



Deliverable 6.1 (v1.0)

Impact Assessment Framework, KPIs, and Prioritization

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Abbreviations

LSI	Logistics Sustainability Index
LMI	Logistics Maturity Index
LTI	Logistics Transferability Index
KPI	Key Performance Indicator
IA	Impact Assessment
GHG	Greenhouse Gas
GLEC	Global Logistics Emissions Council
TRL	Technology Readiness Level
EU	European Union
WP	Work Package
CO2	Carbon Dioxide
GDPR	General Data Protection Regulation
IoT	Internet of Things
EV	Electric Vehicle
t.km	Ton-kilometre
ISO	International Organization for Standardization

Publishable Executive Summary

In a nutshell, the ADMIRAL project wants to change how the transport and logistics industries see emissions to an advanced level by equipping companies with the necessary tools to cater to the needs of consumers and the society. The main goal of the ADMIRAL project is to enhance the cooperation of supply chain actors and facilitate even cross border logistics integration in an optimal way. The practical result is the Admiral marketplace, which connects logistics service providers and cargo owners, serving as managing the whole supply chain infrastructure and related emissions. Moreover, Admiral marketplace allows the European developers to penetrate new markets with their innovative and green ideas and solutions.

ADMIRAL marketplace will enhance the competitiveness of companies by making them more innovative in coming up with innovative solutions and distributing them more efficiently across the market. It will enable greater transparency as to the level of each company emissions across the supply chain, as a result improving the opportunities for purchasing logistics and transportation services which are cost beneficial. Therefore, the results of Admiral project will double the possibilities to decrease emissions: First, developing technological solutions which allow logistics networks to be configured and linked together more efficiently, and second building a marketplace where consumers can buy the least pollution service.

This approach emphasizes transparency, resilience, and emissions reduction across the entire supply chain. ADMIRAL's primary objectives include:

- Developing a marketplace to manage multimodal, low-emission logistics solutions that enable companies to reduce supply chain emissions effectively.
- Encouraging sustainable sourcing, enhancing operational efficiency, and promoting a collaborative platform for innovative, green logistics solutions.
- Reducing overall logistics-related emissions by over 20%, providing tools for companies to monitor and reduce indirect emissions effectively.
- Improving supply chain resilience and transparency by supporting companies in adopting multimodal transport chains with lower environmental impacts.

The objective of ADMIRAL D6.1 Impact Assessment Framework, KPIs and Prioritisation deliverable is the definition of a structured Impact Assessment Framework to account for ADMIRAL's contribution to sustainable logistics. This shall be elaborated in view of formulating, prioritizing and implementing Key Performance Indicators/KPIs that reflect the progresses towards the project results, mainly in terms of emission savings, efficiency increase of multi-modal logistics and stakeholder involvement, based on the deliverable D2.4. In relying on that, the ADMIRAL D6.1 gives a structured approach necessary in assessing and measuring the impacts of ADMIRAL's innovative logistics solutions across its pilot sites in Europe.

The ADMIRAL, a bold initiative to bring down GHG emissions in the sector of freight transportation, has visualized a systemic socio-technical transformation through a multimodal logistics marketplace. The D6.1 introduces a detailed impact assessment framework to support ADMIRAL's goals, set meaningful KPIs, and prioritize KPIs, ensuring that the success of the project can be measured and guided effectively throughout the lifecycle, while actions can be monitored along the project life cycle- and also after it.

The D6.1 Impact Assessment Framework, KPIs, and Prioritization contains the activities done by Task T6.1 as it is also to establish a structured and framework that supports ADMIRAL's objectives by:

- Defining an impact assessment framework tailored to ADMIRAL's goals of emissions reduction and sustainability in logistics.
- Identifying and prioritizing KPIs that will allow for the consistent and meaningful measurement of the ADMIRAL marketplace's environmental, operational, and social impacts.
- Providing guidelines and methodologies for assessing pilot sites' progress, emphasizing mandatory and suggested KPIs to account for diverse data availability across pilot regions.

D6.1 will serve as a foundational tool for ADMIRAL's consortium members, pilot leaders, and stakeholders, providing a roadmap for both evaluating immediate outcomes and tracking the long-term impact of ADMIRAL's solutions on freight emissions.

The ADMIRAL Impact Assessment Framework is designed to operate across two interconnected layers, ensuring alignment with both strategic project goals and pilot-specific objectives, while maintaining relevance beyond the project's lifecycle. First, the framework will link directly to ADMIRAL's strategic objectives in alignment with broader European Union priorities such as the EU Green Deal, the Sustainable Development Goals, and the Smart and Sustainable Mobility Strategy 2030 and beyond. It gives the assurance that ADMIRAL will contribute to long-term sustainability, decarbonization, and multimodal logistics innovation at the EU level. The second layer relates to the national and cross-country targets for each pilot site, which are specific and localized in terms of targets on emission reductions, energy efficiency, and stakeholder collaboration by the end of the project. Additionally, this layer embeds mechanisms for monitoring the implementation of solutions and their impacts through continuous stakeholder engagement that enables the sustainment of actions beyond the life of the project. The framework builds on the initial Sustainability Framework outlined in Milestone MS1, incorporating a dynamic, "living" approach that supports iterative refinement and ongoing alignment with both ADMIRAL's internal priorities and external EU and country-level ambitions.

The impact assessment framework outlined in this deliverable has been designed with adaptability, stakeholder inclusivity, and comprehensive performance evaluation in mind. The framework comprises three core indexes:

- ❖ **Logistics Sustainability Index (LSI):** Measures the environmental and social sustainability of logistics operations by quantifying emissions, energy use, and other relevant sustainability metrics. The LSI enables ADMIRAL to track emissions reductions and align with the project's emissions-reduction targets.
- ❖ **Logistics Maturity Index (LMI):** Evaluates the level of integration and adoption of advanced logistics technologies within ADMIRAL's marketplace, particularly those that enable multimodal and low-emission logistics solutions. The LMI ensures that ADMIRAL can gauge the technological readiness and progress of its platform and services.
- ❖ **Logistics Transferability Index (LTI):** Assesses the potential of ADMIRAL's solutions to be successfully adapted and scaled across diverse European regions. The LTI allows ADMIRAL to evaluate and understand the conditions under which its solutions can be replicated and adopted in different logistics environments and regulatory contexts.

These indices provide a holistic view of ADMIRAL's impact by focusing on sustainability, technological maturity, and transferability, forming the foundation for decision-making, improvement, and growth of ADMIRAL's Logistics Marketplace.

KPIs and Prioritization: The KPIs in D6.1 have been meticulously developed through a collaborative, consortium-wide prioritization process. This process ensured that both core and site-specific KPIs align closely with ADMIRAL’s objectives and address case needs. The KPIs are sub-grouped as follows:

- ✓ **Mandatory KPIs:** Mandatory KPIs: A set of 5-6 high-priority KPIs that all pilot sites are required to measure. These KPIs include emissions reductions, transparency enhancements, and multimodal logistics performance indicators that are essential for tracking ADMIRAL’s primary environmental and operational objectives. The mandatory KPIs will serve as the foundational metrics for evaluating the project’s progress and impact across its pilot sites, aligning with the strategic objectives of reducing emissions, improving energy efficiency, and fostering multimodal logistics innovation. These KPIs include: KPI.1: Unit Emission of Delivery, which tracks the emissions associated with each delivery to assess environmental impact; KPI.2: Unit Cost of Delivery, evaluating the cost efficiency of logistics operations while maintaining sustainability standards; KPI.3: Willingness to Pay for Green Urban Logistics, measuring market demand for sustainable urban logistics solutions; KPI.4: Existing-To-Achieved Technology Readiness Level (Start-to-End TRL), which tracks the technological maturity from development to full deployment, ensuring scalability and adoption; and KPI.5: Solution Integration and Standardization, assessing the integration of new solutions with existing infrastructure and their standardization across pilot sites for broader adoption. These KPIs are central to ADMIRAL’s Impact Assessment Framework, ensuring a standardized approach to measuring outcomes and enabling robust comparability across pilots. By prioritizing these KPIs, ADMIRAL aims to deliver measurable results, supporting both immediate pilot outcomes and long-term scalability in decarbonization and logistics optimization.
- ✓ **Suggested KPIs:** Additional KPIs are suggested to be very informative, particularly for those aspects where data would be more readily available. These KPIs are optional but encouraged for application whenever the collection of data has been or will be set up. These KPIs address impacts that are more localized or context-specific. Stakeholders are encouraged to collect data to measure these KPIs across two or more pilot sites where possible. If data is currently not available, it was recommended that such data shall be identified and collected at a later stage, while making sure that these KPIs can be considered in the long run.

The prioritization of KPIs followed a structured workshop process, in which consortium partners and pilot leaders participated to ensure alignment with ADMIRAL’s goals and data availability across pilot sites. By defining both mandatory and suggested KPIs, D6.1 offers flexibility for pilot sites to adapt measurement strategies according to their capabilities, while still ensuring that core metrics are consistently evaluated across the project.

1 Introduction




The ADMIRAL project represents a ground-breaking initiative to transform Europe's logistics sector by developing an innovative digital marketplace for multimodal, low-emission transport solutions. Since the logistics sector accounts for a substantial share of GHG emissions, especially indirect emissions such as Scope 3, ADMIRAL envisions promoting a systemic shift toward sustainable logistics practices that can significantly reduce emissions across the supply chain. It is also foreseen that this marketplace will help logistics providers shift towards and manage low-emission, multimodal options of transport, promoting environmental responsibility with operational efficiency in logistics networks across Europe. ADMIRAL has the general aim of a 20% reduction of logistics-related emissions, therefore directly contributing to ambitious EU Climate and Sustainability Targets.

ADMIRAL's marketplace will provide a front door for logistics innovation in a global, multifunctional ecosystem of logistics service providers, technology developers, and end-users. In this marketplace, easy access to low-emission transportation solutions is foreseen in order to foster multimodal logistics strategies that optimally exploit all available transport modes for a given distribution task, with an increased reduction in emissions.

By fostering collaboration, ADMIRAL enables logistics companies to transition from traditional, high-emission models to a sustainable logistics approach centred on reducing Scope 3 emissions, improving asset utilization, and supporting innovative technologies. ADMIRAL will demonstrate its marketplace capabilities in four pilot sites across Europe—Portugal-Spain, Slovenia-Croatia, Lithuania, and Finland—where real-world testing will provide insights and confirm the platform's adaptability across diverse operational and regulatory contexts.

This deliverable, ADMIRAL D6.1 Impact Assessment Framework, KPIs, and Prioritization, is related to Work Package 6 (WP6) focused on the impact assessment of ADMIRAL through a structured, multi-dimensional framework. The framework developed in T6.1 will support the quantification of the contribution provided by the project to Emission Reduction, Operational Efficiency, and Stakeholder Acceptance, as well as an in-depth assessment of environmental impacts, socio-economic impacts, and user experience. It would further ensure that the project's solution brings quantifiable benefits within many domains through ADMIRAL's real-life demonstrations in various pilot sites.

ADMIRAL's goals are closely aligned with Europe's climate targets and the push for sustainable transformation in logistics. To reduce emissions and promote systemic socio-technical change, ADMIRAL's objectives include:

-  **Achieving GHG Emissions Reduction in Freight Transportation:** By providing companies with tools for monitoring and reducing indirect logistics-related emissions, ADMIRAL targets a 20% reduction in logistics emissions. This goal is to be achieved by facilitating the adoption of multimodal low-emission solutions through the ADMIRAL marketplace.
-  **Optimizing Energy Use and Traffic Efficiency:** The project will work on integrating energy-efficient practices and enhancing logistics chain transparency. ADMIRAL aims to enable better utilization of existing assets, improving logistics efficiency, and reducing environmental footprints.
-  **Enhancing Stakeholder Acceptance and User Experience:** Through collaborative workshops and active involvement of consortium partners, ADMIRAL emphasizes the importance of user and stakeholder engagement in adopting low-emission logistics solutions. This approach ensures that solutions are well-received and adapted to user needs.

- ✚ **Fostering Transferability and Socioeconomic Equity:** ADMIRAL’s marketplace will support the adoption of low-emission solutions across different European contexts. The impact assessment framework will help identify and facilitate the conditions under which ADMIRAL solutions can be adapted and scaled across the EU, addressing regional variations in logistics practices and regulatory environments.

The project outcomes will be demonstrated and piloted in Portugal-Spain, Slovenia-Croatia, Lithuania, and Finland, allowing ADMIRAL to validate its marketplace model in real-life demonstrations that span diverse logistics environments and regulatory contexts.

WP6 is dedicated to a thorough assessment of ADMIRAL’s impacts, integrating the framework from Task 6.1 with the methodologies and insights developed in WP5. WP6’s objectives encompass evaluating ADMIRAL’s contributions to energy consumption, environmental sustainability, user experience, stakeholder acceptance, socioeconomic equity, and transferability. The framework developed in T6.1 will also enable ADMIRAL to explore strategies for broader market adoption, considering factors such as penetration rates, the influence of technological trends, and the impact of policies on different user groups and business models.

Within **Task 6.1**, specific activities are outlined to establish a robust impact assessment process:

- ✓ **Literature Review and Best Practices:** Task 6.1 incorporates insights from existing frameworks and best practices, referencing other successful EC-funded projects such as SHOW and NOVELOG to align ADMIRAL’s KPIs and impact assessment approach with established methodologies.
- ✓ **Definition of Impact Areas and Key Performance Indicators (KPIs):** Task 6.1 focuses on identifying KPIs that capture ADMIRAL’s impact on logistics sustainability, stakeholder engagement, and transferability. These indicators are derived from extensive literature reviews, conducted primarily in Task 2.4 (D2.4), where a comprehensive list of over 400 logistics KPIs have been drafted and adapted based on the unique conditions of ADMIRAL’s pilot sites.
- ✓ **KPIs Prioritization Through Stakeholders:** A series of workshops and interviews have been (and will be) conducted to ensure that the KPIs reflect the needs and expectations of ADMIRAL. This participatory approach has led to the creation of mandatory and suggested KPIs lists, covering data availability constraints while ensuring consistent evaluation across pilot sites.
- ✓ **Multi-Criteria Decision-Making (MCDM) for KPI Prioritization:** To prioritize KPIs effectively, Task 6.1 employs a multi-criteria decision-making approach. This process considers the diverse requirements of stakeholders and the particularities of each pilot site, providing a balanced and adaptive prioritization framework.

The outputs from Task 6.1 directly contribute to ADMIRAL’s ability to assess its solutions’ impact in areas such as operational efficiency, environmental impact, user satisfaction, and transferability. D6.1 aligns closely with WP6’s broader objective of providing a rigorous, multi-stakeholder assessment of ADMIRAL’s contributions to the logistics sector.

D6.1 Impact Assessment Framework, KPIs, and Prioritization is a key deliverable within WP6. Its primary purpose is to establish a structured framework that enables the evaluation of ADMIRAL’s impact on energy consumption, environmental sustainability, logistics efficiency, and user engagement. Specifically, D6.1 aims to:

- ❖ *Define Impact Assessment Framework:* D6.1 presents a multidimensional framework designed to measure ADMIRAL’s contributions to various impact areas, covering operational and energy efficiency, sustainability, user acceptance, socioeconomic factors, and transferability.

- ❖ *Identify and Prioritize KPIs:* The framework includes a comprehensive set of KPIs, derived from a pool of KPIs that have been identified in Task 2.4, organized into mandatory and suggested groups. Mandatory KPIs provide a consistent basis for evaluating essential outcomes, while suggested KPIs offer additional insights where data availability allows.
- ❖ *Provide a Cross-Analysis Mechanism:* Using a standardized framework, D6.1 ensures that ADMIRAL's performance can be compared across pilot sites. This approach facilitates the assessment of ADMIRAL's overall impact, as well as location-specific variations, in line with WP6's emphasis on cross-analysis and real-life demonstration results.

D6.1 is intended as a reference tool for ADMIRAL's consortium members, stakeholders, and pilot leaders. It establishes a robust foundation for tracking the project's performance and ensuring that all sites contribute to ADMIRAL's environmental and operational goals.

The ADMIRAL Impact Assessment Framework is structured around three core indexes that collectively provide a multidimensional evaluation of the project's contributions:

- ✓ *Logistics Sustainability Index (LSI):* The LSI measures the environmental sustainability of ADMIRAL's solutions by tracking emissions reductions, energy efficiency, and the utilization of multimodal transport modes. This index reflects ADMIRAL's commitment to minimizing the environmental impact of logistics operations.
- ✓ *Logistics Maturity Index (LMI):* The LMI evaluates the technological readiness and adoption of ADMIRAL's low-emission logistics solutions, focusing on the advancement and integration of key logistics technologies. By assessing pre- and post-project Technology Readiness Levels (TRLs), the LMI provides a clear picture of how ADMIRAL's marketplace supports logistics modernization.
- ✓ *Logistics Transferability Index (LTI):* The LTI assesses ADMIRAL's potential for scalability by evaluating the adaptability of its solutions to different regions and logistics settings across Europe. This index helps ensure that ADMIRAL's innovations are versatile and replicable across diverse operational environments.

These indexes are indispensable in understanding the progress of ADMIRAL, as they give a structured way of evaluating the environmental, operational, and regional impacts of the project. Each index will be calculated by multi-criteria analysis methods, combining quantitative metrics with qualitative insights to enable ADMIRAL to comprehensively assess the effectiveness of its solutions.

The impact assessment framework of D6.1 is informed by best practices from successful EU-funded projects, such as SHOW and NOVELOG, and recent advancements in logistics sustainability and digitalization. By adopting lessons from these projects, ADMIRAL's framework is underpinned by proven methodologies while remaining tailored to the unique objectives of the project. Moreover, ADMIRAL's framework includes cross-project collaboration by sharing selected KPIs with a sister project funded under the same Horizon Europe Call. The collaboration supports latitudinal comparisons that extend the scope of ADMIRAL's findings, putting into perspective the effectiveness of low-emission logistics strategies in a wider sense. D6.1 provides a scalable and adaptable framework that acts as a model for future sustainability initiatives in logistics. This deliverable shall provide the means to measure, prioritize, and optimize the impact of the project across the European logistics networks so that the innovations provided by ADMIRAL lead to effective, long-lasting improvements in environmental performance, operational resilience, and market readiness for the consortium, stakeholders, and pilot leaders.

2 Literature Review

The Literature Review performed for ADMIRAL D6.1 aims at providing a full understanding of existing methodologies, frameworks, and best practices that would be relevant for the creation of the IA Framework of logistics operations, thereby allowing the ADMIRAL project to make use of the state-of-the-art approaches, taking into account global standards and practices.

The main objective of the literature review is to identify, analyse, and synthesize relevant studies and frameworks that will inform the design of the LSI, LMI, and LTI. More specifically, the review covers the following key themes: reduction of emissions, energy efficiency, technological maturity, scalability, and socio-economic impacts in logistics. By doing so, it directly supports ADMIRAL's IA Framework.

For performing this literature review, an extensive search through reliable, well-recognized academic databases mainly took into account Web of Science (WoS) and Scopus. Concerning the timeline, within the review scope, targeted documents covered publications between the years of 2008 and 2023 to provide relevance with present state-of-the-art evolution, especially digital/automated, in modern logistics.

The literature review was performed in a structured manner: after selecting the keywords, the list of search queries included words and phrases like "assessment of logistics impacts," "GHG emissions in logistics," "sustainability by multimodal transport," "logistics KPI, TRL in logistics, scalability in logistics innovation." Afterward, the section selected the articles relevant to developing impact assessment frameworks for case studies, theoretical developments, and EU-funded projects such as SHOW, ACCAM, NOVELOG, and SULPITER. Accordingly, the selected articles were analysed in order to extract the frameworks, indicators, and methodologies that might match the objectives of ADMIRAL. Findings were grouped under appropriate themes in order to inform the IA framework.

This systematic review lays a robust foundation for the development of ADMIRAL's impact assessment framework, ensuring alignment with global standards and incorporating proven methodologies tailored to the project's objectives.

2.1 Developing an Impact Assessment Model for CO₂ Emission Measurements in Transport & Logistics

The transport and logistics sector are one of the largest environmental pollution sources, as the vast majority of water, land, and air vehicles currently use petroleum products as the main source of energy (Grechan et al., 2022). Transport and logistics activities (i.e., passenger and freight transport) contribute substantially to the global stock of GHG emissions. They accounted for around 7.98 Gt CO₂ in 2022, which is 23% of global emissions (IEA, 2023).

The emergence of Internet-based business has radically transformed the global economic and social landscape in the last decade. It took a very short span of time for e-commerce to transform from a novelty into a normality, driving a revolution in the way that consumers and businesses interact across the global retail economy. The growing demand for e-commerce also has a lot of impact on the environment. According to the World Economic Forum, the carbon dioxide emissions generated from delivery traffic in the top 100 global cities could reach 6 million tonnes by 2030 — a 32% increase from 2019 (World Economic Forum, 2020).

To meet the demands of the fast-growing e-commerce industry, while ensuring sustainable development, organizations need new strategies to perform more efficient logistics operations. However, designing these new strategies has proven to be difficult as each one has pros and cons, and needs the involvement of different conflicting stakeholders (Silva et al., 2024). These have raised fundamental questions about the unsustainability of transport given its rapid development. Till date there is no established and tested framework that considers the impact of emissions and energy used when giving consumers choices of logistics providers (Banister, 2008).

2.1.1 Selection and Evaluation of Suppliers (Logistics Providers)

Several suppliers compete in different capacities namely: pricing schemes, cost structures, service and quality levels (Ekici, 2013). Thus, procurement decisions play a key role. One of the most important decisions related to green procurement operations is supplier evaluation and selection.

Therefore, choosing the right suppliers involves much more than scanning a series of price list, and choices will depend on a wide range of factors which involve both quantitative and qualitative. (Ho et al., 2010) carried out a literature review on multi-criteria decisions to evaluate and select suppliers. Individual integrated and the most prevalently used approaches were employed to review the relevant papers in this evaluation.

The individual approaches used DEA, which refers to data envelopment analysis, mathematical programming, AHP standing for analytic hierarchy process, case-based reasoning (CBR), analytic network process (ANP), fuzzy set theory, simple multi-attribute rating technique (SMART), and genetic algorithm (GA). Integrated approaches made use of mainly integrated AHP and integrated fuzzy set theory. After analysing the selected literature, the most popular single approach is DEA, mathematical programming, AHP, CBR, ANP, fuzzy set theory, SMART, and GA, in that order. DEA has grabbed more attention principally due to its robustness. The supplier selection problem involves both qualitative and quantitative criteria. In order to handle qualitative data, such as amount of know-how transfer, service, supplier reputation, and so on, DEA has been modified. Furthermore, there are integrated approaches to supplier selection. It was observed that integrated AHP approaches were more common. The wide applicability is because of its simplicity, ease of use, and great flexibility.

After reviewing criteria, the most popular criterion is quality, followed by delivery, price/cost, manufacturing capability, service, management, technology, research and development, finance, flexibility, reputation, relationship, risk, and safety and environment. Although pricing is not the most popular criterion, it is the most widely adopted one. The traditional single criterion approach based on lowest cost bidding is no longer supportive and robust enough in contemporary supply management.

These various selection evaluation approaches have several drawbacks: In the DEA, for instance, the practitioners can easily get baffled with input and output criteria and on matters of subjective rating to the qualitative criteria. Similarly, one potential problem concerning the AHP is the amount of time consumed for it to reach a decision as the decision maker will need to compare each cluster belonging to the same level with each other pairwise against personal knowledge and experience.

Among the literature reviewed on using multiple criteria to evaluate and select supplies, it was found that a set of individual and integrated approaches are capable of handling multiple quantitative and qualitative factors with DEA and AHP being the most prevalent approaches in individual and integrated approaches respectively.

