authorized weight of 25 tonnes, or 26 tonnes where the driving axle is fitted with twin tyres and the air suspension is increased with a maximum of 2 tonnes
Shipment visibility	EU Regulation 2024/1679	Member States should publish on a website the number of days per year where the water levels exceed or do not achieve the specific reference water levels for navigation, as well as the average waiting time at each lock
Changes in legislation	EU Regulation 2021/1119	New legislation and policies need to be consistent with and contribute to, the fulfilment of the climate-neutrality objectives of the EU
Lack of knowledge about stakeholders' requirements	-	-

KPI*	Correlated legislation	Correlation
Empty running	-	-
Fulfilled shipment	-	-
Shipment load-factor	-	-

*List of 22 KPIs selected for the ADMIRAL project

In short, the correlation between KPIs and the regulatory frameworks demonstrates how, among others, **sustainability, digital transformation, and cost efficiency** are shaping the transport and logistics industry. By aligning industry performance metrics with evolving regulations, businesses can optimize operations while complying with sustainability mandates. The interplay between **regulatory compliance, technological advancements, and financial feasibility** will define the future of **efficient, low-carbon transport systems**. Figure 8 shows in a schematic way how the selected KPIs for the ADMIRAL project are interconnected with the current legislation in the EU.

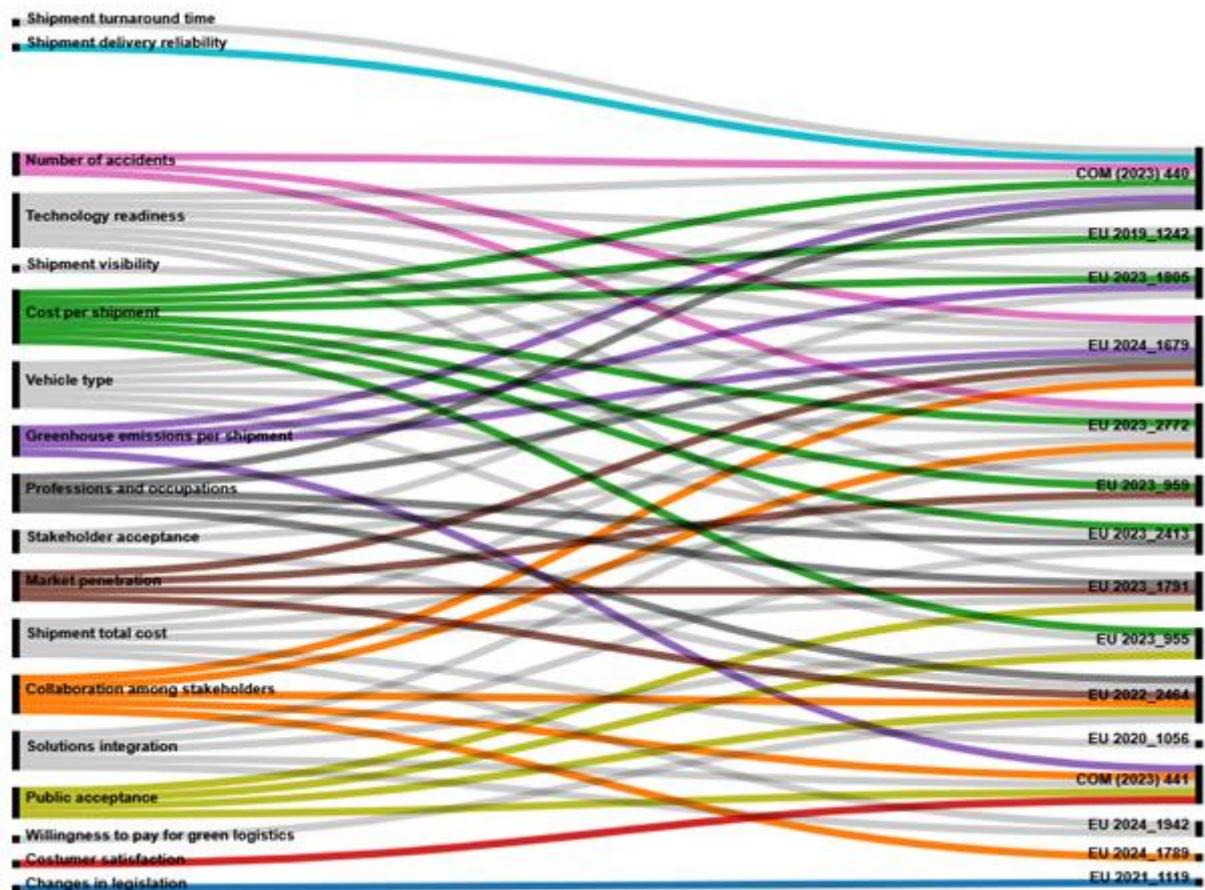


Figure 8: Interconnection between ADMIRAL KPIs and the EU Regulations

For future perspectives, it is important to mention that EU Regulation 2024/1679 emphasizes the need for transport-related infrastructure projects to be resilient to potential adverse impacts of climate change, which could be translated into KPIs to measure the introduction of demand response programs for transportation. The same regulation also indicates the introduction of infrastructure to

identify vehicles that are overweight on the TEN-T, which could indicate a KPI to assess the introduction of lightweight vehicles and vehicle materials in the freight and logistics market.

4.3 Compliance analysis key points

The identification and quantification of social and environmental risks are essential for understanding the project's impact on societal well-being and the environment. This section introduces Bayesian Network risk analysis as a tool for assessing and managing risks. This methodology helps identify potential risks and assess the risk non-compliance of the AM regarding sustainability, thus supporting decision-making. It also provides an in-depth analysis of the regulatory framework, correlating selected KPIs with EU regulations. This ensures that the ADMIRAL project complies with policies that enhance efficiency, safety, and environmental impact. In addition, the importance of technology readiness and integration is emphasized, highlighting the role of digital solutions in achieving sustainability goals, while this section underscores the significance of collaboration among stakeholders, which is crucial for achieving sustainability goals and fostering innovation.

5 Assessing ADMIRAL solutions sustainability

This section presents the adaptation of STAR Logistics methodology to the ADMIRAL project, which was identified as the most relevant framework in section 2.3.1. Building on the results of section 3.2 it provides a comprehensive framework for assessing the sustainability of logistics solutions by integrating economic, environmental, social, and governance dimensions. It begins with an introduction to the STAR Methodology, developed by UPM for evaluating the sustainability of logistics solutions. It then details the steps necessary to tailor this methodology to the ADMIRAL project, including the selection of Key Performance Indicators (KPIs) and the calculation of adjusted weights based on expert consensus and contextual factors. The evaluation process is thoroughly explained, covering the procedures for defining scenarios, obtaining criteria-adjusted weights, and calculating the global sustainability rating for each scenario.

5.1 Adaptation of the STAR model to ADMIRAL

The case studies will be evaluated from a sustainability point of view by adapting the STAR Logistics methodology. **STAR Logistics method** is a UPM-developed methodological tool for assessing the sustainability of logistics solutions by generating an **integrated sustainability rating** (STAR, 2025). This rating supports the decision-making process when choosing among various strategies. The methodology performs a comprehensive impact assessment of logistics solutions from a sustainability perspective, encompassing economic, environmental, social, and governance dimensions. Sustainability criteria, based on Key Performance Indicators (KPIs), are aggregated using a multi-criteria decision analysis. The weights for these criteria are determined based on the geographical and social context of the area where the logistics solutions are implemented, as well as through comparative judgments and preferences based on consensus from expert stakeholders. The model is designed **to provide a sustainability rating for logistics solutions** compared to a baseline scenario (see Figure 9).

The **STAR Logistics method is highly transferable**, as it can be applied to any value case or context where innovative logistics solutions are implemented. It has been applied in previous European Research Projects like LEAD project (2025) “Low-Emissions Adaptive last mile logistics supporting on demand economy through Digital Twins” However, it may require specific calibration of weights for each unique context. The methodology is scalable and can be used by a wide range of end-users, including policymakers, planners, logistics operators, consultants, and researchers. These users can use the methodology to demonstrate and communicate the environmental, social, and economic benefits of innovative last-mile logistics solutions.

The following sections detail the steps necessary to adapt the STAR Logistics method to the use cases of the four ADMIRAL project pilots (see Figure 9). Section 5.1.1 describes the selected KPI-based sustainability criteria. Section 5.1.2 describes the estimate of adjusted weights (AW) for each ADMIRAL pilot. Finally, Section 5.1.3 outlines the final step in obtaining the global sustainability rating of ADMIRAL use cases.

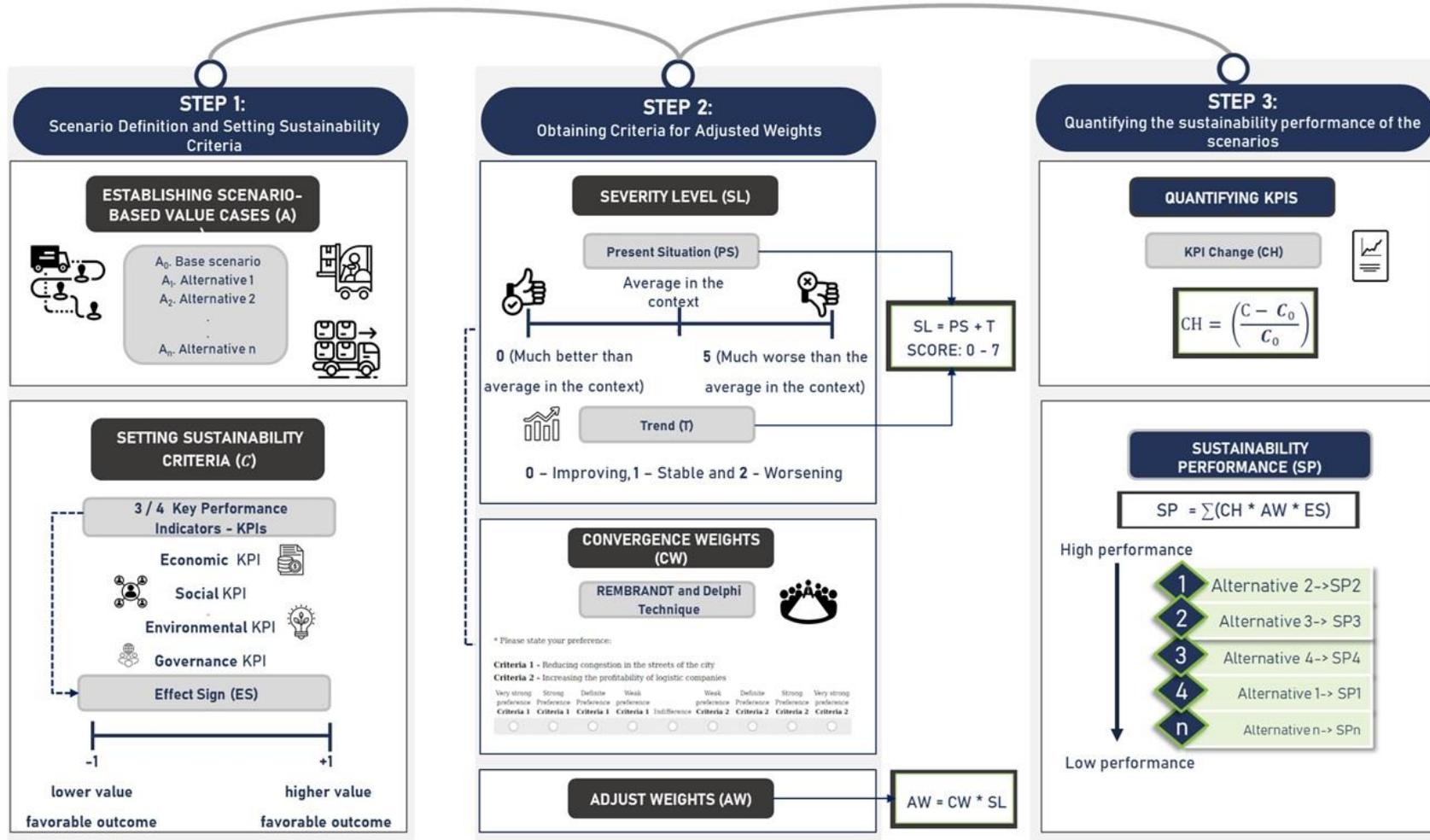


Figure 9: STAR logistics method framework

5.1.1 Step 1. Scenario Definition and Setting Sustainability Criteria.

This step consists of defining a set of scenario-based value cases including the baseline scenario -the Business as Usual (BAU) scenario- and the ADMIRAL value case scenario for each pilot. Furthermore, a set of sustainability criteria (KPIs) is identified to characterize the well-known sustainability dimensions: economic efficiency, environmental preservation, social considerations, and governance reflections. The sustainability criteria for evaluating ADMIRAL solutions within the project were selected by consensus of all ADMIRAL pilot-related partners. To keep it simple and attainable to the pilot, 4 KPIs have been agreed and selected through the core KPIs list (section 3.2), one for each dimension (see Table 21). In WP6, the procedure for the measurements will be defined.

Table 21: KPIs selected

Index category	KPI Name	Description	Direction ^a
Environmental	Unit GHG emissions of delivery	This KPI measures the emissions generated per unit of cargo delivered, expressed as kg of CO ₂ per ton of cargo or kg of CO ₂ per kilometre travelled. This KPI is central to the mission of reducing emissions in logistics operations. It provides a direct measure of the environmental impact of transport operations, helping to evaluate the effectiveness of ADMIRAL's strategies in reducing emissions through multimodal logistics solutions, including the adoption of low-emission vehicles and optimised routing.	-1
Economic	Average delivery cost	This KPI tracks the total cost incurred per unit of cargo delivered, considering key factors such as fuel consumption, labour costs, and operational efficiency. This KPI allows ADMIRAL to assess the financial viability and cost-effectiveness of its logistics solutions. By monitoring the unit cost of delivery, ADMIRAL can identify opportunities to improve cost efficiencies through better logistics coordination, more efficient transport modes and optimized use of resources, thus supporting its goal of providing sustainable, cost-effective logistics solutions.	-1
Social	Professions and occupations	This KPI measures the number of new jobs opportunities in the pilot after developing and using the marketplace. It is based on the needs for the development of skills, capabilities, competencies, etc. to transform jobs/professions into new jobs opportunities. This KPI is related to Task 6.4.	+1
Governance	New governance schemes or business models	This KPI measures the number of new governance schemes or business models' opportunities in the pilot after developing and using the marketplace. This KPI is related to WP3.	+1

The KPIs will compare the impact of implementing the proposed ADMIRAL scenarios with the baseline (BAU) scenario. Additionally, for each KPI, its direction is included (see the last column of Table 17), which means that if it is positive (+1), the more is better and if it is negative (-1) the less is better. The

definition and measurement of such KPIs are included in Task 6.1. Basically, the measurement of the KPIs can be carried out directly by using data provided by the operator or companies involved in the pilot, using the APIs marketplace, or through surveys for qualitative KPIs (such as social and governance ones).

5.1.2 Step 2. Obtaining Criteria-Adjusted Weights

This step addresses the relative impact of each criterion on sustainability by obtaining the adjusted weights (AW). The weight of the criteria reflects the preferences and the geographical and social context in which the logistic solution is implemented. Following the methodology outlined by Bueno & Vassallo (2015), the AW are calculated based on both:

- Consensus-based comparative judgments based on expert opinions (Convergent Weight -CW)
- Sensitivity of sustainability criteria to the geographical and social context (Severity Level -SL).

where AW_i – Adjusted Weight for criterion i ; CW_i – Convergent Weight for criterion i ; SL_i – Severity Level of criterion i .

Convergent Weights (CW)

For the ADMIRAL project, Convergent Weights (CW) will be obtained based on the results of the ADMIRAL survey conducted under Task 2.1 with the objective of prioritising goals for achieving green and sustainable logistics. One section of a comparison of the survey consisted of key logistics goals. That section of the survey asked that “for each pairwise comparison of two sustainability related dimensions, point out the one which is preferable for the logistic sector. If, for example, you select a strong preference for the “economic” criteria over the “environmental criteria”; you implicitly claiming that economic criteria are much more important for the logistics sector than environmental criteria’. They compared the importance of different sustainability dimensions, where a strong preference for one dimension over another corresponded to higher values. The responses are averaged and rescaled according to the AHP methodology (Saaty & Katz, 1990), with a slight modification adjusting the scale from the 9-point to 7-points scale to better fit the data, as shown below:

Dimension i vs. Dimension j	AHP scale (a_{ij}) with reciprocals
(1) Strong preference dimension	7
(2) Moderate preference dimension	5
(3) Weak preference dimension	3
(4) Indifference	1
(5) Weak preference dimension	1/3
(6) Moderate preference dimension	1/5
(7) Strong preference dimension	1/7

Then a 44 x 4 pairwise comparison matrix A was constructed, where each element represents the relative importance of dimension compared to dimension. The matrix satisfies the reciprocity

condition $a_{ji} = \frac{1}{a_{ij}}$, with all diagonal elements equal to 1.

$$A = \begin{pmatrix} 1 & a_{12} & a_{13} & a_{14} \\ \frac{1}{a_{12}} & 1 & a_{23} & a_{24} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & a_{34} \\ \frac{1}{a_{14}} & \frac{1}{a_{24}} & \frac{1}{a_{34}} & 1 \end{pmatrix} \quad (1)$$

Then, a normalised matrix N is calculated as:

$$N = \left(\frac{A_{ij}}{\sum_{k=1}^n A_{kj}} \right), \quad (2)$$

Where $\sum_{k=1}^n A_{kj}$ represents the sum of the elements in the j^{th} column of matrix A. Here, k is the row index.

The weight for each dimension is then calculated on the normalized pairwise comparison matrix N which is:

$$W_i = \sum_{j=1}^n \frac{N_{ij}}{n} \quad (3)$$

The sum of all W_i values equal 1, and each W_i represents the weighted value of a dimension. When ranked from the highest to the lowest, the weights prioritise the criteria.

Finally, to ensure the consistency of the pairwise comparison matrix, the approach proposed by Alonso & Lamata (2006) was applied. Their method provides a simple way to assess the consistency of the matrix, adjusting to different scales and matrix sizes. Specifically, they established threshold values for the maximum acceptable eigenvalue based on Saaty's consistency criteria (Saaty & Katz, 1990). For a 4x4 matrix, the maximum acceptable is 4.27. If the computed eigenvalue remains within this threshold, the matrix is considered sufficiently consistent for AHP analysis.

Severity Level (SL)

On the other hand, Severity Level (SL) index is defined as a composite index including both the Present Situation (PS) and Trend (T) for the four selected sustainability criteria at the site context where the specific case study pilot is implemented. The Present Situation for each criterion (KPI) and pilot is evaluated on a scale of 0 to 5 points based on how it is compared to the average in context. The Trend is classified as “improving”, “stable”, or “worsening” and allocated 0 to 2 points accordingly. The SL is the sum of the PS and T, with a range from 0 to 7.

where SL_i – Severity Level of criterion i ; PS_i – Present Situation for criterion i ; T_i – Trend for criterion i for each LL area.

For each criterion (KPI), the situation of the pilot site context measured through a specific attribute (for instance, job qualification performance) is compared with the average for Europe through the

Present Situation. Suppose that a pilot territory has unemployment rate levels worse than the average of the European countries, and their tendency (*Trend*) in the near future is to keep on worsening. In that case, a higher *SL* will be applied to this criterion compared to other cities where the unemployment rate is not as critical to sustainability as it is for this territory.

The situation in each ADMIRAL pilot context for sustainability criteria can be measured either quantitatively or qualitatively, depending on their nature. Quantitative attributes were consulted in official reports or databases at the country level. Regarding qualitative criteria, LEAD project stakeholders from each pilot (public authorities, logistic operators, or both, depending on the criteria) were asked to rate each criterion. For example, regarding the qualitative criteria "new governance schemes and business models", stakeholders will be asked: "How important are the implementation of new governance schemes and new business models in your pilot compared to similar logistic sector?" with five potential answers: (1) *Not at all important*, (2) *Slightly important*, (3) *Moderately important*, (4) *Very important*, and (5) *Extremely important*. For the qualitative criteria of the "average delivery cost" criteria, stakeholders will be asked: "How are average delivery costs for logistics in your pilot compared to other similar logistics sectors? *Much lower/ Lower/ About the same/ Higher/ Much Higher*."

5.1.3 Step 3. Obtaining the global sustainability rating

Finally, to select the option with the best sustainability score, the final step involves measuring the sustainable performance of each scenario. This process begins by estimating the KPIs for each scenario. Next, the percentage change of the KPIs in each scenario is calculated relative to the BAU scenario. This calculation is made according to the following formula:

$$KPI\ Change\ (CH) = \left(\frac{(New\ Scenario - BAU)}{BAU} \right) * 100 \quad \forall_{KPI}$$

Then, the **Sustainability Performance (SP)** of each scenario is estimated by multiplying the change rate by the adjusted weight (AW calculated in Step 2) and the sign effect of each KPI (or direction).

$$SP = \sum (CH_i \times AW_i \times ES_i)$$

Finally, all values for each scenario are aggregated and ranked from highest to the lowest.

5.2 Conclusion on STAR model adaptation

The adaptation of the STAR Logistics method to the ADMIRAL project provides a robust framework for evaluating the sustainability of logistics solutions. By integrating economic, environmental, social, and governance dimensions, the methodology offers a comprehensive approach to sustainability assessment. The selection of KPIs and the calculation of adjusted weights ensure that the evaluation is tailored to the specific context of each ADMIRAL pilot. The application of the methodology to the project pilots demonstrates its versatility and effectiveness in different scenarios.

The STAR Logistics will assess the sustainability impact of ADMIRAL case studies through different pilots in European regions. The method will be used in the last phase of the project in relation to impact

assessment (WP6), allowing one to make custom decisions according to each region, considering the context's sensitivity of the context and expert perspectives.

6 Sustainability Rating Model and Evaluation

This section describes the methodological steps need to construct a Global Sustainability Model and building on the current Task 2.4 work proposes the ADMIRAL model. It also suggests an evaluation tool for data collection and analysis, based on the work performed in FOR-FREIGHT EU project.

6.1 Global Sustainability Rating Model

A global sustainability rating model (Protic et al., 2019) for logistics solutions is a framework designed to evaluate and measure the environmental, social, and economic impacts of logistics operations on a global scale. By implementing a global sustainability rating model, companies can not only improve their environmental footprint but also enhance their reputation, comply with regulations, and achieve long-term economic benefits.

The key components and features of such a model should include:

- **Environmental Impact Assessment** (e.g., measuring carbon emissions, energy consumption, waste generation, and resource utilization). The goal is to minimize the carbon footprint and promote eco-friendly practices
- **Social Responsibility:** Evaluates the impact on communities, labour practices, and employee well-being. It ensures fair labour practices, safe working conditions, and community engagement.
- **Economic Performance:** Assesses the cost-effectiveness and economic benefits of sustainable logistics practices. This includes evaluating the long-term financial viability and cost savings from implementing sustainable solutions.
- **Compliance and Risk Management:** Ensures adherence to international regulations and standards related to sustainability. It also involves identifying and mitigating risks associated with non-compliance
- **Transparency and Reporting:** Involves regular monitoring, reporting, and verification of sustainability metrics. This helps in maintaining transparency and accountability in sustainability efforts
- **Innovation and Technology:** Encourages the adoption of innovative technologies and practices that enhance sustainability, such as renewable energy, electric vehicles, and advanced data analytics

Task 2.4 builds on the work presented in previous chapters of the current deliverable to develop the ADMIRAL Global Sustainability Model focusing on the three sustainability dimensions, i.e., social, economic, and environmental, and elaborating the risk and regulation compliance analysis. Specifically, the methodological steps to develop the model includes:

STEP 1: Definition and selection of logistics KPIs.

STEP 2: Adopt an impact assessment tool of logistics solutions from a sustainability perspective.

STEP 3: Incorporate a regulation compliance and risk non-compliance assessment feature.

STEP 4: Construct a global sustainability model (framework).

