Deliverable 5.3 (V1.0)

Pilot evaluation summary report

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

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Abbreviations

AFR	Air to fuel ratio
API	Application Programming Interface
CO_2e	Carbon dioxide equivalents is a measure of effect of different greenhouse gases (GHG) on the climate
DAF	Distance Adjustment Factor
DIN	German Institute for Standardization
EC	European Commission
eCMR	Electronic Consignment Note
EDI	Electronic Data Interchange
eFTI	Electronic Freight Information
ERP	Enterprise Resource Planning
ESG	Environmental, Social, and Governance
ETA	Estimated Time of Arrival
ETC	European Transient Cycle for heavy goods vehicles
EV	Electrical vehicle
FD	Fuel density
GHG	Greenhouse Gas
GLEC	Global Logistics Emissions Council
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HVO	Hydrotreated Vegetable Oil, also known as renewable diesel.
ICE	Internal Combustion Engine
IMPC	International Mail Processing Centre
IPC	International Post Corporation
ISO	International Organization for Standardization
JUL	The Logistic Single Window is a digital ecosystem and Port Community System adopted by all the Portuguese ports.
LOPTA	Logistics Planning Tool for Admiral (one of the tools developed as part of Admiral project)
MAF	Mass air flow
MIPS	Material Input per Unit Service
NEXUS	Project and Portuguese ecosystem dedicated to digital and green transition in ports and multimodal networks
NPA	New Parcel Application

OBD	On-board Diagnostics
PUDO	Postal service for pick-up/drop-off
REIMS	Remuneration of Mandatory Deliveries of Cross-Border Mails
RFQ	Request for Quote
SFD	Shortest Feasible Distance
SSP	Super Stop Points
TA	Transport Activity
TCE	Transport Chain Elements
TEU	Twenty-foot Equivalent Unit
TRL	Technology Readiness Level
TTW	Tank-to-wheel refers emissions produced by a vehicle's engine while it is in operation
UN/CEFACT	United Nations Centre for Trade Facilitation and Electronic Business
UNECE	United Nations Economic Commission for Europe
UPO	Universal Counter Application
UPU	Universal Postal Union
VSP	Vehicle Specific Power
WLTP	Worldwide Harmonised Light Vehicles Test Procedure for Personal Vehicles
WMS	Warehouse Management System
WP	Work Package
WPL	Work Package Leader
WTT	Well-to-tank includes emissions related to the point where it is stored in vehicle's fuel tank
WTW	Well-to-wake includes emissions related to every stage in the life cycle of a fuel (for shipping and aviation)
WTW	Well-to-wheel integrated both the Well-to-Tank (WTT) and Tank-to-Wheel (TTW) (for road and rail transport)
XB	Cross-border

Executive Summary

This public report is the Deliverable from the ADMIRAL – Advanced Marketplace for Low Emission and Energy Transportation project, funded by the European Union (Grant Number 101104163). The ADMIRAL project seeks to develop and pilot AI-driven solutions for managing logistics supply chains, including related missions to reduce transport and logistics emissions and increase transparency, resilience of logistics supply chains, and stakeholder cooperation. ADMIRAL's objectives include streamlining supply chain operations, optimising existing assets, fostering sustainable sourcing and developing energy-efficient solutions.

The ADMIRAL project is developing a cutting-edge digital marketplace for multimodal logistics. This marketplace is developed in collaboration with the ADMIRAL pilots representing port operators, postal logistics, and road transport services, each having different requirements. The pilots provide the user needs, the first-hand user experience and guides the development. Each pilot contributes one or more advanced services or solutions to the ADMIRAL Marketplace. The ADMIRAL Marketplace and other developments are demonstrated and piloted in four regions: Portugal-Spain, Slovenia-Croatia, Lithuania, and Finland.

This report summarizes and evaluates the results of ADMIRAL pilots: 1) Digital & Green Multimodal corridor (Portugal-Spain), 2) Green Logistics: Optimizing Postal Sustainability Across Borders (Slovenia-Croatia), 3) Green Route: Emission Aware Logistics Management (Lithuania) and 4) AI-Based Optimization of Logistics for Sustainability (Finland). The purpose of each pilot is to increase utilization of current assets and increase the visibility of emissions of transport chain operations. These emissions will become visible in the multimodal logistics marketplace and are expected to impact positively decision-making of service buyers, enhancing collaboration and sustainability across supply chains. Logistic data collection, processing and analysis methods, test scenarios and selected digital technologies are developed in the pilots. The pilots also test, monitor and analyse the development of other parallel WPs, mainly results from WP3 (Business models for sustainable transports) and WP4 (Multimodal marketplace development). Each pilot is divided in two phases. In the first phase, the solutions are tested as standalone. Then in the second phase, the developed services and solutions are tested as a part of the ADMIRAL Marketplace.

This deliverable is a compilation report of the documentations of all four pilots. Each pilot section has the following subsections: 1) Overview of pilot, which includes the pilot environment description, challenges, purpose of the pilot and involved stakeholders; 2) Tested scenarios; 3) Tested systems, technologies and solutions; 4) Results of tests and 5) Summary of pilot. The purpose of a similar structure is to enable comparison of different pilots and to ensure that the pilots are documented in consistent and comparable manner. After pilot implementation descriptions, section 2 to 5, this deliverable shows the pilots integration with ADMIRAL Marketplace (section 6), collaboration with other pilots (section 7) and ends in the Conclusion section.

Services presented in this report and their integration to the ADMIRAL Marketplace, service catalogue continues in WP4 until end of the project. The pilots impact assessment will be done in parallel WP6 (Assessment of Solutions and Impact Assessment) and reported in public deliverable D6.3. Overall Impact Assessment of Project Results and Cross-Analysis of Pilots (M36).

1 Introduction

ADMIRAL seeks to develop and pilot AI-driven solutions for managing logistics supply chains, including related missions to reduce transport and logistics emissions and increase transparency, resilience of logistics supply chains, and stakeholder cooperation.

1.1 ADMIRAL project objectives

The ADMIRAL project aims at:

- Shifting the focus of the logistics and transport industry towards prioritising **emission reduction** along the entire supply chain by providing tools for companies to respond to regulatory and consumer demands.
- Developing the **ADMIRAL Marketplace**, which will provide information on **multimodal logistics and transport processes** and allow companies to **optimise logistics networks**, **visualise emissions** along the whole supply chain, and thus select the most environmentally friendly combination of service providers.
- **Achieving a 20% emissions reduction** in transportation and logistics by offering **process optimisation and emission monitoring** along the whole supply chain.
- Enhancing **cooperation, visibility and resilience** between supply chain actors by connecting supply and demand through the **ADMIRAL Marketplace.**
- Contributing to the global competition on business-to-business logistics platforms.
- Developing **business models** for multimodal low-emission transport chains.

From the pilots and solution development perspective, ADMIRAL is structured as follows:

- There are four pilots, each of which has selected and planned its own approach to improve logistics by adopting and developing innovative technology or digital solution.
- Additionally, it comprises the development of multimodal marketplace, that is upgraded within the project to give it new features and to enable it to integrate some elements from the solutions, that pilots developed.

1.2 ADMIRAL pilots

Piloting is one of the key activities in the ADMIRAL project, closely engaging logistics sector representatives. The pilots are representing port operators and stakeholders, postal logistics, and road transport services, each having different requirements. These pilots provide the user needs, the first-hand user experience, demonstration environment for solutions and guides the development. Each pilot contributes one or more advanced services or solutions to the ADMIRAL Marketplace. Roughly 40% of the person months of the project is allocated for the Pilot work package. In addition to presenting the pilots, this deliverable also explains, how ADMIRAL Marketplace collaborates with the pilots.

This deliverable focuses on summarising, presenting and evaluating the results for each of the four pilots: 1) Digital & Green Multimodal corridor (Portugal-Spain), 2) Green Logistics: Optimizing Postal Sustainability Across Borders (Slovenia-Croatia), 3) Green Route: Emission Aware Logistics

Management (Lithuania), and 4) AI-Based Optimization of Logistics for Sustainability (Finland). Figure 1 shows the locations of the pilots on the map of Europe.

Figure 1. The locations of pilots. 1) Portugal-Spain, 2) Slovenia-Croatia, 3) Lithuania, and 4) Finland

Each pilot key partners and their roles, for development and implementation, are summarised hereafter. External stakeholders participated in piloting as presented in the following sections of this document.

Pilot 1 - Digital & Green multimodal corridor (Portugal-Spain) key partners

- **APS** (ADMINISTRAÇÃO DOS PORTOS DE SINES E DO ALGARVE S.A.) Portugal-Spain Pilot Coordinator. APS is responsible for operating the port of Sines and the commercial ports of Faro and Portimão. APS is the leading pilot partner for the Portugal-Spain pilot and thus covers overall coordination for this pilot, including data and information flows and framework development.
- **MARLO** (MARLOCONSULT LDA). Data integration and support. Marlo provides consulting and technology-based solutions for transport and logistics clients. It covers data integration and APIs for the multimodal marketplace and supports APS in developing a corridor-level catalogue of low-emission transport and multimodal services in the Portugal-Spain Pilot as well as evaluating pilot impact.

- **UPM (**UNIVERSIDAD POLITECNICA DE MADRID). Scientific Support, UPM is the largest Spanish technical university. UPM, through members of the Transport Research Centre TRANSyT-UPM leads the analysis of policy and regulation on sustainability in transport and logistics; explores stakeholders' perspectives on different sustainability dimensions; supports the Portugal-Spain Pilot with research expertise; contributes to transferring the smart cargo planning tool to the Portugal-Spain Pilot.
- **LNEC** (LABORATORIO NACIONAL DE ENGENHARIA CIVIL). Scientific Support. LNEC is a major Portuguese public research institute devoted to science and technology that leads the analysis of sustainability aspects in the transport and logistics sector and advanced data analytics for the multimodal road/rail/maritime traffic analysis in the "Digital & Green Multimodal Corridor"; it provides scientific support to the Portugal-Spain Pilot and contributes to transferring the smart cargo planning tool to the Portugal-Spain pilot.

Pilot 2 - Green Logistics: Optimizing Postal Sustainability Across Borders (Slovenia – Croatia) key partners

- **PS** (Pošta Slovenije). The national postal operator and the largest logistics provider in the country, plays a pivotal role in optimizing first- and mid-mile logistics flows from Slovenia's North-Eastern regions to Croatia's capital, Zagreb. In collaboration with Solvesall and other technology partners, PS is working to integrate and align currently fragmented logistics networks and cargo owners within a newly developed cross-border logistics framework. This ambitious initiative aims to significantly reduce CO_2 emissions while delivering customized, resource-efficient, and environmentally sustainable logistics solutions.
- **HP** (Hrvatska pošta). The Croatian national postal operator and owner of Locodels, acts as an administrative and strategic advisor within this pilot. HP brings extensive experience in managing complex postal operations, ensuring regulatory compliance, facilitating smooth documentation processes, and providing strategic guidance to optimize the cross-border delivery workflow.
- **Locodels.** Subsidiary of HP, specializes in same-day delivery through its collaborative crowd-shipping platform. Its primary role in this pilot is to test and implement innovative technological solutions aimed at optimizing last-mile delivery operations. Given that last-mile delivery remains one of the largest contributors to CO_2 emissions in the logistics sector, Locodels focus on deploying cutting-edge approaches to minimize the environmental impact and improve delivery reliability.
- **SOLV** (Solvesall)**.** Specialized software development company with deep expertise in designing custom analytics and optimization solutions for the logistics sector. In this pilot, SOLV tackles software engineering challenges by developing a robust digital solution to support the cross-border logistics framework. Its deliverables will include advanced features for route optimization, cargo space utilization, and dynamic distribution planning — all of which are crucial for enhancing operational efficiency and sustainability.
- **UL** (The University of Ljubljana). The largest university in Slovenia and will participate through its Faculty of Maritime Studies and Transport. The faculty will oversee emissions measurement and impact assessment activities, including the calibration and deployment of measurement equipment and the processing of collected data. By integrating vehicle trip data with cargo movement information, UL will calculate key performance indicators (KPIs) before and after the pilot, providing a clear picture of the project's effect on greenhouse gas (GHG) emissions under different scenarios.

Pilot 3 - Green Route: Emission-Aware Logistics Management (Lithuania) key partners

- **TIA** (Transport Innovation Association) – Lithuanian Pilot Coordinator. TIA is responsible for the overall coordination and implementation of pilot activities in Lithuania, including the development of training materials, stakeholder engagement, and leading communication and dissemination tasks.
- **TREVIO.** Digital solution developer tasked with designing and developing digital tools, representing industry knowledge, and ensuring active stakeholder engagement.
- **CSign.** Software solution provider focused on digitising logistics processes. CSign integrates the eCMR into the marketplace and calculates CO_2 emissions based on eCMR data, contributing to paperless and more sustainable logistics.
- **CargoGo.** Industry partner providing operational insights, facilitating pilot testing in real-life logistics operations, and contributing data for tool validation. CargoGo supports stakeholder engagement and provides expertise in eco-driving practices.
- **KFEZ** (Klaipeda Free Economic Zone)**.** Industry partner contributing infrastructure and operational knowledge. Klaipeda FEZ supports piloting through access to real-life conditions, connects local businesses, and addresses digital transformation and data-sharing challenges.
- **NORM** (Normalis Tech). Technology provider, participated in the development of CO2 calculation methods during M1-M18.

Pilot 4 - AI-based Optimization of Logistics for Sustainability (Finland) key partners

- **STE** (Steveco Oy). The pilot coordinator, Steveco Oy is the leading port operator in Finland and leads the transit traffic market and the transport of Finnish wood-processing industry products. Steveco Oy represents the Finnish pilot at the port of HaminaKotka and covers the overall coordination and implementation of pilot activities from planning to evaluation, working as a terminal operator and testing the standalone AI-tool.
- **VTT** (VTT Technical Research Centre of Finland Ltd). VTT is among Europe's leading research institutions and ensures ADMIRAL's overall project coordination. It leads project activities connected to the analysis and development of business models for sustainable transport and developing a global ecosystem for smart logistics. VTT contributes with research expertise on AI to the development of a smart cargo planning tool; supports the implementation of the Finnish pilot and evaluates pilot impact.

The following project partners also participated in the WP5 Pilots.

- **AWA** (AWAKE.AI Oy). Finnish digital solutions company specialised in optimising port operations through an AI-driven Smart Port and Shipping Platform. AWAKE.AI is the leading partner for developing and technically implementing the multimodal marketplace. Together with VTT, AWAKE.AI also works on developing a global ecosystem for smart logistics.
- **CERTH** - The Hellenic Institute of Transport is part of the Centre for Research and Technology Hellas (CERTH/HIT) and offers specialized basic and applied research and highly technical services in all fields of transport. CERTH leads the development of sustainability KPIs, coordinates data collection from the pilot sites for comparative analysis with CTLup and explores the impact of the ADMIRAL pilots on user experience and stakeholder acceptance.
- **CTLup.** CTLup is an Italian company focused on developing ideas, products, and services for sustainable mobility, logistics, road safety and technological innovation. Together with CERTH,

CTLup coordinates data collection from the pilot sites. It also leads the assessment of solutions and pilot implementation.

1.3 Technology and solutions development

In the ADMIRAL project proposal, written during the summer of 2022, the pilots and the developed solutions were named and defined in general level, but the aims of the pilots were already set in a rather exact manner. Table 1 presents the technological solutions developed in the ADMIRAL project and aimed TRL-levels in the beginning and end of the project. The target TRLs are: TRL 6 – technology demonstrated in relevant environment, TRL 7 - system prototype is demonstrated in operational environment and TRL 8 - system is complete and qualified. ADMIRAL is an Innovation Action (IA) project and European Commission has defined that IA activities are expected to achieve TRL 6-7 by the end of the project.

The technology development was carried out in parallel with work packages WP4 (Multimodal marketplace development) and WP5 (Pilots). WP5 ends in December 2025, WP4 continues until end of the project, April 2026.

Table 1. Solutions developed in the ADMIRAL project and their aimed TRL-levels.

Technology / Solution	TRL	
	from	to
Marketplace	5	7
AI-based cargo planning tool	5	7
Transport service order management tool (including integration with the marketplace)	3	7
Transport scheduling tool (dock management, loading and unloading schedules)	5	7
Digital bill of lading (digital documentation and signature)	6	8
Data exchange structures and solutions	3	6
CO_2 calculation methodology, digital tools and data exchange	3	6
Logistics planning tool	5	8
Crowdsourcing tool	5	8
Integration tool	3	7

In the beginning of the project, pilot stakeholders gave a closer look for pilot plans described in project proposal and started to make it as concrete pilot implementation plan. In some pilots, there has happened changes in operating environment, and stakeholders needed to adjust the plans to be in line with current situations.

This deliverable has been written in cooperation with multiple partners. VTT led the writing, compiled the report, while CERTH and CTLup had a major role in deliverable planning. The writing of the description of the pilots was led by the respective pilot leader. Portugal-Spain pilot (Digital & Green Multimodal corridor) was led by APS, the Slovenian-Croatian pilot (Green Logistics: Optimizing Postal Sustainability Across Borders) by PS, the Lithuanian pilot (Green Route: Emission Aware Logistics Management) by TIA, and the Finnish pilot (AI-Based Optimization of Logistics for Sustainability) by STE and VTT.

The following Sections 2 to 5 present each pilot in detailed way. Integration of development to the ADMIRAL Marketplace is shown in Section 6. Section 7 shows collaboration between pilots. Section 8 Concludes the report.

2 DIGITAL & GREEN MULTIMODAL CORRIDOR PILOT (*PORTUGAL-SPAIN*)

2.1 Overview of the pilot

2.1.1 Pilot environment

The Port of Sines is a deep-water port included in the trans-European Transport Network (TEN-T) core transport network. Located 150 kilometres south of Lisbon, it is the main energy supply port in Portugal, and it is already positioned as an important deep sea container hub and cargo gateway for the Iberian Peninsula. Well connected by both road and rail to the main hinterland, the port sits on the cross-roads of two major deep sea shipping routes: the North-South (30 nautical miles away) and the East-West (70 nautical miles), making it an ideal port of call where the two trade routes meet.

PSA Sines (also known as Sines Container Terminal) started operations in 2004, and it is now ranked among the 15th biggest container hubs in European Union. In 2020, the Port of Sines was the second fastest growing European port, with 13% growth, in a year in which many of the main European ports reduced their volume. From Q3-2020 to Q3-2021, the Port of Sines grew by 18.5% in container traffic.

During the last decade, Sines also invested substantially in performance improvements, mostly via initiatives in innovation and digital transition. Because of that, in 2020 it ranked 2nd in Europe and 18th globally in the Container Port Performance Index prepared by the World Bank. The port of Sines serves a hinterland that covers the entire Portuguese territory and a substantial part of Spain, supported by several daily multimodal connections, mostly via rail.

Due to its strategic location, combined with the operational performance of port operations, the Port of Sines has served as a transshipment hub, with this type of cargo representing approximately 75% to 80% of containerized cargo handled. Only 20% to 25% remains for hinterland cargo, which, according to the port's strategy, is intended to be increased by serving the Iberian hinterland, that is, Portugal and Spain. Thus, the Sines-Madrid corridor assumes greater importance, taking advantage of the construction of a new railway line currently underway. This will allow the operation of larger trains to the border, on a fully electrified line, over a substantially shorter distance, increasing the competitiveness of the Port of Sines in the Multimodal Sines-Madrid corridor.

The new rail link under construction could contribute to better serving the hinterland by using a lower-emission mode of transport, such as the train. Naturally, a rail link will also be more cost-effective and, hopefully, will also increase the resilience of the Iberian Peninsula with a better and more sustainable freight transport service. Unfortunately, construction work has been delayed and the entry into operation of the new rail link will not be completed before the end of the project to show real data and the expected model shift.

2.1.2 Challenge and purpose of the pilot

The business case to be demonstrated in the Sines-Madrid digital & green multimodal corridor will involve the port of Sines, multiple logistics service providers (Medway – Rail Operator, Road transport operators, the dry ports in the hinterland) and the authorities. Road and rail transport operators present low-emission transport solutions to be made available in the catalogue developed in the pilot described below, dry ports are essential platforms for providing these same services, and authorities are decisive in the dispatch of goods, especially at the level of existing systems such as JUL - Logistics Single Window[2].

This pilot concerns the creation of a digital, greener and more energy-efficient corridor (using the JUL - Logistics Single Window platform as backbone) to promote network collaboration (horizontal and vertical), real-time data and event sharing, standardized digital processes and Synchromodal operations. To accomplish the goal of the pilot, the solution will integrate and harmonize closed independent logistics networks, providing open and shared low-carbon / low-emission services to shippers. Currently, the small amount of cargo that is moved between Sines and Madrid uses road transport almost exclusively and it refers to containers. Although port systems currently do not allow for quantity accounting, existing business perception and knowledge point in that direction. With the implementation of this solution, a modal shift from road to rail is expected to occur.

The challenge also involves developing the necessary services so that there is more cargo circulating in the corridor and that the train is used more on this route, benefiting the new line under construction. In this context, a constraint that can be identified is related to the continued electrification of the rail in Spanish territory and a small delay on the construction and operation of the new line from Évora to the Elvas (Spanish border), with work expected to be completed by mid-2026. This scenario of a lack of timing alignment between the electrification of the railway line in Portugal and on the Spanish side was highlighted in the study developed within the pilot project by LNEC and UPM (see section 2.2.2).

The goals of this pilot are:

- To establish a Digital & Green Multimodal Corridor between Sines and Madrid, including all the cargo and stakeholders along this route, for horizontal and vertical collaboration, where assets and networks are more efficiently used and CO_2e emissions and energy from fossil fuels will be significantly reduced. Based on the JUL platform and involving terminal operators, multimodal operators, logistics platforms and authorities.
- To focus on the hinterland component, that is, on the study of solutions and services that allow transport in the hinterland in a more efficient way, with fewer emissions and that allows the Port of Sines to expand/improve its offer. In this context, for example, it will be worth taking advantage of the new railway line that is being built between Évora and Elvas, Integrating the South International Corridor, and which will allow larger, electric trains and which will guarantee a shorter distance and less travel time to the border between Portugal and Spain, despite the uncertainties regarding the continuity of electrification on the Spanish side.
- To create a corridor-level catalogue of low emission transport and multimodal strategies and services to be included in the marketplace, identifying which services can be integrated.

In addition to the creation of the Sines-Madrid Digital & Green Multimodal Corridor, and considering that there will be very substantial local investments on green and energy transition, the demonstrator also aims to:

- Create a corridor-level catalogue of low emission transport (and zero tailpipe emissions), energy-efficient and multimodal services to be included in the ADMIRAL Marketplace, with

[2] The Logistic Single Window (JUL) is a digital ecosystem and Port Community System adopted by all the Portuguese ports. It is a platform for value delivery over port and logistic networks. It allows all stakeholders to collaborate, align processes in real-time and synchronise operations. https://www.projeto-jul.pt/en

scientific support, namely Performance Indicators and low emissions targets, provided by MARLO, LNEC, UPM.

- Demonstrate the low-carbon freight services marketplace developed by AWA (WP4).
- Integrate the low-carbon freight services marketplace with Sines' NEXUS[3] initiative that intends to develop a marketplace of applications and Application Programming Interfaces (APIs) for the entire port and logistics community.

Both in the case of the railway operator and in dry ports, the benefit will be precisely the development of the digital integration of its processes through JUL, with all the positive consequences in terms of synchronization and collaboration, greater agility, digital alignment with the authorities and reduction of administrative tasks. The demonstrator associated to digital and green transition will have a significant impact in Sines Fit for 55 strategies. This Fit for 55 package is a set of laws aiming to reduce EU greenhouse gas emissions by at least 55% by 2030 and put the EU to the path to achieve climate neutrality by 2050. With the expected modal shift of containerized cargo from road to rail estimated in 20 to30% as mentioned in the traffic analysis report, this solution for the Sines-Madrid corridor is aligned with the European strategy.

It is also important to develop solutions for road transport, currently the main means of transport in the Sines-Madrid corridor, to speed up the entry and exit of trucks at the port, reducing waiting times through better scheduling of container collection and delivery.

2.1.3 Partners involved and their roles

Development of the solutions was carried out by a team of diverse partners, each bringing specific expertise to support the successful implementation of pilot activities:

- **APS** (Ports of Sines and the Algarve Authority): co-owns JUL the Portuguese Logistic Single Window, which is used by all Portuguese port authorities to oversee schedules, inspections, and customs, with the capability to integrate other platforms and tools, APS is also partner of NEXUS- which is a parallel initiative that develops an innovation agenda and open data platform for information sharing, focusing on smart logistics products. APS does subcontractor integration, brings knowledge, data, information, stakeholders to ADMIRAL, participates to studies.
- **MARLO** (MARLOCONSULT LDA): Integrator and developer of the corridor-level catalogue of low emission transport . MARLO is developing a new transport management system aimed at greener logistics, which will be integrated into the ADMIRAL Marketplace.
- Scientific Support / **LNEC & UPM**: disseminate outcomes, do studies/scientific papers/presentation at international and national events, integrate results in education and policy consultancies. Several scientific outputs by LNEC and UPM are mentioned in this deliverable.

The main actors involved in the implementation of the Portugal-Spain Pilot are the Port of Sines Authority, as the entity responsible for the Port of Sines, the railway operator MEDWAY, as the main railway operator operating in the Port of Sines, the entities managing the railway platforms along from the corridor to Madrid, and the cargo owners (Figure 2). Multimodal logistics operators and first-/last-

[3] NEXUS is digital and green transition Project involving the port of Sines and 34 Portuguese logistic service providers, shippers and technology companies. It represents more than 110 million Euros of investment. https://nexuslab.pt/about/

mile road transporters have cooperated for the pilot works in WP2 Sustainable development of logistics and transports.