It was also observed that price/cost is not the most widely adopted criterion. Instead, the most popular criterion used for evaluating the performance of suppliers is quality, followed by delivery, price/cost, and so on. This proves that the traditional single criterion approach based on lowest cost is not supportive and robust enough in contemporary supply management. The traditional cost-based approach cannot guarantee that the selected supplier is global optimal because the customer-oriented criteria (quality, delivery, flexibility, etc.) were not considered, Ho et al. (2010).

Silva et al. (2024) analysed e-commerce last mile delivery strategies in terms of Operational, Energy and Emissions performances and had the following results. In terms of operational performance, evaluating metrics related to the delivery operation, namely the associated route's length, duration, and waiting time were used. The energy performance is evaluated in terms of the fuel/electricity consumed during the delivery round. The emissions performance is based on the amount of CO, HC, PM_x, NO_x, and CO₂ generated by the vehicles.

One of the biggest challenges in last-mile decision-making is the large number of factors that need to be considered when making a decision. This task is often difficult due to the existence of multiple stakeholders, each with different criteria and goals, which are often in conflict. To address this issue, 81 different decision-making profiles were defined by attributing different weights to the five studied factors (route length, route duration, waiting time, energy consumption, and emissions). These profiles are grouped into nine types of profiles:

- Length-oriented profiles (P1–P11),
- Duration-oriented profiles (P12–P22),
- Waiting time-oriented profiles (P23–P33),
- Energy-oriented profiles (P34–P44),
- Emissions-oriented profiles (P45–P55),
- 2-factors-oriented profiles (P56–P65),
- 3-factors-oriented profiles (P66–P75),
- 4-factors-oriented profiles (P76–P80),
- 5-factors-oriented profile (P81).

This paper (Silva et al., 2024) provides valuable new insights regarding last-mile delivery operations, particularly those conducted in challenging terrains, namely by confirming that the terrain conditions undoubtedly have an influence on these operations and by evaluating which delivery strategy is more adequate in different terrains and for different decision-making profiles.

In short, more time is needed to deliver all packages; there are longer waiting times; the vehicles consume more energy; and there is more generation of pollutant emissions as the terrain conditions worsen i.e., as the roads' slopes increase. Building on this, the article also evaluates which delivery strategies are more adequate for each type of terrain and for different decision-making profiles. In less challenging terrains, two delivery strategies emerge as the best ones.

Buyer–supplier exchange relationships involve both (1) a choice of the activities to outsource and (2) the selection of an appropriate supplier to perform these activities. Transaction cost economics (TCE) is at the core of nearly all discussions of the “make or buy” decision and has generally received strong empirical support across a range of different economic situations. In the case of logistics outsourcing, TCE argues that the buyer/customer will, once they have made the choice to outsource logistics

generally, choose that provider offering the greatest efficiency in terms of “planning, adapting, and monitoring” costs. However, an exclusive focus on TCE as an explanation of the 3PL selection process offers us an incomplete picture of the complexity of the decision being made (ANDERSON et al., 2011).

Traditionally, 3PL providers have offered customers three primary competitive benefits: reduced cost, faster delivery, and improved reliability. However, recent work published last years has suggested that a new paradigm is emerging based on a more sophisticated supply chain. If new competitive pressures are emerging, then an important unanswered research question is: “to what extent has the structure of demand in the 3PL customer base changed?” One difficulty in seeking answers to this question is the very large number of different attributes that have been suggested by different authors.

In broad terms, we can distinguish between economic exchange factors (that will potentially be wider than an initial price); logistics performance (encompassing delivery speed, reliability, etc.); technology (primarily IT-related capabilities); relational attributes (e.g., understanding the customer and fit between cultures); flexibility (being able to respond to changes in requirements); as well as a range of other social exchange factors that do not fit easily into these categories (such as reputation, ability to innovate and managerial involvement). The results clearly indicate that many managers base their decisions on four key factors: (a) reliable delivery performance; (b) price parity with other providers; (c) being among the industry leaders in customer recovery; and (d) not being difficult to deal with. These are the most critical issues for customers, with these attributes explaining 79 percent of the variance in the decisions (ANDERSON et al., 2011).

2.1.2 Measuring Emissions

There are several factors both external and internal, which demand the development of a robust Carbon Footprint model. The growing environmental regulations and awareness have urged companies to investigate carbon emissions and optimization policies (Lagoudis & Shakri, 2015).

For all mobile sources, one may apply either a fuel-based or distance-based methodology to calculate these emissions. In the fuel-based approach, fuel consumption is multiplied by the CO₂ emission factor for each fuel type. This emission factor is developed based on the fuel's heat content, the fraction of carbon in the fuel that is oxidized (generally about 99% but assumed to be 100% in the tool), and the carbon content coefficient. Since this approach uses previously aggregated fuel consumption data, it is considered “fuel-based.” Fuel based approach can be used also when vehicle activity data and fuel economy factors are available enabling the calculation of fuel consumption. In the distance-based method, emissions can be calculated by using distance-based emission factors to calculate emissions.

Dobers et al. researched the preparation of an international standard on emissions accounting in transport and logistics. Using questionnaire-based interviews and pilot tests, findings showed that the main barrier organisations face when attempting to calculate their supply chain emissions are mainly related to the sourcing of data, data communication between the partners of the chain and the quality of the data. They suggested that standardization, like developing an ISO norm, should be implemented to formalize methodologies to measure emissions. One of the ways this research is limited is that it focuses only on logistics hubs and not on the entire supply chain process (Dobers et al., 2019).

Certain standards developed by the Global Logistics Emissions Council (GLEC) have provided methodologies for emissions measurements. The [GLEC Framework](#) offers a methodology for companies to calculate their emissions across various transport modes and logistics hubs.

The European standard EN 16258 establishes a common methodology for the calculation and declaration of energy consumption and GHG emissions related to both different modes of transport and various transport items (passengers, cargo, combinations). It specifies general principles, definitions, system boundaries, calculation methods, apportionment rules (allocation) and data recommendations, with the objective to promote standardized, accurate, credible, and verifiable declarations, regarding energy consumption and emissions related to any transport service quantified.

It also includes examples on the application of the principles (Rybicka et al., 2018; Skrucany et al., 2017). The EN 16258 standard was withdrawn in April 2023 and is now replaced by EN ISO 14083:2023 - Greenhouse gases - Quantification and reporting of greenhouse gas emissions arising from transport chain operations (ISO 14083:2023)

At present, there are three main methods for measuring GHG emissions: actual measurement method based on microscale, mass balance method based on mesoscale, and carbon emission factor method. The actual measurement method mainly measures carbon emissions from agriculture and forest ecosystems. The mass balance method is mainly applicable to specific enterprises or industries. The carbon emission factor method is internationally recognized as a method for measuring carbon emissions. It multiplies various energy consumption with carbon emission factors (Gu et al., 2024).

The IPCC (Intergovernmental Panel on Climate Change) has proposed measurement methods based on the characteristics of the transport sector, including top-down and bottom-up approaches. The "top-down" method calculates transport carbon emissions by multiplying various energy consumption with corresponding carbon emission coefficients. The "bottom-up" method calculates total energy consumption based on driving mileage, vehicle possession, and Energy consumption per unit mileage of various transportation modes, and then multiplies it by the carbon emission coefficient to get the carbon emissions. There are also scholars who combined the two measurement methods to analyse and calibrate the relevant data. At present, the "top-down" method is more commonly applied to measure the carbon emissions in a certain region or industry, while the "bottom-up" method is more likely to be adopted to measure the carbon emissions generated by a certain transportation mode. The transport carbon emission calculated in this article belong to the overall carbon emissions calculation within a certain region, and accurate results can be obtained through the calculation of energy end-use (Gu et al., 2024).

Decomposition analysis and regression analysis are two common approaches for researching the driving factors of carbon emissions. (Henke et al., 2024) proposed in research a BOTTOM-UP approach to estimate energy consumptions and GHG emissions. The primary activity, which also corresponds to the first aim of this study, was to estimate national travel demand by vehicle type (cars, buses, motorcycles for passenger trips, and light and heavy vehicles for freight transport). Travel demand serves as input for energy consumption and GHG emissions estimation methodology. The product of travel demand and unit consumptions (divided by vehicle type and segment, Euro emission class, and road type), produces as output the estimation of GHG emissions and consumption inventory. The second aim of the research was to define possible road transport scenarios to 2030.

Two forecasting scenarios – named “moderate decarbo” and “high decarbo” – were designed in order to represent the evolution of transport demand (passenger and freight) and the impacts of possible mode shift options and technological improvement of the circulating vehicles due to planned investments, currently defined policies and expected trends. The third objective was to estimate the

GHG emissions and energy consumption inventory related to national road transport. This paper concluded that the Italian road transportation system has not yet embarked on an efficient pathway to achieve Fit for 55 decarbonization objectives, even under very favourable assumptions. The results underline also that no policy alone can achieve those objectives for 2030. The currently held belief that shift to rail and electrification can allow to reach decarbonization targets has been proofed unsound also under very favourable assumptions, at least in the medium term. Both the scenarios project prevailing trends and demonstrate that it is essential to keep promoting active sustainable mobility policies with financial support for investments. However, current policies alone are not sufficient for a substantial decarbonization of the transport sector in the short/medium term. It is necessary to complement current policies with additional ones (Henke et al., 2024).

2.2 Specific Assessment of Logistics Emissions

Climate change is an undeniable and inevitable reality in today's world (Xiong, 2022) According to the United Nation's Intergovernmental Panel on Climate Change, the Earth's average temperature may increase by another 1.5°C to 2.0°C in the next thirty years, causing extreme weather, deteriorating air quality, depleting resources, and disrupting economies (Xiong, 2022). As a result, there is mounting pressure from customers, shareholders, governments, NGO's, and other stakeholders to address global-warming and global-reduction of greenhouse-gas emissions (GHG) to mitigate damage from climate change (Ellram et al., 2022).

Among the numerous supply chain activities, transportation and logistics stands as one of the main contributors to greenhouse gases, accounting for 15% to 20% of the world's collective emissions (National Geographic Society, 2020 as cited in Xiong, 2022).

Transportation is one of the fastest growing form of emissions in developing countries and is second only to electricity emissions generation globally (Ellram et al., 2022). These emissions are grouped into three (03) scopes. Scope 1 indicates direct emissions from owned or controlled sources, Scope 2 indicates indirect emissions from purchased energy, and Scope 3 indicates indirect emissions from the corporate value or supply chain (Greenhouse Gas Protocol, 2015 as cited in Ellram et al., 2022). The available literature provides other concepts and definitions of scope 3 emissions around the same common idea. According to Stenzel & Waichman (2023), Scope 3 emissions include all other emissions along the supply chain, both upstream emissions related to the purchased goods and services, and downstream emissions related to sold goods and services in general and detailly, upstream Scope 3 emissions consist of emissions from purchased goods and services, capital goods, transportation of goods and services, waste generated in operations, business travel, employees commuting, and leased assets by Stenzel & Waichman (2023) – just to name these. NGER (2018) as cited in Asif et al. (2022), define scope 3 emissions as the emissions that occur when a facility is activated by a source that is not controlled by its own facility.

This emission is extremely large and includes emissions from purchased raw materials, storage, outsourced, transport, manufacturing, and product sale, use and disposal – all falling within a company's upstream and downstream activities. Scope 3 emissions usually represent a company's largest greenhouse gas impacts. (Ellram et al., 2022). The literature reveals that this emission type surpasses scope 1 and scope 2 emissions.

Blanco et al. (2016) as cited in Ellram et al. (2022) found that 85% of Tesco's emissions are upstream whereas Asda's hits 90%. Similarly, Dragomir (2012) as cited in Ellram et al. (2022) identified that British Petroleum's Scope 3 emissions are 15 times greater than its direct emissions. In another study, Ozawa-Meida et al. (2013) as cited in Ellram et al. (2022) measured a university's carbon footprint discovering that 79% were Scope 3 emissions. These findings are further amplified by Huang et al. (2009) as cited in Ellram et al. (2022) who approximated the upstream emissions of American companies from various sectors and found that scope 3 emissions represent 74% of a firm's total footprint by Asif et al. (2022) Considering the example of port activities with respect to current protocols, organizations distribute port emissions into three categories: those produced by equipment and services under the control of port authorities (scope 1), those generated by the purchase of electricity for all port authority activities (scope 2), and other port activities, including employee travel, outsourced operations, construction, mobile sources such as vessel and truck transportation activity (scope 3), which represent the remaining part of emissions and comprise indirect Greenhouse Gas (GHG) emissions, but which are owned or under the control of port concessionaires (Freitas & Gervásio, 2024).

Although many companies participate in setting their science-based targets and demonstrate concerted efforts to govern Scope 1 and Scope 2 emissions, their Scope 3 emissions remain largely unchecked (Xiong, 2022) According to Velázquez et al. (2013) as cited in Xiong (2022) the difficulty in Scope 3 emissions management primarily lies in a lack of visibility into supplier operations, prohibitive supplier data limitations, and uncertainties around emissions trade-offs. Coincidentally, business operations and external ecosystem partners along the supply chain often produce the majority (potentially up to 90%), of a company's overall emissions by Greenhouse Gas Protocol (2021) as cited in Xiong, 2022).

To assess its Scope 3 emissions, a firm must map its total value chain (that is, cradle-to-gate) and identify all emission sources by Stenzel & Waichman (2023). It is important to understand the components of scope 3, through the analysis of carbon footprints that predominantly address specific calculation methodologies for this scope emission (Freitas & Gervásio, 2024). Basically, the calculation of Scope 3 emissions requires knowledge of the activity, for example, the quantity of a material or other input (transport, but also services), on the one hand, and the associated emission factor or emission intensity, on the other hand, which can be interpreted as the footprint of the input. Both a physical activity quantity, for example, per kilogram of material or per ton kilometre of transport service, and a reference to monetary quantities, for example, per euro, are possible. In practice, the calculation of Scope 3 emissions can cause considerable effort (Schmidt et al., 2022).

To identify Scope 3 emissions in the context of corporate climate targets, annually updated data are necessary; this should apply equally to activity data and emission factors. If emissions are based on empirically collected data, whether along product life cycles or the corporate supply chain, these should be repeated and updated annually.

Since emission factors for energy use are currently very dynamic in many countries, country specific data on energy production and, for example, the linked data for materials from Life Cycle Assessment (LCA) databases or data from suppliers should also be continuously adjusted. The latter is a major effort, as it should also apply to upstream suppliers. The common databases, on the other hand, update their generic data sets, but not in the sense that comparable time series are available for the individual data sets. When Input – Output analyses (IOAs) are used, the emission factors are calculated

continuously for calendar years. The disadvantage is that the data are only available two or more years in retrospect (Schmidt et al., 2022). Regarding this, it is important that data used to calculate Scope 3 emissions should ideally be primary data. Primary data are data on actual emissions that are directly collected by firms (for example, meter readings, purchase records, utility bills, engineering models, direct monitoring, etc.).

With digital production processes, such data are produced as by-products or at very low costs (Stenzel & Waichman, 2023). The analysis that will follow will have to involve identification of indicators, such as the types of activities and operations accounted for, the method used for data collection, sources of estimates, and the guidelines and tools employed. Specifically, in the study of the Port of Chennai, emissions relevant to the investigation were categorized as Scope 1. However, for the study, these emissions were considered as Scope 3. The critical analysis of the case studies aimed to provide a more complete and informed perspective on current practices and limitations in measuring carbon emissions from scope 3 activities (Freitas & Gervásio, 2024).

Scope 3 emission sources were identified and categorized for the analysis based on common operations and facilities among maritime ports (Freitas & Gervásio, 2024). Scope 3 emissions are linked to carbon footprint, and there are various tools for calculating carbon footprints at different levels. Concerning support for calculating the carbon footprint of maritime ports, especially in Scope 3, several tools and methodologies mentioned in the literature have been applied. Among them are BigMile, CleanCargo, Standardized Tool, and Environmental Footprint Assessment Guidelines.

Additionally, in ADMIRAL D2.2 also mentions another organization as similar to the worldwide companies interviewed already estimate direct and indirect CO₂ emissions, e.g., with EcoTransIT (ISO 14083 and GLEC-compliant calculation). These platforms primarily distinguish themselves by the level of detail provided for calculations. This digitalization of seaports has been highlighted as an effective tool for improving port management. One benefit is the ability to monitor operations in real-time, which includes the integration of various data sources, including sensors and vessel management systems, and other port activities. Therefore, an approach based on the integration of digitization and a comprehensive and flexible calculation methodology emerges as a potential strategy to establish a standardized and automated method for assessing the carbon footprint of maritime ports (Freitas & Gervásio, 2024).

Currently, most of the Scope 3 data estimates are calculated based on industry averages, financial information, and approximations by Stenzel & Waichman (2023). The problem of using industry averages is that they may lead to insufficient incentives for firms to adopt cleaner-than-average technologies. By contrast, primary emission data that is shared along the supply chain can provide exact emissions on product- and firm-level. Thus, it allows firms to tackle emissions reduction at the most effective point on the supply chain, and also provides incentives for the adoption of cleaner technologies beyond the industry average by Stenzel & Waichman (2023).

In the seaport industries for example, the approach in determining scope 3 emissions consisted of selecting the case studies analysed based on understanding the components of scope 3, then followed the analysis of carbon footprints that predominantly address specific calculation methodologies for this scope (Freitas & Gervásio, 2024).

On their part, the environmental sustainability of logistics facilities is widely acknowledged as an important issue, however, comprehensive standardised methodology for assessing their environmental impact is lacking (Perotti et al., 2022). In 2011, the World Resource Institute and the World Business Council for Sustainable Development developed and presented a reporting and accounting standard for Scope 3 emissions, referred to as the GHG Protocol Scope 3 Standard (Callahan et al. 2021 as cited in Emborg & Olsen, 2024). The GHG Protocol subdivides Scope 3 emissions into 15 categories. Some of these can be attributed to upstream, such as the purchased goods and services from the supply chain, while some occur downstream, such as emissions caused using sold products. Not all these categories are always appropriate; it depends on the context of the analysis. For example, there is the question of whether employee commuting should be credited to the company (category 7). Categories 10 to 12 may also be accounted by subsequent customers, leading to double counting if several companies in a supply chain progressively establish a carbon footprint for their products or services. Therefore, such categories are also not suitable for further aggregation of emissions to total emissions in supply chain and should be chosen carefully. Categories of Scope 3 emissions according to GHG Protocol (2011 as cited in Schmidt et al., 2022):

1. Purchased goods and services,
2. Capital goods,
3. Fuel- and energy-related activities,
4. Upstream transportation and distribution,
5. Waste generated in operations,
6. Business travel,
7. Employee commuting,
8. Upstream leased assets,
9. Downstream transportation & distribution,
10. Processing of sold products,
11. Use of sold products,
12. End-of-life treatment of sold products,
13. Downstream leased assets,
14. Franchises,
15. Investments (Schmidt et al., 2022).

Categories 11 and 12 present a particular challenge, namely the use and disposal of the products produced by the company to be accounted for. While the other categories mostly include emissions that occurred “ex post”, these emissions are in the near or more distant future, depending on the product. How are they determined and how are they calculated for the fiscal year? They depend on customer usage patterns, which can only be roughly estimated (Schmidt et al., 2022). This applies too to logistics facilities.

With the growing environmental concerns, independent programs like Carbon Disclosure Project (CDP) and Global Reporting Initiative (GRI) started gathering environmental data from companies around the globe using various recognition systems to drive the data disclosures. CDP's data involves disclosures across scope 1, scope 2 and scope 3 emissions (Asif et al., 2022).

Companies often look at carbon footprint protocols for guidance on measuring their GHG emissions, basing their environmental impact quantification on the CO₂eq emission calculation by Yang et al. (2019) as cited in Asif et al. (2022). This method allows for turning every process and activity into a comparable measure that can be used for benchmarking purposes, also considering the system boundaries Nilsson et al., 2017; Helo & Ala-Harja, 2018 as cited in Perotti et al., 2022). To produce accurate, relevant, and reliable reports, organizational alignment is crucial in setting and in adopting standard organizational and operational boundaries through all levels of the reporting company (Greenhouse Gas Protocol, 2015 as cited in Perotti et al., 2022).

Executive buy-in and stakeholder engagement across the supply chain with suppliers, employees, and customers alike are paramount in identifying impactful reduction levers and in driving transformational change (Farsan et al., 2018 as cited in as cited in Perotti et al., 2022).

The second theme is enabling impact sizing and decarbonization through formal processes. Coupled with knowledge of the emissions factors, a thorough understanding of current process information and detailed mapping of inbound logistics activities are essential in quantifying emissions (Greenhouse Gas Protocol, 2013 as cited in Perotti et al., 2022).

Emissions reductions also hinge upon the reporting company's ability to improve its process efficiencies, optimize its upstream transport network, and embed decarbonization and sustainability principles into its procurement practices (Greene & Lewis, 2019 as cited in Perotti et al., 2022).

The third theme is leveraging technology to share information and to enforce accountability. Technologies such as cloud, platforms, electronic data interchange (EDI), and application programming interface (API) facilitate information sharing and transparency across a company's external ecosystem. These technologies also allow for more timely and more accurate data collection for baselining purposes (Greene & Lewis, 2019 as cited in Perotti et al., 2022). The same tools play a key role in fostering cross-company partnerships with logistics suppliers and other third parties while promoting innovative joint solutions and collaborative execution (Farsan et al., 2018).

The fourth theme is collecting and synthesizing high-quality data. Since data forms the foundation of emissions quantification and analysis, the more complete, comprehensive, timely, and accurate the data is, the better the baseline is (Greenhouse Gas Protocol, 2013 as cited in Perotti et al., 2022). High-quality data and sound methods to conduct analysis similarly help to pinpoint emissions hotspots, identify the most impactful improvement levers, determine focus areas, and allocate emissions fairly among upstream logistics suppliers to help prioritize and shape supplier engagement and development (Farsan et al., 2018 as cited in Perotti et al., 2022). The last theme is activating decarbonization through ongoing target tracking, monitoring, and reporting. Similar to baselining Scope 1 and Scope 2 emissions, baselining Scope 3 emissions is a prerequisite to a company's commitment to driving sustainability (Perotti et al., 2022). Setting both absolute emissions targets and emissions intensity targets in the baselining process is necessary to demonstrate a company's ambition and to hold it accountable on concrete, quantifiable terms by How To Guide (2019) as cited in Perotti et al. (2022). In execution, measuring and monitoring impact provides the assurance and credibility while delivering insights to its leadership to drive intended outcomes (Farsan et al., 2018 as cited in Perotti et al., 2022).

Previous approaches do not consider the environmental performance of logistics sites from a holistic perspective, that is, by examining the diverse sources of consumption, nor split the figure by individual operations or functional areas (Perotti et al., 2022). To address an issue for a three-phase methodology can be adopted, combining multiple methods as this helps explore multiple perspectives of a problem (Choi et al., 2016 as cited in Perotti et al., 2022).

Sodhi and Tang (2014) as cited in Perotti et al. (2022) pointed out that addressing a research problem involves four stages, namely motivation, framing, modelling, and validation with the introduction of contextual data. Contextual data refer to conversion factors associated with the model inputs. Multiple sources have been considered, such as DEFRA (2015, 2019) and CLECAT (2012).

DEFRA conversion factors were originally developed for UK-based companies, but their use has been previously acknowledged and extended also to other countries by Mangiaracina et al. (2015) as cited in Perotti et al. (2022). GHG emissions are often calculated on the basis of measured or statistical values related to resource consumption. As a direct measurement of GHG emissions is not practical, it is important to identify appropriate emission/conversion factors (Rüdiger et al., 2016) as cited in Perotti et al. (2022). Looking at fuels, emissions are calculated for each fuel type depending on their quantities and related conversion factors. Both direct and indirect energy consumed, as well as direct and total emissions, are calculated (Perotti et al., 2022). As an output, the model offers a dashboard with Energy Performance Indicators (EPIs), and tables and graphs displaying the results with different views and aggregation levels (e.g., total emissions, direct emissions per source and emission mix composition). Logistics facilities undergo changes in order quantities, logistics items, or demanded services per year (Rüdiger et al., 2016 as cited in Perotti et al., 2022).