STEP 1: Definition and selection of logistics KPIs.

Del. 2.4 defined the ADMIRAL extended and core KPI list (Section 3.2, Tables 15 & 16) after a thorough validation process. Table 22 presents the ADMIRAL KPIs, classifying them according to the framework used and their importance.

Table 22: Global sustainability rating model KPIs

ID	ADMIRAL KPIs	Importance	Framework*
ADM-1	Technology Readiness	Core	BC
ADM-2	Cost per shipment	Core	BC, STAR
ADM-3	GHG emissions per shipment	Core	BC, STAR
ADM-4	Willingness to pay for green logistics	Core	BC
ADM-5	Solution integration	Core	BC
ADM-6	Professions and occupations	Core	BC, STAR
ADM-7	Collaboration among stakeholders	Core	BC, STAR
ADM-8	Number of Accidents	Non-core	BE
ADM-9	Customer satisfaction	Non-core	BE
ADM-10	Shipment turnaround time	Non-core	BE
ADM-11	Shipment load factor	Non-core	BE
ADM-12	Shipment total costs	Non-core	BE
ADM-13	Market Penetration	Non-core	BE
ADM-14	Fulfilled shipments	Non-core	BE
ADM-15	Shipment delivery reliability	Non-core	BE
ADM-16	Public acceptance	Non-core	BE
ADM-17	Stakeholder acceptance	Non-core	BE
ADM-18	Vehicle type	Non-core	BE
ADM-19	Empty running	Non-core	BE
ADM-20	Shipment visibility	Non-core	BE
ADM-21	Lack of knowledge about stakeholders' requirements	Non-core	BE
ADM-22	Changes in legislation (national or EU level)	Non-core	BE

*BC: Bayesian Core relation KPIs; BE: Bayesian Extended relation KPIs

STEP 2: Impact assessment tool

The adaptation of the STAR Logistics methodology to the ADMIRAL project, presented in Section 5.1, provides a robust framework for evaluating the sustainability of logistics solutions. To keep it simple and attainable to the pilot, 4 KPIs have been agreed and selected through the core KPIs list (Table 22). By integrating economic, environmental, social, and governance dimensions, the methodology offers a comprehensive approach to sustainability assessment. The STAR Logistics methodology that will be used to assess the sustainability impact of ADMIRAL case studies is the backbone of the ADMIRAL Global Sustainability Rating Model.

STEP 3: Compliance and Risk assessment

The identification and quantification of social and environmental risks are essential for understanding the project's impact on societal well-being and the environment. Section 4 provided an analytical compliance analysis, including risk and regulation compliance. Specifically, the Bayesian Network risk analysis was introduced as a tool to identify potential risks and assess the risk non-compliance of the AM regarding sustainability. It uses the core and the extended KPI list (Tabel 22) to identify core and non-core interdependencies among the various factors, as well as to perform a sensitivity analysis to explore their influencing relationship. The Bayesian Model as described in section 4.1 is a core part of the ADMIRAL Global Sustainability Rating Model, supplemented by the in-depth analysis of the regulatory framework, correlating the selected KPIs with EU regulations (section 4.2).

STEP 4: Construct a global sustainability model (framework)

The previous steps feed the construction of the ADMIRAL Global Sustainability Rating Model (Figure 10). The figure visually represents how the identified KPIs (Step 1) are integrated into the global sustainability rating model, highlighting their importance and the frameworks they belong to, i.e.:

- the KPIs in green (ADM-2, 3, 6, 7, that have been used in the STAR model adaptation) to be used for sustainability rating model (Step 2),
- KPIs ADM1-7 and ADM8-22 used to identify core/extended interdependencies and risk non-compliance (Step 3),
- under the overall assessment of the regulation compliance (Step 3).

The model aims to provide a holistic evaluation tool for assessing and improving the sustainability of logistics operations within the ADMIRAL project.

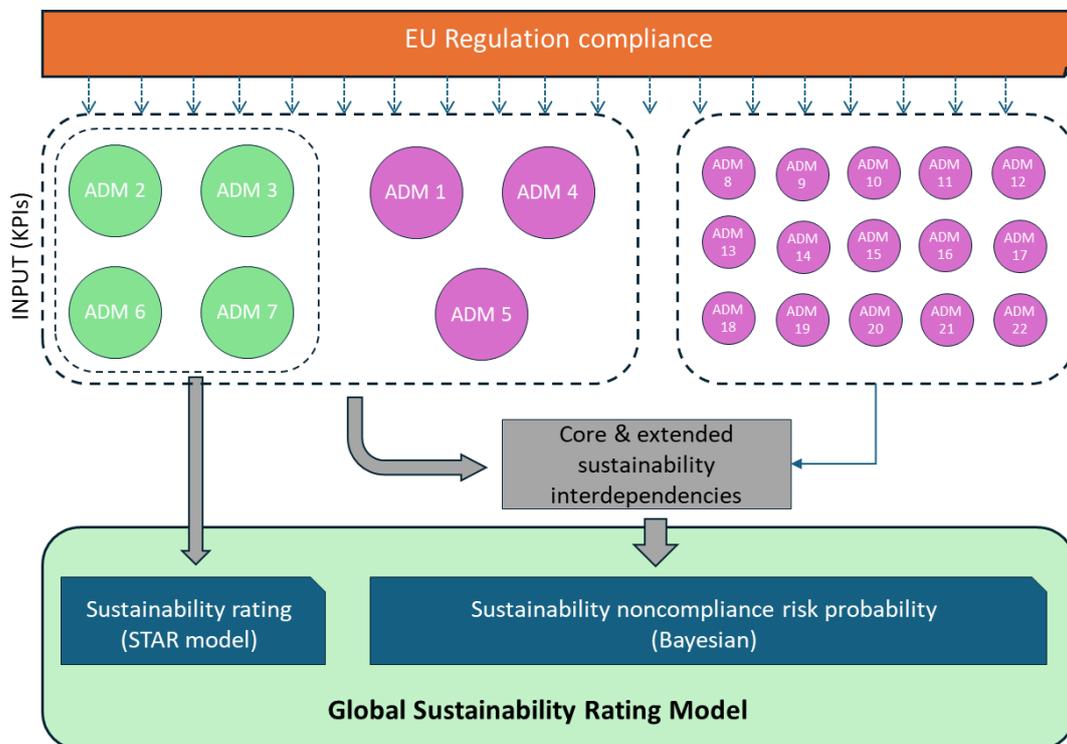


Figure 10: Global Sustainability Rating Model

6.2 Evaluation tool for data collection & analysis specifications

Evaluation is crucial to the successful implementation of the ADMIRAL Marketplace. Therefore, a comprehensive process to gather the necessary data and validate the project's success is essential. For this purpose, the evaluation tool employed in the FOR-FREIGHT project (FOR-FREIGHT, Del. 1.2, 2023) has been adopted and is proposed to be applied in the ADMIRAL project and specifically to support the ongoing work on W6 for the collection and evaluation of pilot data.

The tool aims to ensure a systematic approach to data collection and analysis, facilitating accurate assessment and continuous improvement. It is supported by an Excel template where the involved stakeholders provide the requested information in a uniform way (FOR-FREIGHT, Del. 1.2, 2023).

Table 23 presents the main data collection form and Annex V additional ones (including mid-term and long, providing a detailed framework for further interpretation and application.

Table 23: Evaluation assessment tool for ADMIRAL MP

ADMIRAL KPIS										
KPI id	KPI	KPI Description	KPI measurement	KPI target	Baseline value	ex-post measurement	Comparison baseline/ex-post measurement	Logistics process measured	Partner responsible for the calculation	Means of verification
AMD-01	Technology Readiness	Readiness of ADMIRAL solutions and industry stakeholders for broader implementation across the logistics industry.	TRL 1-9							
AMD-02	Cost per shipment	The unit cost of shipments with the use of AM services.	Euro/shipment							
AMD-03	GHG emissions per shipment	The environmental impact of transport operations per shipment.	t CO2e/shipment							
AMD-04	Willingness to pay for green logistics	The willingness of users to pay for green logistics.	% of users willing to pay for green logistics services							
AMD-05	Solution integration	Integration rate - Degree to which the AM solutions are integrated into existing logistics systems and supply chains.	systems integrated/per total systems across a supply chain							
AMD-06	Professions and occupations	Number of new jobs opportunities in the freight transport and logistics sector.	New jobs/month							
AMD-07	Collaboration among stakeholders	Number of new collaborations among stakeholders that occur after the use of the marketplace.	New collaborations/month							
AMD-08	Number of Accidents	Measures on-site security and safety.	Accidents/month							
AMD-09	Customer satisfaction	What is the satisfaction from the customers by the use of the ADMIRAL Marketplace (AM) service? - Significant or optimal usefulness with current and potential services.	% satisfied/total							
AMD-10	Shipment turnaround time	Overall time from shipment order to delivery to the end-user.	Time (hours or days)							

ADMIRAL KPIS										
KPI id	KPI	KPI Description	KPI measurement	KPI target	Baseline value	ex-post measurement	Comparison baseline/ex-post measurement	Logistics process measured	Partner responsible for the calculation	Means of verification
AMD-11	Shipment load factor	Shipment capacity utilization.	Used/available capacity %							
AMD-12	Shipment total costs	Total Managerial and Operational costs associated to the use of AM services.	Euro							
AMD-13	Market Penetration	The number of companies or logistics providers integrating the AM solutions along their supply chains.	Market share							
AMD-14	Fulfilled shipments	Shipments planned and fulfilled at a specified timeframe.	Number of shipments/month							
AMD-15	Shipment delivery reliability	The proportion of shipments that were successfully delivered on-time.	Actual/planned deliveries %							
AMD-16	Public acceptance	Public/society perception on the importance of AM towards green logistics (behavioural change).	% people willing to adopt green services							
AMD-17	Stakeholder acceptance	Number (rate) of companies using AM or collaborating within the platform.	% supply chain stakeholders willing to adopt green logistics services							
AMD-18	Vehicle type	The type of vehicle used in transport operations.	EURO							
AMD-19	Empty running	Amount of truck kilometres travelling empty.	empty km/total km							
AMD-20	Shipment visibility	Disruptions or inefficiencies in the transmission of data within users and the AM.	Tracked/total shipments %							
AMD-21	Lack of knowledge about stakeholders' requirements	Supply chain awareness - Perception of stakeholders for the level that the AM responds to their technological requirements.	% of supply chain stakeholders claiming to not understand what AM services offer							
AMD-22	Changes in legislation (national or EU level)	Changes in legislation that considerably alter the way the transport and logistics industry operate (e.g., eFTI, Scope 3).	Yes/No							

Table explanation:

- **KPI id:** This column assigns a unique identifier to each Key Performance Indicator (KPI) for easy reference and tracking. The IDs follow a structured format (e.g., AMD-01, AMD-02) to maintain consistency across the dataset and facilitate quick identification in reports and analysis.
- **KPI:** This column provides the name of each KPI, summarizing the key aspect of performance being measured. Examples include "Technology Readiness," "Cost per Shipment," and "Environmental Impact," reflecting different dimensions of project evaluation.
- **KPI Description:** This column offers a concise explanation of what each KPI represents. It clarifies the specific element of the ADMIRAL project that the KPI assesses, such as the level of technological maturity, the cost-effectiveness of shipping operations, or the environmental footprint of logistics processes.
- **KPI measurement:** This column details the unit of measurement or methodology used to quantify each KPI. Depending on the KPI type, this may include numerical scales (e.g., TRL 1-9 for technology readiness), financial metrics (e.g., Euro per shipment), or environmental indicators (e.g., tons of CO₂ equivalent per shipment).
- **KPI target:** This column defines the specific goal or threshold that the project aims to achieve for each KPI. Targets are set based on industry benchmarks, project objectives, or regulatory requirements to guide performance improvements.
- **Baseline value:** This column captures the initial value of each KPI before the implementation of the ADMIRAL project. It serves as a reference point against which progress, and improvements can be measured. Baseline data is essential for assessing the effectiveness of project interventions.
- **Ex-post measurement:** This column records the value of each KPI after the ADMIRAL project has been implemented. By comparing post-implementation results to the baseline, stakeholders can determine the impact of the project on key performance areas.
- **Comparison baseline/ex-post measurement:** This column provides a direct comparison between the baseline and ex-post values, highlighting the extent of change or improvement. The comparison may be presented as an absolute difference, percentage change, or another relevant metric to facilitate performance assessment.
- **Logistics process measured:** This column specifies the logistics operation or process that each KPI is associated with. Examples include cargo handling, vessel-to-port transfers, intermodal transport operations, and warehouse efficiency. Understanding the process being measured ensures that the KPI is relevant to the specific aspects of supply chain performance.
- **Partner responsible for the calculation:** This column identifies the specific partner organization or entity responsible for collecting data, performing calculations, and reporting KPI values. Assigning responsibility ensures accountability and transparency in the monitoring process.
- **Means of verification:** This column outlines the methods, data sources, or tools used to validate the accuracy and reliability of KPI measurements. Verification mechanisms may

include sensor data, financial records, operational logs, industry reports, or third-party audits to ensure the integrity of performance assessments.

6.3 Rating and evaluation key points

This section develops a comprehensive sustainability rating model and evaluation tool for the ADMIRAL project. By adapting the STAR Logistics methodology and employing Bayesian risk analysis, the deliverable proposes a global sustainability rating model that focuses on the three key dimensions of sustainability: social, economic, and environmental. The ADMIRAL KPIs have been classified according to their importance and the framework used, providing a clear structure for assessing the project's impact. The evaluation tool, adapted from the FOR-FREIGHT project, ensures a systematic approach to data collection and analysis. This tool is essential for validating the project's success and facilitating continuous improvement. It includes an Excel template for stakeholders to provide the necessary information in a standardized manner, ensuring accurate assessment and interpretation.

Overall, the adaptation of the evaluation tool from the FOR-FREIGHT project further enhances the accuracy and reliability of the assessment process, providing an evaluation tool proposal for WP6.

7 Green Port Certification Analysis

Ports operations are a special interest focus group in logistics regarding sustainability. Ports play a crucial role in global logistics, but they also have significant environmental impacts, which require dedicated effort, starting with measuring the port sustainability level. To this extent, the ADMIRAL project aims to draft a framework of requirements for a Green Port Certification, based on preceding work, as it is a valuable tool for ports that want to improve their environmental, social, and economic performance and become more sustainable and resilient. A Green Port certification service facilitates the integration of environmentally friendly methods into the operating system, management, port development, and other services to help ports balance environmental impacts and economic interests.

This section discusses the findings of the PIXEL project in conjunction with the ADMIRAL Sustainability rating model and TIC4.0 standards to understand the certification requirements and guide a pathway (specifications) towards a holistic Green Port Certification process.

7.1 Green Port Certification Requirements

Green Port Certification is a comprehensive framework aimed at reducing the environmental impact of ports and maritime companies. To achieve this certification, participants must measure their environmental performance across various indicators, such as air, water, and soil quality, biodiversity protection, and community relations. Ports are required to demonstrate ongoing and measurable improvements in their environmental practices year after year (GreenMarine, 2025). The certification process involves collaboration with environmental groups, government agencies, and academic experts to ensure comprehensive and effective environmental management. By adhering to these requirements, ports can enhance their environmental performance, gain recognition, and contribute to sustainable maritime operations (CIP, 2020).

PIXEL project (2025) established a single-metric index to integrate diverse environmental impacts of a port, provide an applicable environmental assessment tool and serve as a standardized and transparent metric for addressing the environmental impacts of port operations. The Port Environmental Index (PEI) is a global quantitative environmental composite index fed on a variety of data types (including real-time), allowing ports to access the progress of their own environmental performance. The tool enables flexibility and scalability in monitoring environmental performance in real-time through the IoT infrastructure at the port.

It collects environmental data from heterogeneous sources and combines them into a single quantitative composite indicator. Based on this input, PEI can use the complex algorithms developed, the collected data is homogenised and used to calculate the composite indicator which quantifies the environmental performance of the port. The PEI algorithm is based upon the composite index methodology, which includes statistical methods for data processing and integration. PEI is built by integrating three indices: the Ship Environmental Index (SEI), the Terminal Environmental Index (TEI), and the Port Authority Environmental Index (PAEI) (Široka et al., 2021), as Figure 11 presents.

The differentiating points of PEI in relation to the other approaches are that the methodological approach which will be used to construct the PEI is quantitative (data based) and it bypasses the self-assessment procedure. Thus, the PEI can accurately depict the true environmental performance of a

port and will allow for interport environmental comparisons. In addition, if PEI is combined with an automated real-time data collection system obtained through IoT it can monitor the environmental performance of a port in a comprehensive manner.

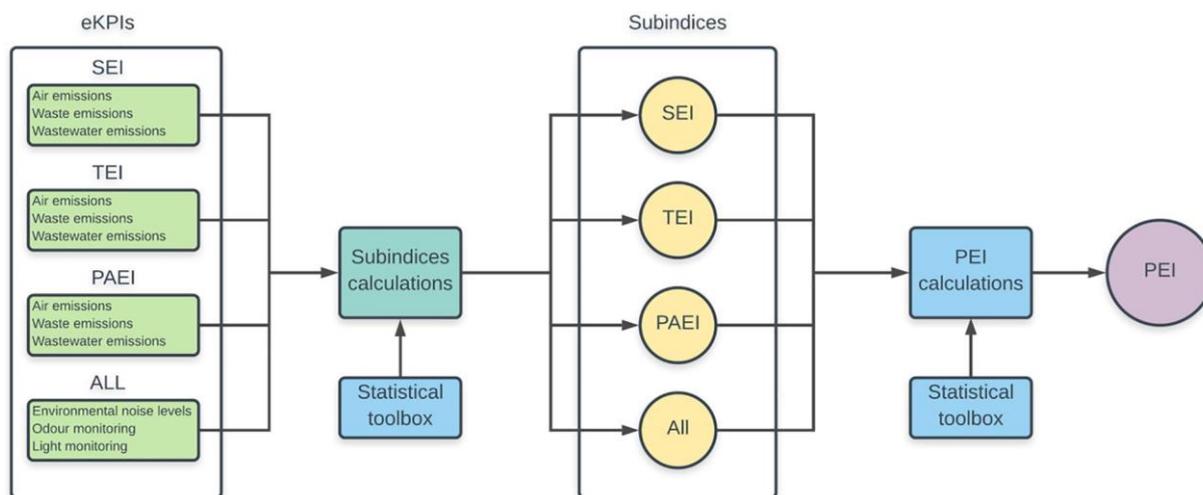


Figure 11: Generalized methodology for executing the PEI calculation (PIXEL, 2025)

Using PEI ports can have a reliable measure of their environmental footprint and so they can plan actions to reduce it to the desired levels and monitor their environmental efficiency per category. As a result, ports can facilitate the reduction of the environmental impact of port activities through the direct measurement and modelling capabilities, optimise their use of resources by including the appropriate monitoring parameters of environmental-related activities and act on them, and enhance the environmental performance planning capabilities to improve the green image of the port and attract new customers.

7.2 Green Port Certification Specifications

After the identification of significant environmental aspects, a set of representative eKPIs were identified for each aspect, assuming that the indicators must be representative and generally available in small and medium sized ports. The most relevant indicators of port processes' impacts on the environment were assessed based on the following features: significance, measurability (meaning the feasibility of having them measured in real-time by IoT systems or using already existing data produced by the ports), representativeness (differentiate the effects of port activities from any other "outside" effect) and their correlation. The list of the eKPIs that are used to build the PEI is given in Annex VI.

However, PEI does not include other sustainability aspects (i.e., social, economic) that the ADMIRAL framework elaborates on. In addition, TIC4.0 standardisation efforts may offer a significant input to the development of the Green Port Certification, as it works on adopting commonly agreed industry standards, equipment/systems specifications and defining the format and protocols for electronic data exchanges. The main key metrics that can be used from the TIC4.0 Framework for the evaluation of port operations, after a review of TIC4.0 white papers and suggestions, are presented in Table 24.

Table 24: TIC4.0 main KPIs for the ADMIRAL Green Port Certification

Name	Description	Measurement
TEU Throughput	Total number of TEUs handled over a given period of time	Total TEUs handled / Time period
Crane Productivity	Average number of TEUs handled by a crane per hour of operation	Total number of moves made by crane / Hours worked by the crane
Vessel Productivity	Average number of TEUs handled by a vessel per hour of stay	Total TEUs handled during vessel call / Time vessel spent at berth
Turnaround Time	Total time taken by a vessel to berth, unload, load, and depart	Time vessel spent at berth + Time container spends at gate
Dwell Time	Average time a container stays in the yard before being loaded onto a vessel or before complete gate out	Time container spends in terminal - Time vessel left the berth
Berth Productivity	Average number of TEUs handled by a berth per hour of operation	Total TEUs handled / Berth length
Equipment Utilization	Percentage of time a crane is being used for cargo handling	Total hours equipment used / Total available hours
Gate Turnaround Time	Average time taken by a truck to enter and exit the terminal	Time truck enters terminal gate to time it exits the gate
Gate Productivity	Average number of trucks processed per hour by a gate	Number of trucks processed / Hours worked at gate
Truck Wait Time	Average time a truck spends waiting at the gate to enter the terminal	Total time trucks spend waiting in line at the gate / Total number of trucks processed
Gate Utilization	Percentage of time a gate is being used for truck processing	Total hours gate is in use / Total available hours
Gate Capacity	Maximum number of trucks that can be processed per hour per gate	Maximum number of trucks that can be processed per hour / Total number of gates
Transaction Time	Average time taken to process one truck transaction at the gate	Total time it takes to complete a gate transaction
Rehandles	Rehandles are a key performance indicator (KPI) for container terminals, as they indicate the efficiency of container movements within the terminal. A rehandle occurs when a container is moved more than once during its time in the terminal, such as when it is picked up from one location and moved to another location for further processing.	(Total moves - Total TEUs handled) / 2
Yard Density	Number of containers per square meter of yard space	Total number of containers in yard / Yard area
Yard Utilization	Percentage of yard space being used for container storage	Total yard capacity used / Total yard capacity available
Gross Crane Rate	Average number of containers moves per hour across all cranes in operation	Total number of moves / Total all crane hours

Name	Description	Measurement
Gross Crane Rate per Hour	Average number of containers moves per hour for a single crane in operation	Total TEUs handled / Total single crane hours
Gross Crane Rate per Move	Average time taken to complete a single container move for a single crane in operation	Total time taken to move all containers / Total number of container moves
Gross Crane Rate per TEU	Average number of TEUs handled per hour for a single crane in operation	Total number of moves / Total TEUs handled

This report suggests enriching the PIXEL index with elements from the ADMIRAL framework and the TIC4.0. The proposed Green Port Certification is built on the above three main pillars, as presented in Figure 11:

- The PEI index as proposed in PIXEL
- The TIC4.0 standards and metrics
- The ADMIRAL Global Sustainability Rating Model.

Following a port stakeholders consultation/survey in the future, the final set of KPIs to be used by the model should be updated and defined. In Figure 12 for example, some ADMIRAL KPIs (ADM-3, 9, 18, 19) that are already included in PEI or are irrelevant to port operations have been excluded.