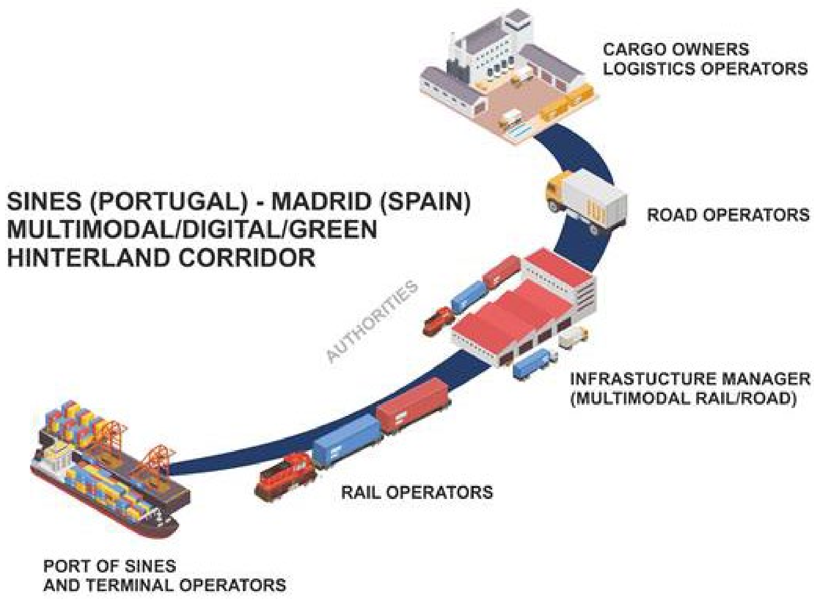

Figure 2. Actors of business case of the Portugal-Spain pilot

2.2 Tested scenarios

ADMIRAL, as piloted in the Sines–Madrid corridor, demonstrates a breakthrough approach to digitalising and decarbonising freight transport by enabling the structured publication, discovery and use of low-emission logistics services across a diverse set of stakeholders. Its value lies in the coordinated use of technological solutions. The **ADMIRAL Service Catalogue** serves as the central entry point in this pilot for transport service providers and terminal operators to expose their services, that according to a proper configuration, are shared with the available marketplaces, such as **Awake.AI**.

The **ADMIRAL Service Catalogue ecosystem** represented in Figure **3**, provides two channels for data input: a web interface (1) and an API (2) to the companies registered and configured inside our platform.

Regarding the **web interface** (1), it is where service providers, like a rail or road transport operator can access to Create Service manually, choosing the level of service to be provided: generic service or specific service.

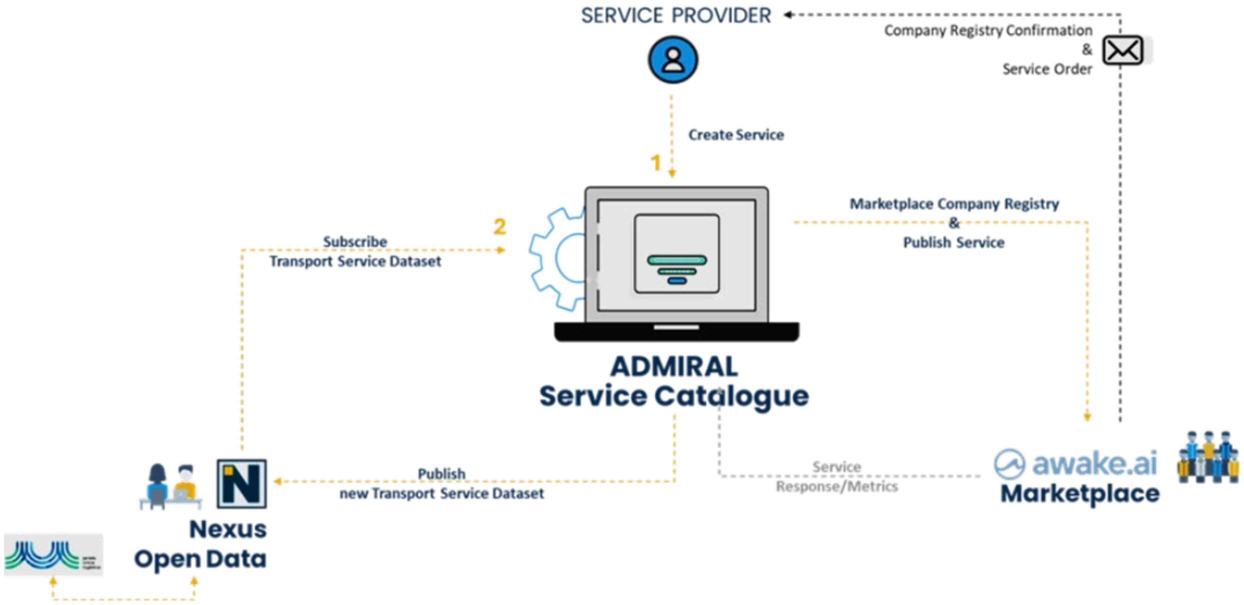

Figure 3. The ADMIRAL Service Catalogue Ecosystem

The **generic service (or service configuration)** can be declared by any company wishing to indicate the main characteristics of the provided service (see Table 2) and it is then displayed in the Service Catalogue as shown in Figure 4, this is the type of information that can be integrated with Awake.AI according to the specific API documentation of the multimodal emissions aware logistic marketplace [4].

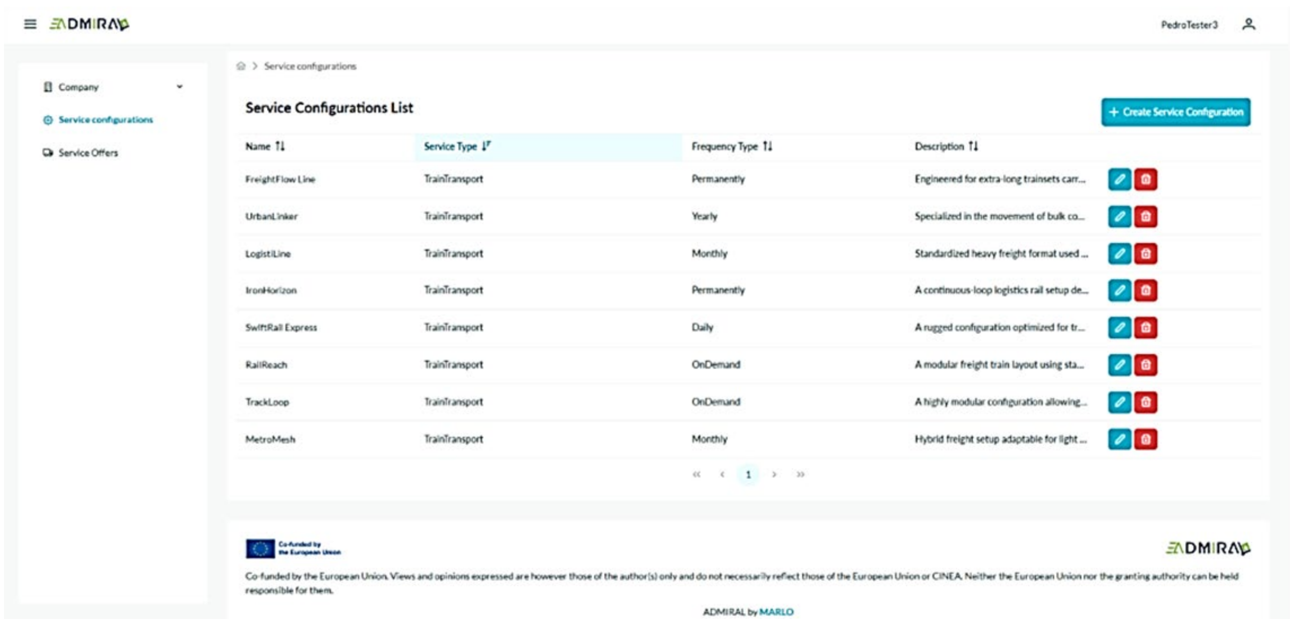

Figure 4. Service Configuration List (generic service) displayed in the ADMIRAL Catalogue interface

In order to publish their services to the marketplaces available through API integration, namely Awake.AI Marketplace, the provider must give permission to integrate with the marketplace in service

[4]https://awake-ai.gitbook.io/awake.ai-partners/multimodal-emissions-aware-logistics-marketplace/api-documentation/api-listings

configuration where administrator allows to share the data provided and selects specifically what are the marketplaces to integrate with.

The **specific service** (or service offer) must be declared to enable optimising the available capacity, requiring more information provided to define this availability that occurs for a specific provider, in a specific route with a specific capacity. In this case, the goal is to integrate with an intelligent marketplace where this level of information can be used to search for and find suitable cargo requests.

Table 2 presents the specific characteristics of the services and lists the "Generic Service" - service configuration in integration with Awake.AI – and also the Specific Service – service offers, within the definitions mentioned above. The mandatory data is market with *.

Table 2. Generic Service and Specific Service Data

Generic Service (service configuration in integration with Awake.AI)	Specific Service (service offers)
▪ Service Configuration • Type (Truck; Train; Land) * ○ Name* ○ Description ○ Service frequency* ▪ Pricing Configuration ○ Pricing Type* (Fixed; RFQ) ○ Currency* ○ Minimum Order Amount* ○ Minimum Order Time (hours)* ○ Unit (Km, TEU, Price/Kg, m^3)	• Service Type (Truck; Train) * ▪ Schedule (start/end) * ▪ Schedule expiration* ▪ Requires Refrigeration ▪ Available Capacity (TEUS)* ▪ Available Weight (Kg)* ▪ Departure address* ▪ Destination addresses* ▪ If Service Type = Truck: ○ Vehicle type* ○ Fuel type* ○ Licence plate number* ▪ If Service Type = Train: ○ Wagon Reference* ○ Energy Type (Diesel; Electricity) * ○ Service Configuration (selection as listed) ○ Country* • List of Stations

With an API integration, it is possible to integrate service providers that are available to provide streamlined information from their systems or even from an Open Data Platform like NEXUS Open Data. This channel enables the communication of transport service availabilities provided from the national PCS to NEXUS Open Data, in a format of a Transport Service Dataset, and integrate this data automatically with the previously defined marketplace.

For the proof of concept of API integration of the Catalogue's service offerings, was selected the rail mode of transport, which guarantees advance planning and knowledge of the available service offering.

Figure 5 illustrates how train service offers are presented in the interface, based on the Transport Service Dataset currently used in the pilot.

These services include details such as:

- Wagon Reference
- Fuel Type
- Available Capacity (TEUs)
- Country and stations of the train route

These details are all associated with train calls originating from the Port of Sines and integrated with the NEXUS Open Data Platform.

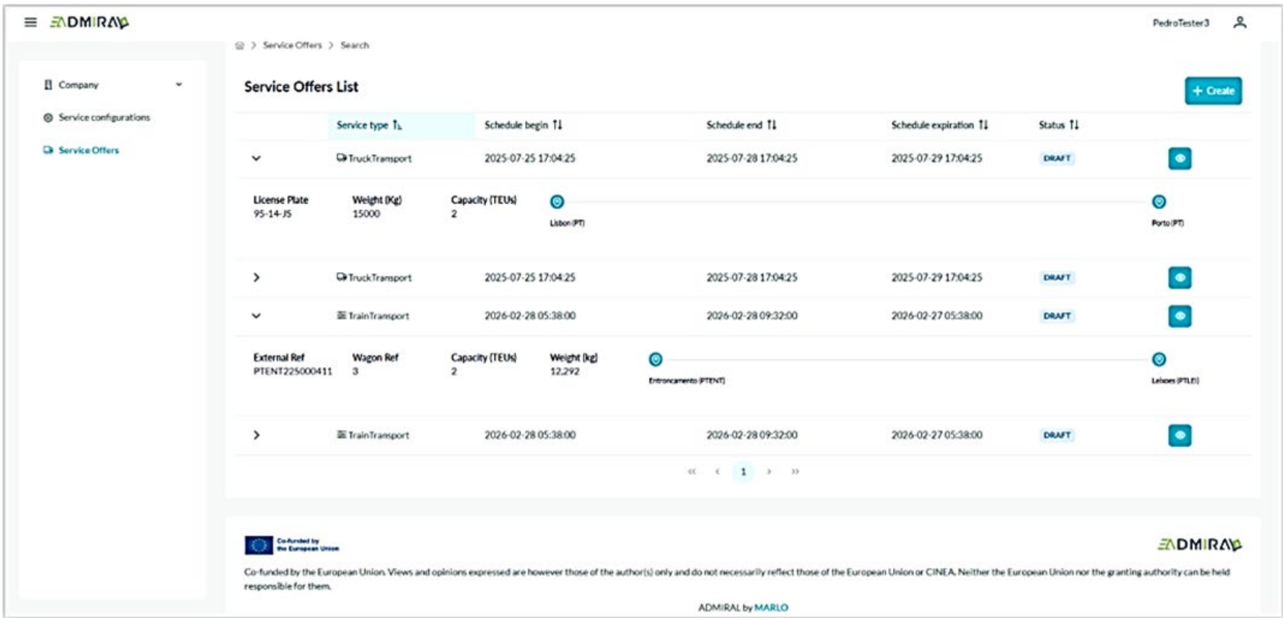

Figure 5. Train service offers (specific service) displayed in the ADMIRAL Service Catalogue interface

2.2.1 Platform users, main functionalities and responsibilities

The ADMIRAL service catalogue serves one main actor: Service Provider. This actor has three specializations:

- **Road service transport provider**: this role needs to provide road service information to integrate with a marketplace in order to get new orders from the shippers.
- **Rail service transport provider** is responsible for providing train service information to integrate with a marketplace in order to get new orders from the shippers.
- **Terminal service provider**: have the role to provide the main characteristics of the inland terminal to integrate with a marketplace, in order to attract new clients to their facilities.

The service provider will use this service catalogue as a service repository that provides updated information that can be further integrated with the available marketplaces. Information regarding Stakeholder Type, Access Interface, and Primary Responsibilities is detailed in Table 3.

The Table 3 presents the access interface and primary responsibilities of the two types of stakeholders identified: transport service providers and terminal operators.

Table 3. Stakeholder access and responsibilities in the ADMIRAL Service Catalogue System

Stakeholder Type	Access Interface	Primary Responsibilities
Transport service providers (rail and road transport)	Web interface via ADMIRAL Service Catalogue	• Register in Service Catalogue • Configure services • Publish transport services
	JUL and NEXUS Open Data - API Rest integration with Admiral Service Catalogue	• Publish transport services
Terminal Operators	Web interface via Admiral Service Catalogue	• Contribute with land hub characteristics

These functionalities are described further in section 2.5.

2.2.2 Baseline study - traffic analysis

Traffic analysis was carried out by LNEC and UPM from data set given by APS. The data analysis covers maritime transport freight and inland transportation modes (road and railway).

The purpose of the study was to characterize the rail and road infrastructure of the Sines-Madrid corridor (current and future). The study includes the analysis of the cargo currently moved between Sines and Madrid and along the corridor associated with the mode of transport used. It also increases the understanding of the amount of cargo that actually circulates in the corridor Sines - Madrid. On the other hand, a forecast must be made of the potential cargo to be transported between Sines and Madrid (including cargo along the entire corridor) and, in a more refined characterization, an analysis of the Spanish market, so that it can be understood where cargo is managed and how first/Last-mile transport is carried out. In this context, it is important to highlight that some work has been done, as in the paper by António, Arsenio and Henriques (2025): conducting a sensitive analysis of various scenarios for freight transport, namely increasing rail-to-road split ratios to reduce carbon emissions, and their potential impacts.

The analysis of cross-modal traffic data contributes to enhance our understanding of the sustainability challenges and magnitude of the traffic related changes related to greening transport within the Sines-Madrid corridor and its hinterland.

Based on study findings, two scientific papers were presented at the XVI Conference on Transport Engineering – CIT 2025, held from 18th to 20th June 2025 in Zaragoza, Spain. Papers are Open Access, the details and abstract are presented here.

Paper 1: José Pedro Antunes, Elisabete Arsenio, Rui Henriques (2025). *Data-centric models for the sustainable development of the multimodal Sines-Madrid transport corridor*. Transportation Research

Procedia 00 (2025) 000–000. XVI Conference on Transport Engineering, CIT2025. A version of the CIT 2025 full paper is attached (**Annex I**).

Abstract: *The multimodal freight transport planning on strategic transnational corridors often neglects critical sustainability criteria. This observation is corroborated by the generalized lack of optimization principles for the carbon-aware allocation of transport modes. This work introduces a prospective study of freight transport along the Sines-Madrid multimodal transport corridor, proposing data-centric models to guide its sustainable growth. The Sines-Madrid corridor represents a critical section in the Trans-European Transport Network Atlantic Rail Freight Corridor. The research explores road-rail transport scenarios until 2030 by: i) consolidating data provided by the Port of Sines and other institutional statistical sources, such as Eurostat, for modelling freight transport.; ii) developing uncertainty-aware time series models to analyse freight trends and forecast demand for road and rail modes in the corridor; and iii) conducting a sensitive analysis of various scenarios for freight transport, namely increasing rail-to-road split ratios to reduce carbon emissions, and their potential impacts. The acquired results from the proposed scenario-based modelling offer stakeholders insights to promote sustainable freight transport strategies. The 2030 horizon is selected to align with the European Union's (EU) climate and transport goals. The explored scenarios account for the impact of road and rail modal split, as well as road fleet configurations, on emissions and costs. These findings, conducted in the context of the Advanced Multimodal Marketplace for Low Emission and Energy Transportation (ADMIRAL) project, provide a blueprint for similar corridors, guiding EU policy and investment toward sustainable transport solutions.*

Paper 2: Natalia Sobrino, José Manuel Vassallo, Elisabete Arsenio, Sofía Cerqueira (2025). *Exploring the potential of the multimodal low-carbon freight corridor Port of Sines – Madrid. Transportation* Research Procedia 00 (2025) 000–000. XVI Conference on Transport Engineering, CIT2025. A version of the CIT 2025 full paper is attached (**Annex II**).

Abstract: *Freight transport contributes significantly to greenhouse gas (GHG) emissions in Europe, primarily due to the reliance on fossil fuels and road transport. With increasingly interconnected supply chains and rising cargo volumes, direct (Scope 1) and indirect (Scopes 2 and 3) GHG emissions are expected to increase unless proactive and effective measures are implemented. European transport policy has emphasized a shift to eco-friendly transport modes, such as rail and inland waterways, to reduce the dominance of road transport and consequently mitigate impacts on climate change. Within the framework of the ADMIRAL Horizon Europe project, this study conducts a detailed analysis of the multimodal freight corridor between the Port of Sines (Portugal) and Madrid (Spain), part of the Atlantic corridor promoted by the European TEN-T initiative. The study characterizes the existing and future rail and road infrastructure of the Sines-Madrid corridor, and analyses the cargo moved between Sines and Madrid by transport mode, estimating the share of the modal freight that the multimodal corridor could potentially capture and evaluating the reduction of GHG emissions. Additionally, feedback from key stakeholders was collected in a workshop with the aim of exploring their interests in this multimodal solution. The results of the analysis indicate that investment in infrastructure and interoperability is crucial for the viability and success of the service, particularly with regard to the possible development of rail motorways.* ***The traffic analysis suggests that approximately 10% to 30% of current cargo could be transferred to rail, leading to significant reductions in emissions.*** *This work enhances understanding of the sustainability challenges and the extended traffic-related changes necessary to greening transport within the Sines-Madrid corridor and its hinterland.*

One additional scientific article has been submitted to Journal, while the article is in the review process only the abstract is presented here. *Multimodal freight transport planning along strategic corridors often over looks carbon-aware optimisation of transport modes, undermining sustainability objectives. This research introduces a data-centric framework to forecast containerised freight flows and quantify well-to-wheel CO_2equivalent emissions along the Sines–Madrid corridor. Uncertainty-aware time-series models that decompose historical trends, seasonality, and residual noise, leveraging privileged access to freight data, are developed. Monte Carlo simulation is employed to generate probabilistic forecasts through 2030 under three scenarios: (i) baseline, (ii) 2.8% annual growth, and (iii) a sustainable modal shift with 20% of road traffic reallocated to rail.* ***Emission estimates use EcoTransIT's well-to-wheel methodology, revealing that electric rail emits 0.28 tons CO2e per twenty-foot equivalent unit (TEU) versus 0.60 tons CO2e/TEU for diesel trucks.*** *Alternative road-fleet mixes of liquid natural gas (LNG), fuel cell electric vehicle (FCEV), and battery-electric vehicle (BEV) show marginal improvements unless energy production is decarbonised;* ***only BEVs achieve substantially lower life-cycle emissions (0.18 tons CO2e/TEU).*** *Across all scenarios,* ***rail remains the most effective near-term decarbonisation lever, capable of absorbing additional volume with modest infrastructure upgrades.*** *Noise-variation tests confirm that Gaussian perturbations matching empirical volatility provide realistic uncertainty bands, as uncertainty ranges are around predictions that realistically capture the expected variability. The findings underscore the need for integrated transport policies prioritising rail expansion and electrification—powered by renewables—while acknowledging the long-term promise of electric trucks. This framework offers stakeholders actionable insights for capacity planning, policy design, and investment to align freight logistics with European climate targets.*

2.3 Tested systems

The implementation of the ADMIRAL pilot in the Sines–Madrid corridor was structured across a series of coordinated phases aimed at gradually building and validating the platform's digital infrastructure and operational capabilities. This process included identifying user needs, analysing corridor logistics, configuring service types and integrating technical components to create a functional and interoperable system.

A central objective of the pilot was to enable the structured registration and publication of transport services. This was achieved through the interaction of two core systems, each with a distinct but complementary role in the ADMIRAL ecosystem (see Figure 3):

- **NEXUS Open Data**: Integrates with the ADMIRAL Catalogue via REST API and functions as a transport service provider by publishing transport-related services. These services are registered directly into the catalogue in the same structured format used by other providers.
- **Awake.AI**: Enables registered services to become visible to end users (shippers and cargo owners) through the marketplace. Once a service is configured in the ADMIRAL Catalogue and the provider has completed the required technical integration, the service becomes accessible to potential clients via the Awake.AI marketplace.

Together, these systems establish a data and service flow: NEXUS enables the structured registration of service data, while Awake.AI enables the publication and visibility of those services in the marketplace. This dual interaction allows the ADMIRAL Catalogue to support multimodal logistics planning across the Sines-Madrid corridor.

2.3.1 Phases of pilot

The implementation of the ADMIRAL pilot in the Sines-Madrid corridor followed a structured sequence of phases ensuring full integration and validation within the marketplace environment as defined in the Pilot Implementation Plan defined in the beginning of project. The phases hereafter described were executed by MARLO, with a strong focus on enabling the connection and interaction between the Awake.AI platform and the NEXUS Open Data system, which together support the publication of low emission logistics services.

Pilot requirement specification

a) Identification of requirements and stakeholder expectations

The initial step focused on defining the functional and technical requirements of the pilot, starting with a detailed identification of the needs and expectations of key logistics stakeholders operating along the Sines–Madrid corridor. These included rail and road service providers, cargo owners engaged in regular import/export flows through the Port of Sines.

For this purpose, MARLO conducted a set of interviews with the main road (TML, Rangel and LASO) and rail transport service providers (MEDWAY).

The objective was to understand each actor's strategic positioning to adopt services in line with the ADMIRAL Catalogue sustainability objectives. This early mapping served as the foundation for designing relevant service configurations and ensuring alignment between operational needs and the platform core functionalities. In summary, stakeholder expectations include, among other things, that the Sines-Madrid corridor should be viewed as a network, not just a point-to-point route; that it should allow cargo tracking within the corridor; and that it should have certified emissions awareness/calculation. Stakeholders are open to emissions reduction, but not at any cost, and expect to reduce empty miles, mainly in road transportation.

b) Traffic and infrastructure analysis

A detailed analysis of the Sines-Madrid corridor was conducted using operational data provided by APS and project partners. In addition to characterising the corridor infrastructure and logistics conditions (including journey times, distance, line electrification, required traction equipment and other relevant factors) the analysis also examined the cargo volumes currently transported along the corridor by mode of transport. This made it possible to understand actual cargo flows between Sines and Madrid. Furthermore, potential cargo volumes were estimated, complemented by a market analysis focused on Spain to identify where cargo is managed and how first- and last-mile transport is carried out. These elements were considered essential to support sustainability goals, including the estimation of CO_2 emissions based on expected cargo shifts. LNEC and UPM carried out comprehensive Traffic Analysis, see subsection 2.2.2.

c) Data and information exchange

To support the interaction between logistics actors, terminal operators and port authorities, a specification for data and information exchange was prepared as part of the system requirements, through the analysis of the information flows anticipated for the success of the catalogue solution. This focused on defining the physical flow, that includes identification and detailed information that is exchanged between these actors.

Pilot system application design and development

a) Design and development of the solution

This involves the design, development and deployment of the solution by MARLO, in collaboration with all relevant stakeholders, including the Port of Sines, multiple logistics service providers (including various inland platforms), Medway Rail Operator and public authorities. The main activities under this subtask are described in the following topics.

b) Service catalogue

The catalogue allows transport service providers and terminal operators to register their services so that they can be published into the marketplace. As part of the registration process, each service provider is added to the catalogue and may choose to activate integration with one or more available marketplaces (in this pilot, only Awake.AI marketplace is available). During service configuration, the provider should provide information about the company and the description of each service provided as defined in Table 2 , to be integrated into the marketplace. Additionally, the service provider can publish updated information regarding the service availability, to find clients/cargo to the service gaps. The fulfilment of these gaps, reducing and avoiding empty trips, is the final goal of sharing information about the available capacity of each mean of transport used along this corridor, promoting a more sustainable and efficient cargo movement to/from the hinterland.

c) Subcontracting services

As outlined in the project plan and considering the lessons learned during the project's development, subcontracting was adopted to accomplish the goals of the pilot, where the upgrade and development of new digital tools (applications and/or services) in the scope of JUL and NEXUS were performed. It is then essential to create digital tools that will establish the collaboration network in the Sines-Madrid corridor and make the necessary adaptations to JUL/NEXUS, including the development of new tools within those systems. Two main developments needed to be subcontracted were identified, as APS does not have the necessary internal resources for their development:

- **Land cargo transport process, digitalization and collaboration improvements**

A digital tool that provides more information about road transport and the corresponding electronic process regarding entering port terminals and dry ports, and consequently the process of picking up goods at the respective terminals by truck.

In this context, two modules are being developed: one, "driver," whose objective is to streamline the process of drivers entering terminals and simplify processes and communication between truck drivers and the terminals or logistics areas. This is expected to reduce waiting times to enter terminals and logistics areas and reduce transport CO_2 emissions and increase visibility and transparency, with the subsequent increase the quantity and quality of data obtained from cargo transport. The “Transport Management” module communicates with the “driver” module, enabling greater visibility and harmonization of processes and communication between the various drivers and carriers with the various terminals and logistics zones and better fleet and driver management, as well as ongoing logistics services and reducing CO_2e emissions and energy consumption from fossil fuels. It results in a harmonization of processes between carriers and the various logistics stakeholders and subsequently increase the quantity and quality of data obtained from cargo transport.