To define appropriate EPIs, it is recommended to analyse how the material flow within logistics facilities is usually described and processed by Dhooma & Baker (2012) and Richards (2018) as cited in Perotti et al. (2022). Thus, in addition to the absolute value of GHG emissions, specific EPIs that put the annual amount of GHG emissions in reference to the relevant logistics performance (e.g., number of goods handled and stored at a logistics facility) are proposed. Further, having introduced an allocation scheme for warehouses' functional areas, additional EPIs can reflect the impact of the different types of logistics activities. Overall, EPIs depicting the current scenario can include the following by Perotti et al. (2022):

- ✓ Direct emissions [kg CO₂eq] due to logistics activities controlled by company (Scope 1),
- ✓ Total emissions [kg CO₂eq], as the sum of direct and indirect emissions (Scope 2),
- ✓ Emissions per m² [kg CO₂ eq/m²], to allow comparisons among logistics sites differing in building features such as floorspace or height,
- ✓ Emissions per pallet stored within the logistics site [kg CO₂eq/ pallet],
- ✓ % saved emissions [%] by sourcing electric energy from certified renewable resources and/or self-production from photovoltaic panels,
- ✓ Emissions [kg CO₂eq and as a % of the total emissions] associated to warehousing functional areas, such as receiving/shipping, put-away/storage/picking, cross-docking/sorting, and offices.

Digitization and its integration with an approach present an opportunity for more accurate calculations and a more effective development of emission reduction strategies Freitas & Gervásio (2024). Many researchers have started finding the hindrances and abnormalities in recording and mitigating these emissions (Asif et al., 2020; Hammami et al., 2015; Zakeri et al., 2015 cited in Perotti et al., 2022).

Stakeholder pressure and customer expectations in terms of emission disclosures are also rising, pushing the firms to adopt systems approach towards environmental management (S. Monteiro & Aibar-Guzmán, 2010 cited in Perotti et al., 2022). Therefore, to meet the emission targets set by the protocols and to address the stakeholder demands, researchers and practitioners need to develop novel mechanisms to assess scope 3 emissions while considering cost optimisation, lead time management and carbon trading by Fard & Hajaghaei- Keshteli (2018) as cited in Perotti et al. (2022).

In the past, environmental researchers used to rely on multiple data sources that were inconsistent and therefore, the authenticity of their environmental assessments was greatly challenged. For example, data was obtained from the annual financial reports, process review reports and the company's website but the credibility of such information depends on the internal reporting ethics and standards as there were no global standards for environmental data reporting until the 21st century by Luo & Tang (2014) as cited in Asif et al. (2022).

Moreover, in terms of the standards for accounting of carbon, different stakeholders focus on different aspects, resulting in the need for data comparability and connectivity (Harmes, 2011 as cited in Asif et al., 2022). CDP's aim is to capture the whole process of companies' carbon emissions by breaking down the survey to the emission types (Camanzi et al., 2017; Depoers et al., 2016 as cited in Asif et al., 2022). Among the 9600 companies reporting to the CDP in 2020, 267 companies were ranked as 'A' based on their disclosure quality and assessment of all categories of emissions including scope 3 emissions by Global (2020) as cited in Asif et al. (2022).

Another approach that was mentioned is the Input Output Assessment method that is based on an economic model originally developed by Nobel Laureate in Economics Wassily W. Leontief (Leontief, 1970 as cited in Schmidt et al., 2022). It represents an intertwining of trade relations between different sectors of the economy and can be extended to several countries and is then called multiregional IOA (Miller & Blair, 1985 as cited in Schmidt et al., 2022). IOA can be used to determine for a given industrial sector from which other sectors (and countries) its upstream inputs originate, and for those sectors, in turn, where their upstream inputs come from. In this way, the entire supply chain of an industry can be represented (Schmidt et al., 2022). Another approach is the Life Cycle Assessment (LCA) Methodology. The LCA was conducted according to the International Reference Life Cycle Data System Handbook for LCA (European Commission 2010).

LCA falls under ISO- 14040 and -14044 standardized methodologies (ISO- 14040/2006a; ISO- 14044 2006b) for assessing the environmental impacts of a product, process, or system, and the framework comprises four iterative steps: (1) Goal and Scope, (2) Inventory Analysis, (3) Impact Assessment, and (4) Uncertainty/Interpretation. The LCA intends to identify input sources within energy, materials, waste, and transport across the entire life cycle of a product or system—from the extraction of raw materials (cradle) to processing, manufacturing, use, and disposal (grave) (Hauschild et al. 2018 as cited in Emborg & Olsen, 2024). The Goal and Scope stage aims to define the purpose of the study and a reference flow (i.e., the quantified amount required to deliver a product or service) (Hauschild et al., 2018 as cited in Emborg & Olsen, 2024).

Open-source software OpenLCA version 1.11 was used to model the environmental impacts using secondary life cycle data from the version 3.7 cutoff database. The impact calculation method ReCiPe 2016 Midpoint Hierarchy was used with impacts assessed for category "Climate Change" at a 100- year global-warming potential. Secondary emission factors were only applied to CO₂, Emborg, Olsen (2024).

2.3 New Approach for CO2 Emissions Monitoring and Reporting

The accurate accounting and reporting of GHG emissions in the logistics sector are vital for addressing the environmental impacts of freight transport. Various international frameworks and standards provide methodologies for emissions quantification, enabling organizations to measure, monitor, and mitigate their environmental footprints effectively. The GHG Protocol, GLEC Framework, and ISO 14083 stand out as key references for emissions accounting in the transport and logistics sector, offering comprehensive guidance on categorizing and calculating emissions across different scopes and transport modes. The GHG Protocol is a foundational framework that divides emissions into three categories: Scope 1 (direct emissions from owned or controlled sources), Scope 2 (indirect emissions from purchased energy), and Scope 3 (all other indirect emissions, including those from the supply chain). This classification allows organizations to systematically address emissions from operations and value chains, making it particularly relevant for complex logistics networks. ADMIRAL applies this framework to ensure its marketplace accounts for the full range of emissions, especially Scope 3 emissions, which are frequently overlooked in logistics operations.

The GLEC framework, developed by the Smart Freight Centre, provides a sector-specific methodology tailored to freight and logistics. Its modular approach allows for detailed emissions calculations across all transport modes, including road, rail, maritime, and air, by Smart Freight Centre (2022). By integrating the GLEC Framework, ADMIRAL ensures that its impact assessment framework can evaluate emissions at the modal level and capture the benefits of modal shifts, such as those envisaged from shifting freight from road to rail in the Portugal-Spain pilot. Additionally, the GLEC Framework emphasizes the inclusion of well-to-wheel emissions, aligning with ADMIRAL's objective of providing a holistic sustainability evaluation.

ISO 14083 fort the standardization of emissions accounting in the logistics sector. This ISO standard specifies methods for quantifying and reporting GHG emissions across entire transport chains, offering consistent metrics for evaluating fuel consumption, energy use, and emissions intensity. Its focus on lifecycle emissions aligns with ADMIRAL's strategy of incorporating well-to-wheel analyses for technologies like electric vehicles and intermodal logistics solutions. By adopting ISO 14083, ADMIRAL ensures that its emissions data is both accurate and comparable across diverse pilot sites, enhancing the credibility of its sustainability claims.

Quantification methods can vary the context of logistics operations. The activity-based approach calculates emissions by combining transport activity, measured in ton-kilometres, with emission factors specific to each transport mode. This method is highly applicable to ADMIRAL's intermodal pilots, where emissions must be distributed proportionally across road, rail, and maritime segments. In scenarios involving fuel-based calculations, emissions are determined by multiplying the volume of fuel consumed by its respective emission factor. This is particularly relevant for pilots that involve internal combustion engine vehicles, such as in the Slovenia-Croatia corridor. For electric vehicles, the energy-based approach is used, combining electricity consumption data with grid emission factors. These ensure that ADMIRAL's logistics operations are evaluated with precision and consistency.

Despite the robustness of these frameworks remain in applying them to multimodal and cross-border logistics. Data gaps, particularly for Scope 3 emissions, complicate comprehensive emissions accounting. ADMIRAL addresses this by integrating real-time data collection through sensors and IoT-enabled devices, ensuring high-quality and granular data.

Additionally, the variability of emission factors across regions and modes necessitates careful standardization. ADMIRAL mitigates this challenge by using emission factors from ISO and GLEC-approved sources to maintain consistency across its pilot sites. This methodological rigor ensures that ADMIRAL's logistics marketplace contributes effectively to emissions reduction while advancing the adoption of best practices in the logistics sector.

By adopting these established methodologies, ADMIRAL Assessment framework aligns with international standards for GHG emissions accounting, providing a reliable basis for evaluating the environmental performance of its logistics solutions. This integration not only supports ADMIRAL's sustainability goals but also positions the project as a leader in fostering systemic change in the European logistics sector.

2.4 Literature Findings and Proceedings

This Literature Review section should provide an in-depth analysis of the existing methodologies, frameworks, and practices informing the development of ADMIRAL's Impact Assessment Framework with a dedicated focus on energy efficiency, reduction of CO₂ emissions, logistics digitalization, and scalability in logistics operations. Accordingly, the review is intentionally structured to respond to relevant research questions such as the following: What are some best practices concerning measuring and assessing logistics sustainability? How can energy efficiency and emissions reductions be properly quantified and integrated into an IA framework? What methodologies are suitable for evaluating maturity and transferability regarding logistics innovations and digitalization? The review was conducted using well-known academic databases, such as Web of Science (WoS) and Scopus, covering literature published between 2008 and 2023 to capture only the most relevant issues related to the current state of the art.

A systematic search was performed using keyword-based searches, such as "logistics impact assessment," "GHG emissions in transport," "sustainability KPIs," "TRL in logistics," followed by the screening of their relevance to the objectives of ADMIRAL. Conclusions are drawn on the design of the IA framework, with a focus on its compliance with international standards and its applicability to the sustainability, innovation, and scalability objectives of ADMIRAL. In addition, a wide literature review on CO₂ emissions tracking and reduction, logistics efficiency in multimodal systems, and Scope 3 emissions assessment underpins the development of the Impact Assessment Framework for ADMIRAL. The following sections discuss recent advancements and best practices in sustainability metrics that will be important for refining ADMIRAL's approach to assessing its impact on the European logistics.

2.4.1 CO₂ Emissions and Energy Efficiency in Logistics

Logistics operations are a significant source of CO₂ emissions, particularly from freight transportation. As the sector intensifies efforts to meet sustainability goals, frameworks for emissions tracking, energy efficiency, and carbon reduction have become crucial for logistics providers and policymakers alike. The following approaches are presenting the methods for emissions tracking:

- ✚ Standardized CO₂ Emissions Tracking: The Global Logistics Emissions Council (GLEC) Framework, adopted widely in recent years, provides a standardized methodology for calculating CO₂ emissions across diverse modes, like road, rail, air, and sea. This framework will allow logistics providers to assess their emissions profiles comprehensively and consistently, and it aligns well with ADMIRAL for standardizing emissions measurement across multimodal logistics scenarios.

Studies suggest that using standardized emissions tracking frameworks can enable more accurate benchmarking and target-setting for emissions reductions, particularly when coupled with real-time data from IoT-enabled vehicles and monitoring systems.

- ✚ Energy Efficiency in Freight Transport: Recent literature emphasizes the role of fuel efficiency enhancements and renewable energy integration as key strategies for reducing CO₂ emissions in logistics. Studies have shown that vehicle electrification, optimized freight consolidation, and improved routing algorithms can reduce energy consumption and CO₂ output, particularly in urban freight transport. Additionally, modal shift strategies have been identified as effective in reducing energy intensity and emissions per ton-kilometre is on promoting low-emission multimodal logistics aligns with these findings, supporting a system-wide reduction in logistics energy consumption through strategic mode selection and operational optimization.
- ✚ KPIs for Emissions and Energy Efficiency: Effective KPI design is critical for tracking CO₂ reductions and energy efficiency in logistics. Literature recommends KPIs such as grams of CO₂ per ton-kilometre and fuel efficiency per vehicle mile as standardized measures for assessing environmental impact. Some recent studies also emphasize the need to incorporate lifecycle emissions metrics, which consider the full environmental footprint of logistics assets over time, including emissions from production, maintenance, and disposal. ADMIRAL's Impact Framework will utilize these insights to ensure that emissions-related KPIs are both comprehensive and aligned with industry standards, enabling ADMIRAL to assess its contributions to emissions reductions meaningfully.

2.4.2 Efficiency in Multimodal Logistics & Transport

Efficiency in multimodal logistics is defined by both operational efficiency and environmental efficiency, with multimodal solutions increasingly seen as a viable means of reducing logistics emissions. Multimodal logistics integrates multiple transport modes to optimize resource use and environmental impact, a principle central to ADMIRAL's approach, as presented followingly:

- *Multimodal Solutions for Emissions Reduction:* Recent studies highlight that a shift to multimodal solutions—integrating rail, waterways, and low-emission vehicles—can achieve substantial emissions reductions. For instance, shift-to-rail initiatives have demonstrated that rail transport emits 75% less CO₂ per ton-kilometre compared to road transport, making it a highly efficient alternative for long-haul freight. However, the effectiveness of multimodal solutions depends on factors such as infrastructure availability, real-time data exchange, and coordination among logistics stakeholders. ADMIRAL's focus multimodal logistics marketplace is well-aligned with these insights, as the platform can support seamless transitions between modes and incentivize sustainable logistics practices.
- *Role of TRLs in Operational Efficiency:* Technological maturity plays a role in multimodal logistics efficiency, especially when integrating advanced logistics technologies like predictive analytics, IoT-enabled tracking, and digital twin solutions. Literature on TRLs emphasizes the importance of gauging TRLs both at project initiation and completion to measure technological progress and integration potential. By assessing the pre- and post-pr of logistics technologies, ADMIRAL's framework will monitor advancements in technology adoption, providing a measurable indicator of logistics modernization that aligns with efficiency and emissions goals.
- *Efficiency KPIs for Multimodal Logistics:* Studies suggest that KPIs like average load factor, transit time reliability, and energy use per ton-kilometre are effective measures of logistics efficiency in multimodal networks. These KPIs capture core operational metrics, allowing logistics providers to monitor and optimize route efficiency, reduce empty miles, and enhance overall productivity. ADMIRAL's efficiency-focused KPIs will be o monitor these aspects, ensuring the project's impact on resource utilization and emissions reduction is accurately captured and evaluated.

2.4.3 Scope 3 Emissions in Logistics and Supply Chains

Scope 3 emissions, which encompass all indirect emissions resulting from third-party logistics and transportation, are a core focus of ADMIRAL. Effective Scope 3 assessment requires well-collaboration across supply chain partners, as these emissions are often distributed and challenging to quantify, as methods are presented in the following part:

- ❖ **Scope 3 Emissions Reporting Standards and Methodologies:** The GHG Protocol's Scope 3 Standard is widely referenced for categorizing and calculating indirect emissions, particularly in Category 9, which addresses downstream transportation and distribution. According to recent research, Scope 3 reporting methodologies are increasingly incorporating data-sharing protocols and digital platforms that streamline emissions tracking across logistics providers. These protocols facilitate more accurate and comparable Scope 3 emissions data, aligning well with ADMIRAL's objective to enhance transparency and stakeholder engagement within the logistics ecosystem.
- ❖ **Challenges in Scope 3 Data Collection:** Data collection for Scope 3 emissions is a persistent challenge due to fragmented data sources, variable reporting standards, and limited visibility into third-party operations. Literature highlights the role of digital transparency tools (e.g., blockchain, centralized data platforms) in improving data integrity and traceability for Scope 3 reporting, enabling companies to account for emissions from outsourced transport more accurately. ADMIRAL's marketplace, by fostering data exchange and collaboration, is positioned to address many of these challenges, encouraging standardized Scope 3 reporting across participating stakeholders.
- ❖ **Scope 3 KPIs and Collaborative Reduction Initiatives:** Recent studies recommend KPIs such as CO₂ emissions per outsourced shipment and emissions per mile for third-party providers as effective indicators of Scope 3 environmental impact. Literature also advocates for collaborative approaches to Scope 3 emissions reduction, such as setting shared emissions reduction targets with third-party logistics providers and incorporating emissions metrics into procurement processes. ADMIRAL's Impact Assessment Framework will incorporate such collaborative Scope 3 metrics, ensuring that ADMIRAL's platform drives meaningful reductions in indirect emissions through incentivized partnerships and transparent reporting.

2.4.4 Final Remarks & Metrics

The literature on CO₂ emissions, logistics efficiency, and Scope 3 emissions offers foundational insights that shape ADMIRAL's Impact Assessment Framework:

- ✓ **Logistics Efficiency:** Efficiency improvements through multimodal transport and TRL assessments are critical for reducing emissions in logistics. Efficiency KPIs like load factor and energy use per ton-kilometre will help ADMIRAL measure its contributions to operational optimization.
- ✓ **CO₂ Emissions:** Standardized tracking and reporting frameworks, such as the GLEC Framework and GHG Protocol, provide established methodologies that ADMIRAL can adopt to ensure emissions metrics are consistent, reliable, and comparable across pilot sites.
- ✓ **Scope 3 Emissions:** Collaborative data-sharing protocols and Scope 3 emissions KPIs will allow ADMIRAL to address indirect emissions comprehensively, promoting stakeholder engagement and transparency.

These insights provide a robust foundation for ADMIRAL's development of an impact assessment framework, ensuring that it effectively captures CO₂ emissions, multimodal efficiency, and Scope 3 emissions. By aligning with industry standards and incorporating best practices, ADMIRAL is positioned to make a meaningful impact on logistics sustainability across Europe.

2.4.4.1 Logistics Sustainability Index (LSI)

Where sustainability in logistics is becoming one of the major tools that help in addressing traffic congestion and emissions, notably within city centres, interchangeably green logistics has gained substantial interest recently. According to Cheng et al. (2024), various discussions among researchers are consistently raising the question of finding a valid and appropriate measure of green performance from logistics and supply chains-which shows the complicated job of aligning their objectives with environmental ones. Optimizing freight transport and logistics operations in urban areas significantly contributes to environmental objectives and enhances efficiency in the city as a whole. Logistics solutions for sustainability are often assessed by multi-criteria approaches, for example, Macharis et al. (2014), which include various dimensions like environmental, social, and economic factors together with economic evaluations such as cost-benefit analysis, for example, Holmgren (2019). These methodologies together present an integrated framework for assessing how effective logistics strategies are in pursuit of environmental sustainability with economic operational cost-efficiency and thus provide a balanced consideration of ecological and economic impacts.

Nathanail et al. (2016) developed one of the most widely applied frameworks for assessing the sustainability of city logistics, which is based on a multi-criteria approach and was further refined in 2018. Within this framework, seven key impact areas are identified as important for a holistic view: Economy and Energy, Environment, Society, Policy and Measure Maturity, Social Acceptance, and User Uptake. These areas are further supported by 26 related criteria and 140 specific indicators, providing an in-depth view of logistics operations. This multi-stakeholder engagement of the framework allows different viewpoints to be put forward for consideration, making the solutions found more relevant and acceptable in various urban settings. The approach is a multi-stakeholder, multicriteria decision-making (MCDM) that can help balance the many different priorities involved, such as environmental sustainability and operational practicality, and identify effective and sustainable logistics solutions for a variety of city contexts.

The LSI therefore quantifies the sustainability of different logistics solutions. The information from the impact areas is consolidated into an integrated performance score under the LSI, allowing customization for various evaluations, such as the assessment of various logistics strategies. The LSI has been extensively tested in key studies, including Sulpiter (2017), Comi et al. (2020), Nathanail et al. (2021), and the SHOW project (Capkin, 2023). By combining qualitative and quantitative indicators, the LSI offers a comprehensive tool for evaluating the environmental, social, and economic dimensions of logistics solutions. This enables a far-reaching judgment on the alignment of a system with sustainability goals, hence allowing a clear understanding of how well it would serve long-term environmental objectives.

For instance, within the **SHOW project**, LSI has been applied to evaluate logistics solutions, providing real-time insights that help guide decision-making and track progress toward sustainability goals. The LSI's capacity to integrate both qualitative and quantitative data allows for a versatile yet rigorous assessment framework, adaptable to a range of logistics contexts and sustainability objectives.

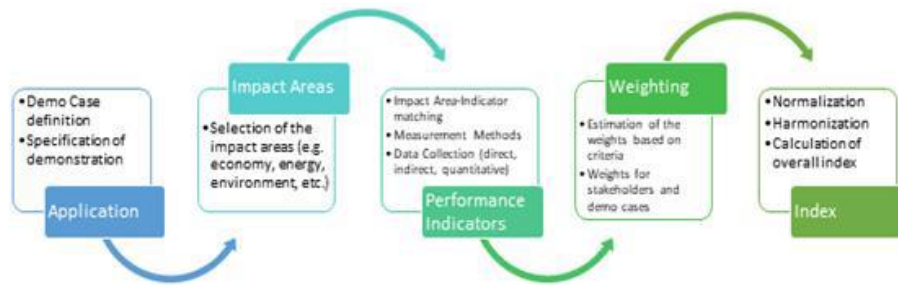


Figure 1: LSI Calculation Process

In conclusion, the LSI is a critical tool for advancing sustainable logistics in urban environments. Through the use of the LSI and multicriteria frameworks, cities and logistics providers can make well-informed decisions that reduce environmental impacts, improve operational efficiency, and enhance societal acceptance of sustainable urban logistics. This approach fosters the development of innovative, low-emission, and efficient transportation networks, aligning urban logistics practices with broader sustainability targets.

2.4.4.2 Logistics Maturity Index (LMI)

According to Capkin (2023), LMI is an overall tool for determining the level of digitalization and integration of advanced technologies within logistics operations, quite close to the Industry 4.0 paradigm. Based on the Fraunhofer IFF's Industry 4.0 stage model, the LMI indicates five different stages of logistics maturity: (1) Standards, (2) Big Data, (3) Smart Data, (4) Dark Factory, and (5) Industrial Ecosystem. The evaluation process begins by collecting foundational business information, followed by targeted questions that capture each logistics element's progress toward full digital transformation.

As Industry 4.0 technologies gain traction in logistics, they promise enhanced operational performance, sustainability, and supply chain optimization. However, many organizations face substantial challenges in implementing these technologies due to the complexities and disruptions they introduce. The Logistics Maturity Model offers logistics providers a structured path for evaluating Logistics 4.0 applications, allowing them to assess their current status, pinpoint improvement areas, and drive efficiency across the supply chain (Facchini et al., 2019). This model is essential for organizations transitioning from traditional logistics practices to more advanced, data-driven systems, helping them adapt to new technologies in a competitive, rapidly evolving market.

Besides, the Logistics Maturity Model has been extended toward the support of transition to Logistics 5.0, focusing not only on advanced, data-driven systems but also on human-centric and sustainable logistics solutions. This model, building on the roots of Logistics 4.0, provides a structured route for logistics providers to consider and implement emerging technologies like AI-driven decision-making, autonomous vehicles, and collaborative robotics, with the addition of social and environmental sustainability in the supply chain. This model is based on Facchini et al. (2019) and Meidute-Kavaliauskiene et al. (2021). This is crucial for organizations that want to go beyond the conventional paradigm of logistics, since Logistics 5.0 will have to balance technological innovation with human well-being and ecological responsibility in a competitive, rapidly changing market. The model helps an organization understand the present maturity level, determines key areas for improvement, and drives both operational efficiency and sustainability across the supply chain.