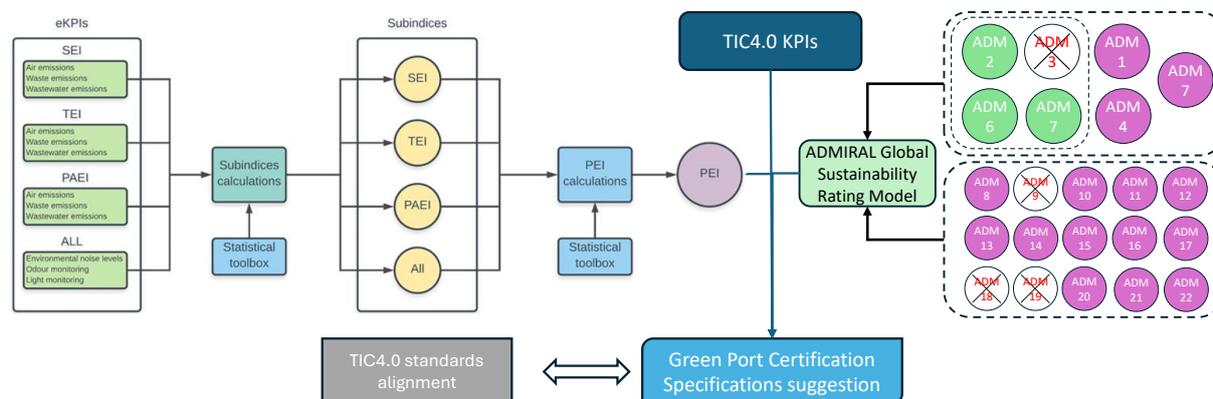


Figure 12: ADMIRAL Green Port Certification suggestions

8 Conclusions

Deliverable, D2.4 focuses on creating a Sustainability Maturity Model that integrates various dimensions of sustainability, including environmental, economic, social, and governance aspects. The report elaborates a multifaceted approach by mixing the following methodological tools and analyses, which includes extensive literature review, pilot site and expert validation (workshops, online consultation, questionnaires), Bayesian Network Risk analysis (questionnaires survey, on site survey, statistical interpretation), Regulation compliance analysis (EU regulation review, schematic correlation), and the STAR model adaptation (adjust current models & weights, multi-criteria decision analysis). The methodologies and tools employed provide valuable insights and practical solutions for enhancing sustainability in logistics operations, contributing to a greener and more efficient logistics ecosystem.

The current work has effectively aligned ADMIRAL impact categories with its sustainability requirements, ensuring consistency with the project Grant Agreement and the proposed KPIs. This alignment has been crucial for maintaining a clear focus on the project's sustainability goals. A detailed list of over 400 logistics KPIs was developed, categorized into seven main areas: Business & Governance, Economic, Environmental, Energy, Operational & Productivity, Societal, and Technological. This extensive KPI framework provides a robust basis for measuring and evaluating the sustainability performance of logistics operations.

The KPIs were refined through consultations with ADMIRAL and industry experts, as well as pilot site validations. This collaborative process ensured that the selected KPIs are relevant, measurable, and aligned with the project's objectives. The final set of KPIs was prioritized through a collaborative process involving stakeholders from the ADMIRAL consortium. This prioritization ensures that the most important and impactful metrics are emphasized for tracking the project's success.

The Bayesian Network risk non-compliance analysis provided a powerful tool for assessing and managing risks related to sustainability noncompliance. It helps to identify potential risks, assess their likelihood and impact, and support decision-making. The regulatory compliance analysis ensured that the ADMIRAL project aligns with relevant EU regulations. This alignment is essential for enhancing efficiency, safety, and environmental impact in logistics operations.

The importance of technology readiness and integration was emphasized, highlighting the role of digital solutions in achieving sustainability goals. The project has successfully integrated advanced technologies to enhance logistics operations. The project underscored the significance of collaboration among stakeholders, which is crucial for achieving sustainability goals and fostering innovation. The ADMIRAL Marketplace has facilitated new collaborations and partnerships.

The adaptation of the STAR Logistics methodology to the ADMIRAL project provided a robust framework for evaluating the sustainability of logistics solutions. This model integrates economic, environmental, social, and governance dimensions, offering a comprehensive approach to sustainability assessment.

The evaluation tool, adapted from the FOR-FREIGHT project, ensures a systematic approach to data collection and analysis. This tool is essential for validating the project's success and facilitating continuous improvement.

Finally, Del. 2.4 proposes a framework for Green Port Certification, integrating the PIXEL project's Port Environmental Index (PEI) with elements from the ADMIRAL framework and TIC4.0 standards. This certification aims to enhance the environmental performance of ports and contribute to sustainable maritime operations.

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ANNEX I – Pool of logistics KPIs

Table A1: Pool of logistics KPIs related to ADMIRAL categories

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
1	Total emissions (GHG, NOx, SO2, CO2)	Environmental	Emissions	kg/km, t/CO2eq	Road, Rail, Maritime	PLANET, D2.2
2	Air pollution	Environmental	Emissions	kg/km, ppm	Road, Rail, Maritime	PIXEL, D2.2
3	CO2 emissions	Environmental	Emissions	l/tkm, g/vkm, g/ton-mile, g/ton-km		URBANE, FENIX, D2.2
4	CO2 emissions per container	Environmental	Emissions	t/CO2		PLANET
5	Reduction in CO2 emissions due to implementation of EEDI	Environmental	Emissions	kg/km	Maritime	D2.2
6	Reduction in CO2 emissions due to implementation of EEXI	Environmental	Emissions	kg/km	Maritime	D2.2
7	Reduction in CO2 emissions per unit of transportation work (EEOI)	Environmental	Emissions	kg/capacity m	Maritime	D2.2
8	Annual reduction factor in operational carbon intensity (CII)	Environmental	Emissions	Percentage	Maritime	D2.2
9	VOC emissions per mile	Environmental	Emissions	g/mile	Road	D2.2
10	NOx emissions	Environmental	Emissions	l/tkm		FENIX, D2.2
11	NO2 emissions	Environmental	Emissions	µg/m ³		URBANE, D2.2
12	SO2 emissions	Environmental	Emissions	µg/m ³	Maritime	e-Ferry, D2.2
13	PM10 emissions	Environmental	Emissions	g/vkm, g/km, g/trip		URBANE, D2.2
14	GHG emissions	Environmental	Emissions	t CO2e, Kgs/stop		FOR-FREIGHT
15	GHG emissions (Total CO2 emissions of the port in a year)	Environmental	Emissions	t CO2e	Maritime	PIXEL
16	Well-to-wheels GHG emissions	Environmental	Emissions	kgCO2e/km	Road	D2.2
17	Tank-to-wheels GHG emissions	Environmental	Emissions	kgCO2e/km	Road	D2.2
18	GHG emissions per tonne-km	Environmental	Emissions	kgCO2e/ton	Rail	D2.2
19	Air pollutant emissions indicator (SUMI 03)	Environmental	Emissions	kg PM2.5 eq./cap per year		URBANE
20	Noise level (pollution)	Environmental	Emissions	dB	Road, Rail	PIXEL, URBANE, D2.2
21	Perception of noise	Environmental	Emissions	dB(A)	Maritime	e-Ferry
22	Unit emission of delivery	Environmental	Emissions	g/km		
23	Risk of oil pollution	Environmental	Waste	spills per year	Maritime	e-Ferry
24	Number of oil spills	Environmental	Waste	1 year, 2020, 2030	Maritime	e-Ferry

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
25	Waste production	Environmental	Waste	kg of saved disposable packaging		URBANE
26	Reduction in water usage per vehicle	Environmental	Waste	l/vehicle	Road, Rail	D2.2
27	Reduction in packaging waste per shipment	Environmental	Waste	kg/shipment	Road, Rail	D2.2
28	Reduction in paper usage through digitalization	Environmental	Waste	%	Road, Rail	D2.2
29	Enhancement in water quality preservation efforts	Environmental	Waste	%	Road, Rail	D2.2
30	Environmental issues raised	Environmental	Awareness	no. of environ. complaints registered / year		PIXEL
31	Introduction of vehicle recycling programs	Environmental	Awareness	Count	Road, Rail	D2.2
32	Decrease in land use for transportation facilities	Environmental	Awareness	m ²	Road, Rail	D2.2
33	Adoption of sustainable land use practices	Environmental	Awareness	%	Road, Rail	D2.2
34	Reduction in deforestation associated with transportation activities	Environmental	Awareness	%	Road, Rail	D2.2
35	Implementation of wildlife conservation measures	Environmental	Awareness	Count	Road, Rail	D2.2
36	Reduction in habitat fragmentation due to transportation infrastructure	Environmental	Awareness	%	Road, Rail	D2.2
37	Willingness to pay for green urban logistics	Environmental	Awareness	€ per shipment		D6.1
38	Impact on the environment for each delivery	Environmental	Green Strategies	kg CO ₂ e/delivery		D6.1
39	Number of Smart and Green Delivery operations for delivery	Environmental	Green Strategies	deliveries per year		D6.1
40	Environmental leadership - Green Marine Indicator	Environmental	Green Strategies	1-5 scale		PIXEL
41	Adoption rate of sustainable delivery options	Environmental	Green Strategies	Percentage of customers who choose sustainable delivery options		URBANE
42	Reduced operating costs for obtaining environmental information	Environmental	Green Strategies	€ / year		PIXEL

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
43	Rail network electrification rate	Environmental	Green Strategies	Percentage	Rail	D2.2
44	Adoption of rainwater harvesting systems	Environmental	Green Strategies	%	Road, Rail	D2.2
45	Usage of sustainable materials in vehicle manufacturing	Environmental	Green Strategies	%	Road, Rail	D2.2
46	Introduction of recyclable packaging materials	Environmental	Green Strategies	%	Road, Rail	D2.2
47	Increase in percentage of recycled vehicle components	Environmental	Green Strategies	%	Road, Rail	D2.2
48	Implementation of eco-friendly cleaning products	Environmental	Green Strategies	%	Road, Rail	D2.2
49	Percentage decrease in fuel consumption	Energy	Consumption	%	Road, Rail, Maritime	D2.2
50	Fuel consumption per Km	Energy	Consumption	MJ/vkm		FOR-FREIGHT
51	Increase in miles per gallon (MPG)	Energy	Consumption	mpg	Road, Rail, Maritime	D2.2
52	Decrease in litres of fuel per 100 kilometres	Energy	Consumption	l/100 km	Road, Rail, Maritime	D2.2
53	Well-to-wheels energy consumption	Energy	Consumption	MJ/km	Road	D2.2
54	Tank-to-wheels energy consumption	Energy	Consumption	MJ/km	Road	D2.2
55	Reduction in energy used	Energy	Consumption	kWh/km	Road, Rail, Maritime	e-Ferry, D2.2
56	Reduction in air conditioning energy consumption	Energy	Consumption	kWh/km	Road, Rail	D2.2
57	Reduction in vehicle idling time	Energy	Consumption	%	Road, Rail	D2.2
58	Reduction in energy consumption during vehicle manufacturing process	Energy	Consumption	kWh/vehicle	Road, Rail	D2.2
59	Reduction in overall energy intensity of transportation systems	Energy	Consumption	%	Road, Rail	D2.2
60	Reduction in energy losses during electricity transmission for transportation	Energy	Consumption	%	Road, Rail	D2.2
61	Reduction in energy consumption during railway electrification	Energy	Consumption	kWh/km	Rail	D2.2
62	Energy efficiency in rail transport	Energy	Optimization	MJ/tonne-km	Rail	D2.2
63	Average locomotive fuel efficiency	Energy	Optimization	gallons/mile	Rail	D2.2

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
64	Energy efficiency ratio	Energy	Optimization	%	Road, Rail, Maritime	e-Ferry, D2.2
65	Introduction of demand response programs for transportation energy	Energy	Optimization	%	Road, Rail	D2.2
66	Increase in the use of energy-efficient heating systems for transportation	Energy	Optimization	%	Road, Rail	D2.2
67	Implementation of energy-efficient route planning algorithms	Energy	Optimization	%	Road, Rail	D2.2
68	Adoption of energy-efficient vehicle tracking systems	Energy	Systems/materials	%	Road, Rail	D2.2
69	Climate Policy Integration	Energy	Adoption	Policies integrated	Road, Rail, Maritime	D2.2
70	Utilization of biofuels	Energy	Resources	%	Road, Rail, Maritime	D2.2
71	Integration of regenerative braking systems	Energy	Systems/materials	%	Road, Rail	D2.2
72	Implementation of carbon capture technology	Energy	Systems/materials	Count	Road, Rail, Maritime	D2.2
73	Introduction of lightweight vehicle materials	Energy	Systems/materials	%	Road, Rail, Maritime	D2.2
74	Implementation of eco-driving training programs	Energy	Adoption	%	Road, Rail	D2.2
75	Adoption of aerodynamic vehicle designs	Energy	Adoption	%	Road, Rail	D2.2
76	Utilization of energy-efficient tires	Energy	Adoption	%	Road, Rail	D2.2
77	Implementation of low rolling resistance tires	Energy	Adoption	%	Road, Rail	D2.2
78	Increase in percentage of electric miles travelled	Energy	Adoption	%	Road, Rail	D2.2
79	Implementation of green building standards for transportation facilities	Energy	Adoption	%	Road, Rail	D2.2
80	Increase in the use of recycled materials in vehicle production	Energy	Adoption	%	Road, Rail	D2.2
81	Adoption of closed-loop manufacturing systems for vehicle components	Energy	Adoption	%	Road, Rail	D2.2
82	Implementation of eco-friendly disposal	Energy	Adoption	Count	Road, Rail	D2.2

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
	methods for end-of-life vehicle					
83	Utilization of carbon capture and storage (CCS) technology in transportation	Energy	Adoption	Count	Road, Rail	D2.2
84	Increase in energy recovery from transportation-related processes	Energy	Adoption	%	Road, Rail	D2.2
85	Adoption of efficient cargo handling systems at ports and terminals	Energy	Adoption	Count	Maritime	D2.2
86	Implementation of green procurement policies for transportation equipment	Energy	Adoption	%	Road, Rail	D2.2
87	Adoption of vehicle-to-grid (V2G) technology for energy storage	Energy	Adoption	Count	Road, Rail	D2.2
88	Implementation of smart grid technology for electric transportation	Energy	Adoption	Count	Road, Rail	D2.2
89	Adoption of energy-efficient practices for railway track maintenance	Energy	Systems/materials	%	Rail	D2.2
90	Adoption of energy-efficient refrigeration systems for transportation	Energy	Adoption	%	Road, Rail	D2.2
91	Introduction of energy-efficient loading and unloading procedures	Energy	Adoption	%	Road, Rail	D2.2
92	Increase in the use of energy-efficient packaging materials for transportation	Energy	Systems/materials	%	Road, Rail	D2.2
93	Utilization of energy-efficient vehicle maintenance practices	Energy	Adoption	%	Road, Rail	D2.2
94	Introduction of energy-efficient warehousing and storage practices	Energy	Adoption	%	Road, Rail	D2.2
95	Increase in the use of energy-efficient cold chain logistics for temperature	Energy	Adoption	%	Road, Rail	D2.2
96	Utilization of energy-efficient intermodal transportation systems	Energy	Adoption	%	Road, Rail	D2.2
97	Implementation of energy-efficient freight forwarding practices	Energy	Adoption	%	Road, Rail	D2.2

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
98	Adoption of energy-efficient reverse logistics processes	Energy	Adoption	%	Road, Rail	D2.2
99	Reduction in energy cost	Energy	Economic	euro/MWh		e-Ferry
100	Reduction in fuel cost per trip	Energy	Economic	Euros		e-Ferry
101	Investment in clean energy networks and vehicles	Energy	Economic	€ per vehicle		URBANE
102	Changes in energy sources	Energy	Resources	%		FOR-FREIGHT
103	Changes in the F-gases used as refrigerant	Energy	Resources	%		FOR-FREIGHT
104	Adoption of electric vehicles (EVs)	Energy	Resources	Count	Road	D2.2
105	Usage of hybrid vehicles	Energy	Resources	Count	Road, Rail	D2.2
106	Adoption of hydrogen fuel cells	Energy	Resources	Count	Road, Rail	D2.2
107	Utilization of natural gas vehicles (NGVs)	Energy	Resources	%	Road, Rail	D2.2
108	Increase in percentage of renewable energy usage	Energy	Resources	%	Road, Rail, Maritime	D2.2
109	Increase in the use of renewable energy sources for transportation	Energy	Resources	%	Road, Rail	D2.2
110	Adoption of energy-efficient lighting systems in transportation facilities	Energy	Resources	%	Road, Rail	D2.2
111	Introduction of energy-efficient HVAC systems in transportation hub	Energy	Resources	%	Road, Rail	D2.2
112	Utilization of passive solar design principles in transportation infrastructure	Energy	Resources	%	Road, Rail	D2.2
113	Introduction of bio-based lubricants for vehicle maintenance	Energy	Resources	%	Road, Rail	D2.2
114	Implementation of energy-efficient propulsion systems for ships	Energy	Resources	%	Maritime	D2.2
115	Utilization of hybrid energy systems for remote transportation facilities	Energy	Resources	%	Road, Rail, Maritime	D2.2
116	Increase in the use of energy-efficient signalling systems for railways	Energy	Resources	%	Rail	D2.2

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
117	Utilization of energy-efficient lighting systems for transportation corridors	Energy	Resources	%	Road, Rail	D2.2
118	Introduction of energy-efficient heating systems for transportation t	Energy	Resources	%	Road, Rail	D2.2
119	Increase in the use of energy-efficient cooling systems for transportation	Energy	Resources	%	Road, Rail	D2.2
120	Increase in energy productivity of transportation operations	Energy	Optimization	%	Road, Rail	D2.2
121	Utilization of energy-efficient traffic management systems	Energy	Systems/materials	%	Road, Rail	D2.2
122	Implementation of low-energy road construction techniques	Energy	Systems/materials	%	Road	D2.2
123	Adoption of energy-efficient tunnel ventilation systems	Energy	Systems/materials	%	Road, Rail	D2.2
124	Utilization of energy-efficient conveyor systems for freight handling	Energy	Systems/materials	%	Road, Rail	D2.2
125	Increase in the use of energy-efficient lighting systems for transportation	Energy	Systems/materials	%	Road, Rail	D2.2
126	Utilization of energy-efficient propulsion systems for marine vessels	Energy	Systems/materials	%	Maritime	D2.2
127	Implementation of waste heat recovery systems for transportation e	Energy	Systems/materials	%	Road, Rail	D2.2
128	Introduction of energy-efficient vehicle sharing programs	Energy	Systems/materials	%	Road, Rail	D2.2
129	Reduction in energy cost	Economic	Energy cost	\$/km	Road, Rail, Maritime	D2.2
130	Reduction in fuel cost per trip	Economic	Energy cost	\$/trip	Road, Rail, Maritime	D2.2
131	Reduction in resources cost	Economic	Energy cost	\$	Road, Rail, Maritime	D2.2
132	Fuel cost (euros per litre) and electricity cost (euros per kWh)	Economic	Energy cost	€/l and €/kWh		URBANE
133	Reduction in energy cost	Economic	Energy cost	€/MWh		e-Ferry

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
134	Reduction in fuel cost per trip	Economic	Energy cost	Euros		e-Ferry
135	Increase in the energy cost for heating and air conditioning	Economic	Energy cost	€/trip		e-Ferry
136	Operational costs associated to the use of resources	Economic	Energy cost	workers		PLANET
137	Detention and demurrage	Economic	Fees & charges	Days/costs		FENIX
138	Customs clearance costs	Economic	Fees & charges	Euros		PLANET
139	Increase in the Public Service Obligation (PSO) cost	Economic	Fees & charges	Euros		e-Ferry
140	Decrease in taxation	Economic	Fees & charges	Euros/year		e-Ferry
141	Decrease in CO2 quotas	Economic	Fees & charges	€/MWh		e-Ferry
142	VAT exemption (if any)	Economic	Fees & charges	€/year		e-Ferry
143	Development & Maintenance	Economic	Operating cost	Euros, €/year		e-Ferry, FENIX
144	Transport cost	Economic	Operating cost	Euros		PLANET
145	Transportation cost per container	Economic	Operating cost	Euros		PLANET
146	Cost of paper-based processes	Economic	Operating cost	Euros		PLANET
147	Operating costs in transport and logistics	Economic	Operating cost	Euros		PLANET
148	Total delivery costs	Economic	Operating cost	€ per parcel		URBANE
149	Total manning costs	Economic	Operating cost	€/year		e-Ferry
150	Repairs' costs	Economic	Operating cost	€/year		e-Ferry
151	Costs for consumables (ex. Lubricating oil)	Economic	Operating cost	€/year		e-Ferry
152	Maintenance costs for shore installations	Economic	Operating cost	€/year		e-Ferry
153	Managerial and Operational costs	Economic	Operating cost	Euros		D6.1
154	Unit cost of delivery	Economic	Operating cost	Euros		D6.1
155	Return on investments	Economic	Financial	%		URBANE
156	Revenue growth	Economic	Financial	%		URBANE
157	Cost for shore-based ship service	Economic	Services	€/year		e-Ferry
158	Dry docking cost (expected to take place every two years)	Economic	Services	€/year		e-Ferry
159	Classification and safety equipment's costs	Economic	Services	€/year		e-Ferry

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
160	Hull and machinery insurance costs	Economic	Services	€/year		e-Ferry
161	Protection and indemnity insurance costs	Economic	Services	€/year		e-Ferry
162	Novel business models	Business & Governance	New models & collaboration	BMs/year	Road, Rail, Maritime	D2.2
163	SMEs using the solutions/marketplace	Business & Governance	New models & collaboration	Count	Road, Rail, Maritime	D2.2
164	Connected logistics services	Business & Governance	New models & collaboration	Count	Road, Rail, Maritime	D2.2
165	Time to set-up an end-to-end multimodal freight transport with multiple stakeholders	Business & Governance	New models & collaboration	days		FOR-FREIGHT
166	Number of transport orders shifted to rail	Business & Governance	New models & collaboration	% orders		PLANET
167	Rail share	Business & Governance	New models & collaboration	%		PLANET
168	Achieved TRL Level (project closure)	Business & Governance	New models & collaboration			D6.1
169	Existing TRL Level (project start)	Business & Governance	New models & collaboration			D6.1
170	Lack of involvement of stakeholders	Business & Governance	New models & collaboration			D6.1
171	Lack of knowledge about stakeholders' requirements	Business & Governance	New models & collaboration			D6.1
172	Lack of knowledge about the operation of logistics process (green or smart)	Business & Governance	New models & collaboration			D6.1
173	Adoption rate	Business & Governance	New models & collaboration			D6.1
174	Changes in legislation (national or EU level)	Business & Governance	New models & collaboration			D6.1
175	Production of suggestions and recommendations	Business & Governance	New models & collaboration			D6.1
176	Workflow automation	Business & Governance	Administration	Process time		FENIX
177	Administration work time	Business & Governance	Administration	Process time		FENIX
178	Orders fulfilled through BC	Business & Governance	Administration	orders		PLANET

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
179	Working time of the Customs Agency	Business & Governance	Administration	minutes		PLANET
180	Working time of the Customs Office	Business & Governance	Administration	minutes		PLANET
181	Total monthly working time	Business & Governance	Administration	hours / month		PLANET
182	Customer satisfaction	Business & Governance	Service level			D6.1
183	Final user-customer acceptance	Business & Governance	Service level			D6.1
184	Market Penetration	Business & Governance	Service level			D6.1
185	Experience (green or smart logistics)	Business & Governance	Service level			D6.1
186	Customer satisfaction	Business & Governance	Service level	Scale (1-5)	Road, Rail, Maritime	D2.2
187	Decision-making capacity of the port authority	Business & Governance	Service level	Likert scale (1-5)		PIXEL
188	Decision-making capacity of the local authority	Business & Governance	Service level	Likert scale (1-5)		PIXEL
189	Modal shift efficiency improvement	Operational & Productivity	Modal share	Percentage	Crossmodal	D2.2
190	Intermodal connectivity efficiency	Operational & Productivity	Modal share	Index	Crossmodal	D2.2
191	Crossmodal freight transfer efficiency	Operational & Productivity	Modal share	Hours/transfer	Crossmodal	D2.2
192	Integrated multimodal transport system efficiency	Operational & Productivity	Modal share	Index	Crossmodal	D2.2
193	Modal split	Operational & Productivity	Modal share	%	Road, Rail, Maritime	D2.2
194	Modal shift	Operational & Productivity	Modal share	Rail or vessel/total cargo		FENIX
195	Adoption of alternative transport routes	Operational & Productivity	Modal share	Count	Road, Rail	D2.2
196	Utilization of multi-modal transportation systems	Operational & Productivity	Modal share	% per mode	Road, Rail	D2.2
197	Vehicle type and data	Operational & Productivity	Modal share	-		D6.1
198	Overall supply chain optimization	Operational & Productivity	Optimization	%	Road, Rail, Maritime	D2.2
199	Increase in energy efficiency of transportation hubs	Operational & Productivity	Optimization	%	Road, Rail	D2.2
200	Reduction in turnaround time at transportation hubs	Operational & Productivity	Optimization	minutes	Road, Rail	D2.2
201	Implementation of route optimization algorithms	Operational & Productivity	Optimization	%	Road, Rail	D2.2