With this digital tool (Land Cargo Transport Process) implemented in the Sines-Madrid logistics corridor it is expected to have digital applications in JUL, which digitize, harmonize and increase the efficiency and effectiveness of existing logistics processes, as well as increase the response and adaptability levels of the APS and the logistics corridor community. On the other hand, it will enable better data collection on truck cargo transport and improve the quality of data obtained from truck cargo transport. This will increase horizontal and vertical collaboration between the various players in the logistics chain and allow timely information to be shared among the various stakeholders involved. This is expected to reduce waiting times, arrivals, and departures for drivers in terminals and logistics areas, while also reducing and increasing visibility of CO_2e emissions from truck cargo transport.

- **Interoperability framework, interfaces and data sharing in JUL/NEXUS with marketplaces, and relevant stakeholder applications**

Contracting services to develop the necessary integrations with JUL/NEXUS that enable a greater range of transport services and interconnections between systems, including JUL and NEXUS with pilot service catalogue, ADMIRAL Marketplace (through the catalogue), and other applications and logistic players that act within the corridor's scope, with the objective to increase CO_2e transparency, reduce CO_2e emissions, improve processes efficiency, improve collaboration between logistic players, increase data transparency and data quality.

To achieve our goals, data analysis and business comprehension are required, as well as knowledge on how to connect and define data pipelines between information systems and how to transform raw data into high valued data in order to better answer the business and operation necessities as well as facilitate and promote digitalization, collaboration, data transparency and data quality, between all Sines-Madrid corridor stakeholders.

Establishing a robust framework for operability is essential to ensure seamless coordination, integration, and performance across complex systems and stakeholders. Such a framework provides standardized protocols, data models, and governance mechanisms that enable interoperability between platforms, applications, and organizations. It fosters consistency in operations, reduces integration costs, and accelerates deployment of new services.

d) Integration with NEXUS Open Data

Automatic integration of the Transport Service Dataset from NEXUS Open Data into the marketplace, including available capacity of train calls from the Port of Sines, provided through the JUL (Logistic Single Window) and NEXUS Open Data platform.

- The integration of road transport services (empty miles availabilities from CargoConnect, an application developed under the NEXUS project) is currently under consideration.

Finally, the low emissions transport catalogue will perform automatic integration with the Awake.AI Marketplace via API to publish logistics services and ensure their availability within the marketplace ecosystem.

2.4 Integration with Awake.AI Marketplace

This integration guarantees that services are integrated with the ADMIRAL marketplace, according to the predefined information structure, ensuring data and operational reliability. Through secure API connections, Awake.AI performs metadata validation, to ensure that it complies with the established standards for communication between systems, while allowing service providers to maintain full control over the data they share and the conditions under which it is shared. As a result, the ADMIRAL Catalogue becomes a truly dynamic environment where service providers are able to register their services considering emissions performance and sustainability criteria.

As previously mentioned, this integration plays a key role in fulfilling the solution purpose: making service capacity visible to potential clients, enabling optimised service usage and contributing to the reduction of emissions.

This integration is carried out through an API connection allowing the configured services to be published externally, in the marketplace. Once activated, selected service and company data, such as company name, description, website, contact details and addresses, are shared with Awake.AI Marketplace. The creation of services and subsequent interaction with AWAKE.AI Marketplace from our Low Emission Catalogue is done in real-time.

The services then become visible to cargo owners using the marketplace and if they are interested in a particular service, they can contact the service provider by email which can result in a transport request being initiated. Any updates made to the service configuration in the catalogue are automatically reflected in the marketplace, ensuring that the information remains updated and accurate.

The integration relies on a set of API endpoints that support organisation, user, office and listing. These endpoints ensure the structured exchange of information between ADMIRAL and Awake.AI, enabling synchronisation of service-related data. Below is the list of available functionalities:

- Organization: registration, update, delete
- Users: registration, update, delete,
- Organization Users: retrieve individual or multiple users
- Offices: registration, update, delete
- Organization Offices: retrieve individual or multiple offices
- Organization Listings: retrieve listings (single or multiple)
- Train Services Listings: create, update, delete
- Truck Services Listings: create, update, delete
- Land Hub Listings: create, update, delete
- Emissions: retrieve CO_2 emissions estimate based on services

2.4.1 How the integration works

The integration between Awake.AI and the ADMIRAL Service Catalogue is established through a structured multi-step process to ensure that services are correctly validated, synchronised and made fully operational within the marketplace environment. The process is exemplified in the next Figures and unfolds as follows:

Step 1: Registration in ADMIRAL Catalogue

The transport service provider initiates the process by completing the company registration form within the ADMIRAL Catalogue. This includes submitting essential company information and contact details (Figure 6).

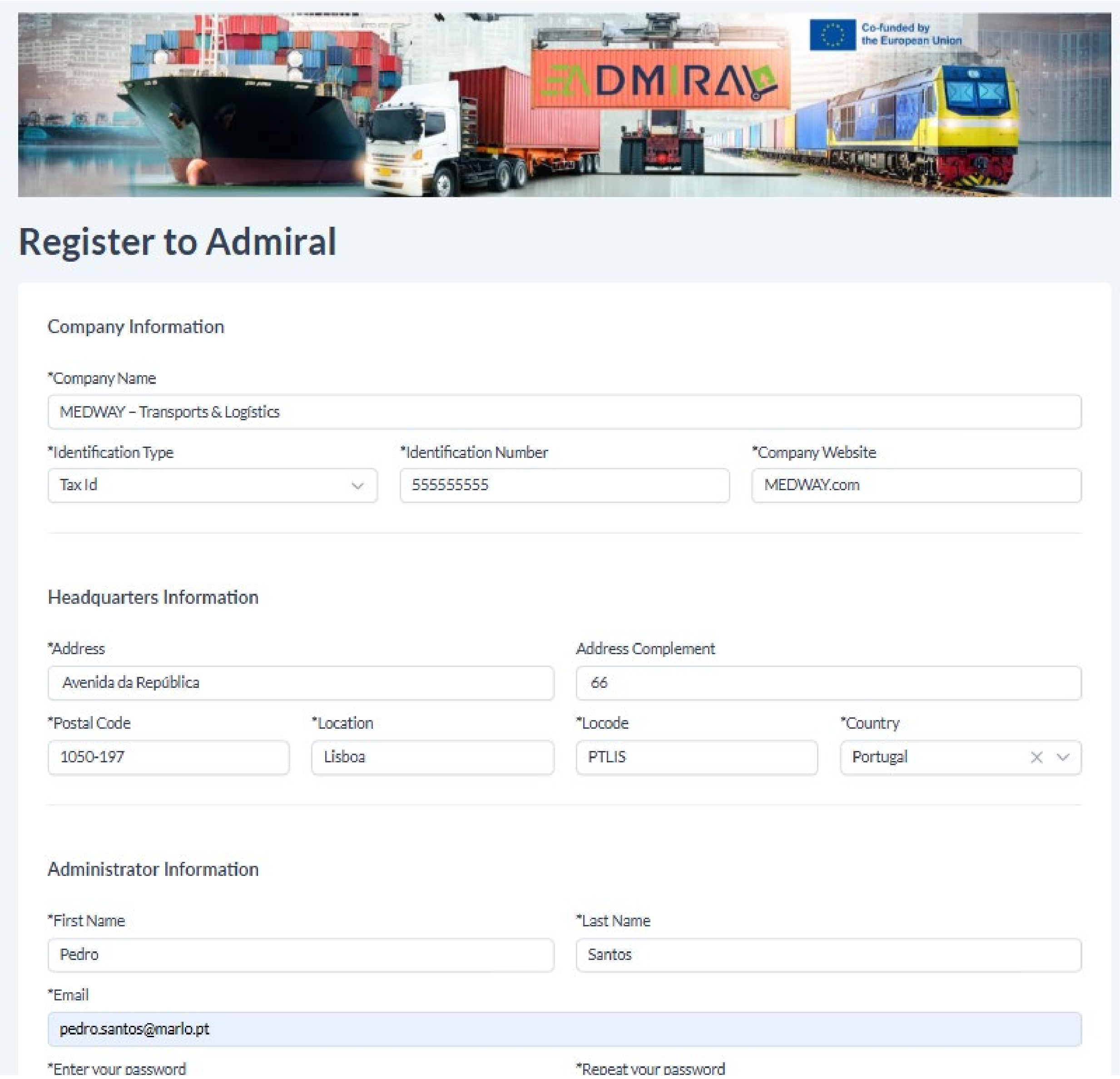

Figure 6. Registration in ADMIRAL Catalogue

Upon submission, a confirmation email is sent to the designated email address. Once confirmed, the account is activated, granting the provider access to the service configuration and management interface (Figure 7).

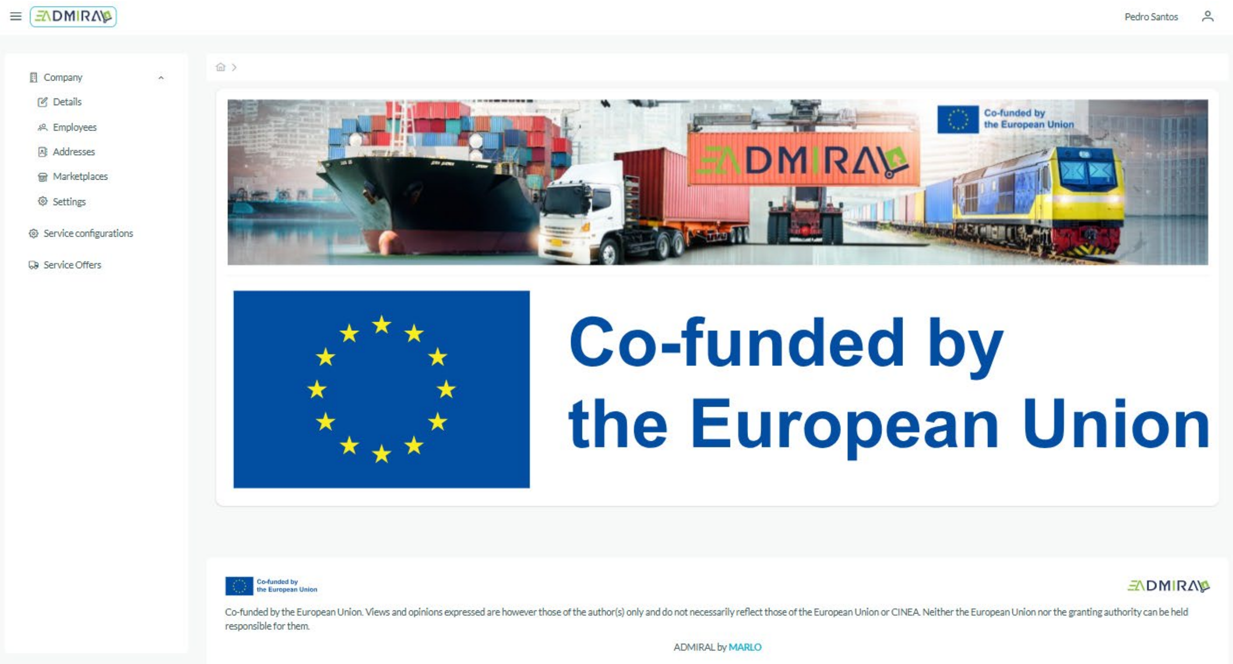

Figure 7. ADMIRAL configuration and management interface

Step 2: Activate integration

Integration with the Awake.AI marketplace is optional and only takes place if the company explicitly chooses to request it. As part of this process the company provides data such as company name, email, website, service description, selected addresses and selected contact person details (name and email). The decision to share this information lies entirely with the company at the time of the integration request (Figure 8). The integration of the services created at our Low Emissions Catalogue is not mandatory and can be disabled. This can be done by the Administrator of the company, it was done this way to give freedom to the data owner to publish the services at marketplaces.

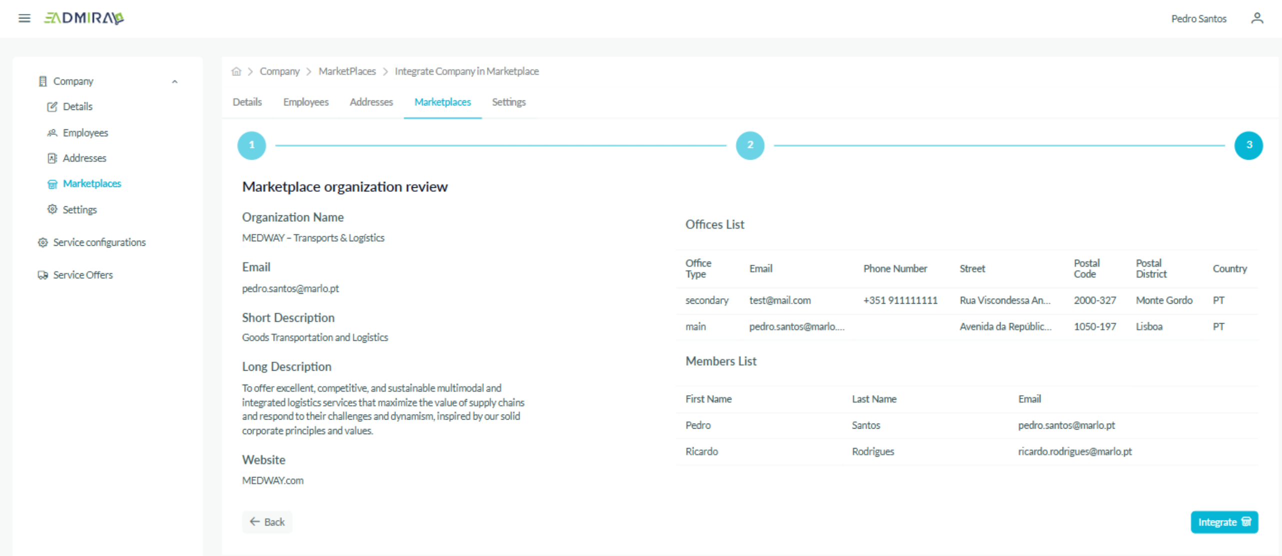

Figure 8. Activate integration

Step 3: Service configuration

Once registered in the ADMIRAL Catalogue the transport service provider is able to configure and manage its transport services through the platform. The service configuration process within the ADMIRAL Catalogue follows two structured steps:

- **Service type selection**

The provider begins by selecting the type of service (rail transport, road transport, land terminal). This selection dynamically adjusts the configuration interface, tailoring it to the specific operational profile (Figure 9).

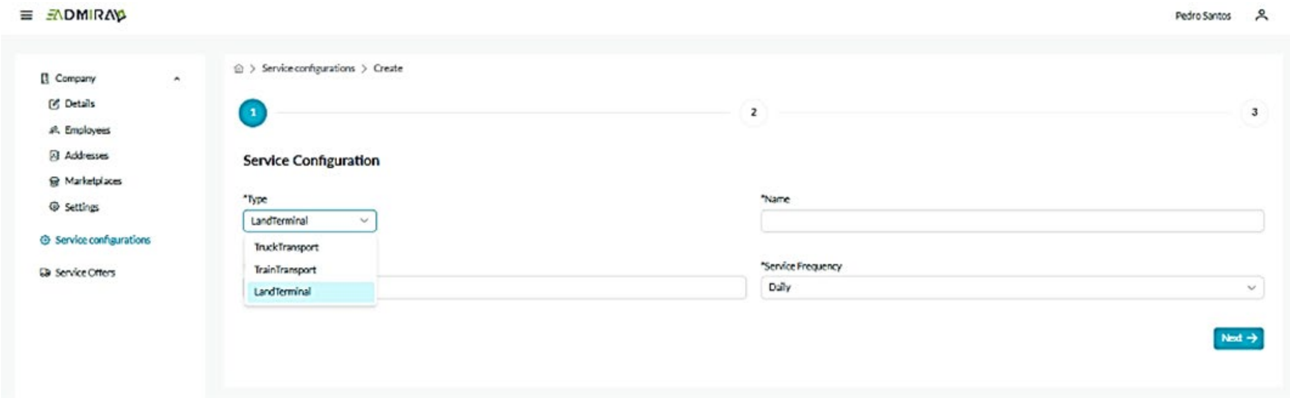

Figure 9. Service configuration

- **Detailed service configuration**

According to the selected type, the provider fills in all relevant operational details (such as cargo type, transport type). These parameters reflect the internal logic and technical capabilities of each provider the train service provider (Figure 10); truck service provider (Figure 11) and land terminal service provider (Figure 12).

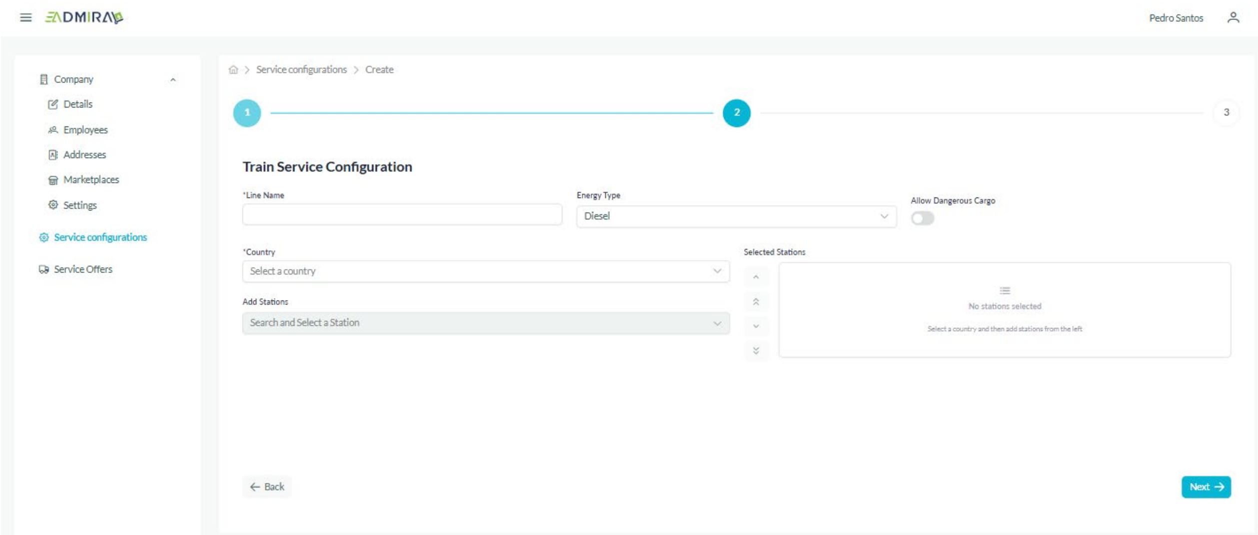

Figure 10. Train service configuration

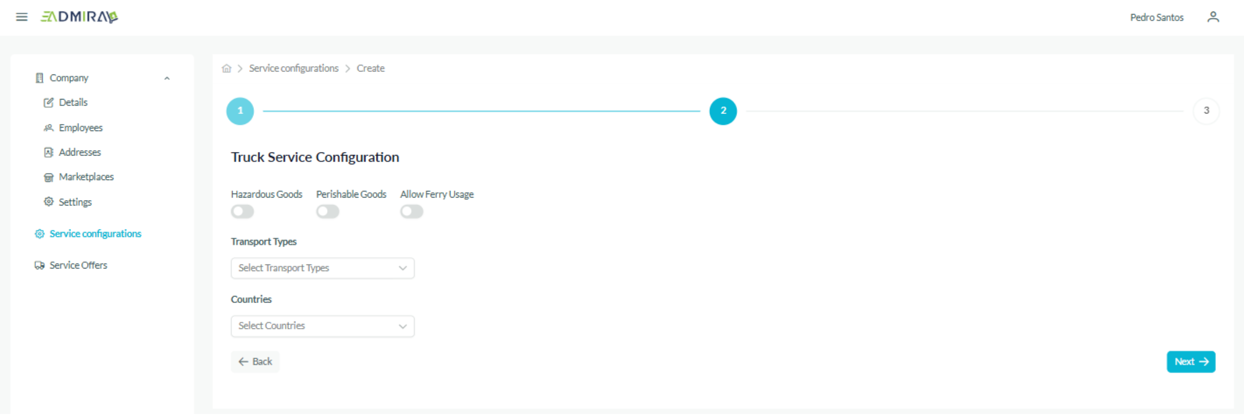

Figure 11. Truck service configuration

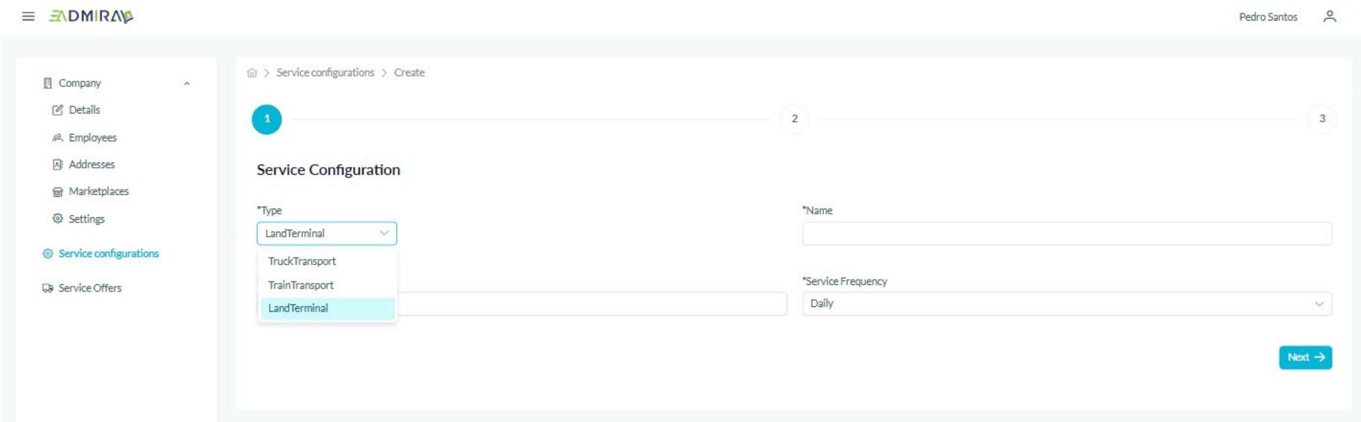

Figure 12. Land terminal service configuration

Step 4: Marketplace integration

If the company has the marketplace integration active, then once the service configuration is completed the service is shared with Awake.AI.

The following steps outline how the integration and data flow are managed between the involved platforms:

- The company activates the marketplace integration, establishing the connection between the ADMIRAL Catalogue and Awake.AI via API, this procedure is seamless to the user.
- Configured service data is transmitted automatically to Awake.AI through API endpoints (API Service Listing)
- Once validated, the service becomes publicly visible in the Awake.AI marketplace
- The service is then accessible to users such as cargo owners and shippers

Step 5: Search services in Marketplace

Considering the previous integration into the marketplace, users (cargo owner/shippers) gain access to new transport services submitted by the service providers through the ADMIRAL Catalogue. This enables service providers to leverage business opportunities by responding directly to demand, improving service visibility in a more dynamic and efficient logistic operation.

Step 6: Service updates

Service providers can update Service Configuration parameters (such as service frequency, pricing type) through the ADMIRAL Catalogue interface ensuring the information remains accurate and aligned with operational changes. This flow ensures that only verified and accurate services declared by the service provider appear in the Awake.AI Marketplace.

This setup is key to ensuring that the ADMIRAL Catalogue operates as a credible, accurate and sustainability-oriented logistics catalogue.

2.4.2 What the integration enables

The integration between Awake.AI Marketplace and ADMIRAL Service Catalogue is more than just a technical connection, it is a fundamental enabler of the platform functionality and value. This integration allows to reach new clients and cargo, through the visibility given to the transport services offered on this corridor.

In the Awake.AI Marketplace cargo owners and shippers can access and view transport services that have been published within the ADMIRAL Service Catalogue. These services may originate directly from transport service providers or be made available through data integrations, such as NEXUS Open Data from the national PCS – Port Community System (JUL). This approach makes the marketplace dynamic and collaborative. The integration ensures a structured and consistent data exchange between platforms.

Additionally, it reinforces stakeholder trust. Each actor maintains full control over what data is shared, with whom and under what conditions. This is a critical requirement for adoption in a competitive and sensitive sector like logistics.

2.4.3 Technical considerations

From a technical standpoint, the integration between ADMIRAL Service Catalogue and Awake.AI Marketplace has been designed to meet high standards of security and scalability.

Security is ensured through encrypted communication channels (HTTPS) and authentication mechanisms using OAuth2 tokens or secure API keys. This guarantees the confidentiality and integrity of data exchanged between systems.

The solution also supports scalability. The solution architecture allows configuring the level of information shared with the marketplace, enabling the communication protocol established with other marketplaces to differ from the one defined with Awake.AI.

The integration ensures real time data availability, allowing the Awake.AI marketplace to display the most current and validated service offerings.

2.5 Results of test

During writing period of this report, November 2025, the ecosystem between ADMIRAL Service Catalogue and Marketplace were under integration developments and concluding the respective tests, so this section is reporting the expected use cases. For that purpose, MARLO and APS will have to find a stakeholder (road and train service providers, along with beneficial cargo owners) to demonstrate and test the scenarios as explained for transport service, namely the integration of rail transport services via JUL/Nexus and the introduction of the service by road transport.

The ADMIRAL Catalogue is intended to serve as a structured service catalogue, where transport services offered by different logistics stakeholders are configured for integration into the marketplace. Each stakeholder plays a specific role within the system, which ensures that users interact with the platform according to their operational responsibilities and data needs, while contributing to a trusted transport services ecosystem. The following diagram illustrates the workflow of the ADMIRAL Catalogue.