Maturity, as defined in the context of this model, refers to an organization's readiness to fully embrace and integrate new technologies. The maturity model offers a clear pathway for assessing this process, starting with less mature operations that lack advanced technological infrastructure, moving through stages of adoption and optimization, and culminating in fully integrated, autonomous logistics solutions. This continuous improvement approach allows logistics providers to evaluate their systems both qualitatively and quantitatively, providing flexibility to adapt to evolving industry needs and operational demands. The five levels of logistics maturity are as follows:

- *Ignoring:* At this stage, logistics operations are entirely reliant on traditional, non-digital methods, with no adoption of Industry 4.0 technologies.
- *Defining:* Organizations begin to outline plans for technological integration, setting the foundation for future advancements.
- *Adopting:* This stage marks the initial adoption of Industry 4.0 technologies, although full integration into all logistics processes has not yet occurred.
- *Managing:* At this level, logistics systems are effectively managed using integrated digital technologies, optimizing efficiency and streamlining operations.
- *Integrating:* The final stage represents full integration of Logistics 4.0 technologies, where systems operate autonomously with real-time decision-making based on data-driven insights.

It gives an account of the maturity level of logistics systems in critical areas, including management, material flow, information flow, and environmental and socio-economic impacts. The information comes through questionnaires, including topics such as technology adoption levels, emissions impacts, and their respective contributions toward sustainability goals. This therefore provides a response about current capabilities, identifying major gaps that are important to be targeted.

After data collection, each assessment area is weighted in terms of its importance to logistics maturity. Then, for each path, a numerical maturity score is calculated that clearly shows the metric of the stage of development of the system. The process of scoring will include not only qualitative but also quantitative analysis of the importance and criticality of each factor. The overall maturity score is synthesized from the scores, reflecting the current development stage of the logistics system with guiding further focus areas.

The TRL framework is important in assessing the maturity of specific technologies within logistics systems. It provides a structured methodology that allows for the determination of how far a particular technology has advanced, from conceptualization to full deployment. TRLs range from TRL 1, which represents basic research or a theoretical concept, to TRL 9, indicating that the technology is fully integrated into operational environments and successfully deployed at scale. From an LMI perspective, the determination of TRLs allows an organization to determine the technological readiness of their logistics systems; these, in turn, facilitate identification of gaps and development opportunities. The methodology for evaluating TRLs in logistics consists of a step-by-step procedure: checking key milestones of the technology development. TRL 1 involves basic principles observed and reported, mostly including theoretical studies or early-stage prototyping. As the technology advances, its readiness will be determined through empirical testing and development in increasingly complex and relevant environments, such as pilots in real-world logistics trials. A detailed evaluation of TRL at each stage involves assessing factors like:

- ✓ **Concept Validation:** At early stages (TRL 1-3), technologies are primarily in the proof-of-concept phase. Evaluators review theoretical models, laboratory experiments, or small-scale prototypes to determine the feasibility of the proposed technology within logistics operations. Criteria include data from literature reviews, academic studies, and early-stage pilot tests.
- ✓ **Prototype Testing:** In stages TRL 4-5, technologies are moved into operational environments for testing. This stage assesses the prototype's performance under real-world conditions, such as in warehouses, transport systems, or urban logistics networks. Evaluators assess performance indicators like efficiency, accuracy, and scalability, and test whether the technology meets the necessary technical and operational requirements for wider adoption.
- ✓ **Pre-Commercial Deployment:** At **TRL 6-7**, technologies undergo further validation, often within larger-scale pilot projects or commercial trials. Evaluation focuses on the technology's integration within existing logistics systems, its ability to operate in real-time environments, and its potential to address scalability issues. Key performance indicators (KPIs) such as cost-effectiveness, energy consumption, and system compatibility are scrutinized to ensure that the technology can be scaled up to meet industry demands.
- ✓ **Full-Scale Implementation:** At **TRL 8-9**, the technology is fully integrated into logistics operations, having proven its effectiveness in real-world environments. The evaluation at this stage assesses whether the technology can be deployed across a wide range of logistics operations and across multiple geographies. Key assessments include operational reliability, risk management, return on investment (ROI), and the technology's ability to meet long-term sustainability goals.

Evaluation of TRLs typically employs a methodology that combines expert evaluation with quantitative performance metrics. The process begins with qualitative assessments from an expert panel familiar with the technology, using specific TRL criteria for each stage. These experts will review prototypes, test data, and operational results to evaluate the maturity of the technology. Besides, each TRL can be attributed to a numerical value based on certain indicators that quantify the readiness of the technology in question, such as performance reliability, scalability, and economic feasibility.

Once the TRL ratings are performed, the findings are integrated with the overall LMI to allow the logistics organization to measure its overall system maturity but also the readiness of technologies that make up their operations. The technologies at a low TRL may need additional development and validation, whereas technologies with higher TRLs, now ready for commercial deployment, can quickly be adopted in support of improved efficiency and sustainability.

The LMI provides diagnosis and a path toward ongoing development. By being able to measure maturity levels and TRLs, it would give a logistics company points to embark on moving to a different maturity stage with actions necessary to achieve sustainability, efficiency, and resiliency in logistics systems. The LMI and TRL frameworks are two frameworks that will continue to assist the industry in attaining its targets on sustainability, improving its operations, and adopting next-generation technologies as it embarks toward full integration of Logistics 4.0.

2.4.4.3 Logistics Transferability Index (LTI)

The LTI is a multi-step evaluation process, which qualitatively estimates the potential for transferring logistics automation applications to different urban environments, according to Capkin (2023). It provides an indication of under what conditions such applications could be transferred and adapted to new locations. Some main steps on this LTI involve the receptor city's complete characterization of the existing infrastructure, which would include the logistics of needs and the socio-economic context.

This is further augmented by a benchmarking analysis in which similar urban contexts in the world are identified to study the challenges and successful path traversed by previous implementations. Automation is defined in specific applications in respect to the receptor city. This step involves a general assessment based on certain criteria set by the city, including infrastructure readiness, local regulations, and community acceptance.

The Logistics Transferability Assessment also focuses on policy-knowledge exchange between similar cities across Europe. As Marsden and Stead (2011) note, "examples from elsewhere are often seen by politicians and civil servants as a quick, cheap and/or simple means to solve their policy problem without reinventing the wheel where solutions to problems already exist." This is the basis of logistics transferability: to exchange policy-knowledge, practices, and technological solutions to enhance logistics operations in a new context. It embraces all the aspects related to logistics, including transport management, digitalization, and procedures, and helps in upgrading logistics in other cities or regions.

The core concept of logistics transferability is the exchange of solutions-based policy knowledge, focusing on the efficient, sustainable, and problem-solving potential of new technology implementations. The idea is to transfer successful innovations from one site to another, based on the similarities and particular challenges of the cities involved, while considering potential barriers to implementation. For example, a city wishing to introduce new logistics technologies or processes would investigate the applied technologies and approaches relevant to successful implementations elsewhere, evaluating how they could be adapted to its own context.

LTI approach necessitates several assessment processes, including implementation, evaluation, and monitoring of the transfer process. These processes aim at ensuring that policy-knowledge can be effectively transferred from the origin city to the destination city (or municipality, region, etc.). The methodology, therefore, focuses on identifying transfer-practices, recognizing barriers to successful policy transfer, and analysing the characteristics of both the origin and destination cities. This ensures that the solution designs proposed are appropriate and feasible for both sites.

In line with the literature, Dolowitz and Marsh (1996) highlight seven critical questions that must be answered during the policy transfer process:

- ✚ What is transferred?
- ✚ Why do actors engage in policy transfer?
- ✚ Who are the key actors involved in the policy transfer process?
- ✚ From where are lessons drawn?
- ✚ What are the different degrees of transfer?
- ✚ What restricts or facilitates the policy transfer process?
- ✚ How is the process of policy transfer related to policy success or failure?

To guide the logistics transferability process, the framework developed by Macario and Marques (2008) for sustainable mobility measures is used. This framework was adapted in the TURBLOG EU FP7 project to create a structured process for logistics transferability. The steps of this framework include:

- ✓ **Diagnostic of the Problems:** Identifying the issues to be addressed in the receptor city.
- ✓ **Characterization of the City:** Understanding the logistics landscape and needs of the receptor city.
- ✓ **Analysis of the City Context and Problem Implications:** Assessing how local challenges influence the logistics system.

- ✓ **Looking for Similar Contexts:** Identifying cities or regions that have faced similar challenges.
- ✓ **Selecting Source Urban Contexts:** Choosing the most relevant examples to draw lessons from.
- ✓ **Identifying Transferability:** Determining which solutions from source cities could be applicable.
- ✓ **Packaging and Dimensioning Measures for Transfer:** Structuring solutions to fit the receptor city's context.
- ✓ **Ex-ante Assessment of Measures:** Conducting a pre-implementation evaluation of the proposed measures.
- ✓ **Identifying the Need for Adjustment:** Understanding necessary adjustments based on the city's unique circumstances.
- ✓ **Implementing Measures and Steering Results:** Putting the measures into practice and tracking their outcomes.

Kijewska and Iwan (2019) also recommend an implementation process that could be analysed with the help of three approaches: creation, transfer, and adaptation. Those approaches explain how new solutions may be created from scratch, copied directly from successful examples, or adapted in such a way that it better suits the specific needs of the receptor city. In its turn, the policy transfer process requires profound assessment through different indicators and parameters for the taken solution to be effective and adaptable to local conditions.

A very important step in the process of transferability is engaging local stakeholders in the receptor city to discuss the potential for transferability, identify success factors, and understand barriers. If direct workshops are not possible, interviews with policymakers and logistics experts should be conducted. This makes sure that the transfer process is fully aligned with the needs of the city and that any implementation challenges are properly addressed. This, in turn, ensures that the Logistics Transferability Index provides a robust framework for assessing the feasibility of transferring automated logistics solutions from one urban context to another by following these steps, thereby ensuring that cities can effectively leverage successful innovations to improve their logistics systems.

3 ADMIRAL Demonstration Sites Overview

ADMIRAL's pilot sites are spread across Europe, since they are located in Portugal-Spain, Slovenia-Croatia, Lithuania, and Finland, each chosen for its specific logistical landscape, transport infrastructure, and regulatory environment. The pilots will demonstrate and standardize the multimodal, low-emission logistics marketplace of ADMIRAL in various operational settings. To these sites, the IA framework will be applied with a view to assessing the contribution of ADMIRAL to sustainability, logistics efficiency, and stakeholder engagement, including data-based recommendations from each unique location.

Each pilot site will apply the LSI, LMI, and LTI in order to obtain a comprehensive understanding of ADMIRAL's impacts. These indexes will assist in monitoring the reduction of emissions, integration of technology, and scalability across regions to create a robust comparative analysis that supports the broader EU-wide goals of ADMIRAL.

The selection of the indexes for the demonstration sites of ADMIRAL-LSI, LMI, and LTI is based on a structured approach, balancing theoretical approaches from the literature with practical relevance to project objectives. While the literature review did lay the foundational understanding for many of the

key impact areas, the final selections involved certain criteria: their responsiveness to ADMIRAL's sustainability goals, efficiency, technologies, and scalability; their multimodal logistics operations applicability at diverse regions; and their previously applied utility in prior EU-funded projects such as NOVELOG, SULPITER, and SHOW. This pragmatic selection process ensured that the indexes were not only theoretically robust but also practical to measure and compare performance across ADMIRAL's pilot sites. In parallel, prioritization workshops held with consortium members and stakeholders further validated these indexes, anchoring them in real-life implementation and evaluation needs of the project.

3.1 Pilot in Portugal – Spain

The Portugal-Spain pilot corridor is a logistics route that facilitates high volumes of freight movement between the two countries, currently dominated by road transport. This Sines-Madrid corridor's importance in cross-border trade and its road traffic density creates a unique opportunity for ADMIRAL to demonstrate the advantages of multimodal transport, by the integration of rail to reduce emissions.

This pilot aims to shift a portion of freight transport from road to rail, decreasing the overall carbon footprint of logistics. By leveraging ADMIRAL's marketplace, logistics operators can access seamless multimodal solutions that optimize route efficiency, reduce road congestion, and minimize emissions.

Respectively, the following section is addressing the Impact Assessment and Data Collection Strategy definition using the evaluation indexes and approach:

- LSI: Baseline emissions data will be presented through calculating the current freight transport operations before implementing ADMIRAL's marketplace. Post-implementation, data on CO₂ emissions from modal shifts to rail will be monitored to quantify the environmental impact. Metrics will include CO₂ emissions per ton-kilometre for both road and rail transport.
- LMI: The pilot will assess the technological integration of ADMIRAL's platform within regional logistics operations, focusing on the use of real-time data for route optimization and scheduling. Surveys and platform usage analytics will capture the extent of digital adoption by operators and their readiness for coordinated data-sharing practices.
- LTI: To evaluate scalability, this pilot will assess cross-border logistics compatibility and policy alignment between Portugal and Spain. Data on regulatory requirements, infrastructure compatibility, and logistics operator engagement will be collected to determine how ADMIRAL's model can be replicated on similar cross-border corridors.
- Expected Data Sources: Data will be obtained from logistics operators, ADMIRAL's platform analytics, and emissions monitoring systems along the Portugal-Spain corridor. Government transportation agencies will also provide infrastructure data and policy alignment information.

This pilot will serve as a model to implement ADMIRAL's multimodal logistics solutions in cross-border contexts, showing the platform's capability to lower impacts while improving operational efficiency.

3.2 Pilot in Slovenia – Croatia

The Slovenia-Croatia pilot has a mixed urban-rural logistics network with diverse infrastructure requirements. This region faces unique logistical challenges, particularly in connecting rural logistics

hubs with urban demand centres, making it an ideal location to test ADMIRAL’s ability to integrate multimodal solutions that balance environmental sustainability and connectivity.

To optimize logistics efficiency and sustainability by implementing ADMIRAL’s multimodal marketplace across a mixed urban-rural network. This pilot will focus on optimizing transport routes and introducing low-emission vehicles to reduce environmental impacts and improve connectivity.

Respectively, the following section is addressing the Impact Assessment and Data Collection Strategy definition using the evaluation indexes and approach:

- LSI: This index will capture emissions reductions from low-emission vehicle adoption and optimized route planning. Data will be gathered from both urban and rural transport operations, comparing emissions before and after implementing ADMIRAL’s marketplace solutions.
- LMI: Digital adoption rates will be monitored, with a focus on the integration of ADMIRAL’s real-time tracking and data-sharing capabilities. Surveys and system usage analytics will assess the progress of logistics providers in managing multimodal solutions across the diverse infrastructure of urban and rural areas.
- LTI: The scalability of ADMIRAL’s marketplace in similar regional settings will be evaluated, focusing on connectivity. Metrics will include stakeholder engagement levels, infrastructure adaptability, and local acceptance rates for low-emission and multimodal solutions.
- Expected Data Sources: Data will be collected from regional logistics providers, ADMIRAL platform analytics, and local government agencies responsible for rural and urban infrastructure. Additional emissions data will be sourced from low-emission vehicle operators.

Insights from this pilot will demonstrate ADMIRAL’s adaptability in diverse logistics networks, supporting its broader application to urban-rural connectivity challenges across Europe.

3.3 Pilot in Lithuania

The Lithuania pilot focuses on a key logistics corridor that connects the Baltic region with central Europe. Known for its strategic importance in long-haul logistics, this corridor presents an ideal scenario for ADMIRAL to showcase the environmental benefits of intermodal transport, particularly shifting freight from road to rail for long-distance transport.

To show the feasibility of sustainable intermodal logistics in the Baltic region, promoting low-emission alternatives for long-haul freight and validating ADMIRAL’s Marketplace in optimizing such logistics operations. Respectively, the following section is addressing the Impact Assessment and Data Collection Strategy definition using the evaluation indexes and approach:

- LSI: Emissions data will be gathered from both rail and road operations, with specific metrics on CO₂ emissions per ton-kilometre. LSI will assess the impact of transitioning freight volumes to rail, supported by ADMIRAL’s marketplace capabilities for route optimization and emissions tracking.
- LMI: Technology adoption will be evaluated, focusing on the readiness of Lithuanian logistics operators to implement ADMIRAL’s digital platform. Surveys, interviews, and usage data will monitor the effectiveness of data-sharing and intermodal coordination.

- LTI: The transferability of ADMIRAL’s intermodal model within the Baltic region will be analysed, with assessing interoperability with existing logistics networks. Data will include operator engagement, policy compatibility, and logistics performance across transport modes.
- Expected Data Sources: Data will be sourced from regional logistics databases, ADMIRAL’s analytics platform, rail and road transport operators, and governmental transportation agencies overseeing Baltic corridor infrastructure.

This pilot will validate ADMIRAL’s intermodal solutions and highlight the impact benefits of reducing reliance on road freight in favour of rail, supporting broader adoption in similar logistics corridors.

3.4 Pilot in Finland

The Finland pilot operates within an advanced logistics environment that prioritizes digital innovation and environmental sustainability. Finland’s commitment to green logistics and its strong digital infrastructure makes it an ideal testing ground for ADMIRAL’s solutions in a high-tech ecosystem.

To showcase ADMIRAL’s ability to support digitalized, sustainable logistics operations by integrating data-based solutions, electric vehicles (EVs), and potentially automated systems within Finland’s logistics network. Respectively, the following section is addressing the Impact Assessment and Data Collection Strategy definition using the evaluation indexes and approach:

- LSI: Emissions reductions will be measured through data on optimized logistics routes, EV adoption, and real-time data exchanges. Metrics will include emissions per kilometre and reductions in fuel consumption achieved through ADMIRAL’s digital routing.
- LMI: Finland’s digital readiness will be assessed by tracking platform adoption, data-sharing practices, and the integration of autonomous logistics technologies. Data will be gathered through system analytics, user feedback, and operator surveys.
- LTI: The scalability of ADMIRAL’s high-tech solutions in other digitally mature regions will be evaluated, focusing on the adaptability of EV infrastructure, digital compatibility, and regulatory frameworks. Metrics will include EV usage rates, stakeholder engagement, and the degree of integration with Finland’s existing logistics technologies.
- Expected Data Sources: Data sources include ADMIRAL’s analytics platform, national logistics operators, EV infrastructure databases, and digital infrastructure operators.

This pilot will provide a model for implementing ADMIRAL’s platform in technologically advanced settings, showcasing how digitalization can support sustainable, low-emission logistics operations.

4 Impact Assessment Framework Overview

The ADMIRAL Impact Assessment Framework is purposed with a structured, multidimensional strategy for evaluating performance in accomplishing the stated sustainability and operational goals in the numerous pilot sites. As such, this framework provides a critical basis from which to assess ADMIRAL's contributions to emissions reductions, enhanced operational efficiency, and stake-holder engagement through using a suit of Key Performance Indicators (KPIs), and targeted impact indices. The framework, therefore, should establish a clear and flexible methodology to ensure coherence across the real-life pilots carried out in ADMIRAL, support cross-site analyses, and the overall assessment of the project's impacts as defined in WP6.

The ADMIRAL IA framework will be further developed and extended to ensure its applicability and effectiveness in assessing sustainability, maturity, and transferability in various logistics contexts. A handbook, being one of the key products of WP6, as a milestone, will provide in-depth guidance on how the framework functions, its application in real-life demonstrations, and the possibility of measuring critical dimensions of sustainability, including efficiency, emissions, and stakeholder acceptance. It provides practical insight into the methodologies and tools used in this framework and will show all stakeholders at different levels how to make better use of its functionalities. Apart from providing relevant descriptions regarding ADMIRAL solutions, it further investigates the assessment of the maturity of technologies implemented by them, as well as their transference towards different regions with different logistic contexts.

The IA framework in ADMIRAL D6.1 is developed to support ADMIRAL's overarching mission of driving sustainable transformation in European logistics. Specific objectives of the framework include:

- ❖ **Evaluating Environmental Impact:** Measure ADMIRAL's contributions to emissions reduction, resource optimization, and energy efficiency. This includes tracking both direct and indirect emissions to provide a complete picture of ADMIRAL's environmental impact.
- ❖ **Assessing Operational Efficiency and Maturity:** Determine the effectiveness of ADMIRAL's solutions in promoting multimodal, low-emission logistics practices, as well as the maturity of integrated technologies and services across pilot sites.
- ❖ **Analysing Stakeholder Acceptance and User Experience:** Capture user satisfaction, stakeholder engagement, and the uptake of ADMIRAL's solutions to ensure the solutions are user-centric and meet the needs of diverse stakeholders in the logistics ecosystem.
- ❖ **Ensuring Transferability and Scalability:** Measure ADMIRAL's potential for widespread adoption by assessing the adaptability of its solutions to different EU regions and logistics environments. This analysis supports ADMIRAL's goal of creating an EU-wide impact in sustainable logistics.

This chapter provides an in-depth description of the framework's objectives, components, and core indices, which collectively offer a holistic view of ADMIRAL's impact on the logistics sector.

4.1 Framework Components

The ADMIRAL IA Framework is built on a structured set of components that guide data collection, indicator evaluation, and overall impact measurement:

- KPI provide specific, quantifiable metrics for tracking ADMIRAL's progress in meeting its project objectives. These KPIs are organized into mandatory and suggested categories, ensuring that each pilot site can contribute essential data while allowing for flexibility in additional insights.
- To ensure the reliability and comparability of data across pilot sites, the framework outlines standardized data collection methods, which include direct measurements, indirect estimates, and stakeholder feedback to allow for consistent monitoring across all pilot locations.
- The framework adopts a multi-criteria decision-making approach for evaluating ADMIRAL's performance, incorporating stakeholder inputs, pilot-specific conditions, and project-specific metrics. This methodology supports comprehensive impact analysis by integrating qualitative and quantitative data to assess ADMIRAL's contributions across several impact areas.

The IA framework is anchored by three core indices, each focused on a key dimension of ADMIRAL's objectives. These indices provide a structured way to evaluate the environmental, operational, and transferability impacts of ADMIRAL's solutions, using targeted indicators for each dimension.

4.1.1 Logistics Sustainability Index (LSI)

LSI is designed to measure the environmental and social sustainability of ADMIRAL’s logistics solutions. This index focuses on quantifying the project’s impact on emissions reduction, resource efficiency, and multimodal transport utilization. The LSI is aligned with ADMIRAL’s goal of achieving a reduction in greenhouse gas emissions within logistics operations, and it evaluates:

- ❖ **Emissions Reduction:** The LSI includes KPIs that track both direct and indirect emissions from logistics operations, with specific attention to Scope 3 emissions from third-party logistics providers. These KPIs are crucial to ADMIRAL’s target of a 20% emissions reduction.
- ❖ **Energy Consumption:** The LSI tracks energy efficiency across ADMIRAL’s logistics activities, measuring the energy required per unit of freight transported. This metric is central to ADMIRAL’s goal of optimizing energy use within logistics.
- ❖ **Multimodal Transport Adoption:** By measuring the rate of multimodal transport adoption, the LSI provides insights into ADMIRAL’s success in promoting sustainable logistics solutions that reduce reliance on single-mode, high-emission transport.

To calculate the LSI, the framework uses a multi-criteria decision analysis (MCDA) approach, assigning weights to each sustainability indicator based on stakeholder input. These indicators are then normalized and aggregated to produce an overall LSI score, which can be used to compare the sustainability performance of ADMIRAL’s solutions across pilot sites and project phases.

LSI is based on a Multi-Criteria Decision Analysis technique, and is calculated according to a five steps process (adapted from Sulpiter, 2017):

- *Application:* Specification of demo case with main performance characteristics;
- *Impact areas:* Selection of the impact areas (e.g. economy and energy, environment, transport and mobility, society, policy and measure maturity, social acceptance and user uptake) depend on the objectives of the stakeholders;
- *Performance indicators:* Selection of the indicators for each impact area, measurement methods and data collection sources (direct, indirect, estimation, quantitative, qualitative);
- *Weighting:* Estimation of weights for combining the criteria through e.g. Analytical Hierarchy Process (AHP) method. Such a task foresees the involvement of stakeholders of the demo case;
- *Index:* Normalization and harmonization of indicators measurements and overall index calculation.

The index is calculated before the implementation (ex-ante) and after the implementation (ex-post) in order to compare the benefits obtained globally. Therefore, the LSI may thus evaluate one or more impact areas jointly and becomes useful when a comparison between the current status and a potential scenario is required, or when two potential scenarios have to be compared.