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
202	Utilization of vehicle platooning technology	Operational & Productivity	Optimization	%	Road, Rail	D2.2
203	Reduction of fuel quantity	Operational & Productivity	Optimization	%		FOR-FREIGHT
204	Number of freight vehicles per category	Operational & Productivity	Optimization	Vehicle category matrix		URBANE
205	Current cargo handling capacity at the airport hub	Operational & Productivity	Optimization	tonnes/year		FOR-FREIGHT
206	Reduction in time spent in traffic congestion	Operational & Productivity	Optimization	minutes	Road, Rail	D2.2
207	Journey length	Operational & Productivity	Optimization	km per shipment		D6.1
208	Loading/Unloading activities (quantity and duration)	Operational & Productivity	Optimization	tons/hour		D6.1
209	Process size/type	Operational & Productivity	Optimization	unit count		D6.1
210	Access availabilities (time-windows, load-factor)	Operational & Productivity	Optimization	%		D6.1
211	Empty vehicle km	Operational & Productivity	Capacity optimization	km	Road, Rail, Maritime	D2.2
212	Load factor	Operational & Productivity	Capacity optimization	%	Road, Rail, Maritime	FENIX, D2.2
213	Increase in vehicle loading efficiency	Operational & Productivity	Capacity optimization	%	Road, Rail	D2.2
214	Increase in inventory turnover rate	Operational & Productivity	Capacity optimization	%	Road, Rail	D2.2
215	Number of parking areas	Operational & Productivity	Capacity optimization	No of areas		FENIX
216	Average delivery loading per van	Operational & Productivity	Capacity optimization	deliveries/van		FOR-FREIGHT
217	Improve existing capacity utilisation	Operational & Productivity	Capacity optimization	%		FOR-FREIGHT
218	Availability of unloading slots	Operational & Productivity	Capacity optimization	% available unloading slots		PLANET
219	Average vehicles load factor	Operational & Productivity	Capacity optimization	% in weight or volume per Km		URBANE
220	Parcel Lockers fill rate (B2C)	Operational & Productivity	Capacity optimization	%		URBANE
221	Number of PuDo in the demo area	Operational & Productivity	Capacity optimization	n		URBANE
222	Number of loading/unloading areas	Operational & Productivity	Capacity optimization	n.		URBANE
223	Number of unauthorised parking in the urban area or in a part of it	Operational & Productivity	Capacity optimization	n.		URBANE
224	Load factor patterns	Operational & Productivity	Capacity optimization	%		D6.1

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
225	Quantity	Operational & Productivity	Capacity optimization	tons		D6.1
226	Empty running	Operational & Productivity	Capacity optimization	% of total distance travelled		D6.1
227	Implementation of dynamic routing algorithms	Operational & Productivity	Routing optimization	%	Road, Rail	D2.2
228	Routing efficiency	Operational & Productivity	Routing optimization	kg/km		FENIX
229	Average number of km per trip	Operational & Productivity	Routing optimization	Km/Trip		URBANE
230	Average number of km per vehicle	Operational & Productivity	Routing optimization	Km/Vehicle		URBANE
231	Total distance travelled in urban area	Operational & Productivity	Routing optimization	Km/Vehicle		URBANE
232	Average vehicles speed per trip	Operational & Productivity	Routing optimization	minutes		URBANE
233	Unit cost of delivery	Operational & Productivity	Delivery efficiency	\$/delivery	Road, Rail, Maritime	D2.2
234	Loss and damage (e.g., parcels)	Operational & Productivity	Delivery efficiency	Count	Road, Rail, Maritime	D2.2
235	Enhancement in last-mile delivery efficiency	Operational & Productivity	Delivery efficiency	%	Road, Rail	D2.2
236	Reduction in delivery lead times	Operational & Productivity	Delivery efficiency	minutes	Road, Rail	D2.2
237	Implementation of just-in-time delivery systems	Operational & Productivity	Delivery efficiency	minutes	Road, Rail	D2.2
238	Reduction in delivery vehicle dwell time	Operational & Productivity	Delivery efficiency	minutes	Road, Rail	D2.2
239	Improvement in on-time delivery performance	Operational & Productivity	Delivery efficiency	%	Road, Rail	D2.2
240	Improvement in order accuracy	Operational & Productivity	Delivery efficiency	%	Road, Rail	D2.2
241	Order fulfilment cycle-time	Operational & Productivity	Delivery efficiency	Actual-Requested Time		FENIX
242	Missed deliveries	Operational & Productivity	Delivery efficiency	%		FOR-FREIGHT
243	Number of vehicles required for last mile delivery with average loading	Operational & Productivity	Delivery efficiency	units/van		FOR-FREIGHT
244	Delivery reliability	Operational & Productivity	Delivery efficiency	Actual/planned deliveries %		FENIX
245	Delivery time reduction	Operational & Productivity	Delivery efficiency	minutes		PLANET
246	Quantities of products, expressed in pieces/packages/pallets, that can potentially be processed through logistics operations in the SC	Operational & Productivity	Delivery efficiency	deliveries per month		PLANET
247	Time to complete a delivery route	Operational & Productivity	Delivery efficiency	minutes		URBANE



#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
248	Average number of stops per route carried out by 1 vehicle (van) to deliver an average of 75 parcels	Operational & Productivity	Delivery efficiency	stops/route		FOR-FREIGHT
249	Average deliveries per trip	Operational & Productivity	Delivery efficiency	n.		URBANE
250	Number of deliveries including the quantity of goods delivered/ collected	Operational & Productivity	Delivery efficiency	unit count		D6.1
251	Precision of deliveries	Operational & Productivity	Delivery efficiency	%		D6.1
252	Punctuality of deliveries	Operational & Productivity	Delivery efficiency	%		D6.1
253	Adoption of blockchain technology in supply chain	Operational & Productivity	Systems/methods	%	Road, Rail	D2.2
254	Utilization of warehouse automation systems	Operational & Productivity	Systems/methods	%	Road, Rail	D2.2
255	Information flow problems	Operational & Productivity	Systems/methods	%		D6.1
256	Lack of a system to monitor the efficiency and effectiveness	Operational & Productivity	Systems/methods	%		D6.1
257	Reduction in inventory holding costs	Operational & Productivity	Administration	%	Road, Rail	D2.2
258	Document number exchange	Operational & Productivity	Administration	No of documents		FENIX
259	Shipment status updates	Operational & Productivity	Administration	No of status updates		FENIX
260	Custom Procedures	Operational & Productivity	Administration	Process time		FENIX
261	Increase in vehicle tracking accuracy	Operational & Productivity	Tracking & tracing	%	Road, Rail	D2.2
262	Product/shipment visibility	Operational & Productivity	Tracking & tracing	Tracked/total shipments %		FENIX
263	Waiting times	Operational & Productivity	Time efficiency	[ATA]-[ETA]		FENIX
264	Delay on the ETA	Operational & Productivity	Time efficiency	Actual- Requested ETA		FENIX
265	Corridor transit time	Operational & Productivity	Time efficiency	Travel+Admin time		FENIX
266	Travel time to Port gate	Operational & Productivity	Time efficiency	Travel time		FENIX
267	Pick up travel time	Operational & Productivity	Time efficiency	Travel time		FENIX
268	Turnaround time	Operational & Productivity	Time efficiency	Gate-in-Gate-out time		FENIX
269	Terminal saturation time	Operational & Productivity	Time efficiency	Vehicles/time slot %		FENIX
270	(Un)Loading time	Operational & Productivity	Time efficiency	Process time		FENIX

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
271	Time to react	Operational & Productivity	Time efficiency	Response time/return time		FENIX
272	Terminal occupancy rate	Operational & Productivity	Time efficiency	Vehicles present/left		FENIX
273	Parking search time	Operational & Productivity	Time efficiency	Parking-entry time		FENIX
274	Current on-time delivery ranges	Operational & Productivity	Time efficiency	~% of shipments		FOR-FREIGHT
275	Delivery lead time in inland transport	Operational & Productivity	Time efficiency	days		FOR-FREIGHT
276	Average loading/unloading time per parcel	Operational & Productivity	Time efficiency	seconds/parcel		FOR-FREIGHT
277	Average urban delivery times for the average number of units in 1 vehicle	Operational & Productivity	Time efficiency	hours circulation/route for units/van/route		FOR-FREIGHT
278	Container idle time at port	Operational & Productivity	Time efficiency	days		FOR-FREIGHT
279	Container idle time at the airport	Operational & Productivity	Time efficiency	hours		FOR-FREIGHT
280	Truck waiting time at terminal	Operational & Productivity	Time efficiency	hours		FOR-FREIGHT
281	Customs clearance process time	Operational & Productivity	Time efficiency	hours		FOR-FREIGHT
282	Truck transportation time ex. port to airport	Operational & Productivity	Time efficiency	hours		FOR-FREIGHT
283	Loading /unloading time in the terminals	Operational & Productivity	Time efficiency	hours		FOR-FREIGHT
284	ITU Dwell time in port	Operational & Productivity	Time efficiency	days		TIC4.0, FOR-FREIGHT
285	Average time for loading/unloading	Operational & Productivity	Time efficiency	minutes		URBANE
286	Time of delivery (pick-up)	Operational & Productivity	Time efficiency	minutes		D6.1
287	Quality of transport services	Operational & Productivity	Service level	% of on time deliveries on total deliveries		URBANE
288	Mishandling errors	Operational & Productivity	Service level	errors/year		FOR-FREIGHT
289	Level of traffic service	Operational & Productivity	Service level	km/h		FENIX
290	Safety of deliveries (no damages)	Operational & Productivity	Service level	%		URBANE
291	Security of deliveries (no losses or thefts)	Operational & Productivity	Service level	%		URBANE
292	Percentage of customers willing to pay a premium for faster delivery	Operational & Productivity	Service level	n.		URBANE
293	Number of failed deliveries per trip	Operational & Productivity	Service level	n		URBANE

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
294	Rate of successful delivery from 1st attempt	Operational & Productivity	Service level	%		URBANE
295	Rate of the failed deliveries	Operational & Productivity	Service level	%		URBANE
296	Loss and damaged parcels	Operational & Productivity	Service level	%		D6.1
297	TEU Throughput	Operational & Productivity	Port operations optimization	Total TEUs handled / Time period		TIC4.0
298	Crane Productivity	Operational & Productivity	Port operations optimization	Total number of moves made by crane / Hours worked by the crane		TIC4.0
299	Vessel Productivity	Operational & Productivity	Port operations optimization	Total TEUs handled during vessel call / Time vessel spent at berth		TIC4.0
300	Turnaround Time	Operational & Productivity	Port operations optimization	Time vessel spent at berth + Time container spends at gate		TIC4.0
301	Berth Productivity	Operational & Productivity	Port operations optimization	Total TEUs handled / Berth length		TIC4.0
302	Equipment Utilization	Operational & Productivity	Port operations optimization	Total hours equipment used / Total available hours		TIC4.0
303	Gate Turnaround Time	Operational & Productivity	Port operations optimization	Time truck enters terminal gate to time it exits the gate		TIC4.0
304	Gate Productivity	Operational & Productivity	Port operations optimization	Number of trucks processed / Hours worked at gate		TIC4.0
305	Truck Wait Time	Operational & Productivity	Port operations optimization	Total time trucks spend waiting in line at the gate / Total number of trucks processed		TIC4.0
306	Gate Utilization	Operational & Productivity	Port operations optimization	Total hours gate is in use /		TIC4.0

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
				Total available hours		
307	Gate Capacity	Operational & Productivity	Port operations optimization	Maximum number of trucks that can be processed per hour / Total number of gates		TIC4.0
308	Transaction Time	Operational & Productivity	Port operations optimization	Total time it takes to complete a gate transaction		TIC4.0
309	Rehandles	Operational & Productivity	Port operations optimization	(Total moves - Total TEUs handled) / 2		TIC4.0
310	Yard Density	Operational & Productivity	Port operations optimization	Total number of containers in yard / Yard area		TIC4.0
311	Yard Utilization	Operational & Productivity	Port operations optimization	Total yard capacity used / Total yard capacity available		TIC4.0
312	Gross Crane Rate	Operational & Productivity	Port operations optimization	Total number of moves / Total all crane hours		TIC4.0
313	Gross Crane Rate per Hour	Operational & Productivity	Port operations optimization	Total TEUs handled / Total single crane hours		TIC4.0
314	Gross Crane Rate per Move	Operational & Productivity	Port operations optimization	Total time taken to move all containers / Total number of container moves		TIC4.0
315	Gross Crane Rate per TEU	Operational & Productivity	Port operations optimization	Total number of moves / Total TEUs handled		TIC4.0
316	Number of new production jobs created	Societal	Employment	Jobs/year	Road, Rail, Maritime	e-Ferry, D2.2
317	Number of new assembly jobs created	Societal	Employment	Jobs/year	Road, Rail, Maritime	e-Ferry, D2.2
318	Number of jobs lost due to lower manning requirements	Societal	Employment	Jobs/year	Road, Rail, Maritime	D2.2
319	Employment rate	Societal	Employment	%		URBANE
320	Personnel turnover	Societal	Employment	Ratio		URBANE

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
321	Average salary	Societal	Employment	€		URBANE
322	Percentage of self-employed workers	Societal	Employment	%		URBANE
323	Percentage of part-time workers	Societal	Employment	%		URBANE
324	Flexibility of working hours	Societal	Employment	Qualitative (Yes/No)		URBANE
325	Percentage of remote work	Societal	Employment	%		URBANE
326	Accidents or incidents	Societal	Health & safety	n.	Road, Rail, Maritime	D6.1, D2.2
327	Reduction in transportation-related accidents	Societal	Health & safety	Count	Road, Rail	D2.2
328	Number of accidents	Societal	Health & safety	Incidents/month		FOR-FREIGHT, FENIX
329	Errors, accidents	Societal	Health & safety	% as ratio of disputes		FOR-FREIGHT
330	Reduction in transportation-related fatalities	Societal	Health & safety	Count	Road, Rail	D2.2
331	Accidents involving freight vehicles	Societal	Health & safety	n.		URBANE
332	People killed or seriously injured in collisions involving freight vehicles	Societal	Health & safety	n.		URBANE
333	Reduction in transportation-related noise pollution	Societal	Health & safety	dB	Road, Rail	D2.2
334	Reduction in transportation-related health issues	Societal	Health & safety	%	Road, Rail	D2.2
335	Enhancement in transportation disaster preparedness	Societal	Health & safety	%	Road, Rail	D2.2
336	Reduction in transportation-related carbon footprint	Societal	Health & safety	kg/km	Road, Rail	D2.2
337	Enhancement in transportation infrastructure accessibility	Societal	Inclusiveness	%	Road, Rail	D2.2
338	Implementation of transportation equity measures	Societal	Inclusiveness	%	Road, Rail	D2.2
339	Reduction in transportation-related social inequities	Societal	Inclusiveness	%	Road, Rail	D2.2
340	Adoption of fair pricing policies for transportation	Societal	Inclusiveness	%	Road, Rail	D2.2
341	Implementation of transportation data privacy measures	Societal	Inclusiveness	%	Road, Rail	D2.2

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
342	Social inclusion	Societal	Inclusiveness	%		URBANE
343	Parking accessibility in existing consolidation/logistics hubs	Societal	Inclusiveness	Likert scale		URBANE
344	Accessibility of lockers (or B2C micro-hubs) to vulnerable users	Societal	Inclusiveness	Likert scale		URBANE
345	Affordability of shared logistics services (cost of service's provision compared to the revenue growth of the companies)	Societal	Inclusiveness	euro		URBANE
346	Gender diversity	Societal	Inclusiveness	% females		URBANE
347	Accessibility	Societal	Inclusiveness	Scale (1-5)	Road, Rail, Maritime	D2.2
348	Improvement in transportation system reliability	Societal	Societal resilience	%	Road, Rail	D2.2
349	Increase in transportation system transparency	Societal	Societal resilience	%	Road, Rail	D2.2
350	Implementation of community engagement programs	Societal	Societal resilience	Count	Road, Rail	D2.2
351	Increase in transportation infrastructure resilience	Societal	Societal resilience	%	Road, Rail	D2.2
352	Increase in transportation-related economic opportunities	Societal	Societal resilience	%	Road, Rail	D2.2
353	Ratio of disputes	Societal	Societal resilience	% disputes		PLANET
354	Residents' acceptance level	Societal	Societal resilience	%		URBANE
355	Precariousness rate	Societal	Societal resilience	%		URBANE
356	Responsiveness to changes	Societal	Societal resilience	Likert scale		URBANE
357	Public acceptance	Societal	Societal resilience	%		URBANE
358	Impact of the urban mobility and territorial planning	Societal	Societal resilience	-		PIXEL
359	Community impact - Green Marine indicator	Societal	Societal resilience	(1-5 Scale of implementation of tangible measures to reduce port impact		PIXEL
360	Parameters exchanged with the cities	Societal	Societal resilience	Number of entities		PIXEL

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
361	Collaboration with the surrounding socio-economic areas	Societal	Societal resilience	Number of entities		PIXEL
362	Public acceptance	Societal	Societal resilience	Likert 1-5		D6.1
363	Stakeholder acceptance	Societal	Societal resilience	Likert 1-5		D6.1
364	Citizen's involvement	Societal	Societal resilience	%		D6.1
365	Implementation of transportation-related cultural preservation programmes	Societal	Competence building	Count	Road, Rail	D2.2
366	Enhancement in transportation-related emergency response capabilities	Societal	Competence building	%	Road, Rail	D2.2
367	Increase in transportation-related educational initiatives	Societal	Competence building	%	Road, Rail	D2.2
368	Improvement in driver safety training programs	Societal	Competence building	%	Road, Rail	D2.2
369	Education level	Societal	Competence building	Distribution per educational degree or level (e.g. High school diploma, Bachelor's degree, Master's degree)		URBANE
370	Customer experience	Societal	Service perception	survey points		PLANET
371	Significant or optimal usefulness with current and potential services	Societal	Service perception	% satisfied		PLANET
372	Awareness level	Societal	Service perception	%		URBANE
373	Effect of solution(s) on community-industry-research	Societal	Service perception	Likert 1-5		D6.1
374	Success rate	Societal	Service perception	%		D6.1
375	Introduction of electric vehicle charging stations	Technological	Technology adaptation	Count	Road	D2.2
376	Implementation of predictive maintenance systems	Technological	Technology adaptation	%	Road, Rail, Maritime	D2.2
377	Increase in vehicle telematics utilization	Technological	Technology adaptation	%	Road, Rail, Maritime	D2.2
378	Internet of Things (IoT) devices deployed	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
379	Implementation of blockchain technology	Technological	Technology adaptation	%	Road, Rail, Maritime	D2.2



#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
380	Utilization of artificial intelligence (AI) algorithms	Technological	Technology adaptation	%	Road, Rail, Maritime	D2.2
381	Integration of machine learning systems	Technological	Technology adaptation	%	Road, Rail, Maritime	D2.2
382	Adoption of augmented reality (AR) applications	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
383	Implementation of virtual reality (VR) training programs	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
384	Utilization of digital twin technology	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
385	Deployment of smart sensors	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
386	Implementation of cloud computing solutions	Technological	Technology adaptation	%	Road, Rail, Maritime	D2.2
387	Development of mobile applications	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
388	Utilization of big data analytics	Technological	Technology adaptation	%	Road, Rail, Maritime	D2.2
389	Adoption of geospatial technology	Technological	Technology adaptation	%	Road, Rail, Maritime	D2.2
390	Integration of autonomous navigation systems	Technological	Technology adaptation	%	Road, Rail, Maritime	D2.2
391	Deployment of predictive maintenance software	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
392	Utilization of 3D printing technology	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
393	Implementation of supply chain management software	Technological	Technology adaptation	%	Road, Rail, Maritime	D2.2
394	Adoption of electronic logging devices (ELDs)	Technological	Technology adaptation	Count	Road, Rail	D2.2
395	Integration of vehicle tracking systems	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
396	Implementation of automated ticketing systems	Technological	Technology adaptation	Count	Rail, Maritime	D2.2
397	Utilization of digital freight brokerage platforms	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
398	Deployment of electronic proof of delivery systems	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
399	Integration of electronic payment systems	Technological	Technology adaptation	Count	Road, Rail, Maritime	D2.2
400	Solution Integration and Standardization	Technological	Technology adaptation	%		D6.1
401	Transferring rate	Technological	Technology adaptation	%		D6.1
402	Application downloading	Technological	Services	No of downloads		FENIX

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
403	Application use	Technological	Services	Uses/week		
404	Data updating frequency	Technological	Services	Mb/day		
405	Digital services	Technological	Services	No of services		
406	Corridor indicators visualized	Technological	Services	No of indicators		FENIX
407	Dashboard tabs	Technological	Services	No of tabs		
408	Number of transport orders fulfilled through Blockchain	Technological	Services	orders		FOR-FREIGHT
409	Time stakeholders interact with each other	Technological	Services	days		PLANET
410	Speed of collaboration decisions -automation in routing decisions	Technological	Services	minutes		PLANET
411	End to end visibility	Technological	Services	% of container route		PLANET
412	Visibility of the spare capacity > speed of inventories	Technological	Services	yes/no		PLANET
413	Access to temperature, humidity, bump, gate opening and tracking information	Technological	Services	yes/no		PLANET
414	Reverse geofencing integration system	Technological	Services	yes/no		URBANE
415	Presence of IT and AI driven optimisation system	Technological	Services	yes/no		URBANE
416	Document digitalization	Technological	Services	GB/year	Road, Rail, Maritime	D2.2
417	Information accessibility	Technological	Services	Likert scale		URBANE
418	Failures in the IT system	Technological	Security	n./month		URBANE
419	Increase in cybersecurity measures	Technological	Security	%	Road, Rail, Maritime	D2.2
420	Degree of innovation of logistics companies	Technological	Innovation	%		URBANE
421	Development of autonomous vehicle technology	Technological	Innovation	-	Road, Rail	D2.2
422	Enhancement in vehicle-to-vehicle communication	Technological	Innovation	%	Road, Rail	D2.2
423	Expansion of vehicle electrification infrastructure	Technological	Innovation	Count	Road, Rail	D2.2
424	Adoption of alternative propulsion technologies	Technological	Innovation	-	Road, Rail	D2.2
425	R&D capability	Technological	Technology readiness	Likert scale		URBANE
426	Technology Readiness Level (TRL)	Technological	Technology readiness	Scale (1-9)	Road, Rail, Maritime	D2.2

#	KPI	Admiral impact categories	Subcategory	Units	Applicable Modes	Reference
427	Technology Readiness	Technological	Technology readiness	TRL 1-9		D6.1
428	Transferability	Technological	Technology readiness	Likert 1-5		URBANE

ANNEX II – Propose ADMIRAL KPIs

Table A2: ADMIRAL KPIs list (Task 6.1)