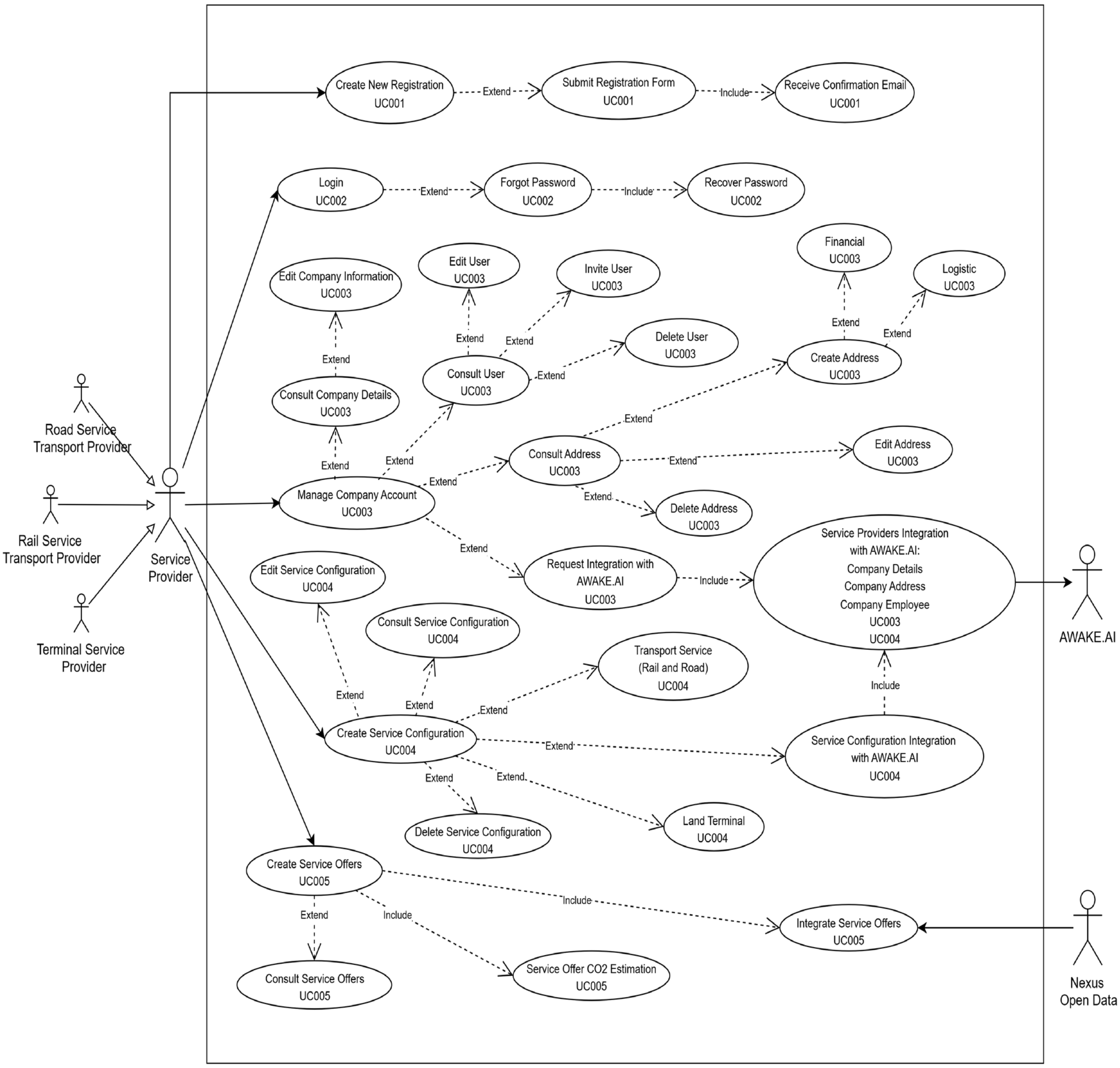

Figure 13. ADMIRAL Use Case Diagram

The process begins with the user (a service provider which may be a road/rail service transport provider or a terminal service provider) completing and submitting the registration form with the company information. After submission, an email confirmation is sent, and once the email is confirmed the user gains access to the catalogue. If the password is forgotten the user can request to recover it using the registered email address.

Within the company account section, the user has access to several options related to company management. The user can consult and edit the company details, such as the company name, email, description, short description, contact information, and website of the company. This ensures that all company related information remains updated and accurate. In addition to managing company information the user can also access the list of associated users (employees with different roles: user or administrator) where they have the ability to consult user details (first name, last name, email, phone number, role and status), invite new users to the catalogue (sending an email invitation) and delete existing users when necessary. This provides clear control over who can access and manage the company account. The platform also allows the user to consult, create, edit and delete company addresses. This includes both financial addresses (for administrative purposes) and logistics addresses (related to operational purposes). An important feature within this use case is the ability to request integration with the marketplace. This action initiates the synchronization process between the ADMIRAL catalogue and the Awake.AI marketplace, which is performed via Rest API. When this request is made the system integrates the following information: company details, address and employee.

Only after this integration is completed can the company services be published and become available in the Awake.AI Marketplace. As such, this functionality is essential for making the company services visible within the marketplace.

Regarding service configuration, users are able to create service configurations for different types of services (rail, road and land terminal) based on the specific services their company provides. Users are also able to edit existing configurations to reflect changes in service details or delete services that are no longer relevant. This ensures that the information about the company service remains accurate and updated for proper integration with the Awake.AI marketplace. If a cargo owner is interested in a particular service, they can contact the service provider by email using the contact associated with the company service information.

Create Service Offer allows transport service providers to consult and define the offers of their services. These offers specify service details such as service type and availability(schedule). In addition to manual creation, service offers can also be integrated into the ADMIRAL Catalogue via NEXUS Open Data through API based input. This enables structured submission of service data, particularly for rail service providers, and ensures that offers are consistently aligned with the company operational systems.

Following the creation of a service offer, the system proceeds to obtain a CO_2 emissions estimate based on the configured service parameters.

2.5.1 Registration

Name	Create New Registration
ID	UC001
Actors	Service providers(admin)

Description	To access the ADMIRAL Catalogue the actor must first complete a registration process. This involves accessing the platform and filling in the corresponding registration form with the required information.
Pre-conditions	1. N/A
Main path	1. The actor accesses the ADMIRAL Catalogue 2. The actor clicks in the Register here option 3. The registration form is displayed, and the actor must fill the required fields: a. Company information: ▪ Company name ▪ Identification type ▪ Identification number ▪ Company website b. Headquarters information ▪ Address ▪ Address complement ▪ Postal code ▪ Location ▪ Country ▪ Locode c. Administrator Information ▪ First name ▪ Last name ▪ Email ▪ Enter your password ▪ Repeat password 4. The actor submits the form 5. A confirmation email is sent to the actor confirming successful registration
Exception Path	1. During step 4 the system detects errors such as: a) Registration form with incomplete or invalid data b) Invalids email format or duplicate email
Post-conditions	1. A new user account is created in the system 2. The user receives a confirmation email
Validations	1. All mandatory fields must be filled in before submission 2. The email address must follow a valid format 3. The email address must not already exist in the system 4. The password must meet the required format criteria (minimum length: 8)

2.5.2 Login

Name	Login
ID	UC002

Actors	Service providers
Description	To access the ADMIRAL catalogue and its functionalities the actor must log in using valid credentials. The login process verifies the actor identity and grants access to authorised features.
Pre-conditions	1. The user inserts valid login credentials
Main path	1. The actor enters valid credentials (email and password) 2. The system verifies the credentials 3. The system grants access and redirects the user to the main dashboard
Alternative Path	1. The actor selects the Forgot Password? option on the login page 2. The actor enters an email address associated with a registered account 3. The system sends a recovery email with a password reset link 4. The actor sets a new password and submits 5. The system confirms the update and redirects the actor to the login page 6. The actor logs in using the new password
Exception Path	1. The actor enters an email address that is not associated with any registered account
Post-conditions	1. Login is successfully completed, and the actor is granted access 2. If the actor followed the password recovery process: a) The password is successfully updated b) The user regains access to the platform
Validations	1. The email must follow a valid format(user@example.com) 2. The credentials must match an existing registered account 3. If credentials are incorrect an error message is displayed 4. In the password recovery flow the new password must meet the required format criteria (minimum length: 8)

2.5.3 Account details

Name	Manage Company Account
ID	UC003
Actors	Service providers(admin)
Description	This use case covers the actions available to a company administrator to manage the company account on the ADMIRAL platform. These actions include viewing and editing company details, managing users, addresses and initiating integration process with marketplace
Pre-conditions	1. The actor is a registered user with administrator privileges for the company

<table>
<tr><td>Main Path</td><td>1. The actor accesses the Company menu
2. Selects the Details option
• The actor is able to consult company information:
▪ Company name
▪ Email
▪ Description
▪ Short Description
▪ Phone Country Code
▪ Phone Number
▪ Website</td></tr>
<tr><td>Alternative Path</td><td>AP1 Edit Company Details

1. The actor is on the Details page
2. Edits one or more of the available fields
3. Select the Save button
4. The system validates the data and saves the changes
5. A confirmation message is displayed with the updated information

AP2 Consult User List

1. The actor selects the Employee option.
2. The system displays a list of existing employees and is presented with following information:
▪ First Name
▪ Last name
▪ Email
▪ Phone Number
▪ Role
▪ Status

AP3 Invite User

1. To invites new employees the actor must fill the form with the following fields:
▪ First name
▪ Last name
▪ Email
▪ Role
2. Select the Submit button

AP3 Edit User

1. Selects the Edit Addresses option
2. The actor is able to edit the following fields:
▪ First Name
▪ Last name
▪ Email
▪ Phone Number
▪ Role</td></tr>
</table>

	AP4 Consult Address 1. The actor selects the Addresses option • The system displays a list of existing addresses, and the actor is presented with the following information: ▪ Address type ▪ Address ▪ Address complement ▪ Postal code ▪ Location ▪ Country AP5 Edit Addresses 1. Selects the Edit Addresses option 2. The actor is able to edit the following fields: ▪ Address type ▪ Address ▪ Address complement ▪ Postal code ▪ Country ▪ Locode ▪ Email ▪ Phone number country code ▪ Phone number AP6 Request Integration 1. The actor requests integration with marketplace 2. Select the Integrate option 3. Fill the integration form with the following fields: ▪ Company Name ▪ Company Email ▪ Description ▪ Short Description ▪ Website ▪ Addresses (adds only the ones that are selected) ▪ Employees (adds only the ones that are selected) 4. Select the Integrate option AP7 Settings 1. The actor provides the NEXUS Client ID in Settings to activate external API integration 2. Select the Save option
Exception Path	1. During any of the available actions (editing, creating, inviting, requesting integration) one of the following occurs: a) Missing filling of mandatory fields b) Duplicate entry detected (same employee email) c) System error during data validation or saving

	d) Integration request fails due to external API error or connectivity issue with Awake.AI e) The system detects that the Client ID is invalid 2. The system displays an appropriate error message 3. The actor corrects the input
Post-conditions	1. The company account data is updated and stored in the ADMIRAL system 2. If integration with Awake.AI was requested the data is synchronised 3. All modifications are reflected in the user interface and available for further actions
Validations	1. All required fields must be completed before saving 2. Email addresses must follow a valid format and not be duplicated within the same company 3. Any failed validation must trigger clear error messages and prevent data submission

2.5.4 Service configuration

Name	Create Service Configuration
ID	UC004
Actors	Service providers
Description	Actor can access the service configuration section to view and manage existing logistics services. The platform allows creating new service configurations, as well as editing or deleting existing ones, across different service types such as rail, road and terminal.
Pre-conditions	1. The actor is logged in and has permission to access and manage service configurations
Main path	1. The actor accesses the Service Configuration menu 2. Selects the option Creates Service Configuration 3. Fills in the required fields in the Create Service Configuration form: ▪ Type ▪ Name ▪ Description ▪ Service frequency 4. Additional fields are displayed depending on the selected service type (road, rail, terminal) 5. The system validates the data and updates the service configuration 6. The new service configuration is saved and added to the list
Alternative Path	A1 Consult Service Configuration 1. The actor accesses the Service Configuration section 2. The system displays a list of existing service configurations

	3. The actor selects a service to view its detail A2 Edit Service Configuration 1. The actor selects an existing service from the list and chooses the Edit option 2. The actor updates the necessary fields 3. The system validates the updated data 4. The updated configuration is saved and reflected in the list A3 Delete Service Configuration 1. The actor selects an existing service from the list and chooses the Delete option 2. The system displays a confirmation message: Do you want to delete this record? 3. The actor confirms the deletion 4. The system deletes the service configuration and updates the list view
Exception Path	1. The actor attempts to save a service configuration 2. If any mandatory field contains missing input the system displays an error message: Required 3. The actor is not able to proceed
Post-conditions	1. The service configuration data is saved and updated in the ADMIRAL system 2. Edited configurations reflect the latest changes
Validations	1. All required fields must be completed for the action to proceed 2. The system must validate and confirm data before saving or creating the configuration

2.5.5 Service offers

Name	Create Service Offers
ID	UC005
Actors	Service providers/ NEXUS Open Data
Description	The actors are able to create service offers in the ADMIRAL platform. These offers can be manually created or automatically integrated from external sources such as NEXUS Open Data
Pre-conditions	1. The actor is logged in 2. Accesses the Create Service option 3. At least one valid service configuration is available and associated with the company
Main path	1. The actor is able to create service offers:

	• Manually through the interface. The actor must fill the required fields depend on the type of service: a) For Truck ▪ Service type ▪ Schedule (start/end) ▪ Schedule expiration ▪ Vehicle type ▪ Fuel type ▪ Licence plate number ▪ Vehicle type ▪ Capacity (TEUS) ▪ Weight (Kg) ▪ Departure address ▪ Destination addresses b) For Train ▪ Service type ▪ Schedule (start/end) ▪ Schedule Expiration ▪ Wagon Reference ▪ Capacity (TEUS) ▪ Weight (Kg) ▪ Stations ▪ Automatically through background processes that receive, and process service offers from external sources (NEXUS Open Data) 2. The system validates and saves the service offer
Exception Path	1. From step 3 of the Main Path the actor attempts to create a service through integration 2. The system receives invalid or incomplete data from external sources the background process logs the error and skips or flags the offer
Post-conditions	1. The manually created service offer ate saved and listed in the ADMIRAL Catalogue 2. Service offers received from external systems (NEXUS Open Data) are processed in the background and, if valid, added to the offer list
Validations	1. The system prevents submission if required fields are missing 2. In background processing (NEXUS Open Data): ▪ Incoming data must comply with the expected structure (Transport Service Dataset) ▪ Invalid or incomplete datasets are rejected and logged

2.6 Summary of the pilot

The Portuguese-Spanish Pilot activities addressed building a catalogue of low-emission services for logistics operations between Sines (PT) and Madrid (ES), bringing together the logistics stakeholders' community in this corridor for increased collaboration, and promoting a modal shift from road to rail freight transport between Sines and Madrid. To identify the potential for reducing emissions, a multimodal and cross-border traffic analysis study including information on available infrastructure and cargo volumes was conducted. Special attention was also given to understanding stakeholder needs through first-hand insights. In summary, stakeholder expectations include, among other things, that the Sines-Madrid corridor should be viewed as a network, not just a point-to-point route; that it should allow cargo tracking within the corridor; and that it should have certified emissions awareness/calculation. Stakeholders are open to emissions reduction, but not at any cost, and expect to reduce empty miles, mainly in road transportation.

Summary of technology developed in this pilot

Marketplace, target TRL 7. The main development was done parallel WP4 Multimodal marketplace development, by AWA. To active TRL 7, demonstrate solution at operational environment, we will bring end-users to publish their services. The services already uploaded from NEXUS/JUL will be updated.

- Pilot 1) Digital & Green Multimodal corridor (Portugal-Spain), has developed the service catalogue integration (inclusion of energy-efficient and multimodal services to the Awake.AI Marketplace).
- Each pilot integrates the suitable service or tool components to the ADMIRAL Service Catalogue. More details in Section 6.

- Current TRL 7.

Integration tool, target TRL 7.

- Pilot 1) Digital & Green Multimodal corridor (Portugal-Spain), has developed the ADMIRAL Service Catalogue integration. The integration enables user login, user and company management, service offers and availability creation and management.
  - API integration with JUL/Nexus Open Data (two-way integration)
  - API integration with Awake.AI Marketplace, development continues in WP4 until end of the project

- Current TRL 7

CO_2 emission reduction

During the reporting period, until end of October 2025, the API for CO_2e for marketplace was in development. The API CO_2 emission calculator is a product from Awake.AI, we received API specifications and we are testing it. The TRL of the integration between our Low Emissions Catalogue and the CO_2 Emission calculator from Awake.AI should achieve TRL 7. Baseline values estimation and CO_2e emissions average and evolution through time based on (see traffic analysis, section 2.2.2):

- Types of vehicles
- Types of cargo
- Routes
- Fuel type / energy

Future scenarios shows that rail remains the most effective near-term decarbonisation lever, capable of absorbing additional volume with modest infrastructure upgrade. Emission intensity estimates, well-to-wheel, reveals that electric rail emits 0.28 tons CO_2e per twenty-foot equivalent unit (TEU) versus 0.60 tons CO_2e/TEU for diesel trucks.

The electrified railway transport on the Sines-Madrid corridor represents an environmentally and economically superior alternative to road transport, driving a greater modal shift by economic agents. This transition is expected due to the significant reduction in greenhouse gas emissions, as electric traction is cleaner than fossil fuel-based traction. Furthermore, shifting goods from road to rail will result in a decrease in heavy goods vehicle traffic on highways and national roads, which consequently increases road safety and reduces accidents across the entire corridor. The operational efficiency and superior capacity of the electrified railway, combined with these environmental and safety benefits, make it the preferred choice for freight movement, aligning with sustainability and economic competitiveness goals.

3 GREEN LOGISTICS: OPTIMIZING POSTAL SUSTAINABILITY ACROSS BORDERS PILOT (*SLOVENIA-CROATIA*)

3.1 Overview of the pilot

3.1.1 Pilot environment

Postal-logistics operations between Slovenia and Croatia are characterized by significant parcel volumes and well-defined cross-border processes, including standardized pickups, shipment acceptance, sorting, mid-mile transport, handover and last-mile processes. These processes are governed by international postal frameworks defined by the Universal Post Union (UPU) and further operationalized through interoperability and performance standards established by the International Post Corporation. The flow of postal traffic between the two national operators is facilitated through two designated Offices of Exchange (OE), as shown in Figure 14, located in Ljubljana and Zagreb, which serve as key points for customs clearance and transshipment.

In addition to the Offices of Exchange, the network relies on two dedicated logistics centers and established transshipment hubs that ensure smooth handling and routing of parcels. The backbone of this operation is an extensive road transport network operating on predefined routes and fixed schedules, providing reliable and predictable service levels for cross-border deliveries.

In 2024, Pošta Slovenije transported 113,525 parcel shipments to Croatia, while Hrvatska Pošta handled 13,049 parcel shipments to Slovenia — a clear indicator that outbound volumes from Slovenia significantly exceed inbound flows from Croatia.

A closer look at these flows reveals that 35% of cross-border parcel traffic originates from the North-Eastern region of Slovenia, where a concentration of e-commerce retailers and industrial clients generate consistent shipment volumes destined primarily for end customers in Zagreb metropolitan area. This corridor - connecting the North-East of Slovenia with Croatia's capital remains the busiest and most strategic axis for postal and logistics exchanges between the two operators and countries.

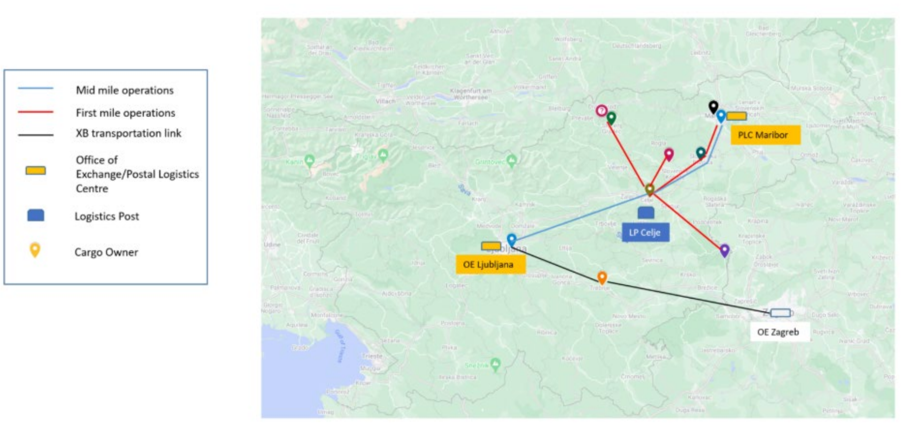

Figure 14. Current shipment flow from companies of North-Eastern Slovenia towards Zagreb

3.1.2 Challenge and purpose of the pilot

Partners managing postal traffic from Slovenia's North-Eastern region to Croatia operate largely independent logistics networks. Cargo owners in this region account for approximately 35%% of all cross-border shipments destined for Croatia. However, these networks lack integration through a common information system, resulting in fragmented and delayed data on shipment volumes, weights, and final destinations. In the current operational setup, Pošta Slovenije exchanges standardized electronic postal data with Hrvatska Pošta to support smooth cross-border (XB) parcel flows. Ahead of physical handover, Pošta Slovenije transmits advance electronic data, including PREDES messages, which contain planned dispatch information such as shipment composition, routing, weights, and scheduled transport details. During the transport and delivery lifecycle, postal event messages—such as EMA (arrival), EMB (departure), and EMC (delivery confirmation)—are exchanged to provide status visibility and support coordinated processing and exception handling. However, this data exchange is largely periodic and event-based rather than real time, relying on predefined reporting intervals and batch transmissions, which limits dynamic operational optimisation and real-time responsiveness across the border. This lack of real-time information makes it difficult to efficiently plan workforce allocation in transshipment warehouses or to organize transport resources, from the number and type of vehicles required to the optimal routing of deliveries.

The consequences of this fragmented approach are significant: lower vehicle load factors, missed opportunities to optimize transport routes, increased delivery delays, and ultimately, reduced service quality for the end recipient. Additionally, the indirect routing of shipments through the Ljubljana Office of Exchange adds unnecessary costs for shipment consolidation and extra transport legs, while also generating negative environmental externalities and prolonging delivery times.

In Croatia, last-mile delivery is currently supported by a collaborative crowd-shipping platform, but this platform operates separately from Pošta Slovenije's ERP (Enterprise Resource Planning) system. The lack of integration means delays in critical information sharing, higher manual workload, greater risk of data entry errors, and reduced efficiency in planning downstream activities. While the platform enables delivery by logistics companies, taxi operators, and licensed couriers, including those serving quick-commerce food deliveries. It does not currently allow private individuals to participate, limiting the flexibility and scalability of the last-mile network. This has contributed to reduced delivery reliability following the COVID-19–driven e-commerce surge, as IPC UNEX quality-of-service measurements reported by Pošta Slovenije show that only around 90 % of international items met next-day (D+1) delivery targets in recent years, below pre-pandemic expectations.

During the COG-LO[5] Horizon 2020 project (2018–2021), Pošta Slovenije (PS) partnered with Hrvatska Pošta (HP) to co-develop a cognitive cross-border postal-logistics framework. This innovative framework enables flexible logistics operations that bypass rigid transport routes through the traditional Office of Exchange, while still adhering to all business and regulatory requirements. It provides the foundation for integrating diverse logistics networks and supports the implementation of new, smart business solutions.

As part of COG-LO's exploitation strategy, PS and its partners developed a prototype logistics tool to optimize last-mile delivery processes, with the twin aims of improving efficiency and conserving

[5] GOG-LO - COGnitive Logistics Operations through secure, dynamic and ad-hoc collaborative networks. Horizon Europe project (2018-2021) https://cordis.europa.eu/project/id/769141

resources. Building on this foundation, the current objective is to develop a multi-modal logistics marketplace that fosters collaboration among stakeholders, enhances cross-border process efficiency, and promotes low-emission transport solutions.

The goals of the Slovenia–Croatia pilot include:

- Integrating, connecting, and harmonizing the demand for logistics services.
- Streamlining first-mile and pre-haulage processes.
- Establishing ad-hoc transport corridors that can bypass the Ljubljana Office of Exchange where feasible, thus reducing transit times and costs.
- Facilitating the seamless integration of independent logistics networks.
- Implementing an information architecture that generates transparent insights into the environmental impact of logistics decisions, supporting greener and more sustainable operations.

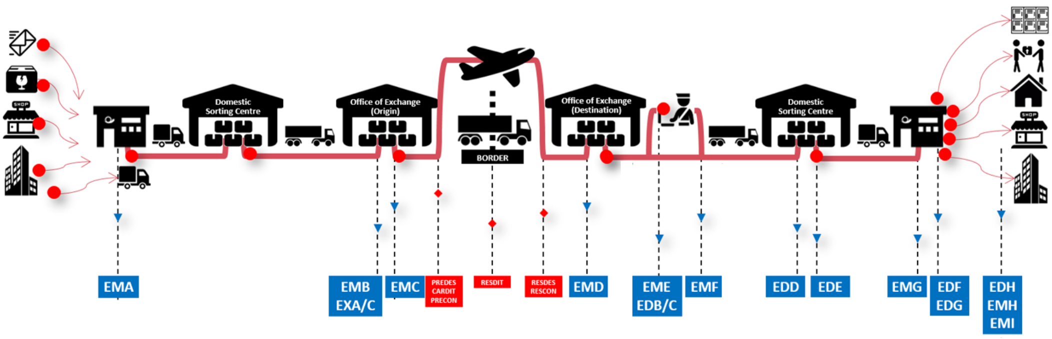

Figure 15. Diagram of international shipment flow in postal operations

Figures 15 and 16 provide a comprehensive overview of the current exchange procedures between Pošta Slovenije and Hrvatska pošta. These visuals map out the entire process chain, starting with first-mile activities such as customer pickup, continuing through mid-mile operations and cross-border handling, and concluding with final delivery in Croatia. In addition to tracing the physical flow of parcels, the illustrations also depict the flow of critical data, which ensures that cross-border operations remain compliant with postal and customs regulations.

Once customers submit shipment details, Pošta Slovenije (PS) initiates the cross-border delivery process. These operations typically follow a structured postal cycle, which is a repeating daily pattern: deliveries are completed early in the day, pickups occur throughout the business day, and consolidation, sorting, and preparation take place in the late evening and overnight hours (Figure 16).

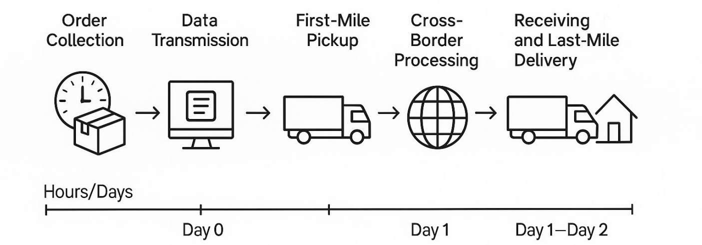

Figure 16. High-level representation of shipment flows

This same cycle applies to international shipments as hereafter described and illustrated in Figure 17.