Given an impact area (e.g. energy consumption, pollutant emission), the related LSI_i is computed as follows (Novelog, 2016, Comi et al., 2020):

$$LSI_i = \sum_m I_m w_m$$

where I_m is the normalized value of indicators m with a minus or plus sign, according to its contribution to the sustainability (i.e. positive if the benefit, negative if costs); w_m is the weight given to the impact area indicator/metric m which can be estimated for example using AHP or a Delphi approach.

$$LSI = \sum_i LSI_i w_i$$

Where are the weights of each identified impact areas, computed in step 4.

4.1.2 Logistics Maturity Index (LMI)

LMI evaluates the preparedness and adoption level of the solutions developed within ADMIRAL, focusing on the integration of low-emission and multimodal logistics technologies. This index will measure the progress made by ADMIRAL in the promotion of Logistics 4.0 capabilities—such as automation, data analytics, and digital connectivity—within its marketplace. Along with general technology readiness, the LMI will specifically assess the TRLs of key ADMIRAL solutions before and after project implementation. Respectively, the key indicators for the LMI are:

- ✓ **Technology Readiness:** The LMI evaluates the maturity of ADMIRAL's technologies, including the marketplace's capabilities to track and reduce emissions in real-time, support multimodal logistics solutions, and integrate with existing logistics infrastructure. To do that, an assessment of the initial TRLs at the project's outset, providing a baseline for evaluating the technological development that ADMIRAL's solutions undergo through the project lifecycle.
- ✓ **Adoption Rate of Low-Emission Solutions:** This indicator refers to the adoption of ADMIRAL's low-emission solutions within the logistics network. This is an indicator of how widely the logistics providers have taken up the challenge to operate with the sustainability-enhanced toolbox developed by ADMIRAL.
- ✓ **Level of Integration:** The LMI shows to what extent the solution from ADMIRAL will be integrated into current supply chain operations; it will express the level of digital connection and interoperability with other logistics services and platforms.

LMI uses a weighted scoring approach where each of the maturity indicators is given a score based on the data collection from the ADMIRAL pilot sites. Such a scoring approach provides an indication of maturity that shows the progress toward disseminated and sustained logistics practices for ADMIRAL.

In addition, as part of LMI, there will be a dedicated TRL assessment that provides in-depth insight into how ADMIRAL's marketplace and its technologies progress along the TRL spectrum—from conceptual or prototype stages toward greater operational readiness and integration within real-life logistics scenarios. The assessment will be carried out in two distinct steps:

- **Project Solutions Assessment:** The first step focuses on assessing the technological readiness of individual ADMIRAL solutions. This includes evaluating the progress of specific technologies developed or integrated within the project, measuring their readiness for real-life deployments.
- **Project as a Whole Assessment:** The second step looks at the overall project's progression, assessing the integration of the entire ADMIRAL marketplace and its collective impact on the logistics ecosystem. This step evaluates how well the project's components work together and how they are being implemented across the pilot sites.

By measuring TRLs at these two critical points, ADMIRAL can quantify the progression of its solutions and provide a clear, data-driven view of the project's contributions to advancing low-emission, multimodal logistics technologies.

For the sake of clarity and completeness of the approach, the approach by Facchini et al., 2019 will be taken as a reference. The Maturity Index MI is calculated as a weighted average of all maturity items/questions in accordance with the following equation:

$$M_D = \frac{\sum_{i=1}^n M_{Di} * g_{Di}}{\sum_{i=1}^n g_{Di}}$$

Where:

M = maturity, D = dimension, i = item,

g = weighting factor, n = number of maturity items

4.1.3 Logistics Transferability Index (LTI)

LTI evaluates ADMIRAL’s ability to scale and adapt its solutions across different European regions. This index is crucial for understanding the conditions under which ADMIRAL’s solutions can be replicated and adopted, supporting the project’s objective of achieving EU-wide impact.

The LTI includes indicators that measure:

- ✓ **Policy Alignment:** This indicator assesses how well ADMIRAL’s solutions align with regional policies and regulatory requirements, identifying potential facilitators or barriers to adoption.
- ✓ **Infrastructure Compatibility:** LTI examines the compatibility of ADMIRAL’s solutions with existing logistics infrastructure, particularly in multimodal transport hubs and high-traffic corridors.
- ✓ **Readiness of Local Stakeholders:** This indicator evaluates the interest and capacity of local stakeholders—such as logistics operators, technology providers, and policymakers—to adopt ADMIRAL’s solutions.

To calculate LTI, the framework incorporates a benchmarking approach, comparing each pilot site’s readiness conditions against best practices and similar successful cases. The final LTI score presents ADMIRAL’s potential for adaptability to identify site-specific modifications to enhance transferability.

After a preliminary literature review to highlight existing logistics transferability processes, the proposed logistics transferability assessment considers the following steps:

- ✓ **Characterisation of the Site (cities, regions, etc.)** refers to have an overview of the city that would be interested in the transfer of the logistics policy concerning population, density, area, socio-economic situations, etc.,
- ✓ **Analysing the Urban Logistics Problems** highlights the problems related to logistics such as traffic-load, a lack of the parking area for loading/loading, etc.,
- ✓ **Analysing of the Logistics Stakeholders** aims to identify operational responsible persons considering customers, senders, receivers, drivers, carriers, managers, etc.,
- ✓ **Searching of the Similarities and Risks/Barriers** targets to define the similarities between reference and implementation sites with also mentioning possible policy-transfer barriers or risks,
- ✓ **Identification of the Impact Areas and Indicators** focuses on the definition of the impact areas, such as environment, safety, efficiency, and performance indicators, to measure the policy efficiency and monitoring, that are related to logistics processing and policy transferability,
- ✓ **Measures and Sources** are used to have an analysis for the reference site and implementation site based on problems measurements,
- ✓ **Assessments and Evaluation** analyses the theoretically-transferred policy and its potential outcomes concerning impact areas and performance indicators, and
- ✓ **Sources-Destination City Similarity Level Analysis** is the last step of the logistics transferability process that works out to compare the transferability index consisting of applicability of one successful logistics policy, from source site to the determined implementation site.

Similarly to the LSI, the LTI will be a weighted mean:

$$LTI = \sum_i I_i w_i$$

where I_i is the normalised value of indicator I and w_i is the weight given to the impact area indicator/metric m estimated for example using AHP or a Delphi approach.

4.2 Key Performance Indicators Definition and Prioritization

In this regard, a set of KPIs has been developed in accordance with the objectives of ADMIRAL to measure the success of the project in different impact areas. These KPIs are necessary for the tracking of the project and for the alignment of the same with its goals of sustainability, efficiency, and technological integration. The KPIs have been categorized under some primary impact areas: Emissions, Efficiency, Maturity, and Transferability. Each KPI has been defined to capture relevant data reflecting outcomes that ADMIRAL wants to achieve.

KPI definition for the ADMIRAL project is done in a very scientific manner, hence every KPI is relevant, measurable, and aligned with the objectives of the project, as well as the wider goals of sustainability, efficiency, and technological integration in logistics. These KPIs are developed from a literature review of established methodologies and best practices, drawing from various EU-funded projects that have implemented similar frameworks for emissions reduction, operational efficiency, and logistics innovation. This review allowed ADMIRAL to identify key metrics commonly used in logistics sustainability research and ensured that the project's KPIs reflect the latest scientific approaches and are aligned with international best practices. Methodological Approach: The structure is done to follow the process starting with Literature Review and Benchmarking.

A wide review of existing frameworks and methodologies was performed to identify those indicators that are widely accepted and effective. This process assured that the selected KPIs reflect state-of-art practices in logistics sustainability and technology evaluation. The stakeholder engagement, through workshops and consultations organized with consortium members, pilot leaders, and technical experts, evaluated the feasibility, relevance, and applicability of the proposed KPIs. Next, results from the Task T2.4 will be integrated since methodology was further refined based on insights obtained from T2.4 focusing on data collection and assessment processes. Deliverable D2.2 provided key foundational metrics, as specified in Section 8.3, supporting the KPI selection process. Meanwhile, Prioritization Workshops were performed via a dedicated KPI prioritization workshop in May 2024, where the interactive scoring on the Wooclap platform was performed. In rating the importance of each KPI, participants rated them against criteria like impact, feasibility, and relevance to the project's goals. Finally, in Iterative Refinement, the selected KPIs underwent iterative review and adjustment in the light of pilot-specific feedback and evolving project requirements, ensuring their robustness and practical applicability. This methodology ensures that the KPIs are not only aligned with ADMIRAL's goals but also actionable and measurable across its pilot sites, providing a robust foundation for evaluating project outcomes.

Beyond these steps, ADMIRAL also looked into further KPIs developed and implemented in other EU-funded projects with similar objectives in terms of sustainability, reduction of emissions, and operational efficiency. Looking at projects like NOVELOG, SULPITER, SHOW, FENIX, PLANET, URBANE, e-Ferry, PIXEL, FOR-FREIGHT, and Augmented CCAM allowed ADMIRAL to adapt and refine KPIs in the light of proven approaches and lessons learned.

NOVELOG focused on city logistics optimization and reduction of emissions in urban freight transportation. The main KPIs from NOVELOG were CO₂ emissions per tonne-kilometer, modal shift in percent, and transport efficiency in tonne-kilometers per unit of energy. These were translated into the ADMIRAL framework to monitor emissions reduction and energy consumption across multi-modal networks.

SULPITER was a project which has combined under one roof the issues of sustainable logistics and efficient use of energy across supply chains. KPIs from SULPITER, like energy consumption per ton-kilometre and the emissions reduction potential of low-emission vehicles, have been included in the ADMIRAL KPI set to determine the performance of electric vehicles and autonomous systems.

SHOW is the project tested autonomous vehicle technology in logistics and public transport. Indicators like the adoption rate of autonomous vehicles, 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.

Augmented CCAM was the project focused on the deployment of connected, cooperative, and automated mobility systems. ADMIRAL developed KPIs based on TRL, autonomy adoption percentage, and energy savings from connected systems to measure the integration of advanced digital tools and autonomous systems in logistics.

Including in it KPIs developed by these projects, and by the literature review work as well-ADMIRAL-D2.2 and ADMIRAL-D2.4-the indicators adopted would be scientifically sound while being representative of the vast studies and policy landscape within the European Union.

Final KPI Selection and Prioritization: Task 2.4 provided a comprehensive list of over 400 logistics KPIs, divided into seven categories (Business & Governance, Economic, Environmental, Energy, Operational & Productivity, Societal, Technological), that have been spotted in EU project and in literature, and directly address ADMIRAL project impacts. Specifically, a list of 427 KPIs was developed in D2.4, divided into the following categories and subcategories:

Table 1: KPIs Table from Task T2.4 to support T6.1

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 	

The identified KPIs were then analysed for their relevance to ADMIRAL's specific goals of reducing emissions, improving operational efficiency, and promoting technological integration across multimodal logistics systems. The final set of KPIs was chosen based on their ability to provide actionable, measurable insights into the project's progress.

The set of KPIs, both short as well as the final list, will feed the Bayesian Network list risk analysis, and will be used to adapt the STAR Model, in Task 2.2, as shown in the following figure.

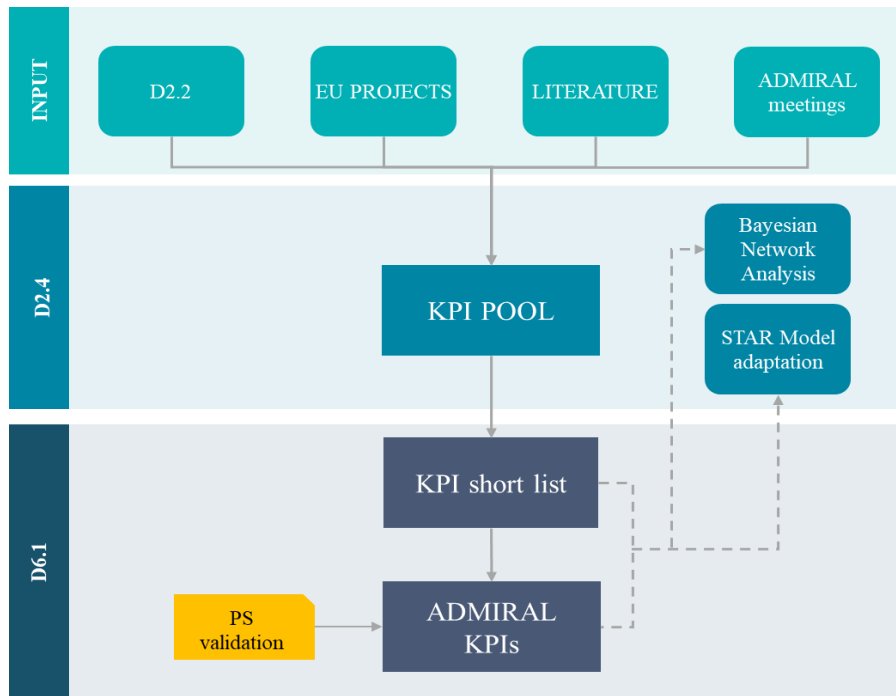


Figure 2: STAR Model from Task T2.4

The KPIs were prioritized through a collaborative process involving stakeholders from the ADMIRAL consortium. During a dedicated workshop held in **Vilnius on 30th May 2024**, participants from the project’s pilot sites and technical teams assessed each KPI’s alignment with the project’s impact areas and the feasibility of data collection. This prioritization exercise ensured that the most important and impactful metrics were emphasized for tracking the ADMIRAL project’s success.

Through this **scientific approach**, which combines a literature review, best practices from EU-funded projects, and collaborative prioritization, ADMIRAL has developed a robust and comprehensive set of KPIs that effectively measure the project’s contributions to logistics sustainability, emissions reductions, and technological advancement.

In the line with ADMIRAL cohesion, the list of KPIs presented has been developed through a structured and collaborative methodology, ensuring relevance, practicality, and alignment with the project’s objectives. The process began with a thorough review of EU-funded best practice projects, including NOVELOG, SULPITER, and SHOW, which have implemented similar KPIs to evaluate emissions, operational efficiency, and stakeholder engagement. These projects provided a foundation for identifying proven frameworks and metrics that are both actionable and aligned with ADMIRAL’s goals.

Following this, subject matter experts within the ADMIRAL consortium, including pilot leaders and technical specialists, evaluated and prioritized the most critical KPIs based on their relevance to the project’s LSI, LMI, and LTI. In addition, the development of the KPI list was supported by Task T2.4, which focuses on integrating data collection methodologies and tools across the project. Key insights were drawn from WP2, which provided foundational metrics and data points instrumental in shaping the final list of KPIs. Task T2.4 ensured that the selected KPIs were compatible with ADMIRAL’s broader data collection strategies and aligned with the pilot sites’ operational and technical capabilities.

This iterative process was refined through stakeholder workshops and collaborative discussions, enabling the incorporation of diverse perspectives, and ensuring feasibility. By combining insights from best practice projects, expert evaluations, and methodological support from Task T2.4, ADMIRAL has developed a robust and actionable list of KPIs. These metrics serve as essential tools for assessing the project's impact on sustainability, technological maturity, and scalability, ensuring that ADMIRAL's solutions are both measurable and effective in driving transformative change in the logistics sector.

The following list of KPIs have been defined based on ADMIRAL's core objectives of reducing emissions, improving logistics efficiency, increasing transparency in data-sharing, and promoting technological integration across multimodal logistics operations.

Logistics Key Performance Indicators for Logistics Sustainability Index

- Accident and Incidents
- Citizens' Involvement
- Customer satisfaction
- Final user-customer acceptance
- Impact on the environment for each delivery
- Journey length
- Load factor patterns
- Loss and damaged parcels
- Managerial and Operational costs
- Market Penetration
- Number of deliveries including the quantity of goods delivered/collected
- Number of Smart and Green Delivery operations for delivery
- Precision of deliveries
- Public acceptance
- Punctuality of deliveries
- Quantity
- Stakeholder acceptance
- Technology Readiness
- Unit cost of delivery
- Unit emission of delivery
- Vehicle type and data
- Willingness to pay for green urban logistics

Logistics Key Performance Indicators for Logistics Maturity Index

- Achieved TRL Level (project closure)
- Empty running
- Existing TRL Level (project start)
- Experience (green or smart logistics)
- Information flow problems
- Lack of a system to monitor the efficiency and effectiveness

- Lack of involvement of stakeholders
- Lack of knowledge about stakeholders' requirements
- Lack of knowledge about the operation of logistics process (green or smart)
- Loading/Unloading activities (quantity and duration)
- Time of delivery (pick-up)

Logistics Key Performance Indicators for Logistics Transferability Index

- Solution Integration and Standardization
- Process size/type
- Access availabilities (time-windows, load-factor)
- Adoption rate
- Changes in legislation (national or EU level)
- Production of suggestions and recommendations
- Effect of solution(s) on community-industry-research
- Transferring rate
- Success rate

The first round of KPI prioritization for the ADMIRAL project was conducted during a dedicated workshop at the ADMIRAL consortium meeting held in Vilnius on 30th May 2024. The workshop was organized with the goal of aligning the project's KPIs with its strategic objectives and ensuring that the most relevant metrics were prioritized for tracking progress across the pilot sites. With over 25 participants from various stakeholder groups—including pilot leaders, technical experts, and consortium partners—the workshop facilitated an interactive and collaborative discussion on the proposed KPIs.



The findings from the KPI prioritization workshop were gathered using an online platform (app.wooclap.com/OAIIYU?from=instruction-slide), a dynamic tool that allowed participants to engage interactively and provide real-time input on the KPIs.

During the workshop, each participant was asked to allocate importance across the impact assessment indexes as well as the specific impact areas related to emissions, efficiency, transparency, and integration. Participants were then asked to evaluate the importance of each KPI within these indices, using a voting scale from 0 (less important) to 100 (more important).

This methodology enabled the consortium to quantitatively assess the relative priority of each KPI, ensuring a clear and consensus-driven approach to determining which metrics would guide ADMIRAL's progress and performance evaluations throughout the project.

The prioritization exercise revealed that the LSI was rated the most important, with a clear focus on reducing emissions and improving energy efficiency. The LMI followed, emphasizing the adoption of innovative technologies and digital transformation in logistics. The LTI was also prioritized, reflecting the need for scalability and adaptability of ADMIRAL’s solutions across diverse logistics contexts.

The participants were tasked with evaluating the importance of the three primary impact indexes: LSI emerged as the highest priority, with a score of 51/100, LMI scored 24/100, while the LTI received a score of 25/100, highlighting its role in ensuring scalability across regions.

These results show that the project’s impact and technological development are central to its objectives, but scalability remains an important, though slightly secondary, goal. The prioritization also aligns with the overarching goals of the project to foster sustainable and scalable solutions for logistics.

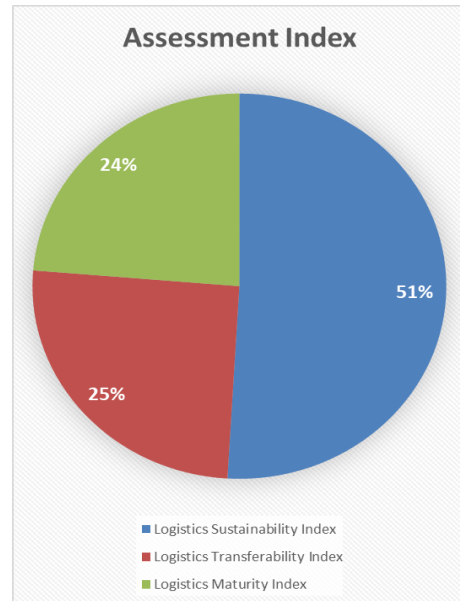


Figure 3: Assessment Indexes Prioritization

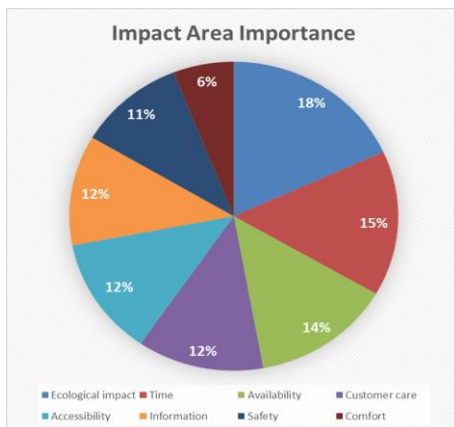


Figure 4: Impact Area Prioritization

In terms of impact areas, Emissions received the highest rating, scoring 85/100, reinforcing the project’s emphasis on reducing carbon emissions. Efficiency, which includes cost and operational efficiency, followed closely with a score of 82/100. Transparency and Integration scored 78/100 and 74/100, respectively. This indicates that while emissions and efficiency are key targets, the project also values transparency in its processes and seamless integration across logistics systems.

These results demonstrate ADMIRAL’s commitment to achieving ambitious environmental goals while maintaining operational viability. The high ranking of Efficiency and Emissions reflects a focus on practical, cost-effective sustainability solutions. However, the slightly lower scores for Transparency and Integration suggest that while these factors are necessary for long-term success, they are secondary to the immediate goals of reducing emissions and improving operational efficiency.

This figure shows how participants voted on the individual KPIs in terms of their importance. Unit Emission of Delivery (KPI.1) was ranked the highest, with an average score of 90/100, making it the most critical metric for the project. This KPI aligns with ADMIRAL's goal to reduce carbon emissions from logistics operations, especially per unit of cargo delivered. Other KPIs, like Unit Cost of Delivery (KPI.2) and Willingness to Pay for Green Logistics (KPI.3), scored 72/100, indicating its relevance but also highlighting its challenges in terms of measurement and implementation.

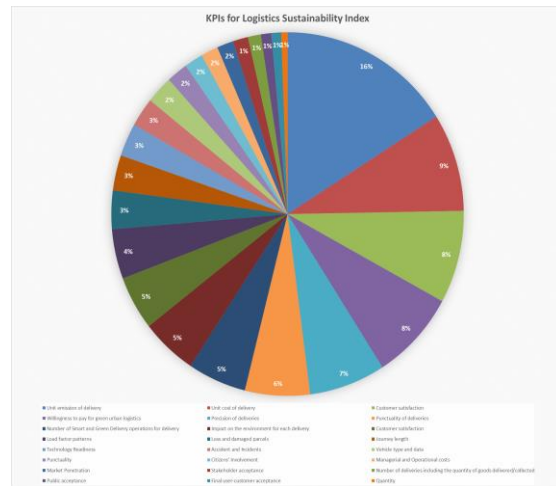


Figure 6: KPIs Prioritization for LSI

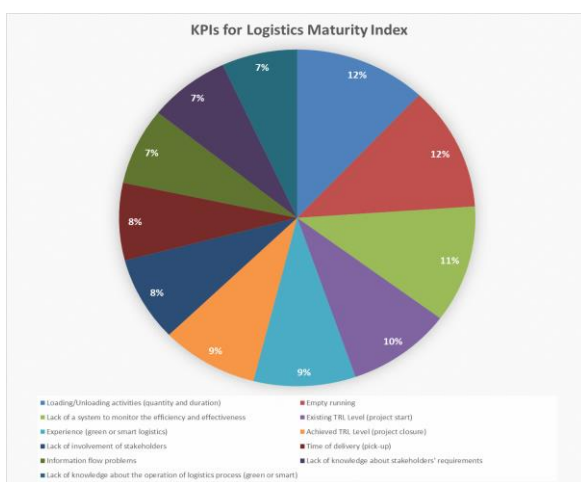


Figure 5: KPIs Prioritization for LMI

Technology Readiness Level (KPI.4) was rated second with 83/100, emphasizing the need for advancing the technological maturity of logistics solutions. This aligns with the Technology Readiness Level (KPI.4) is also a key priority for ADMIRAL, highlighting the importance of driving technological innovations in the logistics sector.

Solution Integration and Standardization (KPI.5) followed with 80/100, indicating its importance in ensuring that the project's solutions can be implemented and scaled across diverse logistics environments.