KPI #	KPI	Admiral impact categories	Index Category (D6.1)
KPI-1	Accident and Incidents	Societal	LSI
KPI-2	Citizens' Involvement	Societal	LSI
KPI-3	Customer satisfaction	Business & Governance	LSI
KPI-4	Final user-customer acceptance	Business & Governance	LSI
KPI-5	Impact on the environment for each delivery	Environmental	LSI
KPI-6	Journey length	Operational	LSI
KPI-7	Load factor patterns	Operational	LSI
KPI-8	Loss and damaged parcels	Operational	LSI
KPI-9	Managerial and Operational costs	Economic	LSI
KPI-10	Market Penetration	Business & Governance	LSI
KPI-11	Number of deliveries including the quantity of goods delivered/collected	Operational	LSI
KPI-12	Number of Smart and Green Delivery operations for delivery	Environmental	LSI
KPI-13	Precision of deliveries	Operational	LSI
KPI-14	Public acceptance	Societal	LSI
KPI-15	Punctuality of deliveries	Operational	LSI
KPI-16	Quantity	Operational	LSI
KPI-17	Stakeholder acceptance	Societal	LSI
KPI-18	Technology Readiness	Technological	LSI
KPI-19	Unit cost of delivery	Economic	LSI
KPI-20	Unit emission of delivery	Environmental	LSI
KPI-21	Vehicle type and data	Operational	LSI
KPI-22	Willingness to pay for green urban logistics	Environmental	LSI
KPI-23	Achieved TRL Level (project closure)	Business & Governance	LMI
KPI-24	Empty running	Operational	LMI
KPI-25	Existing TRL Level (project start)	Business & Governance	LMI
KPI-26	Experience (green or smart logistics)	Business & Governance	LMI
KPI-27	Information flow problems	Operational	LMI
KPI-28	Lack of a system to monitor the efficiency and effectiveness	Operational	LMI
KPI-29	Lack of involvement of stakeholders	Business & Governance	LMI
KPI-30	Lack of knowledge about stakeholders' requirements	Business & Governance	LMI
KPI-31	Lack of knowledge about the operation of logistics process (green or smart)	Business & Governance	LMI

KPI #	KPI	Admiral impact categories	Index Category (D6.1)
KPI-32	Loading/Unloading activities (quantity and duration)	Operational	LMI
KPI-33	Time of delivery (pick-up)	Operational	LMI
KPI-34	Solution Integration and Standardization	Technological	LTI
KPI-35	Process size/type	Operational	LTI
KPI-36	Access availabilities (time-windows, load-factor)	Operational	LTI
KPI-37	Adoption rate	Business & Governance	LTI
KPI-38	Changes in legislation (national or EU level)	Business & Governance	LTI
KPI-39	Production of suggestions and recommendations	Business & Governance	LTI
KPI-40	Effect of solution(s) on community-industry-research	Societal	LTI
KPI-41	Transferring rate	Technological	LTI
KPI-42	Success rate	Societal	LTI

ANNEX III – Bayesian Network Analysis

ADMIRAL Probability Tables

Table A3: Marginal Probability Distribution of the Number of Accidents

	Higher	Similar	Lower
Number of Accidents	0%	68%	32%

Table A4: Marginal Probability Distribution of the Shipment turnaround time

	Higher	Similar	Lower
Shipment turnaround time	20%	33%	47%

Table A5: Marginal Probability Distribution of the Shipment load factor

	Higher	Similar	Lower
Shipment load factor	63%	37%	0%

Table A6: Marginal Probability Distribution of the Shipment total costs

	Higher	Similar	Lower
Shipment total costs	17%	41%	41%

Table A7: Marginal Probability Distribution of the Fulfilled shipments

	Higher	Similar	Lower
Fulfilled shipments	50%	50%	0%

Table A8: Shipment delivery reliability

	Higher	Similar	Lower
Shipment delivery reliability	69%	31%	0%

Table A9: Marginal Probability Distribution of the Vehicle type

	Higher	Similar	Lower
Vehicle type	0%	32%	68%

Table A10: Marginal Probability Distribution of the Empty running

	Higher	Similar	Lower
Empty running	0%	10%	90%

Table A11: Marginal Probability Distribution of the Shipment visibility

	Higher	Similar	Lower
Shipment visibility	86%	14%	0%

Table A12: Marginal Probability Distribution of the Customer satisfaction

	High	Moderate	Low
Customer satisfaction	77%	23%	0%

Table A13: Marginal Probability Distribution of the Market Penetration

	High	Moderate	Low
Market Penetration	55%	41%	3%

Table A14: Marginal Probability Distribution of the Public acceptance

	High	Moderate	Low
Public acceptance	77%	23%	0%

Table A15: Marginal Probability Distribution of the Stakeholder acceptance

	High	Moderate	Low
Stakeholder acceptance	71%	29%	0%

Table A16: Lack of knowledge about stakeholders' requirements

	High	Moderate	Low
Lack of knowledge about stakeholders' requirements	67%	33%	0%

Table A17: Changes in legislation (national or EU level)

	Significantly	Insignificantly
Changes in legislation (national or EU level)	93%	7%

Core KPI Relationships

Table A18: Conditional Probability Table for the Core Relationships of Technology Readiness

Solution integration	Collaboration among stakeholders	Willingness to pay for green logistics	Technology Readiness (High)	Technology Readiness (Medium)	Technology Readiness (Low)
High	High	High	47,0%	36,3%	16,7%
High	High	Medium	47,0%	34,3%	18,8%
High	High	Low	46,8%	31,8%	21,4%
High	Medium	High	47,0%	29,0%	24,0%
High	Medium	Medium	47,0%	27,0%	26,0%
High	Medium	Low	46,8%	24,6%	28,7%
High	Low	High	44,6%	29,0%	26,4%
High	Low	Medium	44,6%	27,0%	28,4%
High	Low	Low	44,3%	24,6%	31,1%
Medium	High	High	20,8%	54,3%	24,9%
Medium	High	Medium	20,8%	52,3%	26,9%
Medium	High	Low	20,6%	49,8%	29,6%
Medium	Medium	High	20,8%	47,1%	32,1%
Medium	Medium	Medium	20,8%	45,1%	34,1%
Medium	Medium	Low	20,6%	42,6%	36,8%
Medium	Low	High	18,4%	47,1%	34,5%
Medium	Low	Medium	18,4%	45,1%	36,5%
Medium	Low	Low	18,2%	42,6%	39,2%
Low	High	High	12,7%	36,3%	51,0%
Low	High	Medium	12,7%	34,3%	53,0%
Low	High	Low	12,5%	31,8%	55,7%
Low	Medium	High	12,7%	29,0%	58,3%
Low	Medium	Medium	12,7%	27,0%	60,3%
Low	Medium	Low	12,5%	24,6%	63,0%
Low	Low	High	10,3%	29,0%	60,7%
Low	Low	Medium	10,3%	27,0%	62,7%
Low	Low	Low	10,1%	24,6%	65,4%

Table A19: Conditional Probability Table for the Core Relationships of Cost per shipment

Willingness to pay for green logistics	GHG emissions per shipment	Collaboration among stakeholders	Cost per shipment (High)	Cost per shipment (Medium)	Cost per shipment (Low)
High	High	High	35,0%	31,4%	15,9%
High	High	Medium	35,0%	24,7%	22,6%
High	High	Low	34,7%	24,2%	23,3%
High	Medium	High	32,3%	31,4%	18,5%
High	Medium	Medium	32,3%	24,7%	25,2%
High	Medium	Low	32,1%	24,2%	25,9%
High	Low	High	29,7%	31,4%	21,1%
High	Low	Medium	29,7%	24,7%	27,8%
High	Low	Low	29,5%	24,2%	28,5%
Medium	High	High	21,0%	40,7%	20,6%
Medium	High	Medium	21,0%	34,1%	27,2%
Medium	High	Low	20,7%	33,6%	28,0%
Medium	Medium	High	18,3%	40,7%	23,2%
Medium	Medium	Medium	18,3%	34,1%	29,8%
Medium	Medium	Low	18,1%	33,6%	30,6%
Medium	Low	High	15,7%	40,7%	25,8%
Medium	Low	Medium	15,7%	34,1%	32,5%
Medium	Low	Low	15,5%	33,6%	33,2%
Low	High	High	16,3%	31,4%	34,6%
Low	High	Medium	16,3%	24,7%	41,2%
Low	High	Low	16,1%	24,2%	42,0%
Low	Medium	High	13,7%	31,4%	37,2%
Low	Medium	Medium	13,7%	24,7%	43,8%
Low	Medium	Low	13,4%	24,2%	44,6%
Low	Low	High	11,1%	31,4%	39,8%
Low	Low	Medium	11,1%	24,7%	46,5%
Low	Low	Low	10,8%	24,2%	47,2%

Table A20: Conditional Probability Table for the Core Relationships of GHG emissions per shipment

Willingness to pay for green logistics	Solution integration	Technology Readiness	GHG emissions per shipment (High)	GHG emissions per shipment (Medium)	GHG emissions per shipment (Low)
High	High	High	29,1%	21,1%	24,8%
High	High	Medium	31,7%	21,1%	22,2%
High	High	Low	35,8%	19,3%	19,9%
High	Medium	High	29,1%	30,1%	15,9%
High	Medium	Medium	31,7%	30,1%	13,2%
High	Medium	Low	35,8%	28,2%	11,0%
High	Low	High	38,0%	21,1%	15,9%
High	Low	Medium	40,6%	21,1%	13,2%
High	Low	Low	44,7%	19,3%	11,0%
Medium	High	High	13,2%	31,7%	30,1%
Medium	High	Medium	15,9%	31,7%	27,4%
Medium	High	Low	20,0%	29,8%	25,2%
Medium	Medium	High	13,2%	40,6%	21,1%
Medium	Medium	Medium	15,9%	40,6%	18,5%
Medium	Medium	Low	20,0%	38,8%	16,3%
Medium	Low	High	22,2%	31,7%	21,1%
Medium	Low	Medium	24,8%	31,7%	18,5%
Medium	Low	Low	28,9%	29,8%	16,3%
Low	High	High	13,2%	21,1%	40,6%
Low	High	Medium	15,9%	21,1%	38,0%
Low	High	Low	20,0%	19,3%	35,8%
Low	Medium	High	13,2%	30,1%	31,7%
Low	Medium	Medium	15,9%	30,1%	29,1%
Low	Medium	Low	20,0%	28,2%	26,8%
Low	Low	High	22,2%	21,1%	31,7%
Low	Low	Medium	24,8%	21,1%	29,1%
Low	Low	Low	28,9%	19,3%	26,8%

Table A21: Conditional Probability Table for the Core Relationships of Willingness to pay for green logistics

Cost per shipment	GHG emissions per shipment	Solution integration	Willingness to pay for green logistics (High)	Willingness to pay for green logistics (Medium)	Willingness to pay for green logistics (Low)
High	High	High	55,5%	30,9%	8,0%
High	High	Medium	49,4%	35,7%	9,2%
High	High	Low	49,4%	30,9%	14,0%
High	Medium	High	55,5%	12,5%	26,3%
High	Medium	Medium	49,4%	17,4%	27,5%
High	Medium	Low	49,4%	12,5%	32,4%
High	Low	High	53,2%	12,5%	28,6%
High	Low	Medium	47,2%	17,4%	29,8%
High	Low	Low	47,2%	12,5%	34,7%
Medium	High	High	11,7%	71,3%	11,3%
Medium	High	Medium	5,7%	76,2%	12,5%
Medium	High	Low	5,7%	71,3%	17,4%
Medium	Medium	High	11,7%	53,0%	29,7%
Medium	Medium	Medium	5,7%	57,8%	30,9%
Medium	Medium	Low	5,7%	53,0%	35,7%
Medium	Low	High	9,4%	53,0%	32,0%
Medium	Low	Medium	3,4%	57,8%	33,2%
Medium	Low	Low	3,4%	53,0%	38,0%
Low	High	High	11,7%	30,9%	51,7%
Low	High	Medium	5,7%	35,7%	53,0%
Low	High	Low	5,7%	30,9%	57,8%
Low	Medium	High	11,7%	12,5%	70,1%
Low	Medium	Medium	5,7%	17,4%	71,3%
Low	Medium	Low	5,7%	12,5%	76,2%
Low	Low	High	9,4%	12,5%	72,4%
Low	Low	Medium	3,4%	17,4%	73,6%
Low	Low	Low	3,4%	12,5%	78,5%

Table A22: Conditional Probability Table for the Core Relationships of Solution integration

Technology Readiness	Collaboration among stakeholders	Cost per shipment	Solution integration (High)	Solution integration (Medium)	Solution integration (Low)
High	High	High	41,3%	35,6%	14,3%
High	High	Medium	43,9%	30,3%	17,0%
High	High	Low	54,5%	22,3%	14,3%
High	Medium	High	35,9%	35,6%	19,7%
High	Medium	Medium	38,6%	30,3%	22,3%
High	Medium	Low	49,2%	22,3%	19,7%
High	Low	High	30,6%	30,2%	30,3%
High	Low	Medium	33,2%	24,9%	33,0%
High	Low	Low	43,8%	17,0%	30,3%
Medium	High	High	22,3%	54,5%	14,3%
Medium	High	Medium	25,0%	49,2%	17,0%
Medium	High	Low	35,6%	41,3%	14,3%
Medium	Medium	High	17,0%	54,5%	19,7%
Medium	Medium	Medium	19,6%	49,2%	22,3%
Medium	Medium	Low	30,2%	41,3%	19,7%
Medium	Low	High	11,6%	49,2%	30,3%
Medium	Low	Medium	14,3%	43,9%	33,0%
Medium	Low	Low	24,9%	35,9%	30,3%
Low	High	High	22,3%	35,6%	33,3%
Low	High	Medium	25,0%	30,3%	35,9%
Low	High	Low	35,6%	22,3%	33,3%
Low	Medium	High	17,0%	35,6%	38,6%
Low	Medium	Medium	19,6%	30,3%	41,3%
Low	Medium	Low	30,2%	22,3%	38,6%
Low	Low	High	11,6%	30,2%	49,3%
Low	Low	Medium	14,3%	24,9%	51,9%
Low	Low	Low	24,9%	17,0%	49,3%

Table A23: Conditional Probability Table for the Core Relationships of Professions and occupations

Technology Readiness	Solution integration	Willingness to pay for green logistics	Professions and occupations (High)	Professions and occupations (Medium)	Professions and occupations (Low)
High	High	High	24,1%	43,9%	11,9%
High	High	Medium	24,1%	40,0%	15,7%
High	High	Low	22,2%	38,1%	19,6%
High	Medium	High	26,9%	35,4%	17,5%
High	Medium	Medium	26,9%	31,5%	21,4%
High	Medium	Low	25,0%	29,6%	25,2%
High	Low	High	21,3%	29,8%	28,8%
High	Low	Medium	21,3%	25,9%	32,7%
High	Low	Low	19,4%	24,0%	36,5%
Medium	High	High	8,0%	53,5%	18,3%
Medium	High	Medium	8,0%	49,7%	22,2%
Medium	High	Low	6,0%	47,7%	26,0%
Medium	Medium	High	10,8%	45,1%	24,0%
Medium	Medium	Medium	10,8%	41,2%	27,8%
Medium	Medium	Low	8,9%	39,3%	31,7%
Medium	Low	High	5,2%	39,4%	35,2%
Medium	Low	Medium	5,2%	35,6%	39,1%
Medium	Low	Low	3,2%	33,6%	43,0%
Low	High	High	8,0%	43,9%	28,0%
Low	High	Medium	8,0%	40,0%	31,9%
Low	High	Low	6,0%	38,1%	35,7%
Low	Medium	High	10,8%	35,4%	33,6%
Low	Medium	Medium	10,8%	31,5%	37,5%
Low	Medium	Low	8,9%	29,6%	41,4%
Low	Low	High	5,2%	29,8%	44,9%
Low	Low	Medium	5,2%	25,9%	48,8%
Low	Low	Low	3,2%	24,0%	52,7%

Table A24: Conditional Probability Table for the Core Relationships of Collaboration among stakeholders

Solution integration	Technology Readiness	Professions and occupations	Collaboration among stakeholders (High)	Collaboration among stakeholders (Medium)	Collaboration among stakeholders (Low)
High	High	High	42,4%	35,9%	17,0%
High	High	Medium	39,5%	35,9%	19,8%
High	High	Low	36,7%	33,0%	25,4%
High	Medium	High	37,4%	30,9%	26,9%
High	Medium	Medium	34,6%	30,9%	29,7%
High	Medium	Low	31,8%	28,1%	35,3%
High	Low	High	34,9%	28,4%	31,8%
High	Low	Medium	32,1%	28,4%	34,6%
High	Low	Low	29,3%	25,6%	40,3%
Medium	High	High	22,3%	52,6%	20,3%
Medium	High	Medium	19,4%	52,6%	23,1%
Medium	High	Low	16,6%	49,8%	28,8%
Medium	Medium	High	17,3%	47,7%	30,2%
Medium	Medium	Medium	14,5%	47,7%	33,0%
Medium	Medium	Low	11,7%	44,8%	38,7%
Medium	Low	High	14,8%	45,2%	35,2%
Medium	Low	Medium	12,0%	45,2%	38,0%
Medium	Low	Low	9,2%	42,4%	43,6%
Low	High	High	22,3%	35,9%	37,1%
Low	High	Medium	19,4%	35,9%	39,9%
Low	High	Low	16,6%	33,0%	45,5%
Low	Medium	High	17,3%	30,9%	47,0%
Low	Medium	Medium	14,5%	30,9%	49,8%
Low	Medium	Low	11,7%	28,1%	55,4%
Low	Low	High	14,8%	28,4%	51,9%
Low	Low	Medium	12,0%	28,4%	54,7%
Low	Low	Low	9,2%	25,6%	60,4%

Extended KPI Relationships

Table A25: Conditional Probability Table for the Extended Relationships of Technology Readiness

Stakeholder acceptance	Changes in legislation (national or EU level)	Market Penetration	Technology Readiness (High)	Technology Readiness (Medium)	Technology Readiness (Low)
High	Significantly	High	44,3%	40,2%	15,4%
High	Significantly	Moderate	39,8%	40,2%	19,9%
High	Significantly	Low	30,8%	32,2%	37,0%
High	Insignificantly	High	32,5%	44,2%	23,3%
High	Insignificantly	Moderate	28,0%	44,2%	27,8%
High	Insignificantly	Low	19,1%	36,1%	44,9%
Moderate	Significantly	High	36,8%	40,2%	23,0%
Moderate	Significantly	Moderate	32,3%	40,2%	27,5%
Moderate	Significantly	Low	23,3%	32,2%	44,6%
Moderate	Insignificantly	High	25,0%	44,2%	30,8%
Moderate	Insignificantly	Moderate	20,5%	44,2%	35,3%
Moderate	Insignificantly	Low	11,5%	36,1%	52,4%
Low	Significantly	High	29,2%	32,7%	38,1%
Low	Significantly	Moderate	24,7%	32,7%	42,6%
Low	Significantly	Low	15,7%	24,6%	59,7%
Low	Insignificantly	High	17,4%	36,6%	46,0%
Low	Insignificantly	Moderate	12,9%	36,6%	50,5%
Low	Insignificantly	Low	3,9%	28,5%	67,5%

Table A26: Conditional Probability Table for the Extended Relationships of Cost per shipment

Shipment total costs	Shipment load factor	Empty running	Cost per shipment (High)	Cost per shipment (Medium)	Cost per shipment (Low)
Higher	Higher	Higher	50,7%	40,3%	9,0%
Higher	Higher	Similar	58,4%	53,1%	11,5%
Higher	Higher	Lower	61,0%	35,2%	3,8%
Higher	Similar	Higher	46,9%	44,2%	9,0%
Higher	Similar	Similar	54,5%	57,0%	11,5%
Higher	Similar	Lower	57,1%	39,0%	3,8%
Higher	Lower	Higher	43,0%	36,5%	20,5%
Higher	Lower	Similar	50,7%	49,3%	23,1%
Higher	Lower	Lower	53,3%	31,4%	15,4%
Similar	Higher	Higher	31,1%	50,1%	18,8%
Similar	Higher	Similar	38,8%	62,9%	21,3%
Similar	Higher	Lower	41,4%	45,0%	13,6%
Similar	Similar	Higher	27,3%	54,0%	18,8%
Similar	Similar	Similar	35,0%	66,8%	21,3%
Similar	Similar	Lower	37,5%	48,8%	13,6%

Shipment total costs	Shipment load factor	Empty running	Cost per shipment (High)	Cost per shipment (Medium)	Cost per shipment (Low)
Similar	Lower	Higher	23,4%	46,3%	30,3%
Similar	Lower	Similar	31,1%	59,1%	32,9%
Similar	Lower	Lower	33,7%	41,1%	25,2%
Lower	Higher	Higher	16,9%	41,8%	41,3%
Lower	Higher	Similar	24,6%	54,6%	43,8%
Lower	Higher	Lower	27,2%	36,7%	36,2%
Lower	Similar	Higher	13,1%	45,6%	41,3%
Lower	Similar	Similar	20,8%	58,5%	43,8%
Lower	Similar	Lower	23,3%	40,5%	36,2%
Lower	Lower	Higher	9,2%	37,9%	52,8%
Lower	Lower	Similar	16,9%	50,8%	55,4%
Lower	Lower	Lower	19,5%	32,8%	47,7%

Table A27: Conditional Probability Table for the Extended Relationships of GHG emissions per shipment

Vehicle type	Empty running	Shipment load factor	GHG emissions per shipment (High)	GHG emissions per shipment (Medium)	GHG emissions per shipment (Low)
Higher	Higher	Higher	36,6%	33,3%	30,1%
Higher	Higher	Similar	33,6%	36,3%	30,1%
Higher	Higher	Lower	33,6%	33,3%	33,1%
Higher	Similar	Higher	39,5%	33,3%	27,2%
Higher	Similar	Similar	36,4%	36,3%	27,2%
Higher	Similar	Lower	36,4%	33,3%	30,3%
Higher	Lower	Higher	48,1%	30,4%	21,5%
Higher	Lower	Similar	45,0%	33,5%	21,5%
Higher	Lower	Lower	45,0%	30,4%	24,6%
Similar	Higher	Higher	30,3%	36,4%	33,3%
Similar	Higher	Similar	27,2%	39,5%	33,3%
Similar	Higher	Lower	27,2%	36,4%	36,3%
Similar	Similar	Higher	33,1%	36,4%	30,4%
Similar	Similar	Similar	30,1%	39,5%	30,4%
Similar	Similar	Lower	30,1%	36,4%	33,5%
Similar	Lower	Higher	41,7%	33,6%	24,7%
Similar	Lower	Similar	38,7%	36,6%	24,7%
Similar	Lower	Lower	38,7%	33,6%	27,7%
Lower	Higher	Higher	20,8%	37,5%	41,7%
Lower	Higher	Similar	17,7%	40,6%	41,7%
Lower	Higher	Lower	17,7%	37,5%	44,8%
Lower	Similar	Higher	23,6%	37,5%	38,9%
Lower	Similar	Similar	20,6%	40,6%	38,9%
Lower	Similar	Lower	20,6%	37,5%	41,9%
Lower	Lower	Higher	32,2%	34,6%	33,2%

Vehicle type	Empty running	Shipment load factor	GHG emissions per shipment (High)	GHG emissions per shipment (Medium)	GHG emissions per shipment (Low)
Lower	Lower	Similar	29,1%	37,7%	33,2%
Lower	Lower	Lower	29,1%	34,6%	36,2%

Table A28: Conditional Probability Table for the Extended Relationships of Willingness to pay for green logistics

Public acceptance	Shipment total costs	Customer satisfaction	Willingness to pay for green logistics (High)	Willingness to pay for green logistics (Medium)	Willingness to pay for green logistics (Low)
High	High	High	36,2%	39,9%	23,9%
High	High	Moderate	36,2%	29,7%	34,1%
High	High	Low	29,4%	29,7%	40,9%
High	Similar	High	44,8%	44,2%	11,1%
High	Similar	Moderate	44,8%	33,9%	21,3%
High	Similar	Low	37,9%	33,9%	28,1%
High	Lower	High	49,0%	39,9%	11,1%
High	Lower	Moderate	49,0%	29,7%	21,3%
High	Lower	Low	42,2%	29,7%	28,1%
Moderate	High	High	11,1%	55,0%	33,9%
Moderate	High	Moderate	11,1%	44,8%	44,2%
Moderate	High	Low	4,3%	44,8%	51,0%
Moderate	Similar	High	19,6%	59,3%	21,1%
Moderate	Similar	Moderate	19,6%	49,0%	31,4%
Moderate	Similar	Low	12,8%	49,0%	38,2%
Moderate	Lower	High	23,9%	55,0%	21,1%
Moderate	Lower	Moderate	23,9%	44,8%	31,4%
Moderate	Lower	Low	17,0%	44,8%	38,2%
Low	High	High	11,1%	39,9%	49,0%
Low	High	Moderate	11,1%	29,7%	59,3%
Low	High	Low	4,3%	29,7%	66,1%
Low	Similar	High	19,6%	44,2%	36,2%
Low	Similar	Moderate	19,6%	33,9%	46,5%
Low	Similar	Low	12,8%	33,9%	53,3%
Low	Lower	High	23,9%	39,9%	36,2%
Low	Lower	Moderate	23,9%	29,7%	46,5%
Low	Lower	Low	17,0%	29,7%	53,3%