- **Order collection:** Businesses accumulate customer orders during the day and must finalize this collection within a specified cut-off window (commonly between noon and 6 PM on Day 0) to guarantee on-time delivery. Based on the order specifics, companies prepare parcels by packaging, weighing, labelling, and compiling an accurate shipment manifest.
- **Data transmission:** The finalized shipment manifest is transmitted to the postal operator via dedicated applications — such as e-waybill systems — or other standardized data export services. Once received, this data triggers the first-mile pickup process.
- **First-mile pickup:** Collection begins at local logistics posts starting around 1 PM (Day 0) and is carried out using trucks with large cargo capacities. Pickup routes and schedules follow a largely static model, with minimal dynamic routing or real-time optimization, primarily due to the lack of integrated digital tools and data-driven planning systems that would enable adaptive, real-time operational decision-making.
- **Local processing and dispatch**: After pickup, parcels are processed at the nearest logistics post and then directed toward the Office of Exchange (OE) and the central postal-logistics hub. This stage usually occurs between 2 PM and 8 PM (Day 0).
- **Cross-border processing**: At the OE, shipments undergo another round of processing in line with standardized cross-border (XB) exchange protocols established between postal operators. These procedures require that all XB shipments pass exclusively through designated OEs, with no provision for alternate or expedited routes. This processing typically takes place overnight, from 8 PM to 4 AM (Day 0–Day 1).
- **Transnational transport:** The movement of cross-border shipments is limited to one predefined transport corridors connecting the Slovenian and Croatian OEs located in Ljubljana and Zagreb respectively. This leg generally runs from 8 AM to midnight on Day 1.
- **Receiving and last-mile delivery**: Upon arrival at the OE in Zagreb, parcels are received, processed according to XB operational standards, and prepared for final distribution. Once processing is complete, shipments are handed off to the last-mile delivery network for final drop-off to recipients (Day 1–Day 2).

In summary, the current exchange model is heavily reliant on rigid scheduling, fixed transport links, and standardized handling protocols. While this ensures regulatory compliance and process consistency, it leaves limited room for dynamic route optimization or ad-hoc adjustments — factors that could otherwise improve operational efficiency, reduce costs, and shorten delivery times.

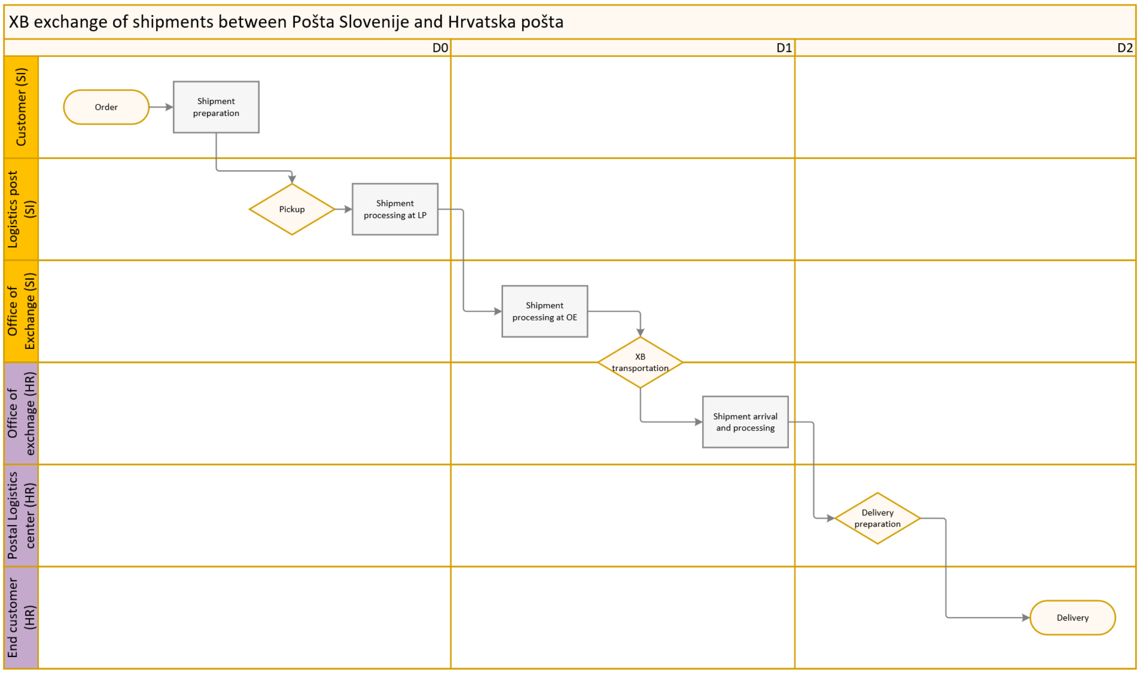

Figure 17. Cross-Border shipment flow diagram

Pošta Slovenije (PS) and Hrvatska Pošta (HP) rely on a suite of internal and external IT systems to manage both domestic and cross-border postal operations. These digital tools enable effective communication and coordination between the two operators during the exchange of shipments across national borders.

For the management of international postal traffic and accounting, PS uses the ILPost system, while HP operates its own dedicated system for similar functions. Data interoperability between the two operators is achieved through well-established EDI (Electronic Data Interchange) protocols, ensuring the seamless transfer of shipment information and related business data.

On the domestic front, PS uses the Universal Counter Application (UPO) to manage postal flows within Slovenia, while HP utilizes Material Input per Unit Service (MIPS) and the New Parcel Application (NPA) for parcel operations in Croatia. All shipment-related information and supporting business data are securely stored within these applications and their respective databases. For customers, shipment data is shared with PS through digital channels such as the E-waybill application or other compatible web services.

Despite this digital backbone, cross-border postal-logistics processes, spanning first-mile to last-mile, remain highly rigid and pre-defined, often remaining unchanged for extended periods. While this provides predictability for resource planning and daily work organization, it significantly limits operational agility in the mid-mile segment. Additionally, the absence of advanced optimization tools means that first- and last-mile pickup and delivery routes are not dynamically planned, leaving considerable potential for efficiency gains untapped – for example, vehicles continue to follow pre-defined routes even when parcel volumes fluctuate significantly or when ad-hoc pickup requests arise, resulting in partially loaded vehicles, unnecessary detours, or delayed collections that dynamic routing could avoid.

Key challenges faced by PS and HP in cross-border (XB) shipment exchange include:

- Strict operational rules that limit flexibility in cargo handling and route optimization.
- Incomplete integration of available data into logistics decision-making processes.
- Highly inflexible postal-logistics workflows that cannot adapt to real-time demand shifts.
- Closed frameworks that do not easily allow third-party logistics providers to participate.
- Demand for services that is neither harmonized nor integrated across networks.
- Limited visibility and options for choosing more sustainable transport solutions.

To address these pain points, the pilot will implement an AI-powered logistics planning tool, with a strong focus on optimizing the first- and last-mile operations for shipments moving between Slovenia and Croatia.

Key functionalities of the AI tool include:

- Pickup route optimization: By analysing real-time shipment data and customer locations, the tool calculates the most efficient collection routes, minimizing unnecessary mileage and vehicle downtime.
- Delivery route optimization: For the last-mile, the tool generates the best possible routes to ensure timely deliveries, reduce fuel consumption, and improve overall customer satisfaction by minimising total travel distance and optimising equal distribution of visits.

The pilot aims to achieve the following tangible outcomes:

- Enhance the overall efficiency of cross-border postal operations between PS and HP.
- Target an average reduction in total mileage by 25%.
- First-mile milage reduction baseline: 161.1 km.
- Mid-mile milage reduction baseline: 282 km.
- Reduce average travel time by 20%.
- Cut greenhouse gas emissions per parcel delivery by 25%.
- First-mile greenhouse gas baseline (normalised per ton kilometre): 0.861 $kgCO_2e$/t-km.
- Mid-mile greenhouse baseline (total emissions): 759.27 $kgCO_2e$.
- Increase vehicle load factors by 20%, supported by better shipment consolidation at nearby logistics posts.
- First-mile load factor baseline: 40.6%.
- Middle-mile load factor baseline: 19%.

The Key Performance Indicators (KPI) are:

- **KPI 1: Carbon Intensity (CI)** – Measures emissions per trip, per parcel, and per weight-distance unit to evaluate the environmental impact of transport activities.
- **KPI 2: Mileage Reduction** – Tracks the decrease in kilometres travelled as a result of route optimization and improved planning.

- **KPI 3: Load Factor Improvement** – Assesses how effectively vehicle capacity is used through consolidation rate and dwell time analysis.
- **KPI 4: Per Trip Time and Velocity Data (Average Values)** – Monitors average travel time and speed to gauge improvements in delivery efficiency.

3.1.3 Partners involved and their roles

The Slovenia-Croatia pilot was implemented by a team of diverse partners, each bringing specific expertise to support the successful implementation of pilot activities:

- **PS (Pošta Slovenije)** , the national postal and leading logistics operator, is key to improving first- and mid-mile flows from North-Eastern Slovenia to Zagreb. Together with SOLV and other partners, PS is integrating fragmented networks into a new cross-border logistics framework aimed at reducing CO_2 emissions and delivering more efficient, sustainable, and tailored logistics services.
- **HP (Hrvatska pošta),** the Croatian national postal operator and owner of Locodels, acts as an administrative and strategic advisor within this pilot.
- **Locodels,** a subsidiary of HP, specializes in same-day delivery through its collaborative crowd-shipping platform. Its primary role in this pilot is to test and implement innovative technological solutions aimed at optimizing last-mile delivery operations.
- **SOLV (Solvesall)** is a specialized software development company with deep expertise in designing custom analytics and optimization solutions for the logistics sector. In this pilot, SOLV tackled software engineering challenges by developing a robust digital solution to support the cross-border logistics framework. Its deliverables include advanced features for route optimization, cargo space utilization, and dynamic distribution planning — all of which are crucial for enhancing operational efficiency and sustainability.
- **UL (The University of Ljubljana)** — UL oversee emissions measurement and impact assessment activities, including the calibration and deployment of measurement equipment and the processing of collected data. By integrating vehicle trip data with cargo movement information, UL calculated key performance indicators (KPIs) before and after the pilot, providing a clear picture of the project’s effect on greenhouse gas (GHG) emissions under different scenarios.
- **Cargo owners** from Slovenia’s North-Eastern region are actively contributing to the pilot by sharing shipment data and operational insights. Their participation will enable data-rich, real-world testing and scenario simulations, ensuring that the solutions developed are grounded in practical business needs and market conditions.

3.2 Tested scenarios

This subsection describes the initial set-up for tested scenarios: pilot requirement specification, needs and constraints mapping, cross-border postal flow evaluation, baseline data for first-mile and cross-border corridor set up. Also, methods for emission measurement and impact assessment with vehicle trip data, carbon aware optimisation design and Green Logistics User Index set-up are presented.

The following section outlines a comprehensive set of scenarios developed and tested within the green logistics pilot, structured around the three core processes of first-, mid-, and last-mile operations. These scenarios were designed to address a range of operational and strategic objectives, including the specification of pilot requirements, identification of key constraints and stakeholder needs, and the evaluation of cross-border postal flows. Initial baseline data was gathered for both first-mile operations and the cross-border corridor setup, forming a foundation for further analysis. In parallel, dedicated methodologies for emissions measurement and impact assessment were applied, using vehicle trip data to track environmental performance. The scenarios also incorporate the design of a carbon-aware optimisation framework and the establishment of a Green Logistics User Index (see subsection 3.2.9), ensuring a data-driven and sustainability-oriented approach to evaluating and improving logistics services across the full transport chain.

3.2.1 Pilot requirements specification

In the initial phase of the Slovenian–Croatian pilot (Green Logistics: Optimizing Postal Sustainability Across Borders), our primary objective was to map and systematize the key requirements necessary for a successful pilot setup. This preparatory step was designed to create a clear framework that will allow us to streamline and better coordinate subsequent piloting activities.

To support this effort, we structured the work into several sub-phases, each focusing on a critical aspect of pilot development. These sub-phases include:

- **Needs and constraints mapping**, aimed at identifying operational, technical, and organizational conditions that shape the pilot;
- **Cross-border postal flow evaluation**, to capture the dynamics, volumes, and characteristics of existing traffic between Slovenia and Croatia;
- **Baseline (as-is) environmental impact assessment**, providing a reference point on emissions and energy use against which improvements from pilot solutions can be measured.

This structured approach ensures that the pilot builds on a **solid evidence base**, aligning identified needs with realistic constraints, while also addressing sustainability objectives from the outset.

3.2.2 Needs and constraints mapping

To obtain a clearer picture of the operational realities, we structured the analysis of needs and constraints by distinguishing between buyers and sellers of logistics services (see Tables 4 and 5). The identified needs and constraints are presented without prioritization and in no specific order. The identified needs and constraints were collected through face-to-face interviews with relevant stakeholders. The assessment covered the entire cross-border logistics chain between Slovenia and Croatia, encompassing postal operators, a delivery crowdsourcing company, end customers/users, and several logistics providers. On the buyer side, the focus was placed exclusively on contractual buyers of logistics services (such as e-commerce and industrial companies), as these actors account for most of the demand generation within the system.

Following the analysis, the identified needs and constraints were grouped into thematic categories: *Service Quality, Speed & Flexibility, Cost & Profitability, Digitalization, Sustainability, Coverage, Customer Experience, and Risk & Resilience*. This categorization was chosen because it reflects the most critical dimensions that shape decision-making and performance across logistics chains. By structuring the findings in this way, we ensure comparability between buyers and sellers while providing a coherent framework that highlights both synergies and tensions in their expectations and limitations.

Buyers

Table 4 summarizes the key needs and constraints identified for buyers of logistics services across core operational, economic, digital, and sustainability dimensions.

Table 4. Buyers' needs and constraints

Category	Needs	Constraints
Service Quality	Reliable and predictable pickup/delivery	Limited transport capacity in peak seasons; service disruptions
Speed & Flexibility	Fast delivery (same/next day), scalable services	Urban congestion, infrastructure bottlenecks
Cost	Competitive, transparent pricing	Rising costs (fuel, labour, tolls)
Digitalization	System integration (ERP/WMS), real-time tracking	Fragmented market, inconsistent digital maturity
Sustainability	Low-emission transport, CO_2 reporting	Green options often limited or more expensive
Coverage	Broad geographic reach, cross-border capability	Customs, regulatory and VAT complexity
Customer Experience	Delivery time-slot choice, parcel lockers, easy returns	Uneven infrastructure availability, lack of harmonized solutions
Risk & Resilience	Stability and reliability of supply chain	Exposure to strikes, border delays, geopolitical risks, climate disruptions

In today's logistics landscape, senders face a persistent gap between their operational needs and the constraints of the market. Companies require reliable and predictable services, fast and flexible delivery options, transparent pricing, digital integration with their internal systems, sustainable transport solutions, broad coverage across markets, and customer-oriented features such as time-slot selection or convenient returns. However, these needs are often constrained by structural realities including limited capacity during seasonal peaks, rising costs of fuel, labor, and tolls, fragmented digital maturity across providers, regulatory and customs barriers in cross-border flows, and infrastructure bottlenecks in urban areas. At the same time, while sustainability has become a central priority, a **paradoxical state emerges: customers increasingly expect zero-emission logistics services, provided free of charge, and delivered as fast as next-day.** This highlights the tension between ambitious customer expectations and the cost related to operational activities, capacity, and regulatory challenges that providers must manage, underscoring the importance of balancing innovation with realistic service capabilities in pilot activities.

Sellers

Table 5 presents the main needs and constraints identified for sellers of logistics services, reflecting the operational, economic, digital, and regulatory shaping their ability to deliver competitive and resilient offerings.

Table 5. Sellers' needs and constraints

Category	Needs (What sellers want)	Constraints (What limits them)
Service Quality	Build reputation for reliability and consistent delivery performance	External disruptions (traffic, weather, strikes), unpredictable sender volumes
Speed & Flexibility	Offer fast and flexible options (same/next day, time windows)	High investment in fleet, staff, and IT required to scale
Cost & Profitability	Maintain sustainable margins, cover rising operational costs	Strong price pressure from senders; low willingness to pay for premium services
Digitalization	Integrate with client systems, leverage automation and real-time data	Legacy IT systems, lack of interoperability, fragmented standards
Sustainability	Develop low-emission fleets and meet ESG requirements	High upfront investment in green vehicles/infrastructure; limited incentives
Coverage	Expand network reach (national and cross-border)	Customs and regulatory barriers; lack of harmonized cross-border infrastructure
Customer Experience	Provide added value (lockers, tracking, returns management)	Infrastructure rollout is capital-intensive, and adoption varies by market
Risk & Resilience	Build resilience against shocks (geopolitical, climate, demand peaks)	High exposure to fuel price volatility, labour shortages, and unforeseen disruptions

The analysis of **sellers of logistics services** shows that providers are striving to balance commercial sustainability with increasing market demands. Their core needs lie in building **service quality and reliability**, ensuring **speed and flexibility** of operations, maintaining **cost efficiency and profitability**, advancing **digitalization and system integration**, and developing **sustainable transport solutions**. At the same time, they seek to expand **geographic coverage**, improve **customer experience** through value-added services, and strengthen **risk and resilience** against external shocks. However, these ambitions are constrained by high capital requirements (for fleets, infrastructure, and IT), strong price pressure from buyers, regulatory and customs barriers, exposure to volatile fuel and labor costs, and the uneven pace of market adoption of new solutions (Bachofner et al. 2022).

A key finding is that while logistics providers are under constant pressure to deliver faster, more reliable, and increasingly low-emission services, their profit margin remains extremely thin. Recent academic studies (Janinhoff et al. 2024) highlight that last-mile delivery is the most cost-intensive segment of the logistics chain – often accounting for more than half of total delivery costs – while providers simultaneously face rising labour, energy, and compliance costs. As a result, even when high service levels and sustainability measures are achieved, the remaining per-shipment margin is minimal, leaving limited financial headroom for reinvestment and innovation.

3.2.3 Cross-Border postal flow evaluation

Governance and procedures

The exchange of postal shipments between operators is primarily governed by the **Universal Postal Union (UPU)**, which provides the global legal and operational foundation for international mail flows. Its core instruments — the **UPU Constitution, Convention, and Regulations** — establish binding obligations for designated operators on the acceptance, routing, transport, and delivery of shipments. The framework ensures that a letter or parcel sent from one member country can be seamlessly delivered in another, regardless of differences in national postal systems.

UPU rules are operationalized through a series of **standardized procedures** that guarantee interoperability. Postal operators must use internationally recognized **International Mail Processing Centre (IMPC) codes**, exchange mandatory **Electronic Data Interchange (EDI) messages**, and comply with security and liability standards. These rules also cover irregularity handling, ensuring accountability and trust across the global network.

In addition to the UPU framework, regional cooperation further strengthens operational exchanges. Within Europe, the **International Post Corporation (IPC)** plays a critical role through its **INTERCONNECT program**, which harmonizes quality of service, tracking, and customer experience for cross-border e-commerce parcels. IPC INTERCONNECT acts as a complement to UPU rules by setting **higher operational and commercial standards** between participating operators, including service performance targets, standardized labelling, enhanced tracking visibility, and coordinated customer service procedures. This has become increasingly important for meeting the expectations of e-commerce merchants and end consumers in terms of speed, reliability, and transparency.

The **financial settlement of costs** is another key obligation. Through the **terminal dues system**, operators compensate one another for handling and delivering inbound mail. For parcels, equivalent schemes apply under UPU Parcel Post Regulations. In Europe, IPC's REIMS agreements (Remuneration of Mandatory Deliveries of Cross-Border Mails) provide a more detailed cost and remuneration framework, ensuring that settlement mechanisms are fair and performance-based.

Oversight remains with the **UPU Congress**, the **Council of Administration**, and the **Postal Operations Council**, which refine regulations and monitor compliance. IPC, although not a regulatory body, provides operational and quality-assurance support that complements the global system.

Core Operational Obligations in Shipment Exchange

- **Mail Routing & Processing**
    - Use of **IMPC codes** to identify dispatch and reception centres.
    - Application of UPU-defined mail classes (letter post, parcel post).
- **Electronic Data Exchange**
    - **EDI messages are mandatory**: ITMATT (customs data), PREDES (dispatch data), CARDIT/RESDIT (transport events).
    - Provides full chain visibility and standardized tracking.

- **Settlement & Accounting**
    - **Terminal dues** system for letter post; equivalent for parcel post.
    - **REIMS agreements** in Europe provide more detailed, performance-based settlement.
- **Security & Liability**
    - Operators must comply with UPU standards to protect mail integrity.
    - Defined liability obligations for loss, damage, or delay.
- **Quality of Service Monitoring**
    - UPU quality standards + IPC INTERCONNECT's higher-level service and tracking benchmarks.
    - Regular performance measurement and reporting required.

Key fact: While the UPU provides the global legal backbone, **IPC INTERCONNECT creates an additional "premium layer" of operational standards** that allow European postal operators to compete with private couriers in the fast-growing cross-border e-commerce market. This layer directly support the pilot's goal by enabling higher service quality, improved interoperability, and more predictable cross-border performance, thereby providing a standardized yet competitive framework within which advanced digital, sustainability, and optimization measures can be tested and validated.

3.2.4 Overview of postal traffic flows

In this sub-chapter, we present the evaluation of postal traffic flows between Slovenia and Croatia carried out during the initial phase of the pilot (December 2023). The purpose of this activity was to obtain a clear overview of the **volumes, structure, and characteristics of cross-border mail and parcel exchanges** between the two countries. By mapping these flows, we aimed to identify operational dependencies, highlight bottlenecks, and establish a reliable baseline for subsequent pilot interventions, drawing on operational data from postal IT systems (e.g. tracking and event data), cross-border exchange messages (UPU/IPC standards), transport and route schedules, capacity statistics, and insights gathered through face-to-face stakeholder interviews.

The analysis was not limited to shipments alone but also focused on the **key actors that participate in this logistics ecosystem**. These include the **two national postal operators**, several **transport companies** involved in cross-border exchanges, one **crowdsourced delivery company**, and—importantly—the **end users/customers**, who represent the main source of demand. Studying these stakeholders allowed us to better understand the interdependencies and expectations that shape the overall performance of the system.

The assessment was conducted through a combination of **data collection from participating postal operators, analysis of shipment categories (letters, parcels, e-commerce items), and examination of seasonal fluctuations**. Special attention was given to the interaction points between operators, as these are often critical for understanding service quality, timeliness, and environmental impacts.

This analysis provides an evidence-based understanding of how the current system functions, offering both a benchmark against which pilot outcomes can be measured and insights that can inform the design of more efficient, sustainable, and customer-oriented cross-border delivery solutions. The underlying dataset is stored in the internal data repository and is documented in the project annex, with access to provide under controlled conditions in line with data protection and confidentiality requirements.

In the initial step, the analysis concentrated on the **primary generators of demand**—namely the contracting companies and other buyers of logistics services—examining both their shipment volumes and their share in relation to the overall postal traffic between Slovenia and Croatia.

Since an unexpected situation occurred at the very beginning of the project, when we lost a client in the North-Eastern part of Slovenia who had generated the largest share of parcels destined for Croatia, we acted quickly and decided to replace those volumes by consolidating parcels from various companies operating in the area defined for the pilot. The primary objective was to secure sufficient parcel volumes to ensure the relevance and feasibility of the core project idea as submitted.

To achieve this, we slightly adjusted the transport routes of our fleet and ensured that the necessary conditions were in place to capture the "as-is" data in a timely manner. These data serve as the baseline dataset on which we intended to verify the validity of the project objectives and KPIs. To achieve this, we introduced limited, operational adjustments to existing transport routes, such as minor changes to pick up sequences and vehicle loading plans

3.2.5 Baseline first-mile data collection

Seven larger companies were included in the parcel collection chain, regularly or occasionally shipping parcels destined for Croatia. To ensure that the baseline data would be as representative as possible, we defined four annual periods, which we assessed as having very different parcel intake dynamics. For each selected period, we decided to collect data over five consecutive working days, as the nature of our operations shows that certain weekdays inherently stand out in terms of the number of parcels collected. This aspect had a significant influence on our decisions regarding adjustments to the operating system, with the objective of reducing emissions.

Accordingly, one working week was selected in November 2024, one in December 2024, one in April 2025, and one in July 2025. The weeks in November and December represent periods of high traffic, April reflects a moderate traffic period, while July represents a period with significantly lower traffic volumes.

The total volumes of parcels destined for Croatia unfortunately did not reach the levels observed at the time of project submission, when we were still working with the client who alone generated exceptionally high volumes for the Croatian market. Nevertheless, they were sufficient for the implementation of the planned pilot activities.

Baseline data from the four weeks selected showed that during the stronger business months (November and December 2024), Mondays and Fridays recorded the highest parcel volumes, clearly exceeding the other weekdays. In April 2025, Mondays still stood out, while in the summer months overall volumes dropped considerably, and the differences between weekdays were not as pronounced—even if on some days, parcel volumes almost dropped to zero.

For the purposes of the pilot, data on the number of parcels destined for Croatia were less relevant than data on their weight and volume, as these two parameters have the most significant impact on vehicle selection for transport. Moreover, data on transported weight along specific routes were required for emission calculations in line with the formulas of the GHG Protocol and the GLEC

Framework (see Figures 17, 18, 19, 20). For this reason, our primary focus was placed on transported weights and parcel volumes, rather than parcel counts.

During the high-volume period, the total daily parcel weights destined for Croatia ranged from just 66 kg to 1,932 kg. This already indicates the need to reconsider the justification of daily transport runs to Croatia, or at least to establish a pool of vehicles from which the most suitable delivery vehicle could be selected in line with the daily parcel volumes. The daily average during the high-volume months amounted to 839 kg, representing just under 17% of the total daily collected parcel weight at client locations.

In April 2025, daily parcel weights for Croatia ranged from 110 to 1,385 kg (average 693 kg/day), with parcels for the Croatian market representing, on average, just under 19% of daily volumes. In July, daily collected weights of parcels destined for Croatia ranged between 144 and 516 kg (average 411 kg/day), corresponding to an average of 10.5% of the total daily collected parcel weight in that period.

Weight alone is not the only parameter influencing the choice of the most appropriate vehicles. Parcel volume must also be considered, as relatively low total weights in themselves do not necessarily mean that the mid-mile can be executed solely with smaller delivery vans.