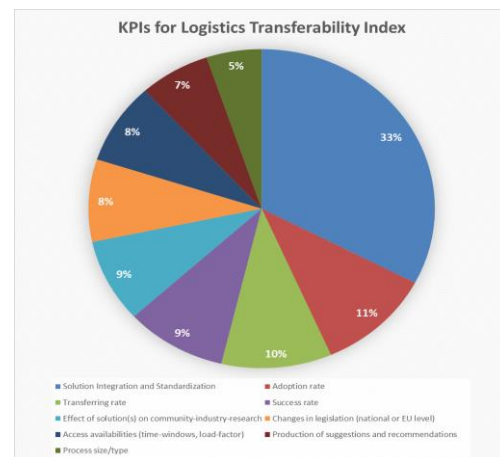


Figure 7: KPIs Prioritization for LTI

These results emphasize ADMIRAL's focus on achieving measurable reductions in emissions and fostering technological innovation. The slightly lower score for consumer willingness to pay shows need for more work in market development and engagement to promote green logistics solutions.

The findings from the KPI prioritization workshop held in Vilnius on 30th May 2024 provided valuable insights into the ADMIRAL project'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, data availability, and feasibility.

The outcomes of workshop established a clear and actionable set of KPIs that will guide the project's evaluation of emissions reductions, operational efficiency, and technological integration across the pilot sites. These prioritized KPIs will serve as the foundation for measuring ADMIRAL's progress and impact, ensuring that the project delivers measurable sustainability and innovation outcomes.

4.3 Impact Index Identified KPIs

The ADMIRAL project aims to transform logistics through the drive for sustainability, fostering technological advancement, and ensuring seamless integration within the logistics ecosystem. In line with these objectives, ADMIRAL has identified a set of KPIs that will be used to measure the success of the project. These KPIs are categorized into three core impact areas: Sustainability, Maturity, and Transferability. Each KPI was drafted so that it would measure, by actual figures and tangible elements, the progress made by ADMIRAL in order for the data collected to be relevant and in direct relationship with the project's vision of a greener, more efficient, and technologically integrated logistics network.

A set of KPIs have been identified and categorized into three main impact areas: Sustainability, Maturity, and Transferability, which will allow effective assessment of the performance of ADMIRAL in terms of its contribution to sustainability, efficiency, and technological advancement in logistics. Each of these impact areas will address a critical aspect of the objectives of ADMIRAL and provide the foundation for tracking progress throughout the project. The KPIs within each area have been carefully selected to reflect ADMIRAL's goals of reducing emissions, optimizing operational efficiencies, fostering technological innovation, and enabling scalability across different logistics contexts. The following section outlines the KPIs identified for ADMIRAL, providing definitions and contextualizing their relevance to the project's goals.

Sustainability Index. The Sustainability area of impact focuses on the environmental outcomes of ADMIRAL in terms of emissions reductions and energy efficiency. Since ADMIRAL aims to contribute to green logistics solutions, the project's contribution to reduced carbon footprint for logistics operations at a comparable or better level of operational efficiency will have to be assessed. KPIs in this area have been developed to demonstrate the extent to which the solutions offered by ADMIRAL support low-emission transition in transport networks, pull consumer demand for sustainable logistics, and contribute to a greener, more sustainable logistics industry.

KPI.1: Unit Emission of Delivery. This indicator measures emissions per unit delivered, presented as kg of CO₂ per ton of cargo or kg of CO₂ per kilometre travelled. Such cargo metrics per mode are also widely recognized in the literature, offering the advantage of capturing modal-specific emissions, which is particularly useful for comparing the environmental impact across different transport modes. This KPI is central to ADMIRAL's mission of reducing emissions in logistics operations. It is a direct measure of the environmental impact of transport operations and helps to evaluate how effective ADMIRAL's strategies are 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 essentially shows the willingness of customers, whether businesses or consumers, to pay a premium for logistics services that implement environmental sustainability and green logistics practices. This reflects the increasing market demand for green logistics solutions. It is crucial in terms of market acceptance and potential for the green logistics marketplace of ADMIRAL. Willingness to pay a premium for sustainable logistics services demonstrates a very strong indication of the potential of the project to drive the adoption of eco-friendly logistics practices across Europe.

Maturity Index. The Maturity impact area concerns the assessment of technological readiness and the innovation fostered by ADMIRAL. This area assesses how well ADMIRAL extends the adoption and integration of such technologies as green logistics vehicles, automated services, and digital platforms in logistics. KPIs in this area measure the improvement of logistics technologies from early stages of development to a full deployment and operational use and ensure that ADMIRAL develops technological readiness and advancement in the field of sustainable logistics.

KPI.4: Achieved TRL from an Existing One - Start-to-End TRL. This KPI monitors the progress of the TRL of technologies concerning logistics and transportation, from concept and early development up to full deployment and operational use. The TRL KPI is critical in gauging the contribution of ADMIRAL to logistics technology maturity. This KPI provides, through the assessment of the advancement in technologies such as green logistics vehicles, autonomous systems, and digital platforms, an indication of how well the project ADMIRAL will drive innovation and technology take-up. It also portrays the readiness of these solutions for wider implementation within the industry and, therefore, how they will be long-term integrated into the European logistics network.

Transferability Index. The Transferability impact area concerns the scalability and adaptability of ADMIRAL's solutions in various regions and logistics contexts. It also concerns the extent to which new technologies, systems, and solutions developed by ADMIRAL can be effectively integrated into existing logistics networks and standardized within the industry. This area ensures that the solutions developed are not only innovative but also practically implementable and adaptable, enhancing the cooperation and interoperability between supply chain actors and logistics infrastructure across Europe. KPIs within this area track the extent to which ADMIRAL's solutions can be transferred and scaled, ensuring that the benefits of the project can be realized across diverse logistical environments.

KPI.5: Solution Integration and Standardization. This KPI shows the degree of integration of the new logistics solutions developed within ADMIRAL into existing logistics systems and their standardization within the industry. It also refers to the degree of interoperability between different systems and technologies in the logistics sector. For ADMIRAL's solutions to have lasting impact, they need to be innovative but also practical and implementable on a wide scale. This KPI makes sure that the solutions developed, such as multimodal coordination tools, low-emission vehicle technologies, and digital platforms, are able to be adapted for existing logistics operations and easily integrated into the greater industry practices. Standardization and interoperability are at the core of ensuring scalability for the solutions developed within ADMIRAL and their potential for wide-scale adoption by a range of logistics providers across the EU.

These KPIs will monitor and measure the contribution of ADMIRAL to achieving its objectives in sustainability and technological integration. By monitoring the indicators, ADMIRAL will learn about the impact of innovative logistics solutions on sustainability, such as a reduction in emissions, cost efficiency, consumer demand for green logistics, technological advancement, and industry integration.

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. Based on the proposed mandatory KPIs, the detailed methodology for calculating each of the defined ADMIRAL logistics KPIs are listed in the following part for each KPI:

KPI.1: Unit Emission of Delivery

Data Collection: Gather data on total emissions (in kg of CO₂) and the total number of delivery units (weight or distance).

Formula: Unit Emission of Delivery=
$$\frac{\text{Total Emissions (kg of CO}_2\text{)}}{\text{Total Delivery Units (e.g., tons of cargo or km traveled)}}$$

KPI.2: Unit Cost of Delivery

Data Collection: Gather data on total delivery costs and the total number of delivery units.

Formula: Unit Cost of Delivery=
$$\frac{\text{Total Delivery Cost}}{\text{Total Delivery Units (e.g., tons of cargo or km traveled)}}$$

KPI.3: Willingness to Pay for Green Urban Logistics

Survey and Data Collection: Conduct surveys to gather data on how much more consumers are willing to pay for green logistics services compared to standard services.

Formula: Willingness to Pay=
$$\frac{\text{Average Amount Consumers are Willing to Pay for Green Services}}{\text{Average Amount Consumers Pay for Standard Services}} \times 100$$

KPI.4: Existing-To-Achieved Technology Readiness Level (Start-to-End TRL)

Assessment: Evaluate the Technology Readiness Level (TRL) at project start and end for each.

Formula:
$$\text{TRL Progress} = \text{End TRL} - \text{Start TRL}$$

KPI.5: Solution Integration and Standardization

Evaluation: Assess the level of integration and standardization based on predefined criteria (e.g., number of systems integrated, compliance with industry standards).

Score Calculation: Assign scores based on the integration and standardization level, using a scoring system (e.g., 1 to 5 scale).

Formula:
$$\text{Integration and Standardization Score} = \frac{\text{Sum of Scores for Each Criterion}}{\text{Total Number of Criteria}}$$

By following these calculation methods, the ADMIRAL project can effectively measure and track the progress and impact of its logistics solutions in reducing emissions, optimizing costs, meeting consumer demand for green logistics, advancing technology readiness, and achieving integration and standardization in the logistics industry.

4.4 Cross-Site Comparability and Analysis

Core within the ADMIRAL Impact Assessment Framework is the possibility it offers for cross-site comparability and analyses across the project's very dispersed pilot locations, namely Portugal-Spain, Slovenia-Croatia, Lithuania, and Finland. Cross-site comparability ensures that the impact metrics collected from each pilot site can be consistently evaluated to enable ADMIRAL to measure the effectiveness of its solutions across different regional contexts and logistical environments. This will help ADMIRAL understand how its marketplace is scalable, adaptable, and effective within the wider European logistics landscape.

Standardized KPIs and indexes, which are the same across all pilot sites, ensure cross-site comparability; thus, the performance outcome can be compared directly. Those standardized metrics also provide an analytical framework to ADMIRAL, ensuring the overall effectiveness of its logistics solution and local impacts concerning local infrastructure, policies, and logistics needs.

4.4.1 Standardized KPI Implementation Across Sites

The set of **mandatory KPIs** selected for the impact assessment of ADMIRAL represents the core metrics without which the main objectives of ADMIRAL cannot be meaningfully evaluated. All pilot sites will have to calculate these mandatory KPIs, which represent the critical dimensions of emissions reductions, energy consumption, and multimodal transport utilization. This harmonized set of KPIs creates a common evaluation basis for measuring the impact of ADMIRAL on sustainability and logistics efficiency across locations.

Suggested KPIs, besides the mandatory ones, are proposed in cases where sites can accommodate extra data. Suggested KPIs are used on a selected basis, considering conditions unique to every site, thus affording a more fine-grained level of regional differences in ADMIRAL's impact. Incorporating both, mandatory and suggested KPIs enable the balance of consistency and adaptability for ADMIRAL, ensuring comprehensiveness of data while accounting for local differences in the logistics practices and accessibility of data.

4.4.2 Benchmarking and Relative Performance Assessment

To contextualize the impact of ADMIRAL's solutions, the framework embeds benchmarking as an integral component of cross-site comparability. Benchmarking entails comparing the performance of ADMIRAL's solutions at each pilot site against internal standards-ADMIRAL's objectives and targets-as well as external benchmarks, where available. These may include logistics performance data from similar projects, such as SHOW and NOVELOG, or industry standards in low-emission and multimodal logistics.

Benchmarking allows ADMIRAL to identify relative strengths and weaknesses across pilot sites, highlighting areas where specific sites may exceed project expectations or require further support to reach ADMIRAL's sustainability and efficiency goals. This benchmarking approach also provides context for interpreting each site's LSI, LMI, and LTI scores, facilitating a comprehensive comparison of ADMIRAL's effectiveness in different operational environments.

4.4.3 Cross-Site Index Comparison Methodology

The framework supports a systematic comparison of the LSI, LMI, and LTI indices across pilot sites to assess ADMIRAL’s impact in environmental sustainability, technological maturity, and transferability. Each index is calculated using a multi-criteria decision analysis (MCDA) approach, enabling ADMIRAL to evaluate multiple dimensions of impact simultaneously while considering local variations and site-specific priorities.

By comparing the Logistics Sustainability Index across pilot sites, ADMIRAL can assess the relative environmental impact of its solutions in different regions. This comparison helps identify which sites achieve the greatest emissions reductions or energy efficiencies, providing insights into the factors that contribute to optimal sustainability outcomes.

The Logistics Maturity Index is used to gauge each site’s progress in adopting and integrating ADMIRAL’s low-emission logistics technologies. Sites with higher LMI scores demonstrate advanced maturity in implementing ADMIRAL’s solutions, providing models for other sites to emulate and informing best practices for scaling ADMIRAL’s technologies.

The Logistics Transferability Index reveals each site’s readiness for and adaptability to ADMIRAL’s solutions, highlighting the regional conditions that facilitate or hinder transferability. This comparison supports ADMIRAL’s goal of achieving EU-wide impact by identifying regions where specific solutions may require modifications to meet local needs.

4.4.4 Aggregation and Comparative Insights for Decision-Making

The aggregated results from cross-site analyses provide ADMIRAL with comparative insights that inform **strategic decision-making and project adjustments**. By analyzing the relative performance across sites, ADMIRAL’s consortium can:

Identify Regional Success Factors: By pinpointing the specific factors that contribute to higher performance at particular sites, ADMIRAL can leverage these insights to refine its approach and replicate successful practices across other sites. For example, a site that achieves high LSI scores may have a specific approach to emissions reduction or energy optimization that can serve as a model.

Adjust Framework and Methodology for Local Needs: The cross-site analysis can reveal regional disparities in logistics infrastructure, policy support, or stakeholder engagement. This understanding allows ADMIRAL to adapt the impact assessment framework to better address local needs and conditions, supporting the framework’s flexibility and scalability.

Inform Stakeholder Engagement and Support: Sites with lower-than-expected performance on certain indices may benefit from targeted stakeholder engagement or additional technical support. Cross-site comparisons provide a clear rationale for prioritizing these interventions, ensuring ADMIRAL’s resources are allocated efficiently to maximize impact.

4.4.5 Supporting Comparisons and Progress Tracking

4.4.5.1 Longitudinal Comparisons

The framework also enables **longitudinal comparisons**, allowing ADMIRAL to track each site’s performance over time and assess the project’s overall progress toward its goals. By conducting regular

assessments and comparing each site's index scores and KPIs at multiple intervals, ADMIRAL can monitor improvements, identify emerging trends, and measure the cumulative impact of its interventions.

This longitudinal tracking capability is essential for evaluating ADMIRAL's success in driving sustained changes in logistics practices and achieving long-term reductions in emissions and energy use. It also supports continuous improvement by identifying trends in site performance, facilitating real-time adjustments, and ensuring that ADMIRAL's solutions remain aligned with evolving regional and project-wide needs.

4.4.5.2 Latitudinal Comparisons

In addition to longitudinal comparisons within ADMIRAL's pilot sites, the framework supports **latitudinal comparisons** by facilitating data exchange and shared KPI evaluation with a **sister project funded under the same Horizon Europe Call ID**. This collaborative approach allows ADMIRAL to broaden its impact assessment by incorporating insights from a similar project, thereby enhancing the robustness and generalizability of ADMIRAL's findings.

Through a coordinated effort with the sister project, ADMIRAL has identified **2-3 core KPIs** for data exchange, enabling a comparative analysis that extends beyond ADMIRAL's pilot sites. These KPIs, selected for their relevance to both projects' objectives, focus on key areas such as emissions reduction, user engagement, and multimodal logistics performance. By aligning a subset of KPIs, both ADMIRAL and the sister project can explore broader trends in sustainable logistics and identify shared challenges and successes. Key elements of the latitudinal comparison and monitoring of progress will include the following:

Cross-Project Data Sharing: ADMIRAL's consortium and the sister project will develop a data-sharing arrangement to ensure the harmonization and transparency of KPI reporting. By means of regular data exchange, each project will receive current performance metrics of the other; this will enable timely comparisons between the projects and allow shared learning.

Comparative Analysis of Common KPIs: These KPIs, selected for cross-comparison, form a basis on which to analyze the relative impact of each project's logistics solution across different operational contexts. In this way, ADMIRAL will be able to contextualize its performance in a wider landscape and gain insight into how similar strategies and solutions are effective in achieving sustainability and efficiency.

Coordinated Workshops and Joint Findings: Periodic workshops will be carried out by ADMIRAL, along with the sister project, for the review of shared KPI data and discussion of findings. This joint session can be used for knowledge sharing and exploring, by both projects, the implications of the findings, especially those related to challenges and best practices in low-emission logistics.

Enriching ADMIRAL Impact Assessment Framework: The insights gained through latitudinal comparisons from the sister project will inform any possible enhancements to ADMIRAL's impact assessment framework. For instance, ADMIRAL may identify KPIs or methodologies which yield better evaluation capabilities on the basis of experiences gathered through the sister project, and these can be used to enhance the ADMIRAL framework for future use.

Developing Broader Recommendations for Sustainable Logistics: By synthesizing results from both projects, ADMIRAL can contribute to the development of broader recommendations and strategies for sustainable logistics. This collaborative approach supports Horizon Europe’s overarching goal of promoting scalable, impactful solutions to environmental and logistical challenges.

Latitudinal comparisons therefore offer ADMIRAL a chance to validate and build its findings in a wider context, allowing ADMIRAL and its sister project to share insights that drive a more comprehensive understanding of sustainable logistics. This approach also strengthens ADMIRAL's impact assessment and supports the creation of actionable recommendations that will have applicability across the European logistics sector.

4.4.6 Framework Alignment with Previous Projects and State-of-the-Art Analysis

The design of ADMIRAL's impact assessment framework draws from best practices and methodologies from a number of EU-funded projects, including SHOW and NOVELOG. These projects bring in valuable insights on logistics impact assessment, stakeholder engagement, and multi-criteria decision-making that have been adapted to ADMIRAL's unique focus on sustainability and multimodal logistics. It also incorporates the best available research on logistics sustainability, technology adoption, and policy transferability to ensure that ADMIRAL's approach is both innovative and firmly grounded in established methods.

Cross-site comparability and analysis thus provide a basis for the development of strategic insights and policy recommendations beyond the immediate goals of ADMIRAL. Aggregated data from the cross-site comparisons feed into WP6 in identifying best practices, assessing scalability of solutions developed by ADMIRAL, and recommending strategies for wider implementation. These may include some recommendations for optimizing low-emission transport chains by identifying the conditions under which ADMIRAL's multimodal solutions are most effective in order to provide actionable guidance for logistics providers seeking to reduce emissions across Europe. Then, it could develop a set of policy recommendations for supporting sustainable logistics with the findings of ADMIRAL in order to highlight regulatory or infrastructural factors that enable successful adoption of low-emission logistics solutions. These can inform policymakers on the development of enabling environments to support sustainable logistics. Other than these, the Guidance on Stakeholder Engagement, based on the ADMIRAL cross-site analysis, can determine those strategies for stakeholder engagement that are most effective in achieving acceptance and support for sustainability initiatives, providing valuable insights for similar projects and industry partners.

The cross-site comparability and analysis capability of the ADMIRAL IA Framework is thus instrumental in realizing ADMIRAL's goals: a reduction of emissions, improvement in operational efficiency, and wider adoption of sustainable logistics solutions. By allowing detailed and consistent evaluation across sites, the framework provides ADMIRAL's consortium, stakeholders, and partners with the information needed to drive meaningful impact in the logistics sector.

5 Data Collection and Evaluation Processes

ADMIRAL's success in driving sustainability, operational efficiency, and technological integration in logistics hinges on a robust and meticulously planned data collection and evaluation framework. This framework ensures the consistent, accurate, and comprehensive measurement of ADMIRAL's impacts across its four pilot sites: Portugal-Spain, Slovenia-Croatia, Lithuania, and Finland. The data collected directly feeds into the impact assessment framework, which consists of the Logistics Sustainability Index-LSI, Logistics Maturity Index-LMI, and Logistics Transferability Index-LTI.

The LSI, LMI, and LTI provide a multi-dimensional view of emissions, energy consumption, technological adoption, and scalability. To achieve this, ADMIRAL employs tailored methodologies respecting the unique characteristics of each pilot site, yet ensuring consistency in the evaluation of project-wide KPIs. This chapter elaborates on data collection methods, pilot-specific approaches, and processes for integrating data into the framework.

In short, the data collection in ADMIRAL is based on an impact assessment framework which measures the contribution of the project to logistics sustainability, digital maturity, and transferability. Each index within this framework is matched with certain project objectives and contexts of pilot sites. LSI: Environmental impacts; it assesses the reduction in CO₂ emissions and energy consumption. It assesses the impact of modal shift and introduction of low-emission vehicles and/or services. It relies on data about emissions, energy efficiency metrics, and sustainability KPIs for measuring progress. LMI quantifies the status of adopting and integrating Industry 4.0 technologies in logistics operations.

Therefore, TRL ratings capture the situation before and after the technological progress during the project. Tracks digitalization progress of the logistics networks and their stakeholders, which enables real-time information sharing and multimodal coordination; LTI is the metric describing the scalability and adaptability of ADMIRAL solutions to varying geographical and operational contexts. It focuses on cross-regional applicability, infrastructure compatibility, and stakeholder buy-in. These indexes are populated with data collected using direct measurements, indirect estimates, and stakeholder feedback, as these ways will be further explained, ensuring a comprehensive evaluation across various dimensions. Data collection to achieve comprehensive and actionable recommendations is divided into three key components:

- **Realization:** Identifying the required datasets for each pilot, such as emissions, energy usage, operational metrics, and stakeholder input.
- **Acquisition:** Deploying direct measurements, indirect estimates, and stakeholder engagement tools to gather relevant data.
- **Evaluation:** Synthesizing and analysing data through the impact assessment framework to assess ADMIRAL's performance.

5.1 Data Collection Overall Strategy

ADMIRAL employs a mix of quantitative and qualitative data collection methods to capture the full scope of its impacts. These methods are tailored to pilot-specific conditions, allowing for localized insights while maintaining consistency for cross-site comparisons.

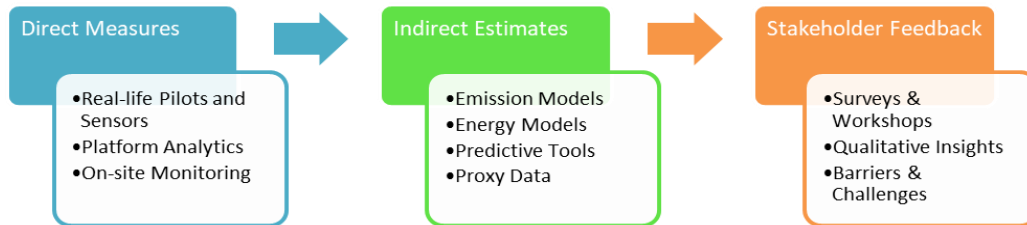


Figure 8: ADMIRAL IA Data Processes

Direct Measurements will be a quantitative dataset that is collected through static and/or dynamic monitoring systems integrated with ADMIRAL’s marketplace. This method provides objective insights into logistics operations and impacts. These direct measurements will include the Sensors and Devices presented, infrastructure, and hubs to measure emissions, fuel consumption, and energy use. Then, it will further focus on the Static and/or Dynamic Analytics with having data on route optimization, modal shifts, and load factors is captured through ADMIRAL’s platform. In the end, the Pilots will have On-Site Monitoring that work on measurements of energy consumption and emissions at logistics hubs.

Indirect Estimates will work with the in-scenarios where direct measurements are impractical to allow ADMIRAL employs validated models and simulations. At this case, there will be the target to use the GLEC Framework to be used for emissions modelling, leveraging activity data and emission factors to estimate CO₂ reductions. To support that, there will be also Energy Simulation Tools focusing on the predictive models to simulate energy savings from optimized logistics operations. Beyond these, the Proxy Data will be also considered as such data would be founded on the historical and regional datasets fill gaps in real-time measurements.

Stakeholder Feedback will then be a qualitative dataset for insights to provide context and enrich quantitative findings. For this, the Surveys and Interviews will capture operator and user experiences, focusing on the adoption of ADMIRAL’s solutions. Beyond that, the organized Workshops will facilitate user-centric feedback on system performance and pilot-specific challenges. Moreover, the Focus Groups will engage stakeholders in discussing scalability, barriers, and policy alignment, regarding the ADMIRAL overall objectives.