Table A29: Conditional Probability Table for the Extended Relationships of Solution integration

Lack of knowledge about stakeholders' requirements	Stakeholder acceptance	Market Penetration	Solution integration (High)	Solution integration (Medium)	Solution integration (Low)
High	High	High	39,2%	47,8%	13,0%
High	High	Moderate	34,9%	52,1%	13,0%
High	High	Low	34,9%	47,8%	17,3%
High	Moderate	High	30,7%	39,3%	30,0%
High	Moderate	Moderate	26,4%	43,6%	30,0%
High	Moderate	Low	26,4%	39,3%	34,3%
High	Low	High	26,4%	39,3%	34,3%
High	Low	Moderate	22,1%	43,6%	34,3%
High	Low	Low	22,1%	39,3%	38,6%
Moderate	High	High	25,8%	43,4%	30,8%
Moderate	High	Moderate	21,5%	47,7%	30,8%
Moderate	High	Low	21,5%	43,4%	35,1%
Moderate	Moderate	High	17,3%	34,9%	47,8%
Moderate	Moderate	Moderate	13,0%	39,2%	47,8%
Moderate	Moderate	Low	13,0%	34,9%	52,1%
Moderate	Low	High	13,1%	34,9%	52,1%
Moderate	Low	Moderate	8,8%	39,2%	52,1%
Moderate	Low	Low	8,8%	34,9%	56,4%
Low	High	High	21,4%	43,4%	35,2%
Low	High	Moderate	17,1%	47,7%	35,2%
Low	High	Low	17,1%	43,4%	39,6%
Low	Moderate	High	12,9%	34,9%	52,2%
Low	Moderate	Moderate	8,6%	39,2%	52,2%
Low	Moderate	Low	8,6%	34,9%	56,6%
Low	Low	High	8,6%	34,9%	56,5%
Low	Low	Moderate	4,3%	39,2%	56,5%
Low	Low	Low	4,3%	34,9%	60,8%

Table A30: Conditional Probability Table for the Extended Relationships of Professions and occupations

Market Penetration	Stakeholder acceptance	Changes in legislation (national or EU level)	Professions and occupations (High)	Professions and occupations (Medium)	Professions and occupations (Low)
High	High	Significantly	55,7%	31,8%	12,5%
High	High	Insignificantly	44,6%	31,8%	23,6%
High	Moderate	Significantly	47,7%	27,8%	24,4%
High	Moderate	Insignificantly	36,6%	27,8%	35,5%
High	Low	Significantly	43,8%	27,8%	28,4%
High	Low	Insignificantly	32,7%	27,8%	39,5%

Market Penetration	Stakeholder acceptance	Changes in legislation (national or EU level)	Professions and occupations (High)	Professions and occupations (Medium)	Professions and occupations (Low)
Moderate	High	Significantly	31,5%	56,0%	12,5%
Moderate	High	Insignificantly	20,5%	56,0%	23,6%
Moderate	Moderate	Significantly	23,6%	52,0%	24,4%
Moderate	Moderate	Insignificantly	12,5%	52,0%	35,5%
Moderate	Low	Significantly	19,6%	52,0%	28,4%
Moderate	Low	Insignificantly	8,5%	52,0%	39,5%
Low	High	Significantly	31,5%	31,8%	36,6%
Low	High	Insignificantly	20,5%	31,8%	47,7%
Low	Moderate	Significantly	23,6%	27,8%	48,6%
Low	Moderate	Insignificantly	12,5%	27,8%	59,7%
Low	Low	Significantly	19,6%	27,8%	52,6%
Low	Low	Insignificantly	8,5%	27,8%	63,6%

Table A31: Conditional Probability Table for the Extended Relationships of Collaboration among stakeholders

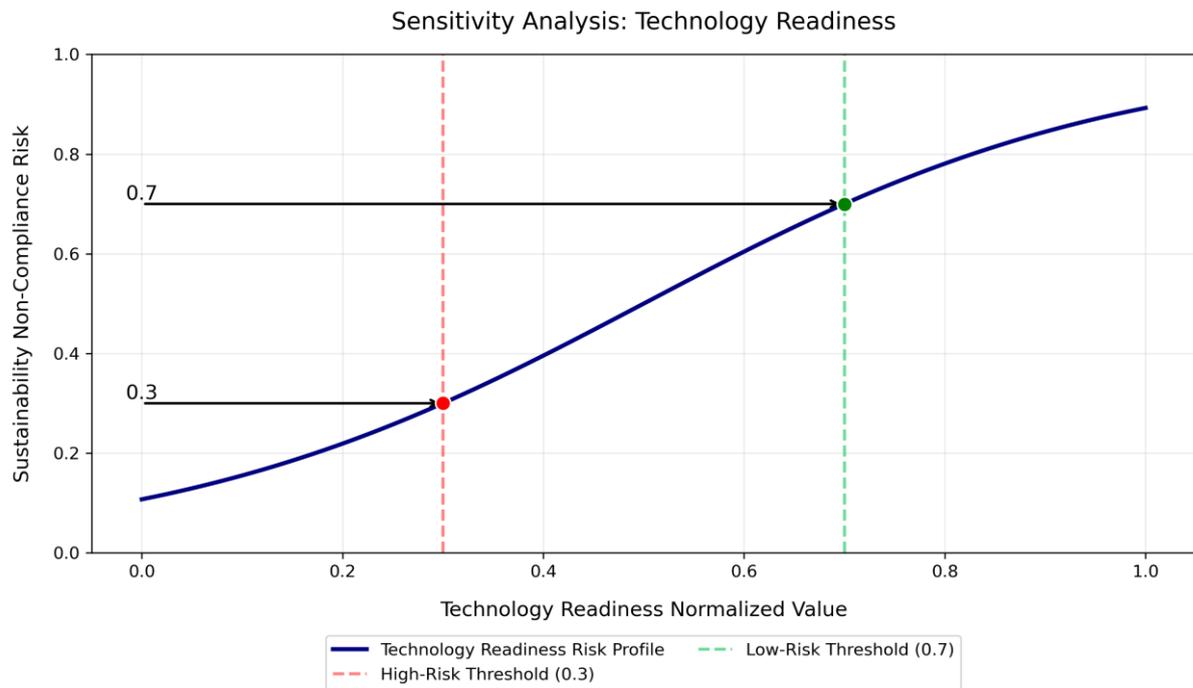
Stakeholder acceptance	Changes in legislation (national or EU level)	Market Penetration	Collaboration among stakeholders (High)	Collaboration among stakeholders (Medium)	Collaboration among stakeholders (Low)
High	Significantly	High	55,1%	34,9%	10,0%
High	Significantly	Moderate	50,1%	34,9%	15,0%
High	Significantly	Low	45,1%	29,9%	25,0%
High	Insignificantly	High	41,0%	34,9%	24,1%
High	Insignificantly	Moderate	36,0%	34,9%	29,1%
High	Insignificantly	Low	31,0%	29,9%	39,1%
Moderate	Significantly	High	34,1%	50,7%	15,2%
Moderate	Significantly	Moderate	29,1%	50,7%	20,2%
Moderate	Significantly	Low	24,1%	45,7%	30,2%
Moderate	Insignificantly	High	20,0%	50,7%	29,3%
Moderate	Insignificantly	Moderate	15,0%	50,7%	34,3%
Moderate	Insignificantly	Low	10,0%	45,7%	44,3%
Low	Significantly	High	34,1%	34,9%	31,0%
Low	Significantly	Moderate	29,1%	34,9%	36,0%
Low	Significantly	Low	24,1%	29,9%	46,0%
Low	Insignificantly	High	20,0%	34,9%	45,1%
Low	Insignificantly	Moderate	15,0%	34,9%	50,1%
Low	Insignificantly	Low	10,0%	29,9%	60,1%

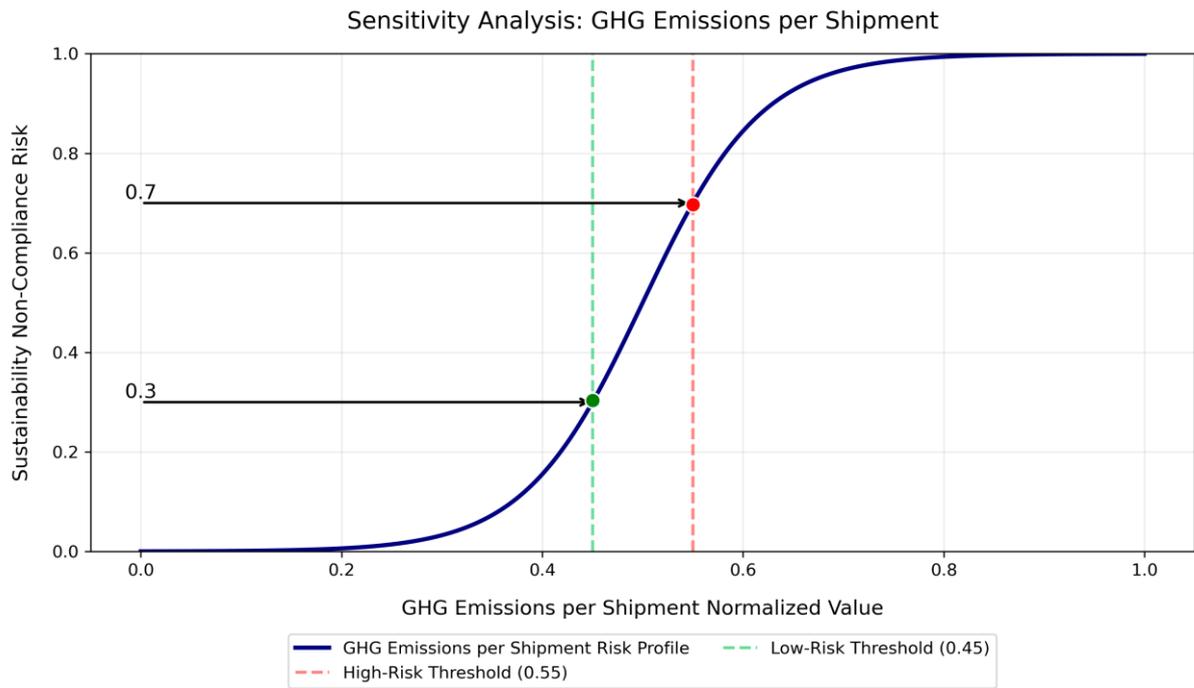
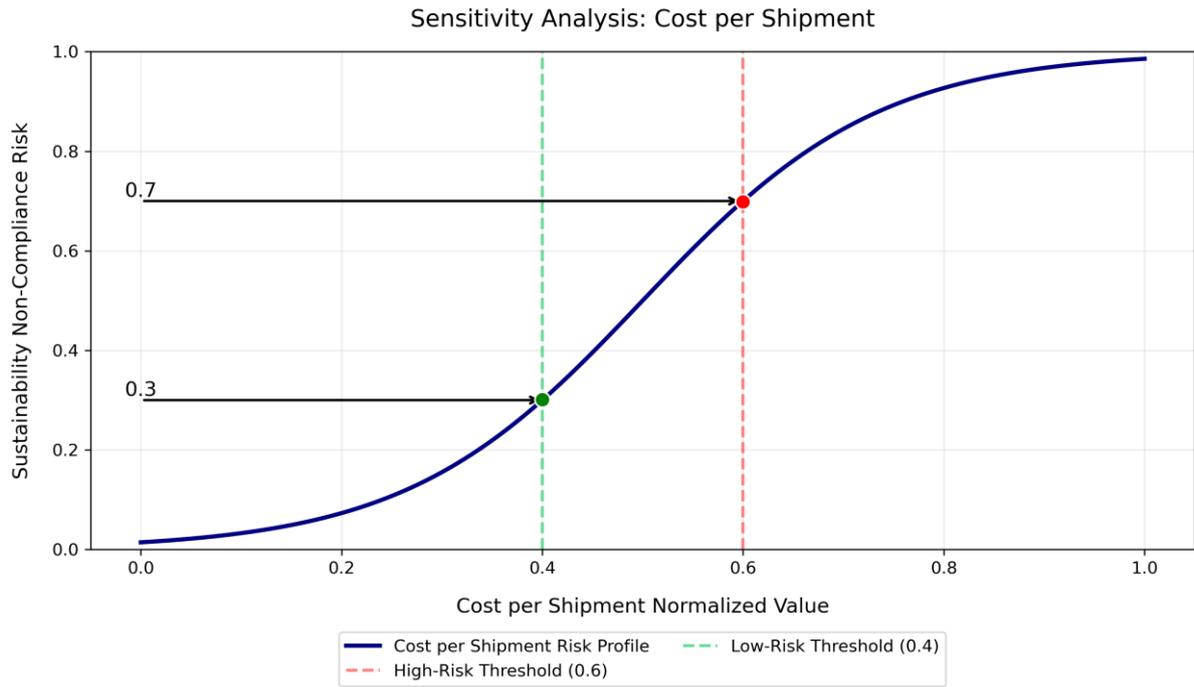
Table A32: Influence Rating table for sustainability non-compliance

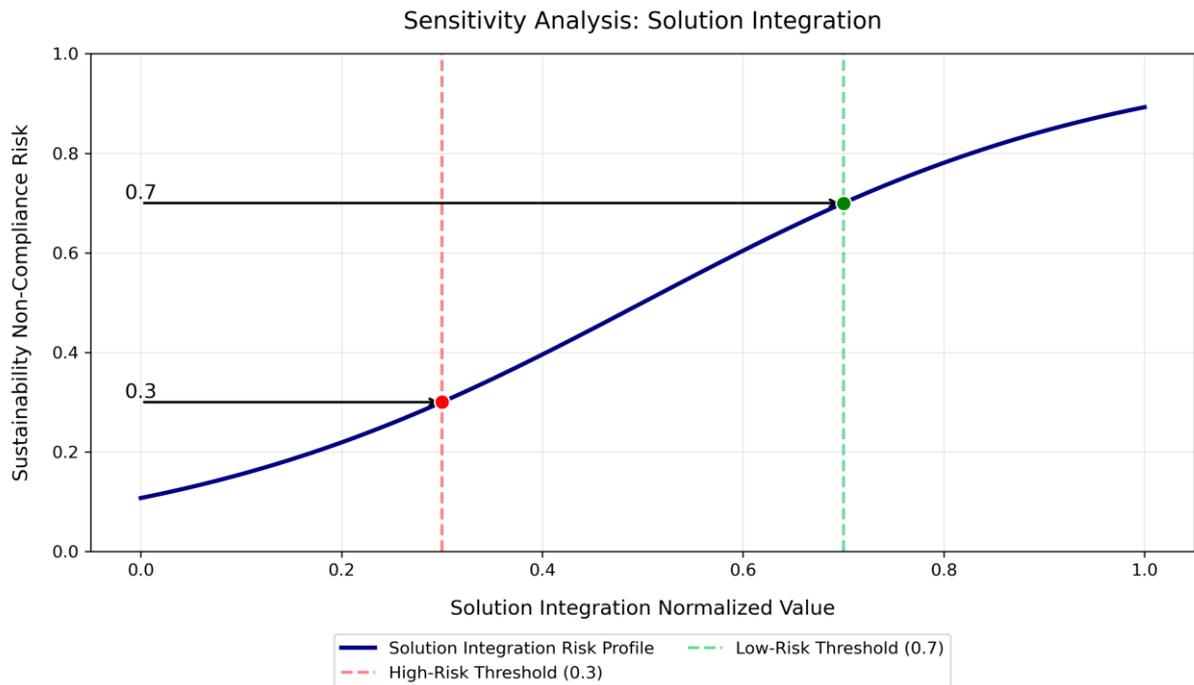
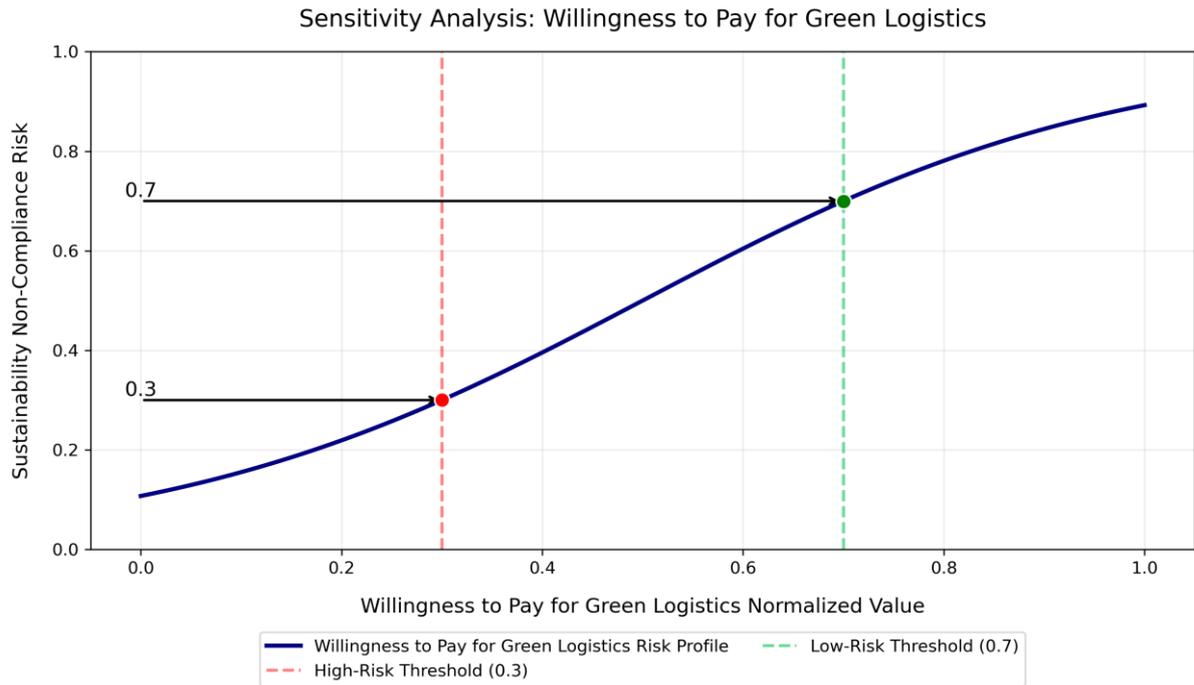
KPI-Node	Influence on sustainability non-compliance
Technology Readiness	3,97
Cost per shipment	4,13
GHG emissions per shipment	4,62
Willingness to pay for green logistics	3,61
Solution integration	4,29
Professions and occupations (e.g., new jobs)	3,12
Collaboration among stakeholders	4,56

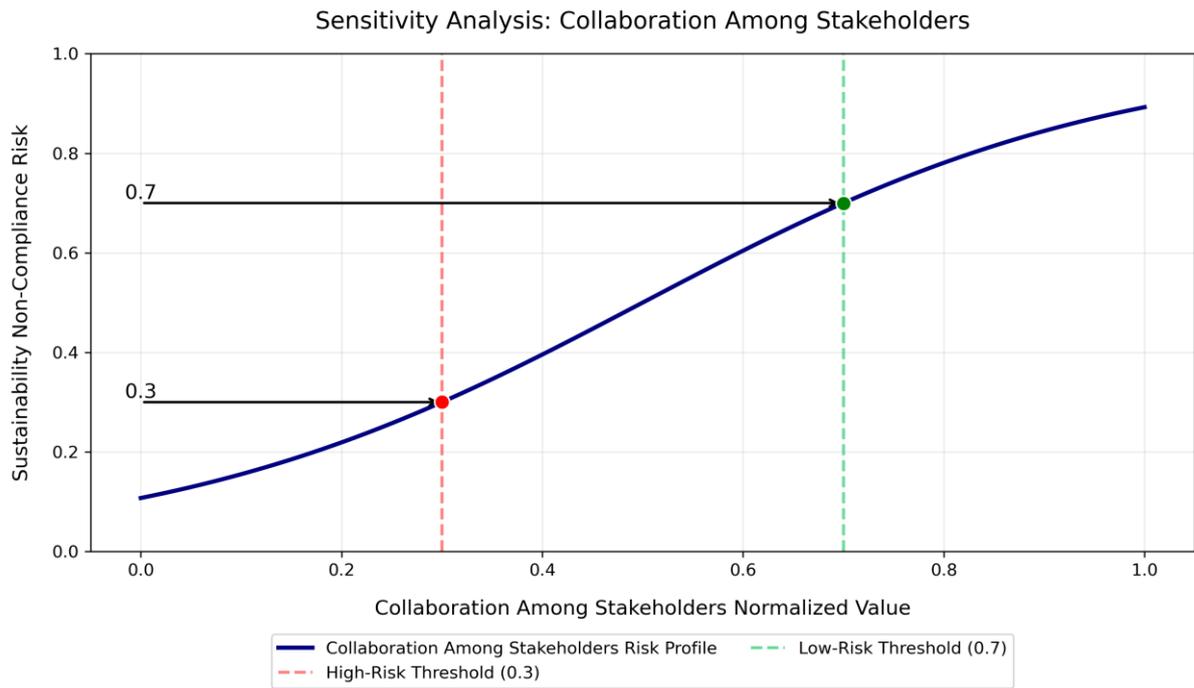
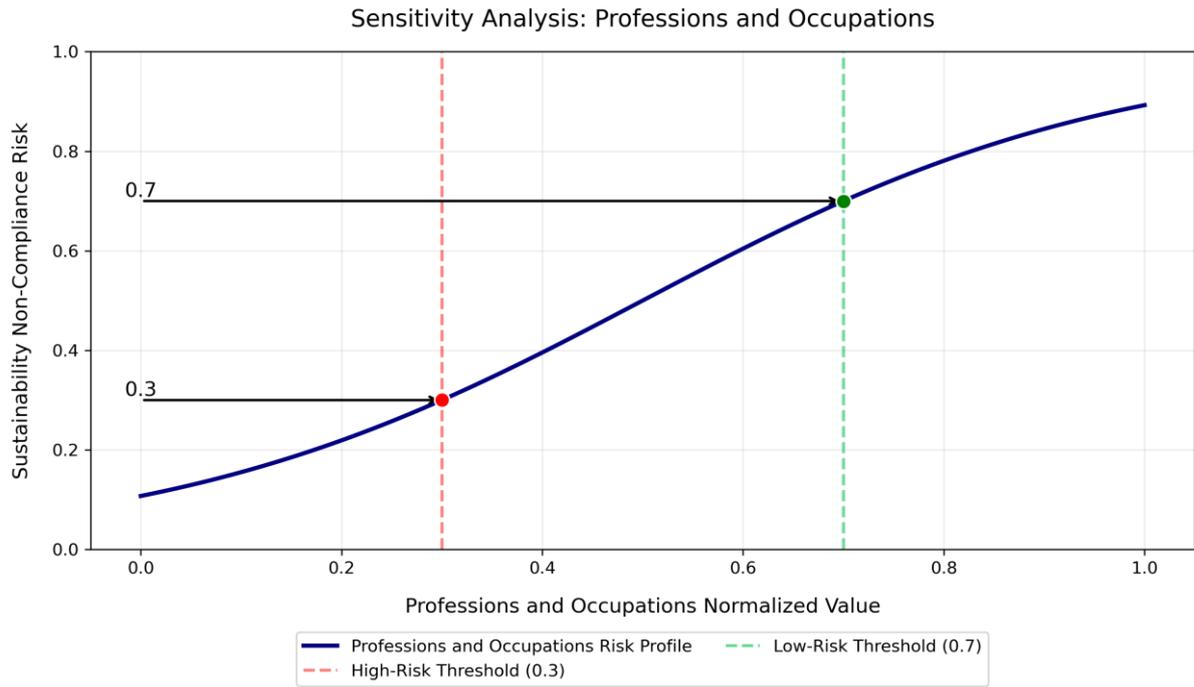
ANNEX IV – Bayesian Network sensitivity analysis