Example of CO_2e emission calculation for the first-mile

Transport Chain Elements	Activities	Transport activity	Loacation	Weight of packages [kg]	Weight for Croatia [kg]	Km driven	TA calculation [tkm]	Emissions [kg CO2e]
TCE 0	parking - logistics center (LC)		LC					
TCE 1	empty run	TA 1				25,8		22,66
TCE 2	loading		COMPANY 1	1.868	0			
TCE 3	transport	TA 2				6,9	12,89	2,46
TCE 4	loading		COMPANY 2	1.539	436			
TCE 3	transport	TA 2				23,4	79,72	15,23
TCE 4	unloading at LC		LC	UNLOADING				4,43
TCE 5	empty run	TA 3				1,2		1,05
TCE 6	loading		COMPANY 3	60	46			
TCE 7	transport	TA 4				2,7	0,16	0,03
TCE 8	loading		COMPANY 4	21	6			
TCE 9	transport	TA 5				3,3	0,27	0,05
TCE 10	loading		COMPANY 5	182	0			
TCE 11	transport	TA 6				1,2	0,32	0,06
TCE 12	loading		COMPANY 6	142	0			
TCE 13	transport	TA 7				1,9	0,77	0,15
TCE 14	unloading at LC		LC	UNLOADING				0,53
TCE 15	empty run	TA 8				47,40		41,62
TCE 16	loading		COMPANY 7	2.327	940			
TCE 17	transport	TA 9				47,30	110,07	21,02
TCE 18	unloading at LC + parking		LC	UNLOADING AND PARKING				3,03
				6.139	1.428	161,10		**112,31**

Figure 1818. Example of emission calculation for the first-mile (GLEC Framework)

Data sources used for calculations (GLEC Framework - Smart Freight Centre (2025). Global Logistics Emissions Council)

Figures 19, 20 and 21 show selected examples from the GLEC Framework (2025) data. The GLEC Framework (Global Logistics Emissions Council Framework) is an internationally recognised and widely applied methodology for the calculation and reporting of greenhouse gas emissions from logistics and transport activities across all transport modes. Developed by Smart Freight Centre in collaboration with industry, academia and standard-setting bodies, it provides a harmonised approach that enables consistent, transparent and comparable CO_2e calculations along complex and multimodal transport chains. The framework includes both Tank-to-Wheel and Well-to-Wheel emissions, ensuring a comprehensive representation of transport-related climate impacts.

Methodologically, the GLEC Framework is fully aligned with the GHG Protocol and ISO 14083. It promotes the use of primary activity data wherever available and provides scientifically validated default emission factors when primary data is not accessible. The emission factor tables included in the framework are derived from internationally recognised sources and peer-reviewed datasets, ensuring traceability and credibility. For these reasons, the GLEC Framework was used as the methodological basis for CO_2 calculations and as the reference source for emission factors, providing a robust, transparent and verifiable foundation for logistics emission reporting.

Table 8
Europe and South America road emission intensity values

* LNG/bio-LNG consumption # diesel consumption

Vehicle characteristics and size	Load characteristics	Basis		Fuel	Fuel intensity (kg/t-km)	Fuel intensity (l/t-km)	Emission intensity (g CO_2e/t-km)		
		Load Factor	Empty Running				WTT	TTW	WTW
Rigid truck 3.5–7.5 t GVW	Average/mixed	60%	17%	Diesel	0.080	0.096	78	258	335
				CNG	0.084	-	86	231	317
Rigid truck 7.5–12 t GVW	Average/mixed	60%	17%	Diesel	0.053	0.064	52	172	223
				CNG	0.056	-	58	154	211
Rigid truck 12–20 t GVW	Average/mixed	60%	17%	Diesel	0.046	0.055	44	147	191
				CNG	0.048	-	49	131	181
Rigid truck 20–26 t GVW	Average/mixed	60%	17%	Diesel	0.033	0.040	32	107	139
				CNG	0.036	-	37	99	136
				LNG	0.037	-	47	105	152

Figure 19. Data sources used for calculations (GLEC Framework) CO_2e emission intensity values for trucks

Emission factors: European sources

Energy carrier	Example application	Lower heating value MJ/kg	Density kg/l	GHG emission (operational/TTW) g CO_2e/MJ	GHG emission (total/WTW) g CO_2e/MJ	GHG emission (operational/TTW) kg CO_2e/kg	GHG emission (total/WTW) kg CO_2e/kg	Non-CO_2 GHG emissions (operational/TTW) g CO_2e/MJ	Biogenic GHG emissions (operational/TTW) in g CO_2e/g	Source
Gasoline		42.5	0.74	75.0	99.0	3.19	4.21	0.14	n.a.	ecoinvent v3.9.1[3]
Ethanol (40% maize, 35% sugar beet, 25% wheat)		27.0	0.78	0.1	48.0	0.00	1.30	0.14	1.91	ifeu, infras & Fraunhofer IML, 2024[18]
Diesel		42.8	0.83	75.3	97.8	3.22	4.19	1.16	n.a.	ecoinvent v3.9.1 cut-off[3]

Figure 20. Data sources used for calculations (GLEC Framework) emission factors European sources

Table 3
Logistics hubs emission intensity values

Hub type unit	Ambient	Sample size	Temperature-controlled	Sample size	Mixed	Sample size
Transshipment kg CO_2e/t	1.3	(99)			2.5	(8)
Storage + transshipment kg CO_2e/t	5.6	(57)			18.4	(10)
Warehouse kg CO_2e/t	45.5	(67)			≥ 50.0	estimate by Fraunhofer IML
Liquid bulk terminals kg CO_2e/t	3.3	(23)			7.2	(23)
Maritime container terminals kg CO_2e/ container	10.7	(15)	12.6	(15)		

Figure 21. Data sources used for calculations (GLEC Framework) hubs emission intensity

Baseline data on parcel weights on Monday 2nd of December 2024, from the selected companies are presented in Figures 22 and 23.

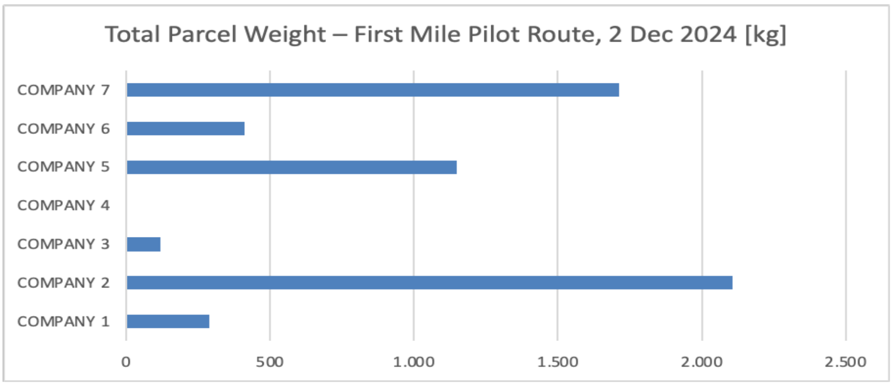

Figure 22. Total parcel weight in the first-mile route - 2nd of December 2024 (in kg)

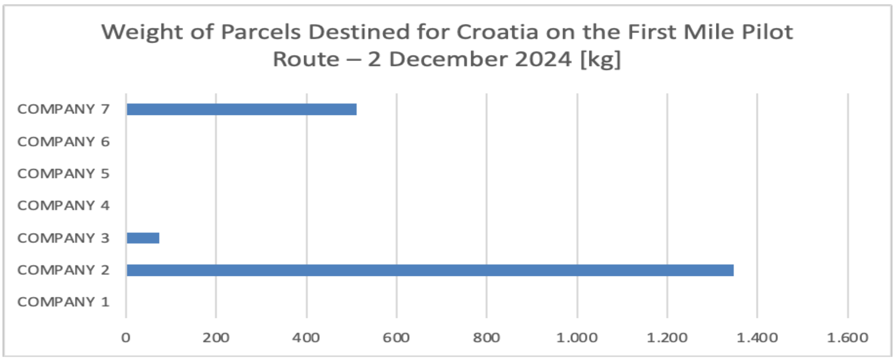

Figure 23. Weight of parcels destined for Croatia in the mid-mile route - 2nd of December 2024 (in kg)

3.2.6 Cross-Border corridor set-up

The current operational set-up for cross-border postal exchanges between Slovenia and Croatia follows the standard framework prescribed by the Universal Postal Union (**UPU**) and reinforced through the International Post Corporation (**IPC**) cooperation mechanisms. In line with these rules, shipments are first routed through the designated national hub — the Office of Exchange in Ljubljana — where they are consolidated and dispatched onwards to Zagreb. This configuration was established to streamline the international flow of postal shipments, ensure harmonization with global practices, and create efficiency by processing items centrally before they cross the border.

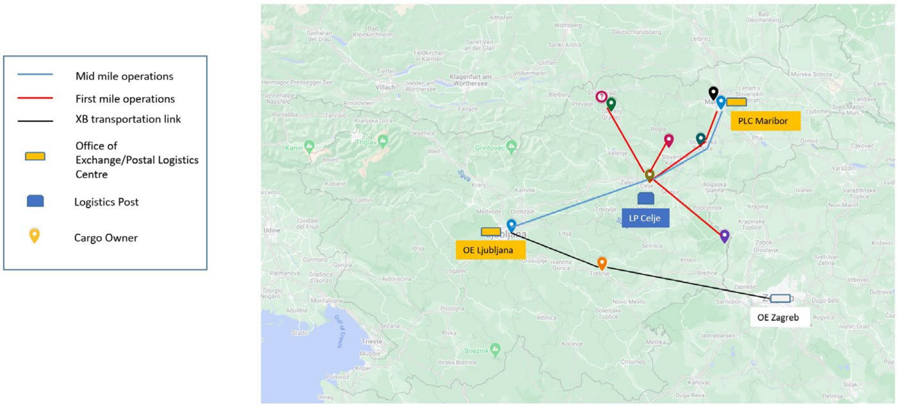

Figure 24. Current flow of shipments from the North-Eastern region of Slovenia towards Zagreb

While this model provides clear advantages in terms of control and standardization, the analysis of traffic volumes has highlighted significant regional imbalances (see Figure 24). In particular, the **North-Eastern region of Slovenia** has emerged as a disproportionately large generator of postal flows destined for Croatia. Channelling all these shipments through Ljubljana before forwarding them to Zagreb adds additional handling steps and transport distance, creating inefficiencies both in terms of time and environmental impact.

To address this challenge, it was necessary to make use of alternative procedures foreseen under the **UPU Convention**. Specifically, the framework allows for **direct injection operations**, which enable the direct transfer of shipments from a regional hub to the receiving country's network, bypassing the need for routing through the national office of exchange. As illustrated in Figure 25 this operational and procedural adjustment, we were able to lay the foundation for **mileage reduction and, consequently, emission reduction**. This ensures that cross-border exchanges are not only faster and more efficient, but also more sustainable, aligning the corridor set-up with broader environmental objectives.

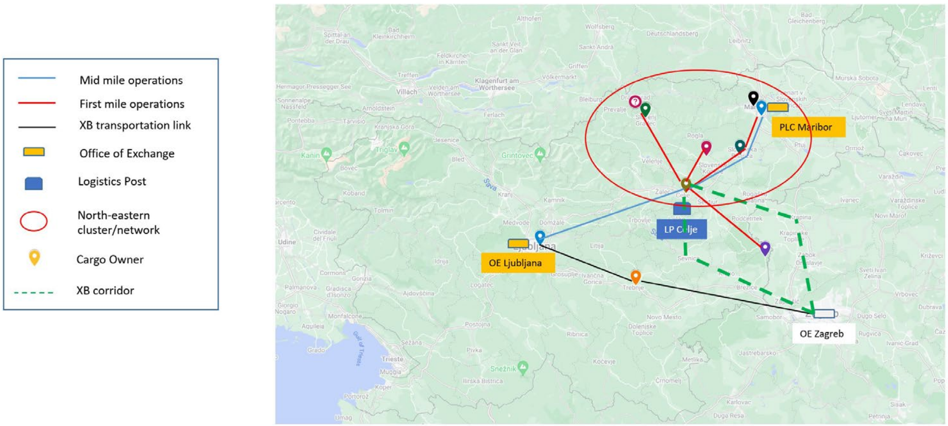

Figure 25. Introduction of the Cross-Border Corridor, bypassing the Office of Exchange in Ljubljana (Green Route)

3.2.7 Emission measurement and impact assessment with vehicle trip data

Emissions measurement and impact assessment activities with detailed vehicle primary trip data, including the calibration and deployment of measurement equipment and the processing of collected data are presented in this subsection.

Integrating detailed vehicle trip data such as fuel consumption, distance, speed, acceleration, road elevation with cargo movement information enables more accurate assessment. The University of Ljubljana (UL) calculated key performance indicators (KPIs) before and after the pilot, providing a clear picture of the project's effect on greenhouse gas (GHG) emissions under different scenarios.

GHG emission measurement methodology

The elaborated methodological framework evaluates emissions from current activities involving the Post of Slovenia (PS) hub in Ljubljana and projects emissions for future activities that aim to reduce costs, distances, and emissions.

The Slovenian-Croatian transport chain is divided into six Transport Chain Elements (TCE) to enable the disaggregation of the transport chain into analytically independent units. This level of detail allows precise attribution of emissions to specific vehicles or hubs. TCEs are defined as activities provided by a single vehicle or activities provided by a single hub, which are crucial for precise emissions calculation (Table 6):

Table 6. Transport Chain Elements (TCE) of Slovenian-Croatian post

	TCE 1 – first-mile road transport, where multiple parcels are collected by a postal operator along a predefined route known as a milk-run route. PS utilises vans or trucks weighing less than 3.5 tons for this purpose.
	TCE 2 – PS hub Celje.
	TCE 3 – PS hub Ljubljana.
	TCE 4 – mid-mile road transport, from Ljubljana to Zagreb, using trucks from external logistics providers weighing more than 3.5 tons but less than 7.5 tons.
	TCE 5 – Post of Croatia (PC) hub Zagreb.
	TCE 6 – last-mile road transport that covers last-mile distribution activities to final consumers, carried out using cars, vans, bicycles, and designated distribution routes

The total well-to-wake (WTW) emissions of all six TCEs represent the emissions of the entire transport chain in the Slovenian-Croatian pilot, considering all purchased energy for operations, and emissions across the entire fuel energy life cycle:

$$WTW_{GHG-T} = \sum_{i=1}^{6} WTW_{GHG-i} \quad \text{(Eq. 1)}$$

Also, Well-To-Wheel ($WTW_{GHG\text{-}T}$) emissions are composed of two parts: Well-To-Tank ($WTT_{GHG\text{-}T}$) emissions, as emissions generated from fuel production to the point of fuel supply at petrol or recharging stations, and tank-to-wheel ($TTW_{GHG\text{-}T}$) emissions, which encompass emissions generated during transport activities or hub operations:

$$WTW_{GHG-T} = WTT_{GHG-T} + TTW_{GHG-T}. \quad \text{(Eq. 2)}$$

It is important to note that it is also necessary to address emissions from empty miles, since TCE1 and TCE6 revolve around a round-trip method. This means emissions account for the necessary return of a vehicle, even if it's only transporting goods from the hub to the customer, or vice versa, without making the journey back, see Smart Freight Centre (2023) and GHG Protocol (2013).

- In TCE1, the Slovenian Post transport fleet is utilised for short distances.
- In TCE4, emissions only consider the distance travelled from the truck's origin to the PS hub in Ljubljana, and then from the hub in Ljubljana to the hub in Zagreb. The return distance is not considered, since the external logistics provider from Slovenia will not return empty from Zagreb but will instead find other freight for the return journey.
- In TCE6, for short distances, Croatian Post employs external logistics providers exclusively for their deliveries, which don't serve other customers.

The transport activities of each TCE are measured in ton-kilometres [*t-km*]. Parcel mass is measured in kilograms and includes only the weight of the product and the packaging provided by the shipper. The actual mass of the parcels will be used. The transport activity distance is determined by the Shortest Feasible Distance (SFD), which will be collected for each TCE either through direct measurements or estimations.

Following equation are using primary data. Primary is the "quantified value of a process or an activity from a direct measurement or a calculation based on direct measurements."

First-mile road transport emissions and emissions per parcel by using primary data

First-mile (TCE 1) road transport includes the collection of parcels by different freight owners based on a milk-run route. This means that one van of PS picks up many parcels from different freight owners on one route. So, it is important to guarantee emissions are equitably distributed among all transported parcels. This can be done in two ways A) or B):

A) Splitting emissions individually for each package based on its share of transport activity [*t-km*]

The total WTW emissions are calculated using next formulas:

$$G_{WTW-T} = F \cdot g_{WTW}. \qquad \text{(Eq. 3)}$$

Where:

- G_{WTW-T} are the well-to-wheel Green House Gas (GHG) emissions in [*kg*CO_2e] per litres [*l*], kilograms [*kg*] *or* kilowatt-hours [*kWh*].
- F is the energy consumed in litres [*l*], kilograms [*kg*] or kilowatt-hours [*kWh*].
- g_{WTW} is the emissions factor in [*kg*CO_2e/*kWh*], [*kg*CO_2e/*l*] or [*kg*CO_2e/*kWh*].

The Transport Activity (TA) in [*t-km*] is calculated for each parcel as:

$$TA_{parcel_i} = w_{parcel_i} \cdot SFD, \qquad \text{(Eq. 4)}$$

and $w_{parcel_i}$is the weight of parcel i in tons and *SFD* is the shortest feasible direct distance from the PS hub to each pick-up point i and not cumulative distance driven in the round trip.

Total *TA* is calculated as:

$$TA = \sum_i TA_{parcel\,i}. \qquad \text{(Eq. 5)}$$

The $\boldsymbol{G_{WTW-T}}$ **of parcel** $\boldsymbol{i}$ are the share of total emissions respect the parcel *i* transport activities:

$$^{TA}G_{WTW-parcel\,i} = G_{WTW-T} \cdot \frac{TA_{parcel\,i}}{TA} \qquad \text{(Eq. 6)}$$

B) Calculate emissions per item uniformly, regardless of weight or destination, although packages may vary in both aspects.

In case of small parcel delivery, pick-up or for mail items, generally the transport is not tracked, and a bulk collection system is performed (very short distances and parcel senders are very close to each other). In these cases, a per-item emission calculation is possible. The G_{WTW-T} emissions are calculated using Eq. 3.

If the pick-up activity is untracked, then data about the total fuel consumption, F, for the pick-up round, the number n of picked-up parcels, and an emission factor g_{WTW} are necessary (GLEC Framework).

The $\boldsymbol{G_{WTW-T}}$ **emissions per item**:

$$^{I}G_{WTW-parcel\,i} = \frac{G_{WTW-T}}{n} \qquad \text{(Eq. 7)}$$

Mid-mile road transport emissions and emissions per parcel by using primary data

Mid-mile (TCE 4) includes logistic operations from the Slovenian region, PS hub Ljubljana, to the PC hub Zagreb in Croatia. Parcels are distributed using trucks, from external logistics providers, weighing between 3.5 tons and 7.5 tons.

Eqs. 1, 4 and 5 are used to calculate WTW emissions on the route from Ljubljana to Zagreb, parcel transport activity and total transport activity.

Last-mile road transport emissions and emissions per parcel by using primary data

Last-mile operations (TCE 6) are known as "delivery rounds," where shared transportation is used to deliver packages to multiple recipients in a single trip. This practice highlights the need to divide emissions equally across all packages transported by as is shown in earlier in **First-mile road transport emissions calculation** on previous pages.

Emission measurement devices

The objective is to analyse delivery routes and estimate CO_2 emissions that could be achieved in several ways, such as using origin and destinations and distance, or by using fuel flow or dynamic measurements. When designing the measurement setup, different factors have been considered, such as:

- Precision

- Ease of installation and removal
- Data accessibility
- Power supply.

Intuitively, it would be possible to obtain fuel consumption directly from the On-board Diagnostics (OBD) port measurements; however, there are differences in certain protocols between the vehicle manufacturers, and also fuel flow is not available directly, but it is estimated from motor revolutions and mass air flow through the engine [*l/h*], assuming certain combustion efficiency:

$$FuelFlow = \frac{MAF \cdot 3600}{AFR \cdot FD}, \qquad \text{(Eq. 8)}$$

Where:

- *MAF* is mass air flow.
- *AFR* is air to fuel ratio.
- *FD* is fuel density.

Although the AFR can be estimated from the lambda value provided by certain vehicles, the accuracy of this method is uncertain due to variations in diesel blends (such as winter and biodiesel content) and the limitations of oxygen sensor measurements. A more robust alternative is the specific power-based method, which estimates vehicle power demand from universally available kinematic data – such as speed, acceleration, and road grade – that can be reliably obtained from Global Navigation Satellite System (GNSS). This makes the method preferable for consistent and transferable emissions assessment across diverse vehicle types and operating conditions.

The power-based methods also have an edge in ease of device installation and removal, as the only sensor required is a GNSS logger with a dual-band magnetic-mounting antenna, see Figure 26.

Figure 26. Magnetically mounted GNSS antenna

Regarding data accessibility, the device uses Wireless Fidelity (WI-FI) communication for data download and analysis and is powered using a USB battery pack in order to avoid missing positions during the cold-start time. Considering that measurement devices had to be installed quickly during short breaks when vehicles were parked at logistic centres, we decided that the optimum approach is to calculate emissions using recorded trajectories. The data logger is built around a **u-blox ZED-F9P GNSS** receiver paired with a multi-band GNSS antenna to provide high-precision, centimetre-level positioning capability (Figure 27). The ZED-F9P supports concurrent reception of multiple constellations, Global Positioning System (GPS), Globalnaya NAvigatsionnaya Sputnikovaya Sistema (GLONASS), Galileo, and BeiDou across L1/L2 frequency bands, enabling fast convergence and robust Real-Time Kinematic (RTK) positioning. This feature could be used to achieve 1 cm positioning accuracy.

Figure 27. Measurement devices are mounted in an enclosure

The receiver interfaces directly with a Raspberry Pi via USB, which acts as the central processing and storage unit. The Raspberry Pi manages data collection, logging of raw GNSS observations (RINEX format optional), and, if required, real-time correction streams through NTRIP clients or local base/rover setups. The entire system is USB-powered, making it lightweight, portable, and energy-efficient. Power can be supplied from a laptop, a USB power bank, or any standard USB supply, eliminating the need for bulky external power systems. This design provides a compact, flexible, and low-cost platform for applications such as geospatial surveying, precision agriculture, autonomous navigation, and timing synchronization, while retaining the ability to integrate additional sensors or wireless communication modules through the Raspberry Pi's interfaces. Figure 28 shows installation and testing of data download in a delivery truck.

Figure 28. Rapid installation and testing of measurement devices

Measurements and calculations equations

On-vehicle measurement devices were initially intended for the validation of telemetry system trajectories that were not obtained due to issues with an outsourced provider. Eventually, the measurements became the only source of data. The Vehicle Specific Power (VSP) model has been used to estimate vehicle power requirements that are used as an input for the emissions model (Figure 29).

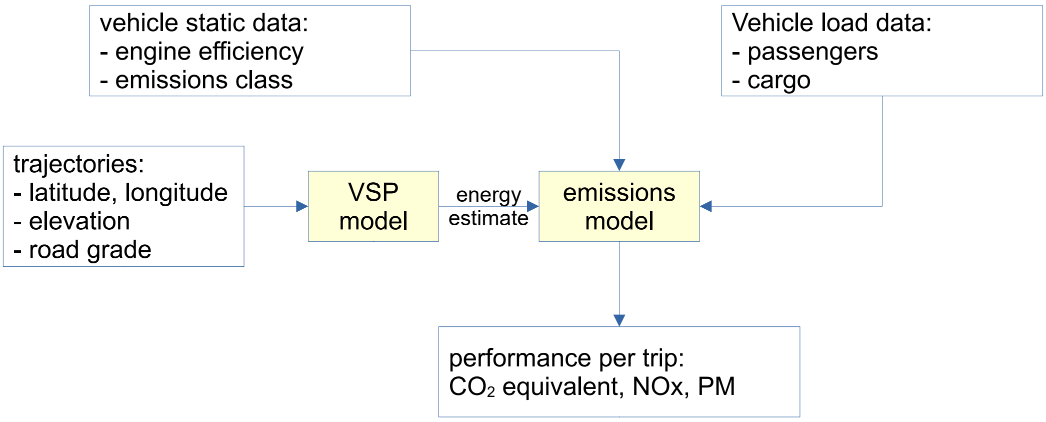

Figure 29. Emissions estimate using the VSP model

Vehicle power, P in $[kW]$ is calculated as:

$$P = m \cdot VSP + A + C \cdot (v + v_w)^2 \cdot v. \qquad \text{(Eq. 9)}$$

Where m is vehicle mass in tons, VSP is vehicle specific power $[kW/tons]$, A is auxiliary power consumption (air conditioning, lighting), C is air drag constant, v is vehicle speed and v_w is wind speed. Further, VSP is calculated from:

$$VSP = k_1 \cdot v \cdot a + g \cdot k \cdot v + B \cdot v. \qquad \text{(Eq. 10)}$$

Where k_1 is the acceleration constant, a is the vehicle acceleration, k is the road grade and B is the friction constant.

For simulating electrical vehicles (EVs), the model can be further coupled into the EV energy flow model, as shown in Figure 30.

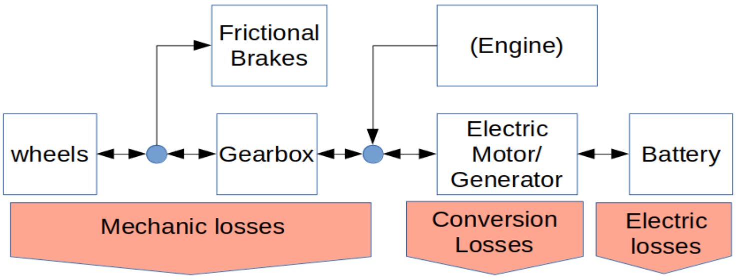

Figure 30. Energy flow in electric, ICE and hybrid vehicles

Energy consumption for EVs and Internal Combustion Engine (ICE) based vehicles is calculated to account for power requirements, when they are positive, and ignored, when they are negative, as in this case, energy is lost due to braking.

$$E_v(t+\Delta t) = E_v(t) + M \cdot \begin{cases} \int_t^{t+\Delta t} P(t)dt\,, & E_b = 0 \wedge P > 0 \\ 0, & E_b > 0 \vee P \leq 0 \end{cases}. \qquad \text{(Eq. 11)}$$

Where:

- $E_v(t+\Delta t)$ is the amount of energy at time $t+\Delta t$, the end of the current time interval.
- $E_v(t)$ is the amount of energy at time t, the current time.
- M is a factor related to the efficiency.
- $P(t)$ is the power at time t.
- E_b is the boundary energy level. The associated conditions are used to explain when energy can be added to the storage.