5.2 Pilot-Specific Methodologies

ADMIRAL’s pilot-specific methodologies are designed to account for the unique characteristics of each site, ensuring that the data collected is both relevant and actionable. Each pilot operates within a distinct logistical, geographical, and regulatory framework, requiring tailored approaches to capture key metrics effectively. The methodologies are aligned with the project’s impact assessment framework, ensuring that data feeds into the LSI, LMI, and LTI to evaluate sustainability, technological readiness, and scalability. The following parts provide a further explanation of methodologies employed in each pilot, including data collection strategies, evaluation techniques, and relevant formulas or methods.

5.2.1 Portugal-Spain Pilot

The Portugal-Spain pilot centres on a major cross-border logistics corridor characterized by high freight volumes and road transport dominance. The pilot aims to demonstrate the environmental benefits of shifting a significant portion of freight from road to rail.

Data Collection methodology for the Portugal-Spain pilot focuses on capturing metrics related to modal shifts from road to rail, emissions reductions, and operational efficiency in a cross-border logistics corridor. Sensors and devices are deployed to monitor freight movements, energy consumption, and CO₂ emissions, while real-time analytics from the ADMIRAL marketplace provide insights into load optimization and transit times. Baseline data on road freight operations are collected to establish a reference for evaluating the environmental and operational benefits of rail integration. At the frontline, the Emissions Tracking will focus on the CO₂ emissions that will be monitored using static and dynamic approaches to be implemented on logistics vehicles or infrastructures. The formula applied for emissions per ton-kilometre is:

$$\text{Emissions}_{\text{CO}_2} = \frac{\text{Fuel Consumption (L)}}{\text{Distance (km)}} \times \text{Emission Factor (g/L)}$$

where the emission factor varies based on the fuel type (e.g., diesel for trucks, electricity for rail).

Furthermore, the volume of freight shifted from road to rail is quantified using logistics data from ADMIRAL’s data-platforms and marketplace. In parallel, the further static and dynamic analytics will rely on analysis from the ADMIRAL platform to capture transit times, load factors, and route efficiency regarding cost, energy, and emission savings.

Following that, **Evaluation Techniques** will have 3-assessment-pillars starting with LSI that compares pre- and post-pilot emissions per ton-kilometre for road and rail freight, providing a direct measure of the pilot’s environmental impact. Following that, the LMI will be implemented to assess the adoption of rail-focused digital tools, such as real-time tracking systems and route optimization software. Besides, there will be also LTI measurement to evaluate the scalability of the modal shift strategy for similar cross-border corridors, considering infrastructure compatibility and policy harmonization.

5.2.2 Slovenia-Croatia Pilot

The Slovenia-Croatia pilot addresses the challenges of connecting rural logistics hubs with urban demand centres. It emphasizes the integration of multimodal solutions, including low-emission vehicles and optimized routing.

Data Collection for Slovenia-Croatia pilot emphasizes energy efficiency and emissions tracking in a mixed urban-rural logistics network. Data is collected using telematics systems on low-emission vehicles to monitor energy consumption, route optimization, and vehicle performance. Surveys and workshops with rural and urban stakeholders provide qualitative insights into infrastructure utilization and scalability. These efforts are supplemented by data from sensors installed at logistics hubs to measure load factors and operational throughput. Based on the main project aim, the pilot will principally work on Energy Use and Emissions performance to be monitored via telematics systems, capturing data on energy consumption (kWh) and CO₂ emissions per kilometre.

$$\text{Energy Efficiency (kWh/t-km)} = \frac{\text{Total Energy Consumed (kWh)}}{\text{Freight Weight (tons)} \times \text{Distance (km)}}$$

This will also be supported with further Infrastructure Utilization implementing the sensors at logistics hubs track vehicle load factors and infrastructure usage rates. Thus, the surveys and workshops with local logistics operators will capture qualitative insights on the feasibility and acceptability of multimodal solutions.

Then, **Evaluation Techniques** will start with the LSI that will assess emissions reductions achieved through LEV adoption and optimized routing. Moreover, the LMI will evaluate the readiness of logistics operators to adopt ADMIRAL’s platform for multimodal coordination, using pre- and post-project TRLs. Following these, the LTI will then analyse the potential for replicating ADMIRAL’s solutions in other mixed urban-rural regions, focusing on stakeholder engagement and infrastructure adaptability.

5.2.3 Lithuania Pilot

The Lithuania pilot targets developing sustainable intermodal logistics within a key Baltic-European corridor. This site emphasizes integrating rail and road transport to reduce long-haul freight emissions.

Data Collection in the Lithuania pilot focuses on intermodal logistics within the Baltic-European corridor. Freight movement efficiency and emissions reductions are measured using GPS tracking, sensor-based monitoring, and GLEC-aligned emissions modelling. The methodology also includes the collection of rail and road emissions data to evaluate the environmental and operational impacts of intermodal integration. Regional policy and infrastructure data are gathered to assess cross-border scalability and alignment with ADMIRAL’s logistics objectives.

To start with, the Intermodal Performance will work on the freight volumes transported via rail and road are recorded, with emissions data estimated using the GLEC Framework.

$$\text{Emissions Reduction (g/t-km)} = \text{Emissions}_{\text{Road}} - \text{Emissions}_{\text{Rail}}$$

To move forward, the Freight Movement Efficiency will be planned to be analysed with GPS tracking monitors transit times and delays, providing data on the efficiency of intermodal transfers. Then, the Technology Integration will be assessed with surveys and system analytics to measure the adoption of ADMIRAL’s intermodal tools by logistics operators.

After that, **Evaluation Techniques**, as already also presented within the previous demonstration sites approaches, the LSI quantifies the logistics emissions reductions resulting from rail adoption. Thus, the LMI will track improvements in intermodal logistics technologies, focusing on TRLs for digital coordination platforms. Followingly, the LTI will assess the transferability of ADMIRAL’s intermodal model within the Baltic region, analysing cross-border policy and infrastructure alignment.

5.2.4 Finland Pilot

The Finland pilot leverages a digitally mature logistics environment to test ADMIRAL’s marketplace in a high-tech ecosystem. It focuses on integrating green and efficient services and vehicles, automated systems, and dynamic data-sharing mechanisms.

Data Collection for the Finland pilot leverages advanced digital tools and green energy infrastructure to assess the performance of ADMIRAL’s marketplace in a high-tech logistics environment. Data collection focuses on tracking energy consumption and emissions from green vehicles and automated services using telematics systems and devices. Dynamic data-sharing metrics are captured from

ADMIRAL’s platform to evaluate digital integration, while focus groups and stakeholder interviews provide qualitative insights into the scalability and transferability of the solutions. At the core, the EV Emissions and Performance will be surveyed with telemetry systems to monitor usage, capturing data on emissions reductions compared to fossil-fuel logistics vehicles.

$$\text{CO}_2 \text{ Savings (g/km)} = \text{Emissions}_{\text{Diesel}} - \text{Emissions}_{\text{EV}}$$

Digital Integration Metrics within ADMIRAL platform analytics track the adoption of static and dynamic data-sharing features and automated system performance. This will also have a specific work with focus groups and interviews to capture insights on the integration and scalability of digital solutions.

Following that process, **Evaluation Techniques** employed in ADMIRAL’s pilot assessments are designed to align with the project’s impact assessment framework, utilizing the LSI, LMI, and LTI. The LSI focuses on quantifying emissions reductions achieved using electric vehicles and automated services. This index evaluates the environmental benefits by analysing key metrics such as CO₂ savings and energy efficiency improvements, providing a clear measure of the pilot’s contribution to sustainability goals. The LMI measures the readiness and adoption rates of advanced digital tools, offering insights into the technological maturity of logistics systems. This index assesses progress by comparing pre- and post-pilot stages, tracking the integration of technologies such as data-sharing platforms and automation. Finally, the LTI examines the scalability of ADMIRAL’s solutions for deployment in other technologically advanced regions. It evaluates compatibility with existing EV infrastructure and assesses stakeholder readiness for adopting ADMIRAL’s innovations, ensuring that the solutions are both transferable and impactful across diverse logistical contexts.

While each pilot employs unique methodologies tailored to its context, data is aggregated and synthesized within ADMIRAL’s overarching framework. This integration ensures cross-pilot comparability, allowing the project to identify trends, best practices, and regional variations. By aligning pilot-specific data collection with the LSI, LMI, and LTI indices, ADMIRAL ensures that its impact is assessed comprehensively and consistently across diverse operational environments.

5.3 ADMIRAL Cross-comparability Route

Cross-comparability is a vital part of the impact assessment strategy in ADMIRAL, enabling the project to assess the scalability and adaptability of its solutions across diverse pilot sites and align with broader European sustainability goals. This effort is further strengthened through structured collaboration with a sister project funded under the same Horizon Europe Call. This section outlines the methodologies for ensuring cross-comparability both within the ADMIRAL project and between ADMIRAL and the sister project.

5.3.1 Cross-Comparability Within ADMIRAL

The pilot sites of ADMIRAL are operated within very different contexts, which range from cross-border freight corridors, rural-urban logistics networks, to digitally mature ecosystems. Cross-comparability will ensure that insights gained from one pilot can be applied to others, creating a unified understanding of the marketplace's impacts.

All pilot sites share the same set of mandatory KPIs, such as CO₂ emissions reductions, energy efficiency, load factors, and digital adoption rates. These are defined within the Logistics Sustainability Index, Logistics Maturity Index, and Logistics Transferability Index to provide a common comparison basis. Suggested KPIs, including stakeholder satisfaction and policy alignment, are collected where site conditions allow, which may provide further localized insights.

The data collected is all normalized using standard units and methodologies to ensure meaningful comparisons. For instance, the emissions data are in grams of CO₂ per tonne-kilometre, while energy consumption is in kWh per tonne-kilometre.

ADMIRAL's impact assessment framework integrates data from all pilot sites into one system, allowing cross-site analysis. The method uses statistical methods, including weighted averages and variance analysis, to find out patterns and outliers. Example: The LSI of the Portugal-Spain pilot-which focuses on modal shift-is compared with the result of intermodal logistics from the Lithuania pilot to analyse the relative effectiveness of strategies for integrating rail.

Cross-comparability underlines how ADMIRAL's solutions adapt to different logistical challenges, infrastructure conditions, and stakeholder environments. Example: Insights from the Slovenia-Croatia pilot on connectivity can inform scalable strategies for mixed logistics networks in the Baltic region.

5.3.2 Cross-Comparability with Sister Project

ADMIRAL collaborates with its sister project to extend the scope of its impact assessment and create a common understanding of low-emission logistics innovations across Europe.

For shared KPI definition and reporting, ADMIRAL is involved with its sister project: the project also funded under the same Horizon Europe Call ID "HORIZON-CL5-2022-D6-02-01." The projects cooperate to produce a set of 2-3 shared KPIs necessary for direct benchmarking. These will span three essential dimensions: Technology diffusion; and finally, CO₂ emissions reductions KPI ascertains grammes of CO₂ reduced per tonne-kilometer across transport modes, clearly indicating environmental performance. Technology adoption will be examined in the light of digital tools and Industry 4.0 readiness for integration in the operations and highlighting the pace of digitalization and related innovations in logistics services. Operational efficiency will be monitored by metrics such as transit times and load optimization, reflecting how logistics processes contribute to the effective performance of the overall system. These shared KPIs will ensure consistency and comparability between ADMIRAL and the sister project, fostering collaboration toward the goals of sustainability and efficiency in logistics.

To further support this, the Joint Workshops and Data Exchange will proceed with some workshops for facilitating the exchange of findings, methodologies, and best practices between ADMIRAL and the sister project. ADMIRAL provides open access to anonymized datasets and analysis reports in compliance with GDPR to enable collaborative research.

The sister project provides complementary geographical contexts for latitudinal comparisons. For example, emissions reduction strategies tested in ADMIRAL's one pilot can be compared with similar approaches in the sister project's justified similar site(s).

ADMIRAL and the sister project will contribute to a joint impact assessment report, emphasizing their combined contributions to the sustainability of logistics in Europe. This report will contribute to the objectives of Horizon Europe by showing the greater impact of their innovations.

Several evaluation techniques are being used within ADMIRAL and with its sister project in order to ensure meaningful cross-comparability. The correlation analysis will spot the relationship between KPIs of pilots/projects by using a statistical method like the Pearson or Spearman correlation coefficient. This will point out patterns and dependencies from different factors on the three main targeted areas: reduction of emissions, energy efficiency, and technological adoption.

Benchmarking serves as another critical technique, allowing ADMIRAL’s results to be compared against those of the sister project. This evaluation helps assess relative performance in achieving emissions reduction targets, integrating advanced technologies, and ensuring the scalability of logistics solutions. Benchmarking not only highlights strengths but also identifies areas for potential enhancement.

Gap Analysis is done to analyse the performance gaps between ADMIRAL and the sister project, funded under the same Horizon Call ID "HORIZON-CL5-2022-D6-02-01". Through this, ADMIRAL can identify points of learning and thus allow both projects to develop better methodologies, solve problems, and improve results. This is a way for collaborative growth to take place and will keep the solutions of ADMIRAL competitive and effective.

Visualization Tools are developed to present data in a clear and accessible manner. Dashboards compare KPIs across sites and projects, offering stakeholders actionable insights into performance trends and project impacts. These visual tools enable decision-makers to quickly interpret complex datasets, facilitating informed strategies for advancing ADMIRAL’s sustainability and operational objectives. Together, these evaluation techniques ensure robust cross-comparability and drive continuous improvement.

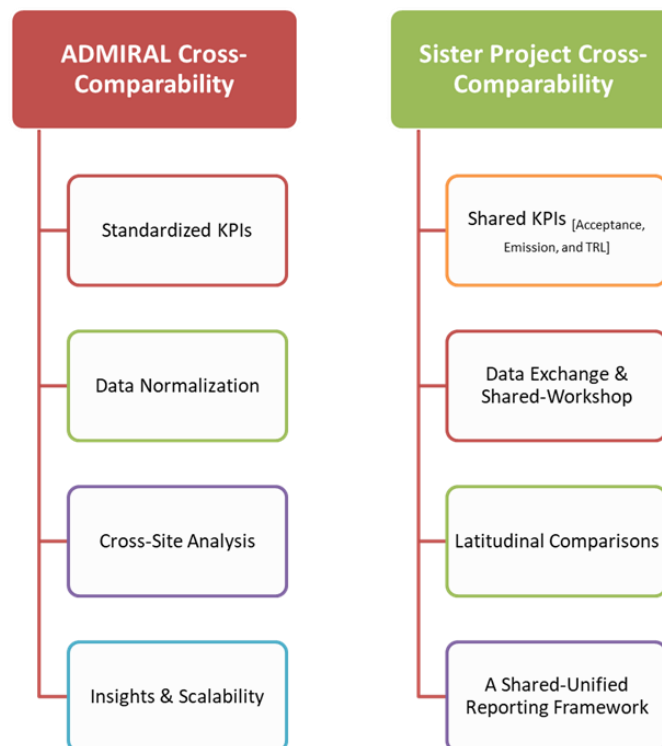


Figure 9: ADMIRAL IA Cross-Comparability Approach

Anticipated Outputs of Cross-Comparability, following implementation of cross-comparability in analysis and performance across different contexts, ADMIRAL would ensure that marketplace solutions developed in the project can be exported within a broad range of logistics environments. In this vein, the cross-project insights would next inform recommendations for harmonized policies and regulations to promote sustainability in logistics across Europe.

In addition, collaboration with the sister project will further magnify the contributions of ADMIRAL to the sustainability and innovation goals of Horizon Europe by showing a united front in solving logistics challenges. By embedding cross-comparability methodologies, ADMIRAL enhances the validity and applicability of its findings, ensuring meaningful change can be driven within Europe's logistics sector. This approach not only enhances the internal coherence of the project but also shows leadership in fostering collaborative innovation.

5.4 Logistics Impact Assessment Framework: Emissions and Energy Consumption

ADMIRAL's focus on developing a Logistics Impact Assessment Framework emphasizes sustainability as a cornerstone of modern logistics. Guided by the GHG Emissions Accounting and Reporting for Transport report and aligned with ADMIRAL's objectives, the framework is designed to assess the emissions and energy consumption of multimodal logistics operations. By leveraging internationally recognized standards such as the GHG Protocol, GLEC Framework, and ISO 14083, ADMIRAL seeks to ensure methodological rigor, data transparency, and insights for emissions reduction.

The Logistics Impact Assessment Framework focuses on evaluating emissions and energy impacts across all pilot sites, aiming to:

- Quantify **GHG emissions** using harmonized methodologies.
- Assess **energy efficiency** at each stage of multimodal logistics operations.
- Provide actionable insights to enable **20% emissions reduction**, as targeted by ADMIRAL's goals.
- Support informed decision-making for stakeholders by linking energy consumption patterns to operational efficiency.

This addresses both direct (Scope 1) and indirect (Scopes 2 and 3) emissions and incorporates life-cycle emissions (well-to-wheel) to provide an understanding of environmental impacts.

5.4.1 Methodological Alignment

ADMIRAL's framework integrates best practices from global emissions accounting methodologies:

- ❖ *GHG Protocol Scopes Framework*: Ensures a structured breakdown of emissions into: Scope 1 for Direct emissions from transport vehicles owned by operators; Scope 2 for Indirect emissions from purchased energy (e.g., electricity for EVs); and Scope 3 for Indirect emissions across the value chain, including upstream logistics operations and downstream freight movement.
- ❖ *GLEC Framework*: Adapts its sector-specific guidance to calculate emissions across all freight modes (road, rail, maritime, air), ensuring alignment with multimodal logistics.
- ❖ *ISO 14083*: Employs its standardized approach for transport chain operations, ensuring consistency in emissions quantification across ADMIRAL's pilots.

Key Metrics for Emissions and Energy Assessment. The framework evaluates emissions and energy impacts using the following metrics:

CO₂ Emissions per Ton-Kilometer (gCO₂/tkm):

$$\text{Emissions}_{\text{CO}_2} = \frac{\text{Fuel Consumption (L)}}{\text{Distance (km)}} \times \text{Emission Factor (gCO}_2\text{/L)}$$

This metric measures the emissions intensity of logistics, essential for modal shift evaluations.

Energy Efficiency (kWh/tkm):

$$\text{Energy Efficiency} = \frac{\text{Total Energy Consumed (kWh)}}{\text{Freight Weight (tons)} \times \text{Distance (km)}}$$

It assesses the energy required for logistics operations, highlighting opportunities for optimizing fuel and electricity use.

Emission Intensity Reduction (%):

$$\text{Reduction (\%)} = \frac{\text{Baseline Emissions} - \text{Current Emissions}}{\text{Baseline Emissions}} \times 100$$

This metric evaluates progress toward ADMIRAL’s emissions reduction target.

Share of Green Energy Use (%): Tracks the proportion of energy derived from renewable sources in logistics operations.

5.4.2 Pilot-Specific Supports for Data Collection and Evaluation

ADMIRAL's pilot-specific methodologies ensure the local relevance and scalability of the emissions and energy assessments. The Portugal-Spain Pilot will focus on modal shift from road to rail. Data Sources will have onboard tools/sensors on the vehicle, energy usage logs, and GLEC-aligned emissions models. Expected Outcome is a reduction in gCO₂/tkm due to rail adoption. The Slovenia-Croatia Pilot will then focus on low-emission vehicle integration and rural-urban connectivity. For that, the Data Sources will cover EV measurements/calculations for energy use and emissions, infrastructure utilization rates. Expected Outcome is improved energy efficiency (kWh/tkm) and reduced emissions. In parallel, the Lithuania Pilot will then focus on intermodal logistics and cross-border efficiency. Data Sources for that will have freight hub monitoring systems, energy consumption data for rail-road integration. Expected Outcome is enhanced operational efficiency and lower emissions intensity. In the fourth pilot, the Finland Pilot will focus on the digital integration and EV deployment in a high-tech ecosystem. Data Sources will include digital-twin analytics for real-time emissions tracking, renewable energy contribution rates. Expected Outcome: Maximized renewable energy use and emissions reduction.

ADMIRAL follows a very robust approach to ensure the accuracy and reliability of its data collection processes, supporting a comprehensive evaluation of its logistics solutions. The project collects primary data through direct measurements from IoT-enabled vehicles and logistics hubs. This involves sensor-based monitoring of energy consumption, fuel use, and operational performance that provides high-resolution insights into environmental and operational impacts from logistics activities.

For scenarios where direct measurement is not possible, ADMIRAL uses secondary data, such as industry benchmarks and standardized emission factors from frameworks like ISO 14083. Proxy data is also used to fill gaps, ensuring consistency and completeness in emissions and energy assessments. Additionally, stakeholder feedback is integrated into the process through workshops and surveys. These engagements validate the data collected and align it within operational contexts of the real world, capturing qualitative insights into enriching quantitative metrics.

The data collected is integrated in a structured manner into the impact assessment framework of ADMIRAL, which is based on three key indices: the LSI, aggregating emissions and energy metrics into one single score of sustainability, allows monitoring progress at the pilot level regarding emission reduction targets; LMI expresses the extent to which low-emission technologies and digital tools have been adopted and implemented in logistics operations, underlining advances in technological readiness. Finally, the LTI provides insight into the scalability of ADMIRAL's solutions in terms of their replicability in various logistical and geographical contexts within the EU. The combination of these indices yields a multidimensional understanding of the impact of ADMIRAL for informed decision-making and facilitating the adoption of sustainable logistics practices.

By systematically quantifying emissions and energy consumption, ADMIRAL's Logistics Impact Assessment Framework supports its overarching goals of fostering systemic change in logistics. The insights derived from this framework will empower stakeholders to adopt low-emission, energy-efficient practices, advancing the EU's sustainability agenda.

5.5 ADMIRAL Impact Assessment Process

The next figure succinctly summarizes the developed Impact Assessment Framework of the ADMIRAL project. It represents the successive unfolding of activities and methodologies for evaluating the performance of the project in three core indexes, namely LS, LMI, and LTI, ranging from data collection on pilot sites to the inclusion of emissions and energy metrics, technological readiness data, and stakeholder feedback. These inputs are then pre-processed and standardized to ensure consistency and reliability using industry standards such as ISO 14083 and the GLEC framework. The framework proceeds with the calculation of KPIs for each index, followed by cross-comparability analysis across ADMIRAL's pilots and collaboration with sister projects. Finally, the aggregated results feed into the impact evaluation and reporting process, providing actionable insights and recommendations to stakeholders. This structured approach ensures that ADMIRAL's contribution to sustainability, technological advancement, and scalability are comprehensively and transparently measured.



Figure 10: ADMIRAL Impact Assessment Framework

6 Data Realization, Acquisition, and Information Exchange

The backbone of ADMIRAL includes mechanisms for data realization, acquisition, and information exchange across its four demonstration sites: Portugal-Spain, Slovenia-Croatia, Lithuania, and Finland. The project's success is based on the harmonization of these mechanisms to facilitate seamless collection and use of high-quality data that will drive the evaluation of environmental, operational, and technological impacts of ADMIRAL's multimodal logistics marketplace.

Each demonstration site pursues a strategy tailored to its specific logistic and operational environment. The strategies guarantee that the project impact assessment framework, in particular LSI, LMI, and LTI, is appropriately aligned. For instance, as described in D5.1, data from infrastructure already in place and new data collection systems installed for the purposes of ADMIRAL are used at pilot sites to address site-specific needs while providing cross-site comparability.

The project is based on an integrated data management system to ensure consistency of data and enable interoperability across sites. Each site contributes to a central repository that aligns with the collaborative marketplace structure of ADMIRAL. Data inputs range from sensor-based measurements, digital platforms such as the JUL platform in the Portugal-Spain pilot, to real-time logistics data shared through standardized APIs. This system will grant real-time insights while adhering to the data privacy and security standards defined in ADMIRAL's D1.4.

Types of Data Collected

- **Quantitative Data:** Includes emissions metrics, energy consumption rates, and operational KPIs derived from sensors and automated tracking systems.
- **Qualitative Data:** Includes stakeholder feedback collected via surveys, interviews, and workshops, enriching the quantitative findings by providing context and additional layers of insight.
- **Hybrid Metrics:** Combines real-time logistics data with simulation results to model potential optimizations, especially in scenarios tested during pilots.