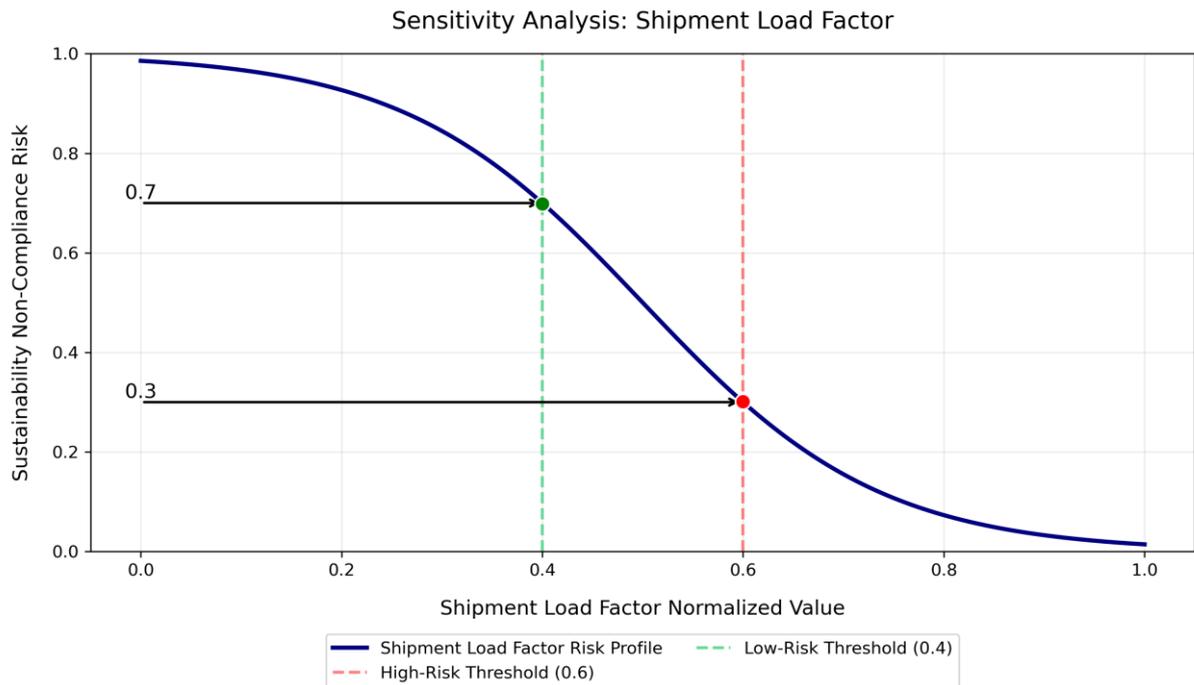
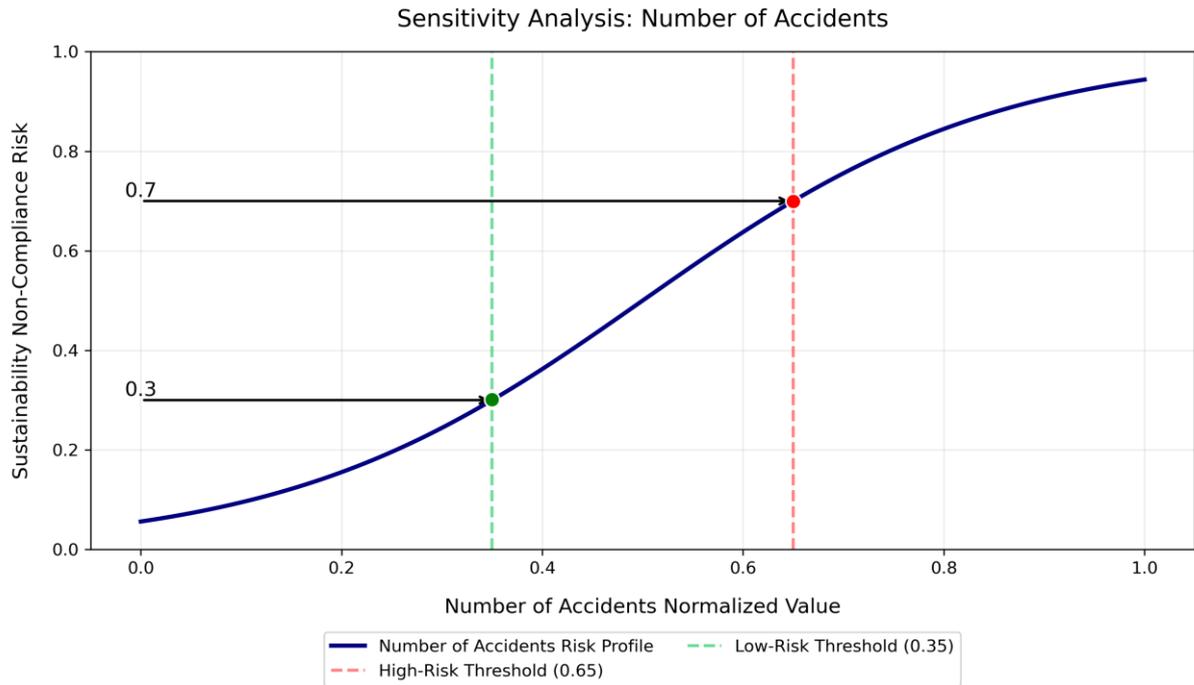
Sensitivity Analysis- Sensitivity Curves

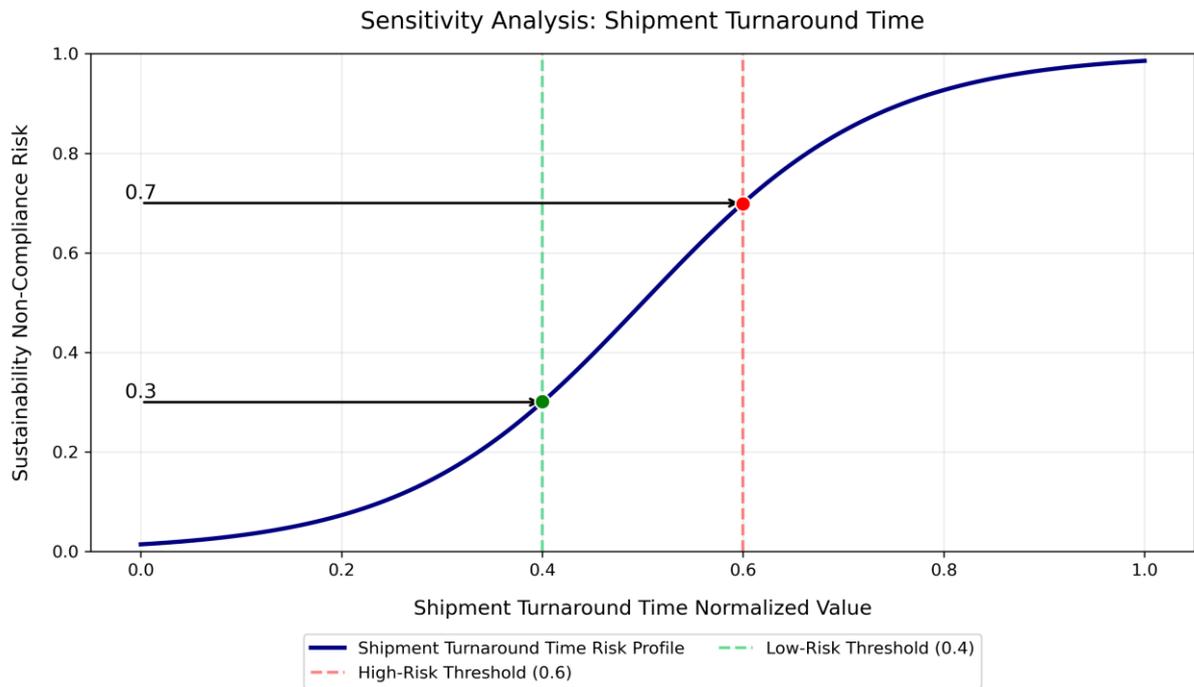
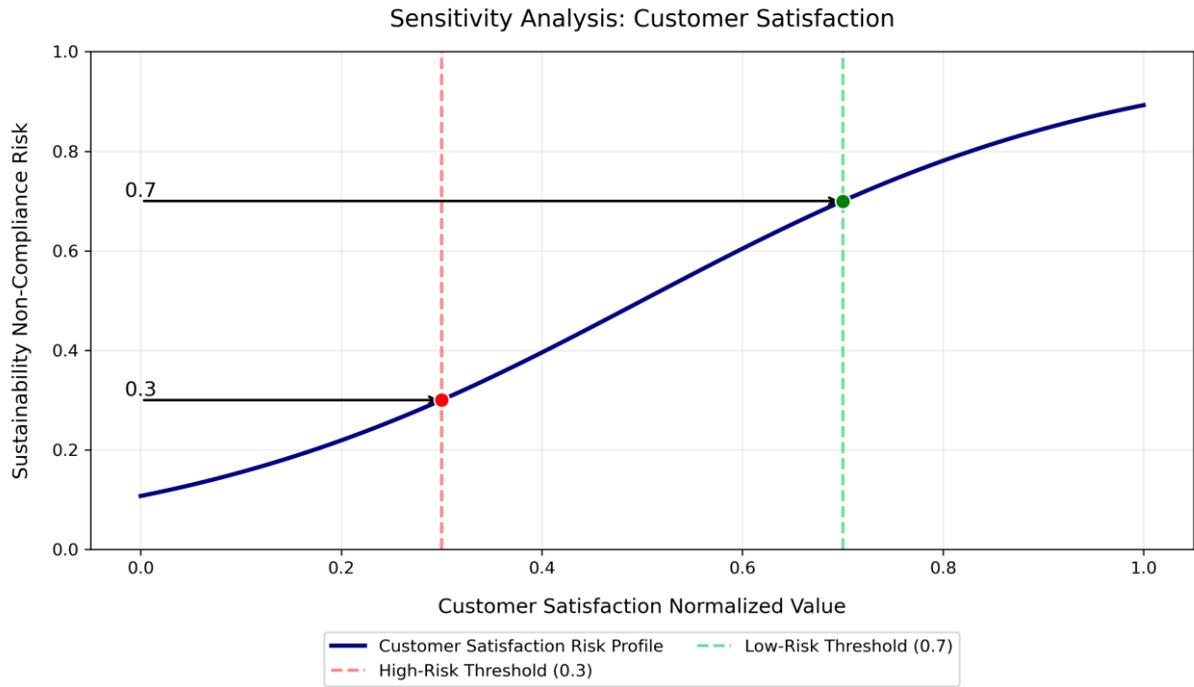


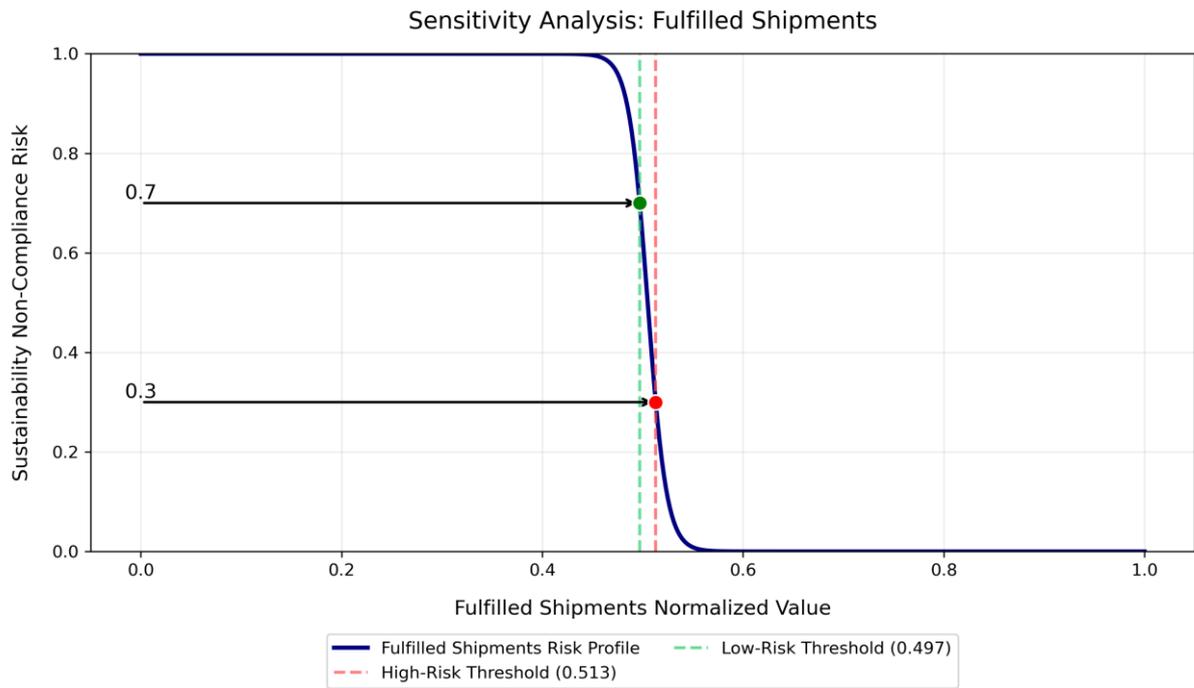
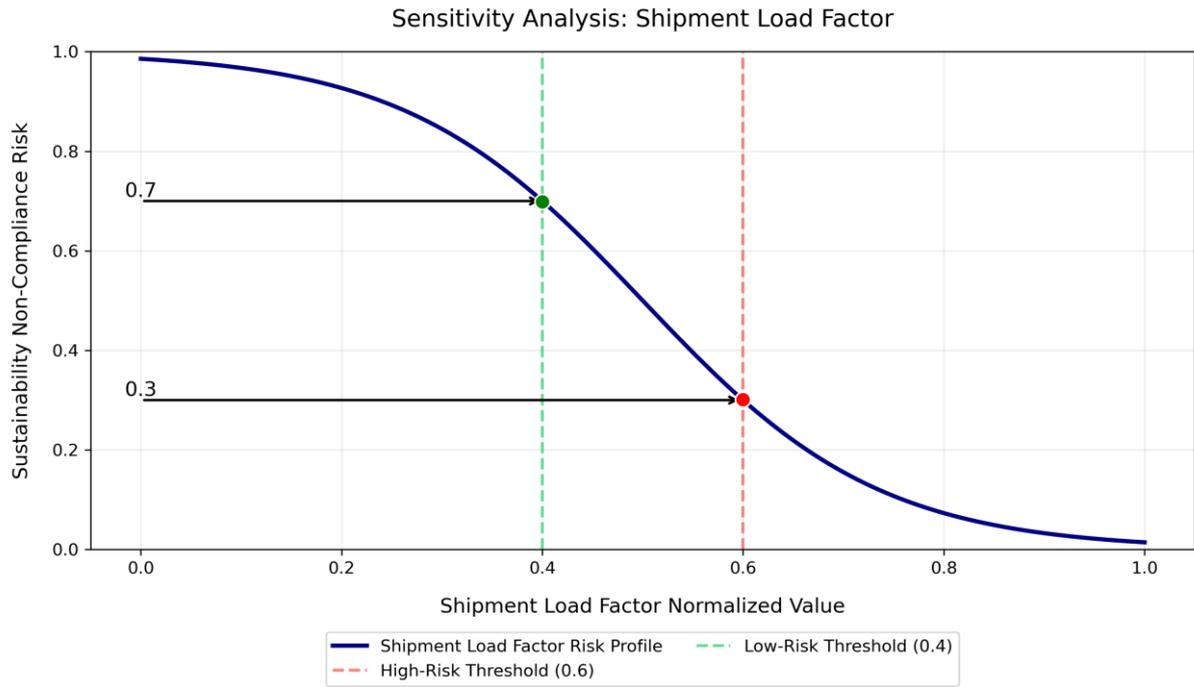


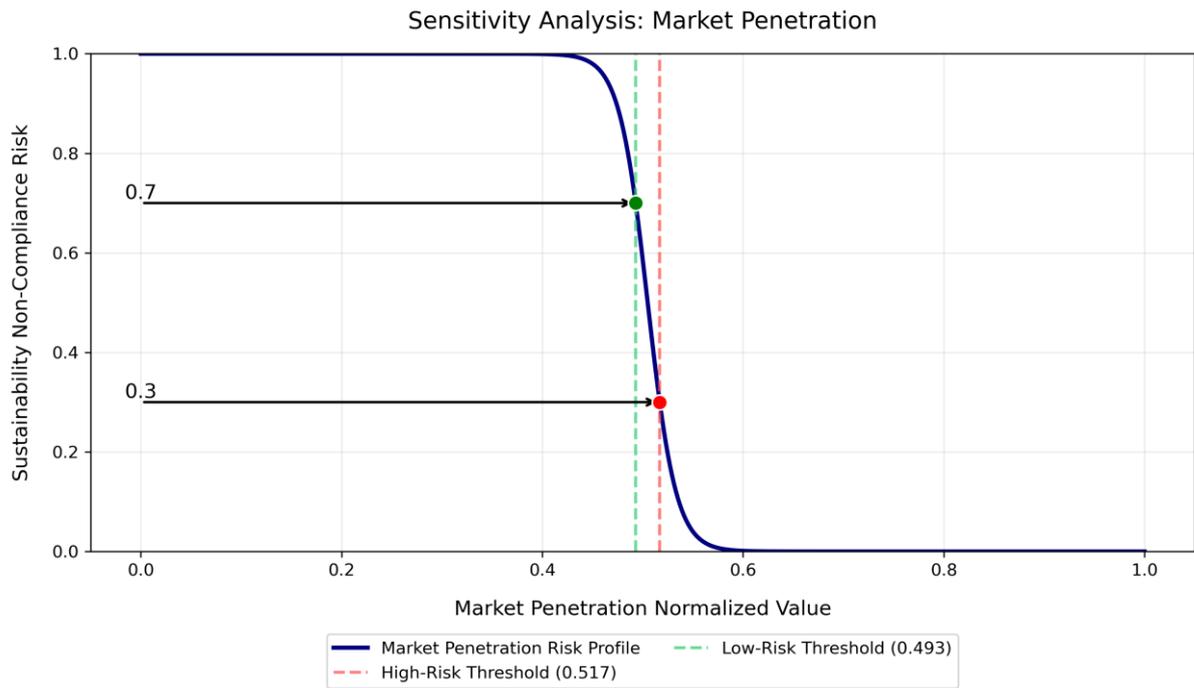
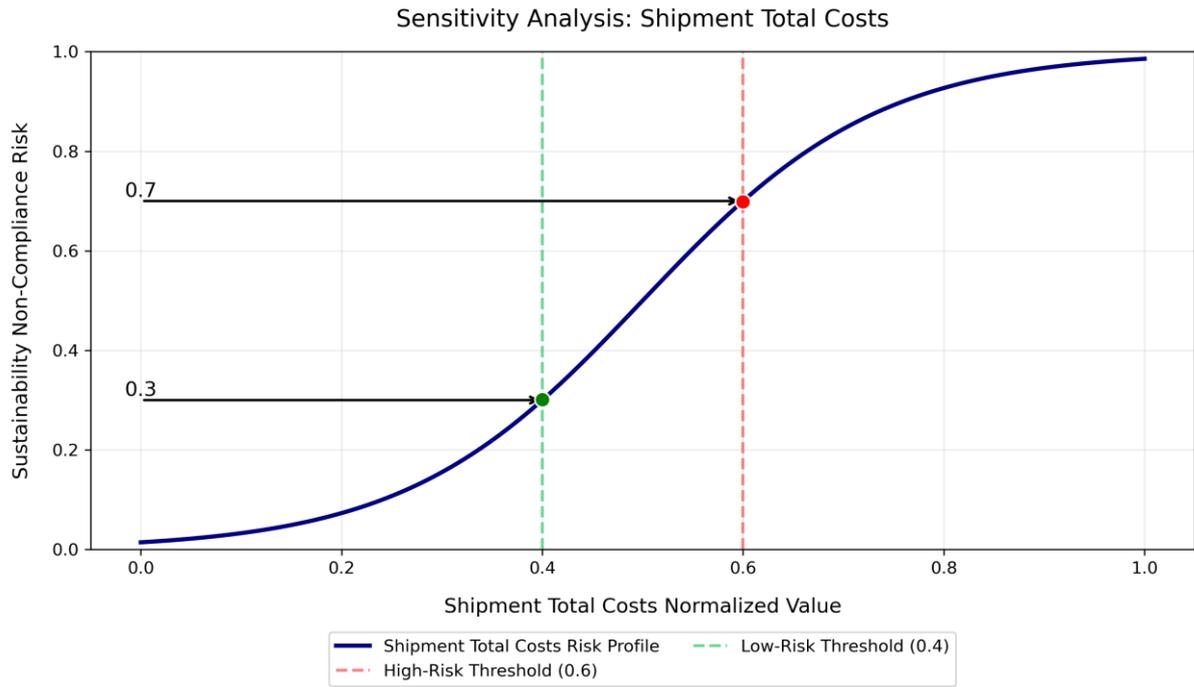