The details of the model and its calibration have been published in Jimenez-Palacios (1998), Luin et al. (2017), Fiori et al. (2016), Fiori et al. (2018), Luin et al. (2019).

The models have been calibrated using standard cycles, such as the Worldwide Harmonised Light Vehicles Test Procedure (WLTP) for personal vehicles and the European Transient Cycle (ETC) for heavy goods vehicles. Once calibrated, the vehicles models were fed with recorded trajectories of the delivery vehicles.

3.2.8 Carbon aware optimisation design

This subsection presents the design and implementation of this pilots' carbon-aware optimization framework, a key enabler for sustainable logistics decision-making. The framework is built to integrate environmental considerations, particularly CO_2 emissions, into the core planning and execution layers of cross-border logistics. It encompasses four interconnected components: the development of green optimization algorithms, the creation of a CO_2 tracking system, the setup of a Green Logistics User Index, and the integration of these tools into the ADMIRAL Marketplace. Together, these elements form a cohesive system that enables route optimization based on emissions, supports transparent emissions reporting, and encourages marketplace users to prioritize low-carbon logistics services.

3.2.9 Green Logistics User Index set-up

Establishing a **Green Logistics User Index** within the pilot means creating a clear and measurable benchmark that reflects how environmentally friendly cross-border logistics services are from both an operational and a user perspective. The index brings together key factors such as mileage reduction, CO_2 emissions per shipment, vehicle load efficiency, and translates them into a single, comparable score. Its purpose is to provide transparency and decision support for buyers of logistics services, allowing them to see the environmental value of different delivery options alongside price and speed. For the pilot, the index serves as both a **proof of concept,** demonstrating that innovations like **direct injection operations** result in tangible emission reductions—and a **scalable tool** that can later be replicated across other corridors to promote greener, more sustainable cross-border delivery models.

The Green Logistics User Index is composed of several key components that together capture the environmental performance of cross-border logistics services. These include **mileage and route efficiency** (reflecting kilometres travelled per shipment and the reduction achieved through optimized routing such as direct injection), **vehicle load factor utilization** (measuring how effectively transport capacity is used in terms of weight and volume), **emissions per shipment** (quantifying CO_2 output relative to distance and item count), **energy source and transport mode share**(tracking the proportion of shipments moved by low-emission vehicles), and **packaging sustainability** (assessing the use of recyclable or reusable materials and packaging-to-content ratios). Each of these components was identified by linking the pilot's operational adjustments to their direct environmental impacts, while also considering EU and UPU reporting obligations, established industry standards (e.g., GLEC framework), and the practical expectations of logistics buyers for transparency in sustainability reporting.

The index is designed as a **weighted composite score** in which each component is first normalized to a common scale (e.g., 0–100) to allow comparability. The most critical factors -**mileage reduction and emissions per shipment,** are assigned the core weight, as they represent the primary environmental outcomes of cross-border logistics operations. **Load factor and packaging efficiency** are included as supporting weights, capturing how well transport capacity is utilized and how sustainably items are packed. Finally, service quality is integrated as a balancing weight to ensure that environmental improvements do not come at the expense of reliability, speed, or overall user satisfaction. In the context of the Green Logistics User Index, service quality refers to the performance and consistency of delivery operations as experienced by the end user. It is measured through a combination of indicators such as on-time delivery rates, delivery accuracy, responsiveness to disruptions, and user feedback where available. By including these elements, the index maintains a realistic balance between environmental objectives and the operational expectations of logistics service users. This approach ensures that sustainability gains are achieved without compromising the core standards that define effective and trusted delivery services.

3.3 Tested systems

This pilot: Green Logistics: Optimizing Postal Sustainability Across Borders, addresses the specific characteristics of postal transport services. Unlike conventional transport, which typically operates from point A to point B, postal operations involve multiple stop points for both pick-up (first-mile) and delivery (last-mile). Only the middle-mile resembles the classical A-to-B transport model.

Due to these specifics, the calculation of CO_2 emissions requires a tailored approach, leading to the development of a dedicated CO_2 Calculation Engine. To support this pilot, a Logistics Optimisation Planning Tool for ADMIRAL (LOPTA) is developed. The following subsection describes the development steps of solutions LOPTA and Crowdsourcing.

3.3.1 Initial rollout for LOPTA

Initially, the pilot partners consolidated the requirements for the LOPTA.

From here, we were able to define the initial rollout in scope of this pilot:

- **Develop routing service:** The routing service was developed and upgraded as the foundation of all optimisation tasks.
- **Develop last-mile optimisation service**: This service needed to be also integrated to the Locodels' Crowdsourcing tool.
- **Continuously test and adapt the last-mile optimisation**: Iterative refinement of plans with project partners and adapt the optimisation constraints to the needs of the last-mile process.
- **Develop and test the first-mile optimisation service**: For this service we took the experience from the development of the last-mile development and applied it to first-mile optimisation. The results were used in the pick-up process of Pošta Slovenije and for the in-depth analysis of the pilot.
- **Develop and evaluate CO_2 Emissions Calculation service**: The service is used to calculate the emissions caused by the first-mile processes.
- **Define and revise the use cases for ADMIRAL Marketplace integration**: To create usable services we had meetings with Awake.AI to determine how to correctly implement postal workflows in the ADMIRAL Marketplace and the requirements of the API to implement the optimisation services to the marketplace.

All these steps are needed to achieve the desired **delivery accuracy**. Delivery accuracy refers to the ability to deliver shipments on time, to the correct location, and in the correct quantity and condition. It is a key indicator of logistics performance and directly affects customer satisfaction, operational efficiency, and service reliability. In the Slovenian-Croatian pilot this concept was not only treated as a performance metric but also as a quality benchmark that guided the development of tools and services across the pilot. Accurate deliveries reduce the need for redeliveries, customer complaints, and unnecessary emissions—all of which align with the project's environmental and operational goals.

Throughout the project, delivery accuracy was improved by integrating carbon-aware optimization algorithms. Mid-mile route planning, especially for the cross-border corridor between Celje and Zagreb, enabled more predictable and consolidated flows. Together, these elements formed a digitally supported logistics ecosystem that minimized delays, route errors, and service mismatches—thereby increasing overall delivery precision.

In parallel, the University of Ljubljana (UL) **measured the actual emissions for the whole pilot logistics chain**, which gave us useful insights to our results (see Results of test subsection 3.4.1 Vehicle trip data measurements for emission assessment).

3.3.2 Evaluation and iterative adjustments

Workshops and tutorials for deployment support

As part of the original project plan, workshops and tutorials were intended to support the deployment and user adoption of the developed solutions, particularly the CO_2 tracking system, optimization engine, and green logistics service catalogue. These activities were designed to foster user engagement, collect operational feedback, and build capacity among stakeholders through interactive, hands-on sessions.

However, due to shifting priorities during pilot implementation, formalized workshops and tutorials in their originally planned format were not carried out. Instead, knowledge transfer and solution familiarization were conducted through **informal consultations, internal testing sessions, and iterative partner meetings**. These ad-hoc interactions allowed for direct feedback loops with key users (e.g., dispatchers, IT teams, pilot coordinators) and helped ensure the solutions were adjusted to fit real-world operational needs. While not publicly documented as formal events, these internal processes effectively served the same purpose—enabling the progressive deployment and integration of the developed tools across the ADMIRAL ecosystem.

3.3.3 Final rollout

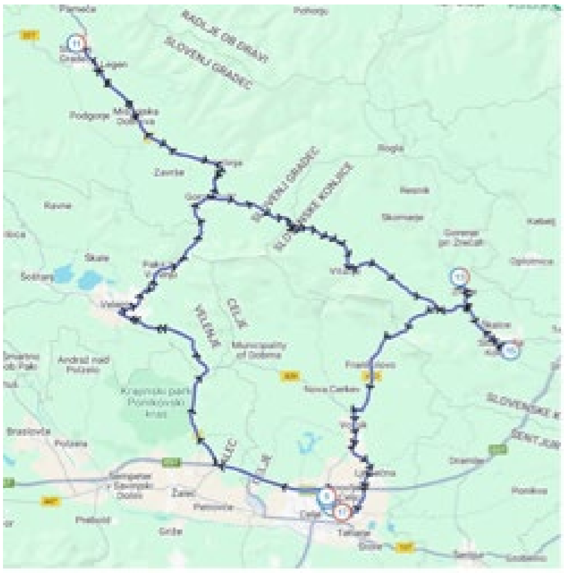

Figure 31. Map illustrating the implemented test pickup route, designed based on the optimization plan

In line with the polished optimization plans for shipment pick-up operations, a real-life test drive was conducted to validate how the proposed optimizations perform under actual conditions. The primary objective was to assess the feasibility, reliability, and adaptability of the optimized route when applied in a dynamic operational environment. By observing real-time vehicle movement, stop durations, and route efficiency, the test provided valuable insights into how theoretical routing improvements translate into tangible field performance.

The test drive conducted on 18 August 2025 in the North-Eastern region of Slovenia aimed to simulate a shipment pick-up route using a truck. The route covered a total of **124.4 kilometres** and included 5 **recorded stops**, spanning key locations at our contractual customers. The route log reveals a diverse mix of short- and mid-distance movements, with stop durations varying between a few minutes and over 2 hours, reflecting realistic operational conditions for parcel collection across urban and semi-urban environments. The log provides valuable data for refining pick-up scheduling, vehicle utilization, and route optimization strategies.

Key highlights:

- **Total distance covered:** 124.4 km
- **Total events recorded: 5** stops
- **Representative locations:** Gaji 13 (starting location – consolidation hub in Celje), Trnoveljska cesta 2F (customer nr. 1), Mariborska cesta 143 - Celje (customer nr. 2), Mariborska cesta 127 - Celje (customer nr. 3), Kidričeva ulica 9 – Slovenj Gradec (customer nr. 4), Tovarniška cesta 5 - Zreče (customer nr. 5), Tovarniška cesta 6 – Slovenske Konjice (customer nr. 6)
- **Variation in stop durations** reflects flexible and adaptive routing needed for real-world parcel pick-up scenarios.
- **Data includes GPS points**, timestamps, and odometer readings – useful for further GIS-based route analysis and efficiency scoring.

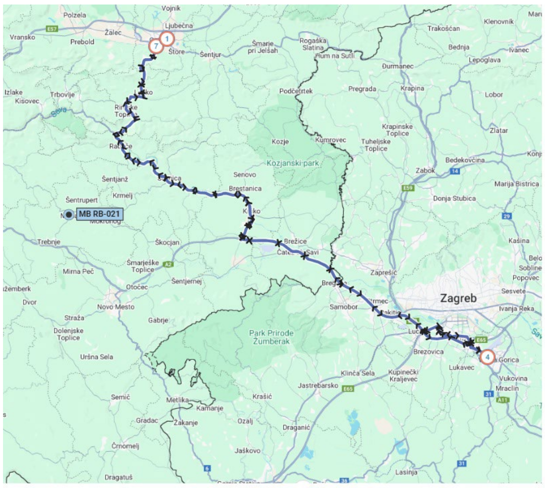

Figure 32. Map illustrating the implemented mid-mile transport route, developed according to the optimization plan

As part of our ongoing pilot activities, a **mid-mile test route** was executed on 21 August 2025 in line with the optimized pickup strategies developed under the project. This specific corridor was established **ad-hoc** and later recognized as the most **direct and operationally efficient route towards Zagreb, Croatia**. The aim of the test was to observe how the results of the optimization algorithm would perform in a real-life logistics environment. The drive served to validate distance assumptions, stop durations, and overall suitability of the chosen path as a repeatable corridor for mid-mile cross-border transport.

The test was executed using a truck and included a **total distance of 121 kilometres** between two postal hubs. The route began in Trnovlje pri Celju, passed through Velika Gorica (Croatia), and returned to Celje, forming a realistic mid-mile loop covering both national and cross-border territories. This log provided concrete insights into speed profiles, duration of each segment, and potential points for aggregation and handover.

Key highlights:

- **Total distance covered:** 121 km
- **Total route segments logged:** 7
- **Representative locations:** Gaji 13 (Trnovlje pri Celju), Velika Gorica (HR), Krekov trg 9 (Celje)
- **Route confirmed as the most efficient direct corridor** for mid-mile logistics to Zagreb
- **Real-life stop durations** support route adaptability under various scheduling and operational constraints
- **Detailed GPS tracking and odometer data** support further optimization for fuel usage and CO_2 tracking.

3.3.4 Crowdsourcing tool

Technology overview

The Locodels platform is a crowd-shipping software solution that enables fast, flexible, and cost-efficient last-mile delivery by leveraging a network of independent drivers and partner companies. It provides an end-to-end digital environment for managing on-demand, same-day, and scheduled deliveries in urban areas.

Before implementing the algorithm from Solvesall, routing and optimizing of the driving schedule was done through our crowd-shipping platform.

The crowd-shipping platform assigned routes on the point-to point basis, as that was the business model while developing the app (circa 2016). Through the years the business model has changed, and the need arose for multi-point capillary delivery and a new way of route optimization. In this iteration of the platform there was no built-in optimization nor the tools to easily integrate it, as the whole logic behind the platform was point-to-point delivery.

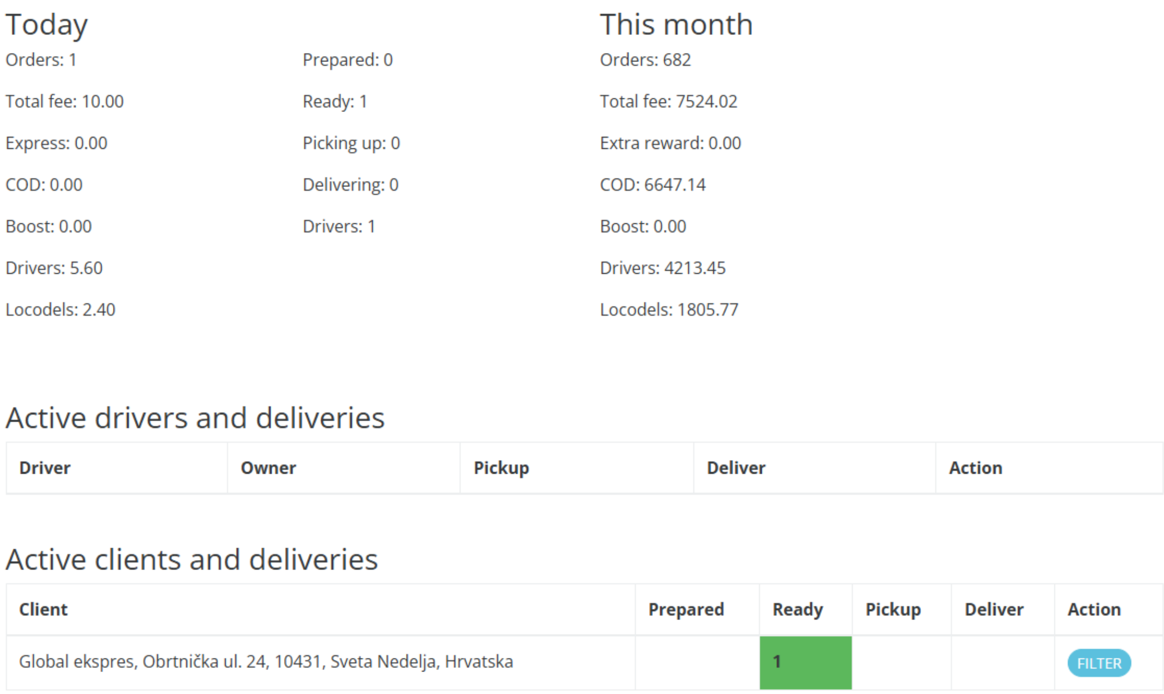

Figure 33. Admin's Home Page in the Crowd-shipping Platform

Business overview

In 2024, Locodels transported 32,629 parcels in Croatia. Shipments have been carried out through three major cities: Zagreb, Split and Rijeka. The vast majority was handled in Zagreb 32,535 parcels then Split 68 and Rijeka 26. With those numbers in mind, we can conclude that the concentration of demand is almost exclusively tied to Zagreb and its outer region.

We have a clear indicator of seasonality in the fact that 25,289 parcels are managed during the period from April to November. That is 77.51% of total annual shipments that occur in just 6 months. The reason for this is closely tied to the industry branch in which our biggest clients operate. That is fresh food and produce. Fast, secure and hassle-free delivery is a must to keep the satisfaction of their customers at the highest level.

Initial state at start of project

Before the start of the ADMIRAL project, the Locodels platform had been repurposed for a new capillary-delivery model, shifting from a simple point-to-point crowd-shipping service to a multi-node, capillary distribution network capable of consolidating and re-routing parcels across multiple delivery stops.

Although the previous version of the software had already reached full commercial readiness for point-to-point operations, the pivot to capillary delivery introduced fundamentally new logistics logic and system architecture.

As a result, the technology had returned to TRL 5, defined as “technology validated in a relevant environment”, because the key components for capillary routing were only experimentally validated in limited pilot settings.

Key limitations at TRL 5 included:

- Absence of a production-grade routing engine for capillary distribution.
- No proven scalability, security hardening, or commercial SLA compliance for the new model.
- Incomplete integration with billing, partner APIs, and analytics needed for full operations.

The focus during the early project period was therefore on validating the technical feasibility of the new capillary business logic within a relevant but controlled environment before progressing to TRL 6–8 demonstrations and eventual production deployment.

The point-to-point logic is still visible in the platform as it still works for smaller clients and webshops.

Development path for Crowd-shipping

Table 7. TRL progression for Crowd-shipping platform

TRL Stage	Key Activities	Achieved Outcomes
TRL 5	*Defined new capillary-delivery architecture and business logic.* *Implemented a stand-alone prototype of Solvesall's multi-stop optimization algorithm in a sandbox version.* *Ran small-scale pilots (limited routes, test data) to validate routing logic and user-interface changes.*	*Technology validated in a relevant environment.* *Proof of feasibility for multi-stop optimization.*
TRL 6	*Developed API connectors and middleware to exchange data with Solvesall's optimization service while keeping the algorithm separate.* *Performed real-environment pilot deliveries with selected partner couriers and early customers.* *Collected performance metrics (route efficiency, driver workload).*	*Prototype demonstrated in a relevant environment.* *Initial operational KPIs confirmed.*
TRL 7	*Expanded pilots to multiple cities and commercial partners.* *Conducted stress testing and route visualizations.*	*System prototype demonstrated in an operational environment with paying pilot customers.* *Stable multi-stop routing at pre-production scale.*
TRL 8	*Deployed production-ready capillary-delivery platform with the optimization service operating as an external module.* *Introduced automation upgrades to minimize manual dispatching.*	*Actual system completed and qualified for commercial use.* *Active paying customers and sustained daily operations.*

Current state

The Locodels capillary-delivery platform is now a production-ready, commercially operated system that is fully qualified for daily use by paying customers.

The platform supports large-scale, multi-stop urban deliveries through a scalable cloud architecture and a live network of partner couriers.

Co-funded by
the European Union

Today we use the route optimization algorithm for our bigger clients (as stated before, point-to-point still has some uses) whose daily intake of same day deliveries exceed the capacity that the crowd-shipping platform can efficiently route with its point-to-point logic. Route of for example, 10+ parcels are optimized using the algorithm to make the whole delivery process as fast as possible and to take away stress from the driver who no longer has to optimize and plan ahead the route he will take.

This brought a major improvement at optimizing last-mile delivery operations, cutting down costs for the drivers, expediting the delivery process, the drivers participated less in traffic because the routes where shorter and the deliveries faster for the sake of lowering CO_2 emissions and making the whole operation more transparent, carefree and future proof.

Platform workflow

Figure 34. Crowd-shipping platform workflow

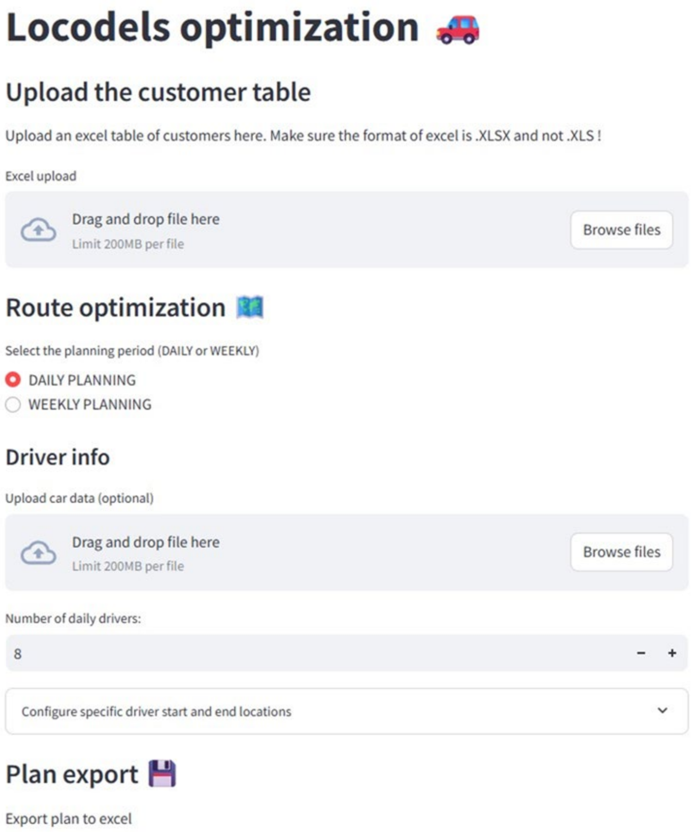

Figure 35. Standalone optimisation algorithm home page

Home page interface in the standalone optimization tool, Locodels, as shown in the Figure 35, has the functionality to input several parameters – selection of daily or weekly planning, upload of car data, selection of the number of drivers and their individual starting locations (via address).

Daily or weekly planning – daily planning is standard, and weekly planning is a mode developed for one specific large client who on Friday announces shipments for the whole next week.

Number of drivers – we have the option to select the number of available drivers which in turn correlates to the number of routes. We can also specify the starting point of each driver.

Upload car data – in addition to the manual selection of the number of drivers and their starting locations, we have the option to upload an Excel file with specification of the number of drivers, their starting points and their names for added personalization.

The whole routing process starts with the upload of an Excel file with full shipment data – recipient, full address, recipient e-mail, phone number, etc. The result of the routing process is a downloadable delivery plan in Excel file consisting of all the data from the upload phase with additional data added to every shipment – route number (vehicle ID), name of the driver, sequence of delivery within the route, ETA and geocoordinates of the delivery address. Additionally, daily routes preview on the map is generated, as shown in Figure 36.

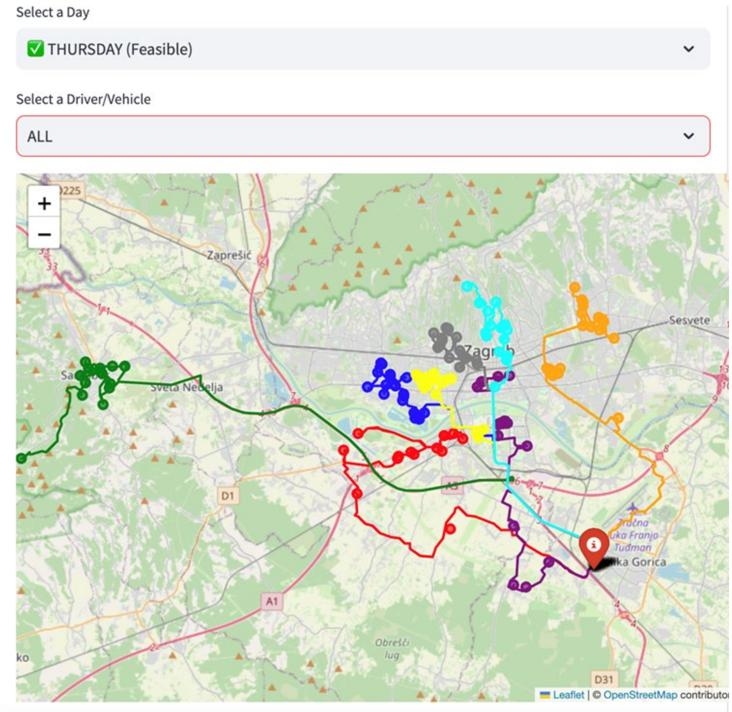

Figure 36. Standalone optimisation algorithm daily routes preview

3.3.5 Logistics Optimisation Planning Tool for ADMIRAL - LOPTA

Besides reaching the CO_2 improvements and other KPIs through AI and optimization tools (Logistics Optimisation Planning Tool for ADMIRAL (**LOPTA**), the focus and goal of developments (WP4, WP5) is to address the issues of postal logistics. The goal is that the developed tools will be kept in use after the project ends. At this stage, we reached a decent maturity level on parts of the tools, where the main parts (capabilities) are:

- Detection of stoppage times (How long is the service time at a specific location).
- Route optimization (Order of the pickups, deliveries, and the vehicle used).
- Scalable optimization worker services (optimization algorithms are separate and independent from the main app, to improve scalability).
- Routing engine (Open source-based routing algorithms, which can be extended and have better price/performance as compared to some enterprise versions).
- CO_2 Emission Calculation (solution for assessing the CO_2 emissions for delivery).
- Mobile application (monitoring, location attribute crowdsourcing, local navigation).

Detection of stoppage times

With the stoppage times algorithm, LOPTA calculates the time a delivery agent needs to perform a postal service for pick-up/drop-off (**PUDO**) task for a specific location (e.g. business, household, etc.). The algorithm uses GPS traces of delivery agents to determine the time of stoppage for carrying out the task. Here, we distinguish between **stop time** and **service time**.

- **Stop time**: The actual time the agents spend at a specific location.
- **Service time**: An estimate of the time required for an agent to perform a PUDO task.

In other words, stop time is measured stop time on a specific location and service time is an expected value calculated by considering several factors.

As input, we use a list of GPS records taken from mobile phone. The first algorithm is straightforward: the stop time is calculated by summing the total duration during which the postman was located within the polygon of the object. The second algorithm is more advanced and divided into two stages:

1. **Clustering:** Using the InfoStop algorithm, clusters of points are identified where the postman remained for an extended period. These clusters are referred to as Super Stop Points (SSPs).
2. **Polygon Check:** Each SSP is checked to determine whether it lies inside the polygon of the object. If the SSP is outside the polygon, the duration of the postman's stay at that SSP is added to the stop time of the corresponding object.