As detailed in D5.1, the data collected directly supports WP6 by feeding into evaluation models that assess emissions reductions, energy efficiency, and technological advancements. The framework also ensures that lessons learned from WP5's pilot activities are incorporated into ADMIRAL's broader goals, enabling informed decision-making and strategic adjustments. For example, the alignment of data acquisition with specific pilot goals ensures that logistics systems are not only evaluated for current performance but also for their potential scalability and adaptability.

By utilizing tailored approaches, rigorous methodologies, and advanced digital tools, ADMIRAL ensures that its data collection and exchange processes comprehensively support its objectives to achieve a sustainable and efficient multimodal logistics ecosystem.

6.1 Data Realization

Data realization refers to identifying the key datasets required to monitor and evaluate ADMIRAL's impacts comprehensively. Each pilot site is designed to collect data reflecting its unique geographical, operational, and regulatory context while ensuring consistency across the indices. The realization process focuses on three primary data dimensions starting with the Environmental Data to address the quantification of CO₂ emissions for current and ADMIRAL-enabled logistics operations. Measures of consumption, energy use, and modal emissions differences such as road to rail or electric vehicles. Assessment of air quality and environmental benefits derived from optimized logistics practices.

Then, Operational Data will continue with the coverage of logistics efficiency metrics, such as transit times, load factors, and utilization rates across transport modes. Static and dynamic tracking and optimization data to evaluate logistics performance enabled by ADMIRAL's platform. Asset utilization data captures the performance of infrastructure and multimodal hubs.

The Technology and Stakeholder Data will finally work on the level of digital adoption by logistics operators, measured by system usage, stakeholder engagement, and platform integration rates. Data on TRLs for logistics innovations, highlighting advancements from baseline to post-project implementation. Socioeconomic and stakeholder acceptance data: data that shows the wider impact of the solutions being delivered by ADMIRAL.

The realization of data is done in collaboration with the coordinators at pilot sites, operators, and local authorities to make sure that it is relevant and precise, while it corresponds to the objectives of the project.

6.2 Data Acquisition

The data acquisition involves direct measurement, surveying, and integrated analytics that result from the marketplace platform of ADMIRAL. Every pilot site has an acquisition strategy meant for its logistical and regional peculiarities but assures coherence in reporting and evaluation.

Pilot in Portugal-Spain: Modal Emissions Tracking. Automated data collection systems will monitor emissions between road and/or rail freight. Sensors and tracking devices integrated with the ADMIRAL platform will provide real-time emissions data. Operational Efficiency Data. Digital tools within the ADMIRAL platform will capture route optimization performance and modal transition rates. Stakeholder Engagement Surveys. Interviews and surveys with logistics operators and policymakers will provide qualitative insights into the adoption and scalability of multimodal solutions.

Pilot in Slovenia-Croatia: Rural-Urban Connectivity Metrics. Data collection will focus on the efficiency of connecting rural hubs with urban centers, measuring transit times and reductions in emissions because of optimized logistics routes. Low-Emission Vehicle Adoption. Data on the integration of EVs and hybrid vehicles will be captured through fleet operators' usage records and ADMIRAL's system analytics. Infrastructure Utilization. Sensors at logistics hubs will collect data on load factors and usage rates.

Pilot in Lithuania: Intermodal Freight Metrics. Data acquisition shall focus on rail-road integration metrics, such as emissions per ton-kilometer and volumes of modal transition. Technological Readiness: TRL data shall be obtained by means of technology audits and pilot testing of logistics innovations regarding the progress of solutions toward operational readiness. Cross-Border Performance: GPS tracking and multimodal platform data will assess the efficiency of movement across Baltic corridors.

Finland Pilot: Advanced Digital Integration The data acquisition shall highlight how ADMIRAL increases electric vehicle usage, enhances the performance of autonomous logistics systems by enabling real-time data-sharing mechanisms. Environmental Data of the Electric Vehicle Contributory Emissions by Pure Electric and Hybrid Electric vehicles will be recorded by Telematics system real time and under various real time operational metrics. Stakeholder feedback through surveys and usage statistics of the advanced operator about the integration and scalability of the ADMIRAL's solution in a tech-savvy environment.

6.3 Information Exchange

Information exchange is the very essence of the ADMIRAL project, since data from all pilot sites should be aggregated, shared, and analysed. The stone for this exchange is given by the ADMIRAL marketplace, which will enable seamless communication among stakeholders, operators, and the project consortium.

ADMIRAL's marketplace is a central hub collecting and processing data from all the pilot sites. Real-time analytics will allow continuous monitoring of logistics performance, reduction in emissions, and scalability of systems. Standard reporting templates ensure that data submission would be consistent and can allow for seamless integration of quantitative and qualitative metrics across regions.

At this point, it will be relevant to have secure, GDPR-compliant data-sharing mechanisms that allow the transfer of sensitive operational data, such as route optimizations, emissions figures, and

stakeholder feedback. Cross-site data sharing between pilot locations will support cross-comparability, enabling the project to evaluate how different regional contexts impact ADMIRAL's performance and scalability.

Beyond the edge, the Collaboration with Sister Project will be also processed. Under the Horizon Europe Call ID HORIZON-CL5-2022-D6-02-01, there are two funded projects-one is ADMIRAL and another one is the sister project of ADMIRAL, namely eFTI4EU. Hence, the information exchange in ADMIRAL will include 2-3 shared KPIs with its sister project under the same Horizon Europe Call, allowing for latitudinal comparisons and wider impact assessment. Regular workshops and joint reporting activities will be organized to ensure the flow of knowledge and data between ADMIRAL and the sister project.

Finally, all stakeholders at different levels, from logistics operators to policy makers and technology providers, will have the opportunity to work with the project data through customized dashboards within the ADMIRAL platform. These tools will provide insights into regional performance and allow stakeholders to make data-driven decisions.

6.4 Ensuring Data Quality and Reliability

The ADMIRAL project has a strong focus on data quality and reliability to ensure that the results from its impact assessment framework are actionable and trustworthy. In this regard, ADMIRAL employs several key strategies: data validation processes are regularly conducted through audits and cross-checks to ensure the accuracy and consistency of emissions data, operational metrics, and stakeholder feedback. It makes sure that the data collected is robust and aligns with the project's objectives. Real-time monitoring systems are also very essential in maintaining the integrity of data. The integrated sensors and tracking devices deployed on all pilot sites ensure high-frequency data collection, hence minimal data gaps and errors in the process of data capture. To further strengthen these, ADMIRAL uses periodic reporting cycles whereby the coordinators at each pilot site should report to a standardized reporting timeline. This approach ensures that the process of data submission and its review are uniform across regions to offer a reliable basis for comprehensive analysis and evaluation.

6.5 Contribution to Impact Assessment

By integrating robust data realization, acquisition, and exchange strategies, ADMIRAL ensures that its impact assessment framework effectively evaluates the project's performance in reducing emissions, enhancing logistics efficiency, and supporting scalability. The high-quality data collected across pilot sites will form the basis for the LSI, LMI, and LTI, enabling ADMIRAL to meet its ambitious goals of fostering sustainable, multimodal logistics solutions across Europe.

7 Ethics & Approvals

The ADMIRAL project is committed to observing the highest standards of ethics in the conduct of its activities, especially in data collection, management, and stakeholder engagement. Ethics and approvals are central to ensuring that ADMIRAL's operations align with legal frameworks, respect participant rights, and uphold the principles of transparency, accountability, and data protection. This chapter outlines the ethical considerations, approval processes, and mechanisms established to ensure compliance with ethical guidelines throughout the project lifecycle.

7.1 Ethical Considerations

The ethical approach of ADMIRAL will be informed by the principles underpinning the EU Horizon Europe Ethics Guidelines, as well as any other relevant national and international laws governing research and innovation. The activities of this project entail several dimensions of ethical responsibility, including data that might be sensitive in nature, contact with human subjects, and the potential impact on the environment based on logistics solutions.

ADMIRAL will collect and process data from logistics operators, pilot sites, and stakeholders. In the frame of GDPR, strict protocols for personal and operational data protection are implemented. All data will be anonymized whenever possible, and consent will be requested in advance from participants before the collection of data. Within ADMIRAL, there is an assurance that individuals and organizations are well informed about the purpose, extent, and handling of their data.

Free, informed consent is an ethical and legal prerequisite for surveys, interviews, or workshops when human participants are involved. The participants will be informed in detail about the project, their role in it, and their rights, among them the right to withdraw at any time without negative consequences. Consent forms will be designed according to the requirements of GDPR and Horizon Europe to ensure that participants are aware of how their data will be used and stored. In parallel, ADMIRAL prioritizes transparency in its interactions with stakeholders, including logistics operators, policymakers, and end-users. Clear communication channels are established to keep stakeholders informed about the project's progress, findings, and potential impacts.

Thus, ADMIRAL is deeply committed to minimizing the environmental footprint of its activities. The project assesses its logistic solutions not only for operational efficiency but also for their contribution to sustainability goals, making sure that interventions do not cause unintended ecological damage. In addition, ADMIRAL ensures that its activities foster inclusivity and does not discriminate based on gender, ethnicity, socio-economic status, or geographic location. This applies to stakeholder involvement, the selection of pilot sites, and the communication of project results.

7.2 Ethical Approval Processes

The ethical approval processes in the ADMIRAL project are guided by the Ethics Plan outlined in Deliverable D1.2, ensuring compliance with the highest ethical standards and relevant legislation throughout the project's lifecycle. The consortium is committed to the principles of the Horizon Europe Ethics Appraisal Procedures, as outlined in the Summary Report that assessed ADMIRAL as "ethics ready." In so doing, it ensures that all activities within the framework of the project will respect individual rights and dignity, taking into consideration the protection of the environment and societal impact.

Respecting that, to address ethical concerns proactively, ADMIRAL employs a robust governance framework: Ethics are a fixed agenda item in all General Assembly meetings, allowing for continuous oversight and collaborative resolution of any emerging issues; and a designated mentor/actor, led by the project coordinator (VTT), oversees ethics compliance across the consortium and provides guidance to partners as needed.

More critically, the ADMIRAL involves certain activities, like interviews, questionnaires, and workshops, all combining to ensure handling of personal data in general, and in contexts which are

pilot-specific. Expressing participant rights, all the participants will receive understandable, clear consent forms that involve the purpose of the research, the use of data, and the rights they have under the GDPR. Consent can be obtained in written, verbal, or implied forms, depending on the activity. Personal data collected is processed according to GDPR guidelines, and all project partners ensure secure storage and limited access to data on a need-to-know basis. The use of VTT-administered Microsoft Teams environments ensures compliance with EU data protection standards; and Participants are fully informed about the scope of the research, including the handling of responses, anonymization practices, and their ability to withdraw consent at any time.

As expected, ADMIRAL incorporates Artificial Intelligence in its technological solutions. In pursuit of ensuring trustworthy AI systems: The project applies the Ethics Guidelines for Trustworthy AI by the European Commission, using the Assessment List for Trustworthy Artificial Intelligence for development and monitoring; keeping human oversight in all processes where AI is involved, it aligns with societal norms and avoids potential biases; and ADMIRAL partners continuously monitor AI systems for inconsistencies and to ensure that ethical principles are upheld.

Besides, the project's ethics plan outlines a formalized process of risk management: Specific ethical dimensions, including personal data treatment and human-centered research, were identified within the proposal phase of the project; and the Consortium members should report new ethical issues that might arise to the project coordinator, who should then evaluate and resolve them with the help of relevant stakeholders.

These structured ethical approval processes implemented by ADMIRAL are in line with its commitment to the highest ethical standards, the protection of participants' rights, and the assurance of public trust in the results of the project.

In addition, each pilot site undergoes a local ethics review in order to be compliant with both regional regulations and cultural considerations.

This is particularly true for cross-border contexts, as in the case of the Portugal-Spain and Slovenia-Croatia pilots, where different national laws might apply. Local ethics committees are consulted during the design and implementation phases of the pilot activities to ensure that ADMIRAL meets all the ethical requirements. In parallel, ADMIRAL seeks approvals from relevant authorities before actual data collection is initiated, including institutional review processes and data protection offices. These approvals confirm that methods for data collection are ethical, transparent, and compliant with GDPR and other applicable regulations. Special attention is given to the handling of potentially sensitive data, such as real-time logistics tracking information and participant responses from surveys or interviews.

7.3 Data Management and Security

Data management and security within the ADMIRAL project are done according to the principles and guidelines developed in Deliverable D1.4: Data Management Plan (DMP). The framework ensures that all research data is managed, stored, and shared securely and efficiently, following the FAIR principles- aka Findable, Accessible, Interoperable, Reusable-while meeting the requirements of the GDPR and the project-specific security protocols.

7.3.1 Data Management Framework

Data Description and Metadata: ADMIRAL has developed a comprehensive Data Description Template, which details all datasets generated or reused during the project. This template ensures clarity by including metadata fields such as dataset titles, creators, methodologies, file formats, and project objectives. The data is categorized according to ADMIRAL’s Data Classification Matrix, which defines levels of openness:

- *Open and Public:* Accessible to all.
- *ADMIRAL Confidential:* Shared within the consortium.
- *ADMIRAL Restricted:* Available only to designated partners.
- *Security Classified:* Accessible to authorized personnel only.

The DMP establishes clear practices for data collection, processing, sharing, and preservation throughout the project’s lifecycle. The VTT-managed ADMIRAL Teams Group serves as the primary platform for document and dataset storage, ensuring secure, centralized access. Sharing of files is conducted via links to this environment, avoiding the use of email attachments.

7.3.2 Data Security Measures

The project will store all data within secure IT environments, protected by firewalls, and hosted on authorized cloud platforms or premises of consortium members. Access is granted based on authentication, with registration and multi-factor authentication in cases of sensitive data. Thus, the transmission of data can be encrypted, and the security of data files and data in transit can be guaranteed. All sensitive datasets are encrypted, and data transfers by consortium members are strictly monitored. The processing of personal data, where applicable, is done in accordance with the relevant provisions of the GDPR, such as consent, anonymization, and pseudonymization. For processes involving human participants in data collection, privacy notices and informed consent forms are used. No sensitive personal data, as defined by GDPR, are being collected in the framework of the ADMIRAL project. During this stage, the data management and security will be reviewed on a regular basis in both General Assembly and Management Committee meetings. Datasets identified are tracked, and the Data Description Template is updated periodically to reflect any changes in data types, classifications, or accessibility. Until recently, part of D1.4, identification of the 41 datasets was done, including the Pilot Datasets for certain WP5 tasks, also related to WP6 tasks, categorized by pilot sites, such as Portugal-Spain and Finland. For this reason, these would generate the Research Datasets supporting WP6 impact assessments, with the Interview and Workshop Notes to be generated in stakeholder engagement activities.

7.4 Monitoring and Compliance

ADMIRAL has put in place robust mechanisms to monitor ethical compliance and address any ethical issues that may arise throughout the course of the project. These mechanisms are designed to ensure that the project adheres to high ethical standards and that ethical considerations are thoroughly integrated into all aspects of the project’s activities. One of them is regular ethics audits by the Consortium and Advisory Board, which are periodic to review the project for its compliance with established ethical standards. Audits include the thorough review of data management practices, so

that data is handled accordingly to protect privacy regulations. It also involves the evaluation of informed consent procedures and environmental impact assessment in order for the project to be within the ethical and regulatory bounds of the operation.

In addition to audits, ethics training for consortium members will be provided to ensure that all participants are well-informed about the ethical dimensions of ADMIRAL's work. This training covers a wide range of ethical issues relevant to the project, such as data protection, stakeholder engagement, and environmental responsibility, helping consortium members understand their individual and collective responsibilities. The training ensures that all those involved are informed about the ethical implications of their work and are capable of acting in accordance with the ethical guidelines of the project. ADMIRAL has also set up a reporting system for ethical concerns, whereby consortium members and stakeholders will be able to report incidents or other ethical issues arising during the course of the project.

It has a clear and confidential system for raising concerns, so that any possible ethical issues are promptly resolved. The Board investigates reported incidents and institutes corrective action if required, thereby maintaining ethical compliance in the project. This proactive approach to ethical monitoring and resolution reinforces ADMIRAL's commitment to upholding the highest ethical standards in its operations.

7.5 Contribution to Ethical Best Practices

ADMIRAL contributes, by prioritizing ethics and approvals, to the responsible development of best practices that ensure ethical research and innovation in logistics and sustainability. The commitment to data protection, transparency, and inclusivity in the project's activities secures their coherence with societal values and respect for all stakeholders' rights. Ethical behaviour in ADMIRAL is exemplary for every future project that wants to balance innovation with responsibility.

8 References

- ANDERSON, E. J., COLTMAN, T., DEVINNEY, T. M., & KEATING, B. (2011). WHAT DRIVES THE CHOICE OF A THIRD-PARTY LOGISTICS PROVIDER? *Journal of Supply Chain Management*, 47(2), 97–115. <https://doi.org/10.1111/j.1745-493X.2011.03223.x>
- Asif, M. S., Lau, H., Nakandala, D., Fan, Y., & Hurriyet, H. (2022). Case study research of green life cycle model for the evaluation and reduction of scope 3 emissions in food supply chains. *Corporate Social Responsibility and Environmental Management*, 29(4), 1050–1066. <https://doi.org/10.1002/csr.2253>
- Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy*, 15(2), 73–80. <https://doi.org/10.1016/j.tranpol.2007.10.005>
- Blockchain Council. (2023). "Enhancing Transparency in Scope 3 Emissions."
- Capkin S.O.K. (2023), *An impact assessment methodology development for transport automation within the concept of logistics as a service*, <https://iris.uniroma1.it/handle/11573/1689647>
- Dobers, K., Ehrler, V. C., Davydenko, I. Y., Rüdiger, D., & Clausen, U. (2019). Challenges to Standardizing Emissions Calculation of Logistics Hubs as Basis for Decarbonizing Transport Chains on a Global Scale. *Transportation Research Record: Journal of the Transportation Research Board*, 2673(9), 502–513. <https://doi.org/10.1177/0361198119844252>
- Ekici, A. (2013). An improved model for supplier selection under capacity constraint and multiple criteria. *International Journal of Production Economics*, 141(2), 574–581. <https://doi.org/10.1016/J.IJPE.2012.09.013>
- Ellram, L. M., Tate, W. L., & Saunders, L. W. (2022). A legitimacy theory perspective on Scope 3 freight transportation emissions. *Journal of Business Logistics*, 43(4), 472–498. <https://doi.org/10.1111/jbl.12299>
- Emborg, M., & Olsen, S. I. (2024). Meeting Increasing Demands for Upstream Scope 3 Reporting: A Framework for the Drilling Industry. In *SPE Journal* (Vol. 5207). <http://onepetro.org/SJ/article-pdf/29/10/5207/3676743/spe-217701-pa.pdf/1>
- European Commission, DG MOVE (2022). "Shift-to-Rail Initiatives and Emission Reductions."
- European Environment Agency (EEA). (2023). "Technology Readiness Levels (TRLs) in Logistics."
- Freitas, D., & Gervásio, H. (2024). SCOPE 3 CARBON EMISSIONS IN SEAPORTS. *Ce/Papers*, 7(1–2), 102–111. <https://doi.org/10.1002/cepa.3027>
- GHG Protocol Scope 3 Standard. (2021).
- Global Logistics Emissions Council (GLEC) Framework.
- Grechan, A., Bezuglyi, A., Parfentieva, O., Kompanets, K., Hroza, A., & Kara, I. (2022). FULFILMENT OF SUSTAINABLE DEVELOPMENT GOALS BY THE EXAMPLE OF THE TRANSPORT AND LOGISTICS SECTOR. *Financial and Credit Activity Problems of Theory and Practice*, 4(45), 191–201. <https://doi.org/10.55643/fcaptp.4.45.2022.3802>
- Gu, J., Jiang, S., Zhang, J., & Jiang, J. (2024). *An analysis of the Decomposition and driving force of carbon emissions in transport sector in China*. <https://doi.org/10.21203/rs.3.rs-4404929/v1>
- Henke, I., Carteni, A., Beatrice, C., Di Domenico, D., Marzano, V., Patella, S. M., Picone, M., Tocchi, D., & Cascetta, E. (2024). Fit for 2030? Possible scenarios of road transport demand, energy consumption and greenhouse gas emissions for Italy. *Transport Policy*, 159, 67–82. <https://doi.org/10.1016/j.tranpol.2024.10.002>
- Ho, W., Xu, X., & Dey, P. K. (2010). Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. *European Journal of Operational Research*, 202(1), 16–24. <https://doi.org/10.1016/j.ejor.2009.05.009>

- IEA. (2023). *CO2 Emissions in 2022*. <https://www.iea.org/reports/co2-emissions-in-2022>
- Kuehne + Nagel. (2021). "Multimodal Solutions for Emissions Reduction."
- Lagoudis, I. N., & Shakri, A. R. (2015). A framework for measuring carbon emissions for inbound transportation and distribution networks. *Research in Transportation Business & Management*, 17, 53–64. <https://doi.org/10.1016/j.rtbm.2015.11.001>
- Logistics Sustainability Index. (2022). "Efficiency Metrics in Multimodal Transport."
- Perotti, S., Pratavia, L. B., & Melacini, M. (2022). Assessing the environmental impact of logistics sites through CO2eq footprint computation. *Business Strategy and the Environment*, 31(4), 1679–1694. <https://doi.org/10.1002/bse.2976>
- PwC. (2023). "Collaborative Approaches to Scope 3 Reduction in Logistics."
- Rybicka, I., Stopka, O., Łupták, V., Chovancová, M., & Drożdziel, P. (2018). Application of the methodology related to the emission standard to specific railway line in comparison with parallel road transport: a case study. *MATEC Web of Conferences*, 244, 03002. <https://doi.org/10.1051/mateconf/201824403002>
- Schmidt, M., Nill, M., & Scholz, J. (2022). Determining the Scope 3 Emissions of Companies. In *Chemical Engineering and Technology* (Vol. 45, Issue 7, pp. 1218–1230). John Wiley and Sons Inc. <https://doi.org/10.1002/ceat.202200181>
- Schulte, L., & Blau, J. (2021). "Advances in Transport Energy Efficiency." *Journal of Sustainable Logistics*.
- Silva, V., Vidal, K., & Fontes, T. (2024). Evaluating parcel delivery strategies in different terrain conditions. *Transportation Research Part A: Policy and Practice*, 187, 104158. <https://doi.org/10.1016/j.tra.2024.104158>
- Skrucany, T., Kendra, M., Skorupa, M., Grenčík, J., & Figlus, T. (2017). Comparison of Chosen Environmental Aspects in Individual Road Transport and Railway Passenger Transport. *Procedia Engineering*, 192, 806–811. <https://doi.org/10.1016/j.proeng.2017.06.139>
- Smart Freight Centre. (2022). **GHG Emissions Accounting and Reporting for Transport**. Retrieved from <https://www.itf-oecd.org/ghg-emissions-accounting-reporting>
- Sprott, K., & Yan, F. (2022). "Lifecycle Emissions Metrics in Freight Transport." *Environmental Logistics Studies*.
- Stenzel, A., & Waichman, I. (2023). Supply-chain data sharing for scope 3 emissions. *Npj Climate Action*, 2(1). <https://doi.org/10.1038/s44168-023-00032-x>
- UNFCCC. (2022). "Scope 3 Emissions Reporting in Transportation Networks."
- WHO. (2023). *Global Status Report on Road Safety 2023*. <https://iris.who.int/bitstream/handle/10665/375016/9789240086517-eng.pdf?sequence=1>
- World Economic Forum. (2020). *The Future of the Last-Mile Ecosystem*. https://www3.weforum.org/docs/WEF_Future_of_the_last_mile_ecosystem.pdf
- Xiong, J. Y. (2022). *The Impact of Logistics Provider Data Maturity in Defining Scope 3 Transportation Emissions*.