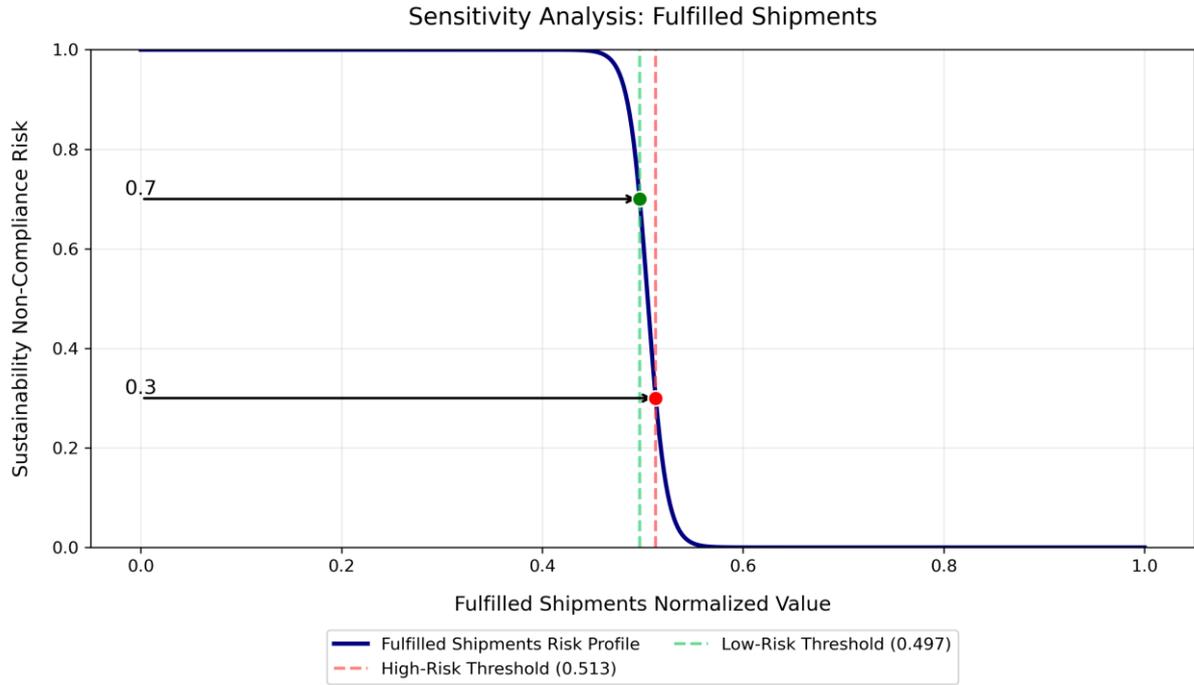


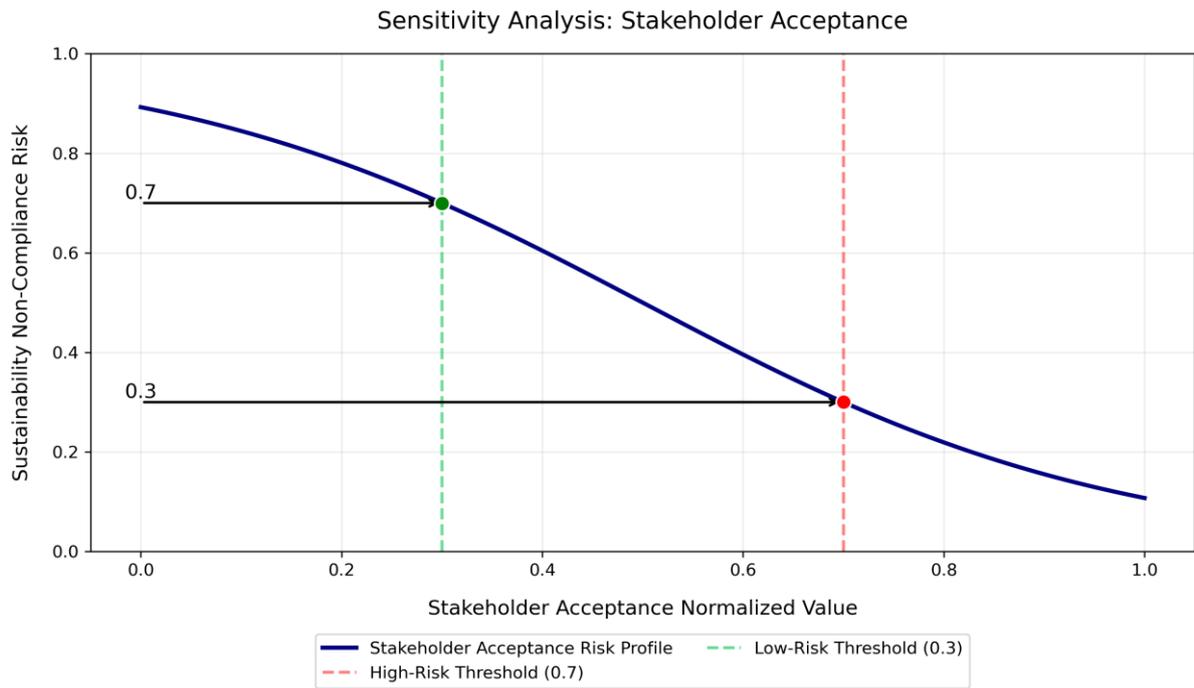
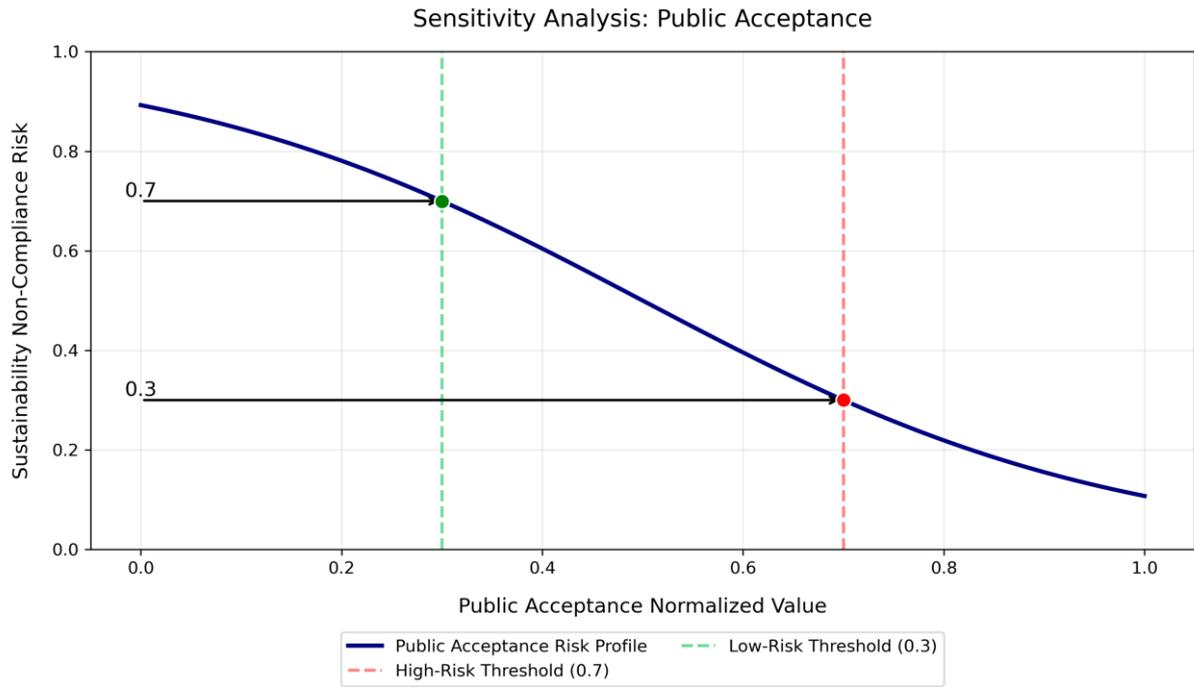


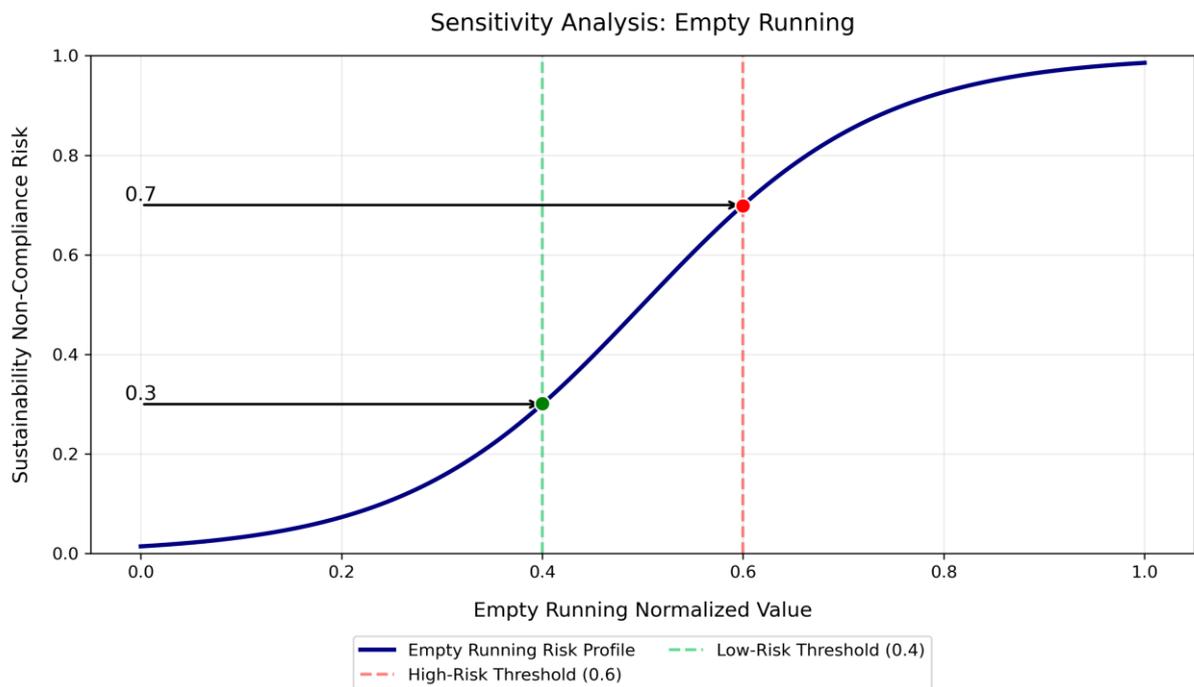
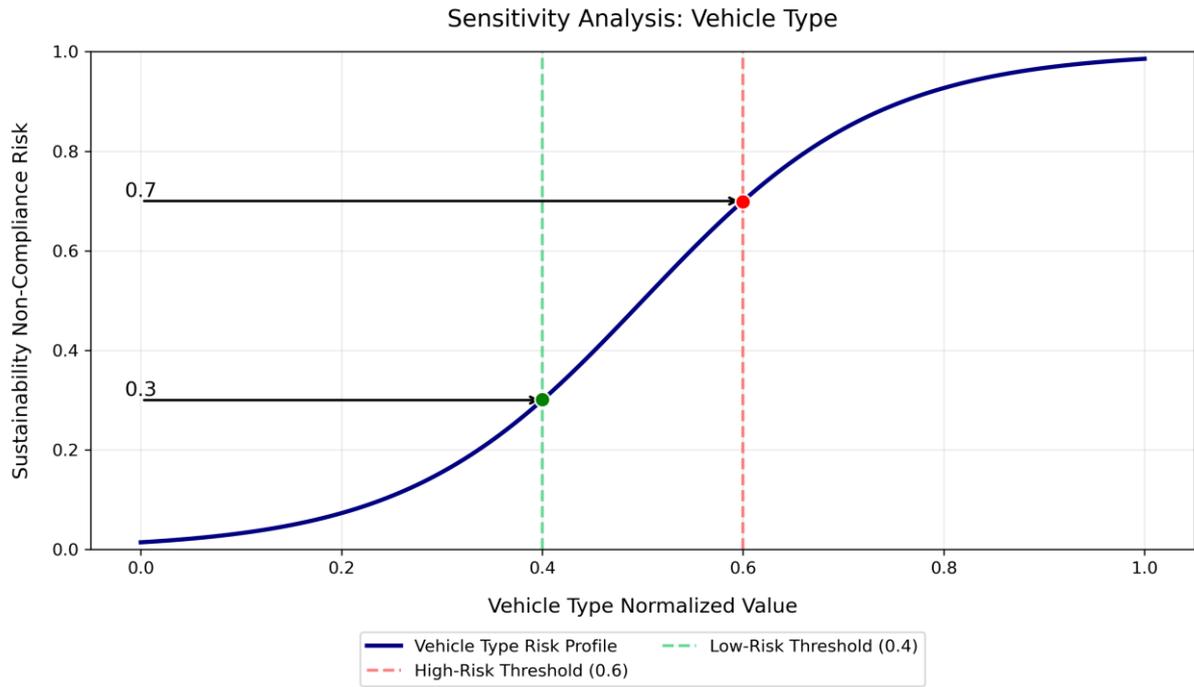


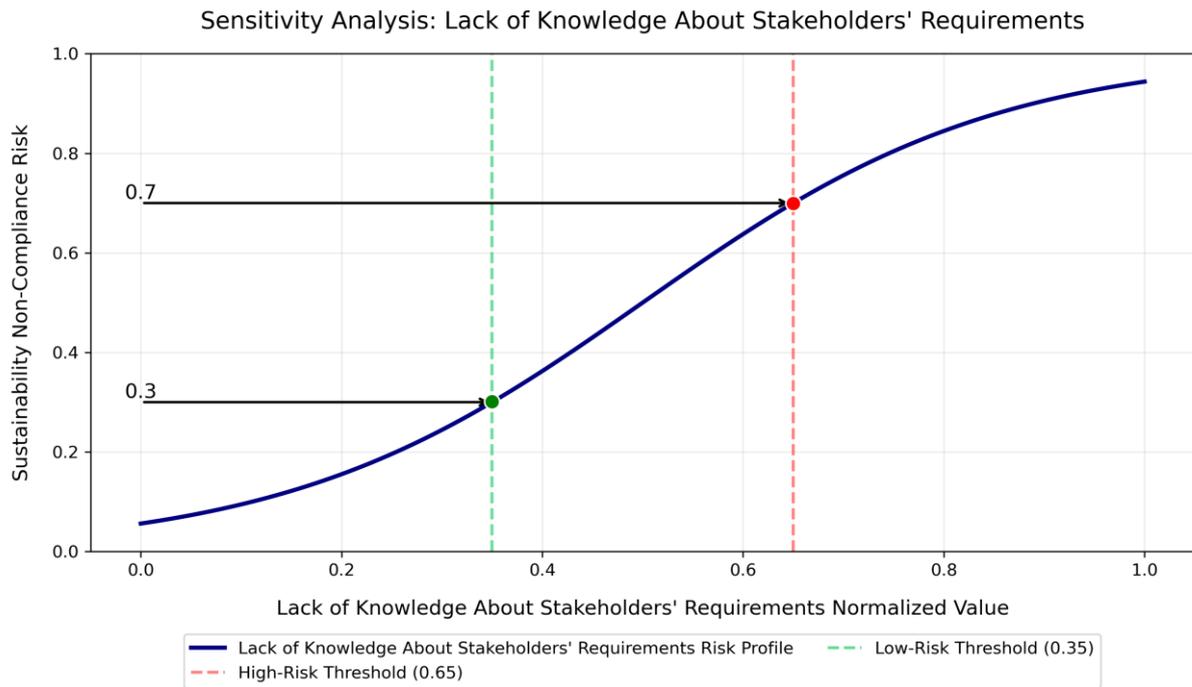
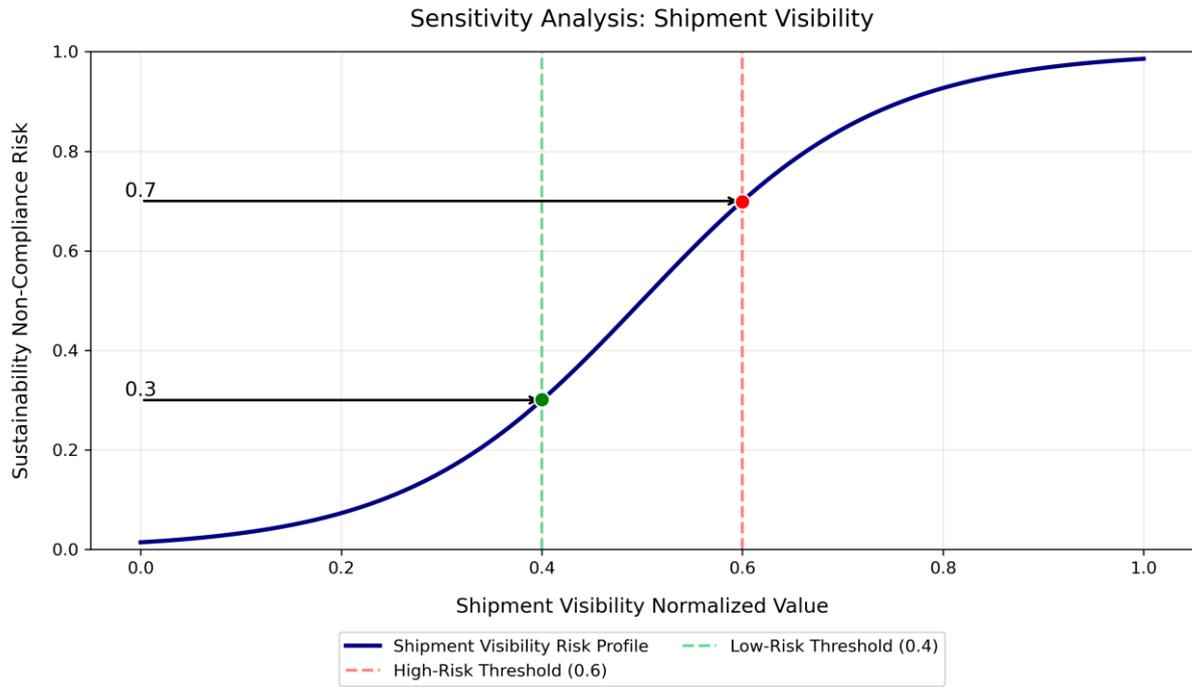


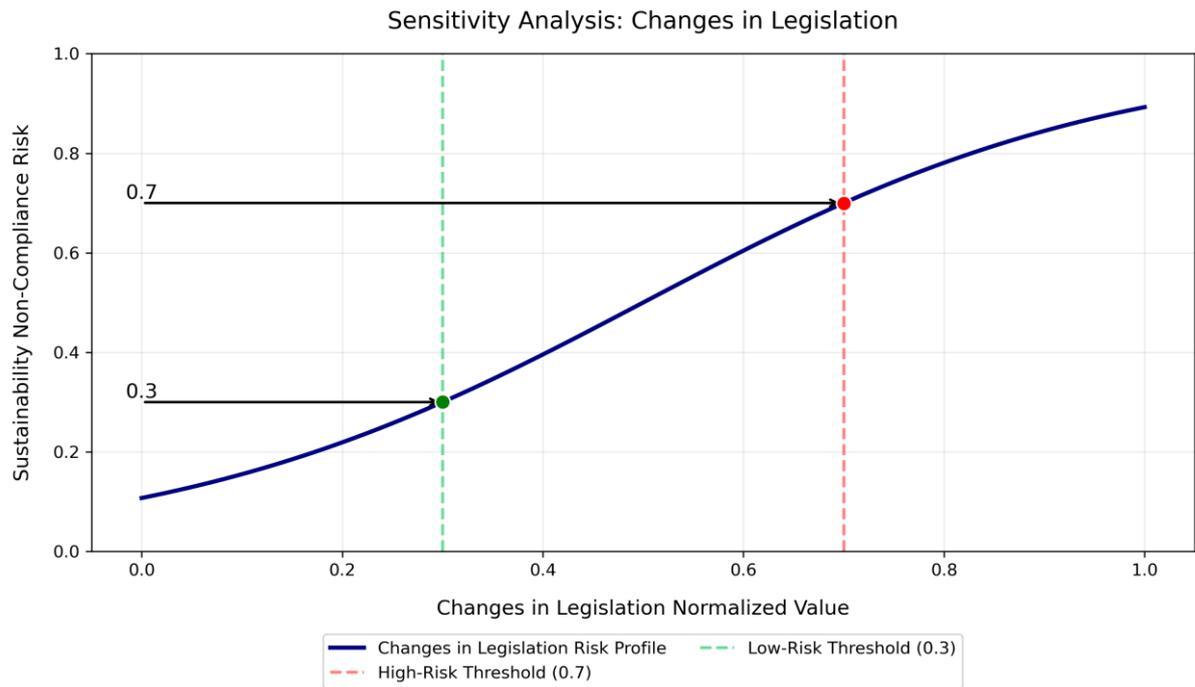












ANNEX V – ADMIRAL evaluation tool tables

Table A33: Proposed Evaluation tool data collection template (baseline)

Data collection - Baseline										
Stakeholder										
Pilot site	KPI ID	Data Description	Data Origin/Source	Data Format	Data owner	Frecuency of collection	Average value	Confidentiality	Technology/technologies fed by	Use case's involved

Table A34: Proposed Evaluation tool data collection template (ex-post)

Data collection - Ex-post										
Stakeholder										
Pilot site	KPI ID	Data Description	Data Origin/Source	Data Format	Data owner	Frecuency of collection	Average value	Confidentiality	Technology/technologies fed by	Use case's involved

ANNEX VI – PEI KPIs

Table A35: eKPIs for the calculation of the ship, terminal and port authority environmental index

eKPI name	associated index	eKPI description	SEA	units
CO2	ships	CO2 emissions by ships	emissions to air	kg or tonnes
NOx	ships	NOx emissions by ships	emissions to air	kg or tonnes
PM10	ships	PM10 emissions by ships	emissions to air	kg or tonnes
PM2.5	ships	PM2.5 emissions by ships	emissions to air	kg or tonnes
SO2	ships	SO2 emissions by ships	emissions to air	kg or tonnes
HC	ships	HC emissions by ships	emissions to air	kg or tonnes
CO	ships	CO emissions by ships	emissions to air	kg or tonnes
N2O	ships	N2O emissions by ships	emissions to air	kg or tonnes
CH4	ships	CH4 emissions by ships	emissions to air	kg or tonnes
Plastics	ships	Plastics wasted by ships	waste	kg or tonnes
Food waste	ships	Food wasted by ship crew and passengers	waste	kg or tonnes
Domestic waste	ships	Domestic waste created by ship crew and passengers	waste	kg or tonnes
Cooking oil	ships	Cooking oil used by the ship crew and passengers	waste	kg or tonnes
Incinerator ashes	ships	Incinerator ashes created	waste	kg or tonnes
Operational waste	ships	Waste created during maintenance or ship operations	waste	kg or tonnes
Animal carcass(es)	ships	Self-explanatory	waste	kg or tonnes
Fishing gear	ships	Self-explanatory	waste	kg or tonnes
E-waste	ships	Electronic waste (from electronic devices)	waste	kg or tonnes
Cargo residues (harmful)	ships	Self-explanatory	waste	kg or tonnes
Cargo residues (non-harmful)	ships	Self-explanatory	waste	kg or tonnes
Passively fished waste	ships	Waste caught in the next during fishing	waste	kg or tonnes

eKPI name	associated index	eKPI description	SEA	units
other substances	ships	All waste not covered with other categories	waste	kg or tonnes
Oily bilge water	ships	Water accumulated in the bilge	wastewater	m ³
Oily residues (sludge)	ships	mixture of oily residues created by ships	wastewater	m ³
Oily tank washings	ships	Washing out the residue using crude oil	wastewater	m ³
Dirty ballast water	ships	Seawater pumped in fuel tanks for ship stability	wastewater	m ³
Scale and sludge from tank cleaning	ships	Self-explanatory	wastewater	m ³
Other - oil	ships	Oil substances not covered above	wastewater	m ³
Noxious liquid substances (NLS) - type X	ships	Present major hazard to marine resources or human health, prohibited from discharging	wastewater	m ³
NLS - type Y	ships	Present hazard to marine resources or human health, limited discharging allowed	wastewater	m ³
NLS - type Z	ships	Minor hazard to marine resources or human health, more discharging allowed	wastewater	m ³
NLS - other	ships	No harm to marine resources or human health	wastewater	m ³
Sewage	ships	Domestic wastewater created by crew and passengers	wastewater	m ³
CO2	terminals/ Port Authority	CO2 emissions by terminals	emissions to air	kg or tonnes
NOx	terminals/ Port Authority	NOx emissions by terminals	emissions to air	kg or tonnes
PM10	terminals/ Port Authority	PM10 emissions by terminals	emissions to air	kg or tonnes
PM2.5	terminals/ Port Authority	PM2.5 emissions by terminals	emissions to air	kg or tonnes
SO2	terminals/ Port Authority	SO2 emissions by terminals	emissions to air	kg or tonnes
HC	terminals/ Port Authority	HC emissions by terminals	emissions to air	kg or tonnes
CO	terminals/ Port Authority	CO emissions by terminals	emissions to air	kg or tonnes
N2O	terminals/ Port Authority	N2O emissions by terminals	emissions to air	kg or tonnes

eKPI name	associated index	eKPI description	SEA	units
CH4	terminals/ Port Authority	CH4 emissions by terminals	emissions to air	kg or tonnes
Sanitary wastewater	terminals/ Port Authority	Wastewater created by usual domestic activities	wastewater	m3
Technological wastewater	terminals/ Port Authority	Wastewater created by industry and ship maintenance	wastewater	m3
Storm water	terminals/ Port Authority	Water resulting from rain, snow, etc.	wastewater	m3
Municipal solid waste	terminals/ Port Authority	garbage ("everyday items discarded by the public")	waste	kg or tonnes
Inert waste	terminals/ Port Authority	Waste that is not decomposable, but also not chemically or biologically active	waste	kg or tonnes
Hazardous waste	terminals/ Port Authority	Waste hazardous for public health or environment	waste	kg or tonnes
Noise pollution (Lden)	terminals/ Port Authority	Noise levels calculated from day, evening and night levels	noise	dB
Noise pollution (Lnight)	terminals/ Port Authority	Noise levels during the night	noise	dB
Odour	terminals/ Port Authority	Self-explanatory	odour	ouE/m3
Light pollution	terminals/ Port Authority	Self-explanatory	light pollution	lx