The algorithm then links each building node to its nearest SSP. If two building nodes are connected to the same SSP, the SSP stop time is divided proportionally according to the number of tenants associated with each building.

The considered scenarios for detecting stoppage time are depicted in Figure 37 below.

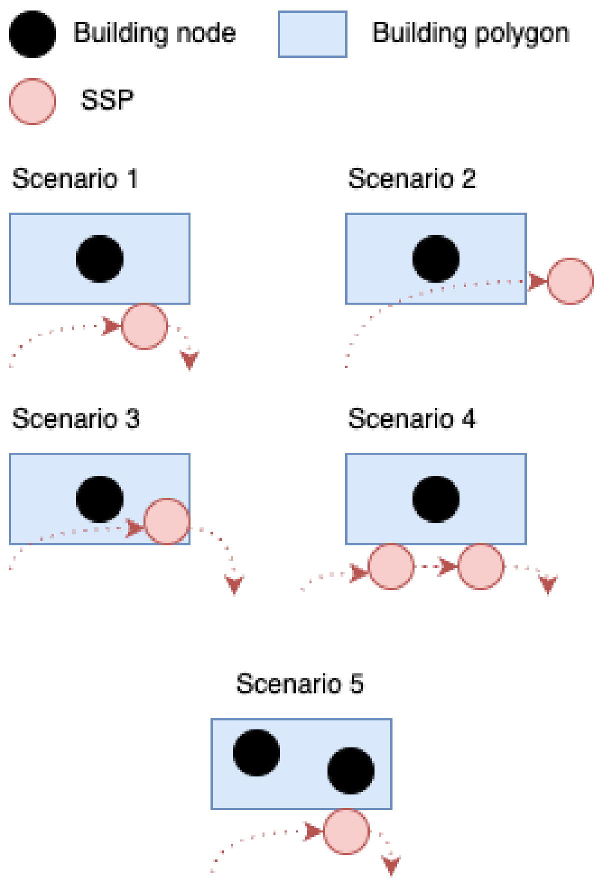

Figure 37. Stoppage times scenarios

The algorithm provides precise and accurate PUDO point locations, which can serve as input for subsequent route optimisation processes. The example of PUDO point locations for a specific region in Ljubljana postal region is depicted in the next Figure 38. In the figure we can see the red dots are building centroids and the green dots are the actual PUDO locations.

Figure 38. PUDO points

In the next Figures 39 and 40, we can see PUDO point in a map.

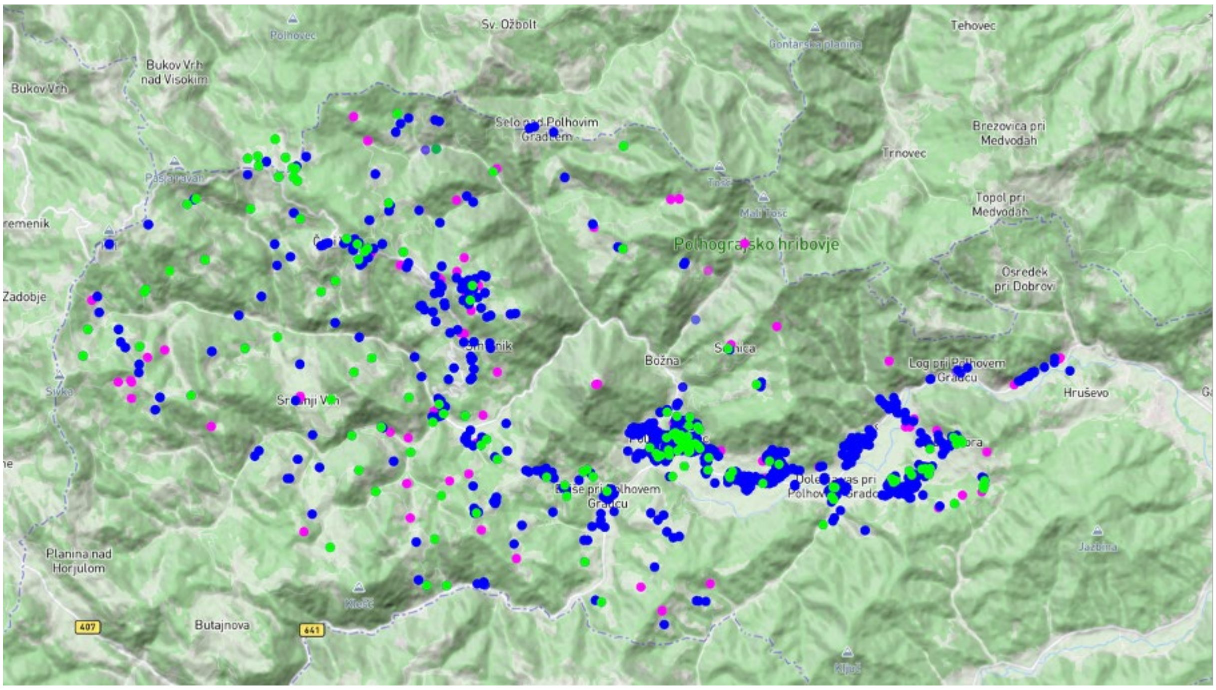

Figure 39. Locating buildings and delivery points for a selected region

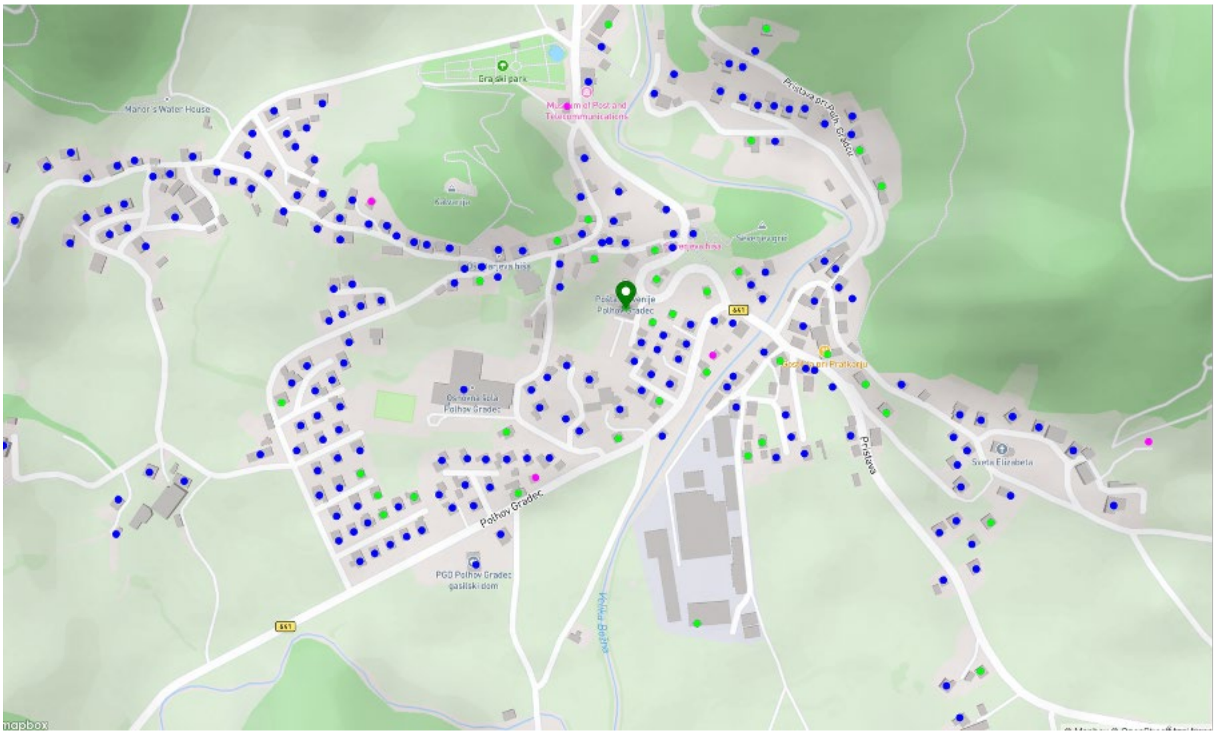

Figure 40. A zoomed in precise buildings and pick-up/drop-off points

Route optimisation

Route optimisation refers to the process of planning and coordinating deliveries supporting heterogeneity of fleet (motorcycles, cars, vans, trucks). Different vehicle types have distinct operational characteristics that affect routing efficiency, costs, and environmental performance. The key elements that the algorithm needs to handle are the following:

- Vehicle capacities (weight and volume limits).
- Range and energy restrictions (length of routes, number of charging stations in the area).
- Access restrictions (narrow roads, pedestrian zones).
- Cost parameters (fuel, driver costs differ per vehicle type).
- Service characteristics (stoppage times vary per vehicle type).

As mentioned before, the optimisation is either done for the selected or on the points created by stoppage time algorithm.

In the scope of Green Logistics: Optimizing Postal Sustainability Across Borders (Slovenia-Croatia) pilot we tested the performance of the Route optimisation for first-mile of postal process. The test setup is described in the result section 3.4 of this deliverable.

In the next Figures 41, 42 and 43 we show examples of optimisations for one postal region and comparison with the baseline route. The optimisation considers different vehicle types (motorbike, car), as well as vehicle stoppage times and driving ranges.

In the Figure 41 we show the result of optimisation of a selected postal region. The optimisation was done for 3 districts for 3 vehicles, one motorbike (blue line) and two cars (red and green line). The optimisation addresses 1029 delivery locations. The optimisation provides optimised route plans which has 1035 points, total distance of 312.761 km, total time of 17.098 hours, service time of 4.147 hours and drive time of 12.951 hours.

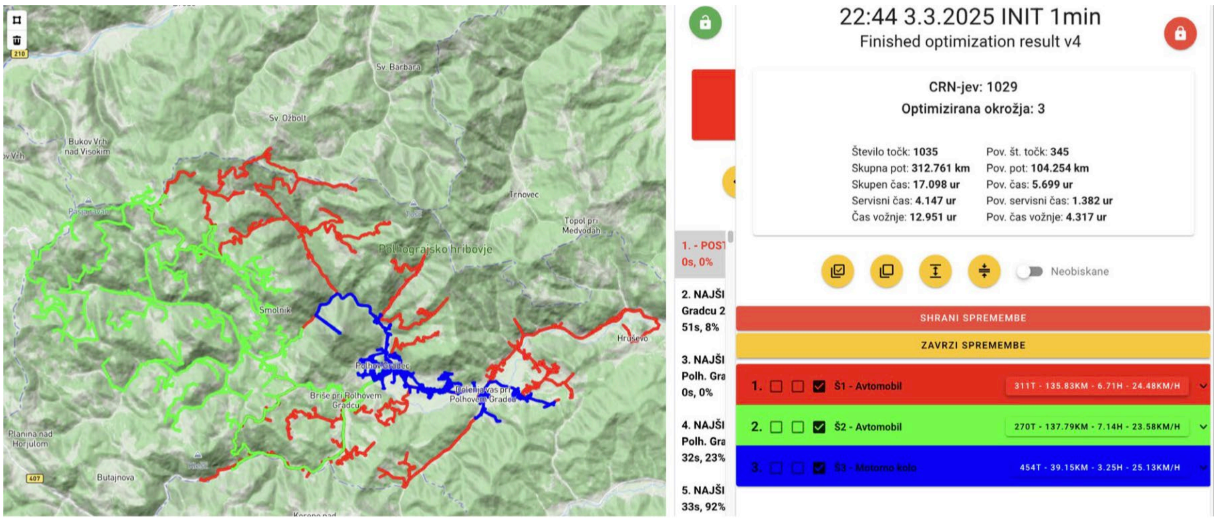

Figure 41. Multimodal optimised last- mile plan for postal region

In Figure 41 the blue route is optimised for motorcycle, the red and green route are optimised for car.

In the Figures 42 and 43 we compare the baseline route and the optimised route for which the optimisation process was running for 120 minutes, which ensures that the optimal routes were found.

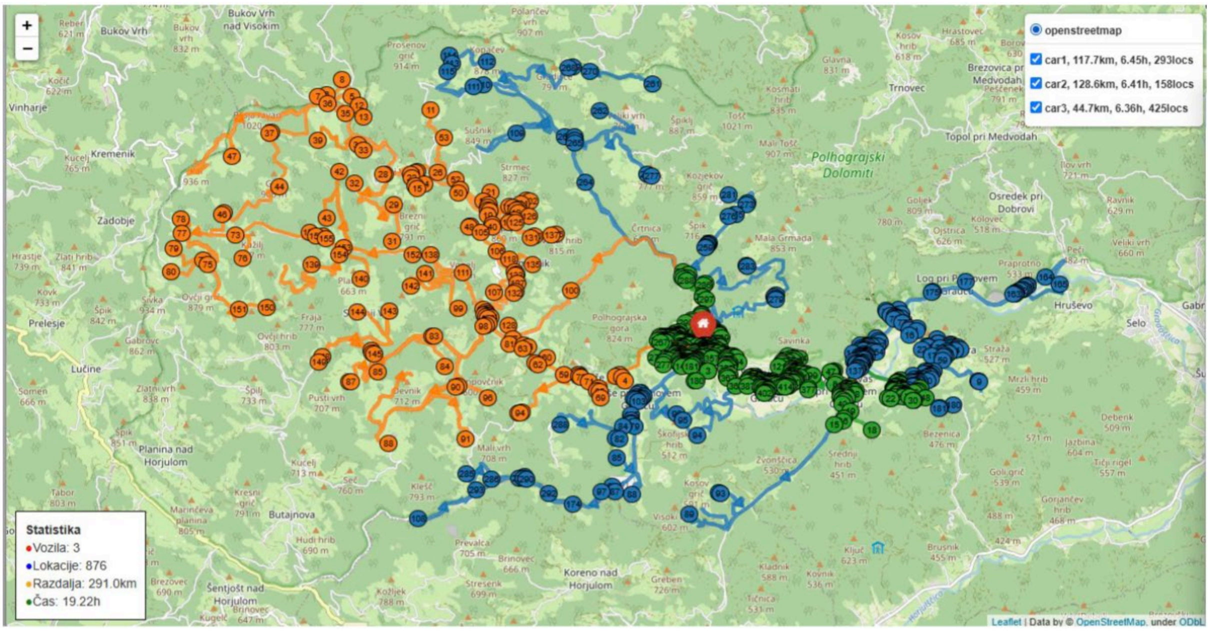

Figure 42. Comparing baseline and optimised route plans - baseline route plan

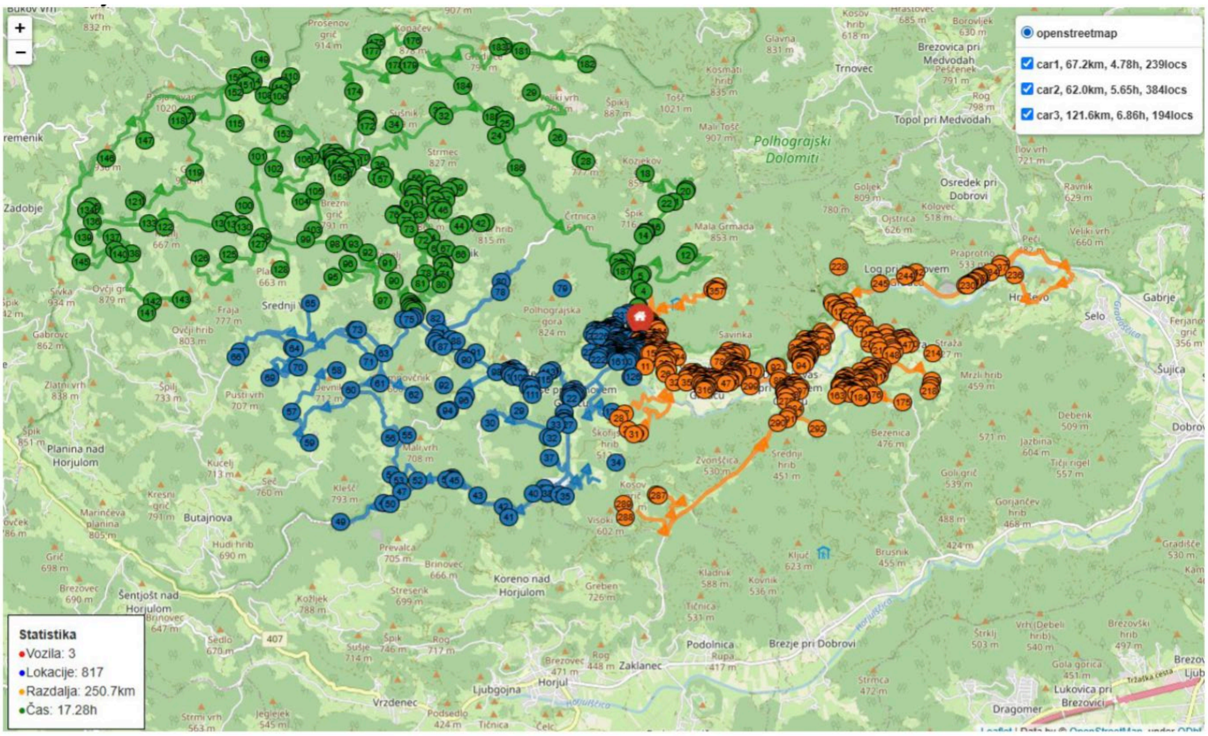

Figure 43. Comparing baseline and optimised route plans – optimised route plan

Table 8. Comparing baseline and simulated route plans

	Vehicles	No of Locations	Distances	Time on the road
Optimal Baseline	3	876	291 km	19.22 h
Optimized	3	817	250.4 km	17.28 h

This test was done for 3 cars showed promising results. We saw a reduction of unnecessary visited locations by **6%.** The distance for the route plan was reduced by **14%** and the time on the road was reduced by **10%**.

In Table 8, we used the "Optimal Baseline" wording, because the actual route the courier does is unknown – he only has a list of locations, which he visits on his own ordering, most often leading to much worse routes as presented in the table.

Development progression for LOPTA

The development of the LOPTA was done the following progression steps (Table 9.).

Table 9. LOPTA development steps

TRL	Activities	Outcomes
TRL 5 -> TRL 6	*Analysing available prototype;* *Specifying needed upgrades;* *Analysis of optimisation parameters;* *Selecting a region for pilot demonstration*	*Upgrading routing engine* *Developed algorithms for stoppage times.* *Developed new optimisation algorithms.* *Demonstration in the pilot region.*
TRL 6 -> TRL 7	*Scaling the solution with multiple workers.* *Testing the route optimisation with heterogeneous fleet (bicycle, motorbike, car, truck)* *Optimisation of all postal regions*	*Scaling the optimisation loads with autonomous worker services.* *Optimised plan for different modalities.* *Every postal region was optimised and reviewed.*
TRL 7 -> TRL 8	*Deployment of the solution to the Pošta Slovenije.* *Analysing possible update and maintenance.* *API for external connection.*	*Using the solution across all regions.* *Identifying future upgrades and monitoring the system.* *Developing the API for external connection.*

3.4 Results of test

In this chapter, we describe the methodology, data collection, and the results of the testing of the developed tools on the Slovenian/Croatian use-case. Besides the very good result of production usage of a few tools, we also tested for CO_2 emissions and cost reductions, which both show that the tools improve the situation for **more than 50%.** The improvement was achieved with a combination of process change (direct driving) and also the route optimization of the existing and new routes. The improvement is very substantial as well, because on some parts there was no automatic (algorithmic) planning before. The biggest achievement that we count on this pilot is that we developed systems that will survive the project and continue to be used by postal operators, also after the Admiral project ends.

3.4.1 Vehicle trip data measurements for emission assessment

Emission measurement and calculation based on vehicle trip measurement with on board equipment. Methods are presented in subsection: 3.2.7 Emission measurement and Impact Assessment with Vehicle Trip Data. This section show measurement for first-mile, mid-mile and last-mile.

The goals were to optimise the pick-up route in the NE part of Slovenia and to establish a green corridor between Celje and Zagreb. We aimed to reduce CO_2e emissions and increase load factors with the help of the optimisation algorithms and consolidation of the parcels.

First-mile measurements

First-mile (TCE 1) road transport includes the collection of parcels by different freight owners based on a milk-run route. Measurements were performed on two first-mile trips that are labelled as case 1 and case 2. The results obtained from measurements are presented in Figures 44, 45 and 46 for case 1 and Figures 47, 48 and 49 for case 2.

From speed histograms is evident that the route includes relatively steady driving at 80-100 km/h on motorways and some waiting during stops. Mild changes of elevations across the road were observed.

For first- and mid-mile deliveries following vehicle type was used:

- Vehicle type: MAN TGS 18.440 4X2 LL CH
- Gross vehicle mass: 18 tons
- Fuel type: Diesel
- Load capacity: 7,5t
- Average fuel consumption: 28 L/100km (ETC cycle)

Figure 44. First-mile, case 1, speed vs. position

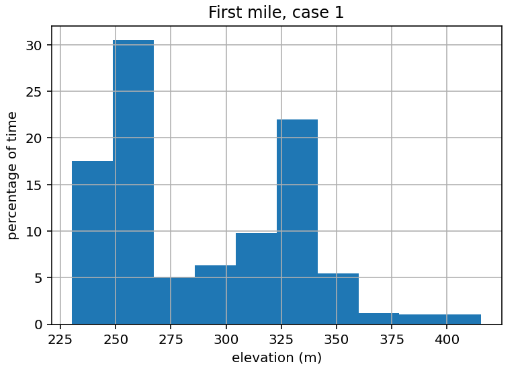

Figure 45. First-mile, case 1, elevation histogram

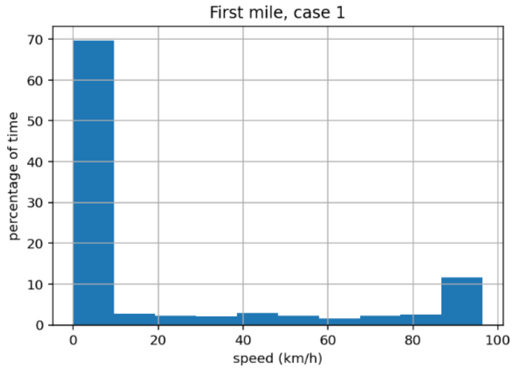

Figure 46. First-mile, case 1, speed histogram

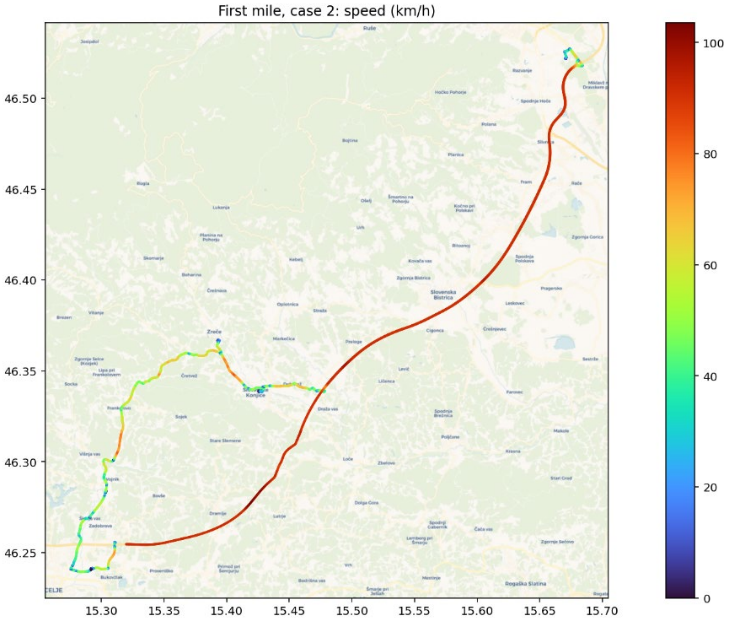

Figure 47. First-mile, case 2, speed vs. position

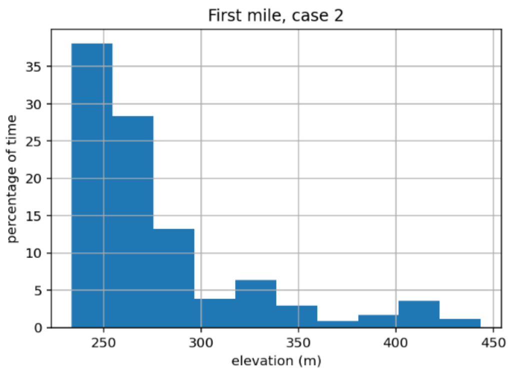

Figure 48. First-mile, case 2, elevation histogram

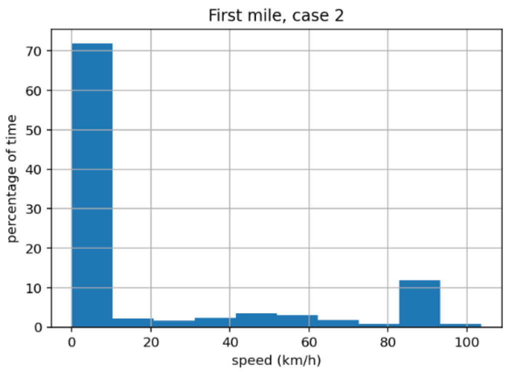

Figure 49. First-mile, case 2, speed histogram

Mid-mile measurements

The mid-mile measurements consist of pre-pilot and post-pilot cases. Pre-pilot delivery route from Celje (CE) went through Ljubljana (LJ) hub, extending the delivery distances significantly. Post-pilot assumes direct delivery from CE to ZG, bypassing Ljubljana.

Initial situation for mid-mile delivery represents the sum of Celje – Ljubljana (CE-LJ) and Ljubljana - Zagreb (LJ-ZG) routes that are shown in next pages, as well Celje – Zagreb (CE – ZG) post-pilot route data.

For first and mid-mile deliveries following vehicle type was used:

- Vehicle type: MAN TGS 18.440 4X2 LL CH
- Gross vehicle mass: 18 tons
- Fuel type: Diesel
- Load capacity: 7,5t
- Average fuel consumption: 28 L/100km (ETC cycle)

Celje – Ljubljana (CE – LJ) route mid-mile measurements

In this subsection, two mid-mile measurements on the route Celje – Ljubljana are presented. The results obtained from measurements are presented in Figure 50, Figure 51, and Figure 52 for case 1 and in Figure 53, Figure 53, and Figure 55 for case 2. From speed histograms it is evident that the route includes very steady driving at 80-100 km/h on motorways most of the time. Mild changes of elevations across the road were observed (between 200 and 450 m elevation).

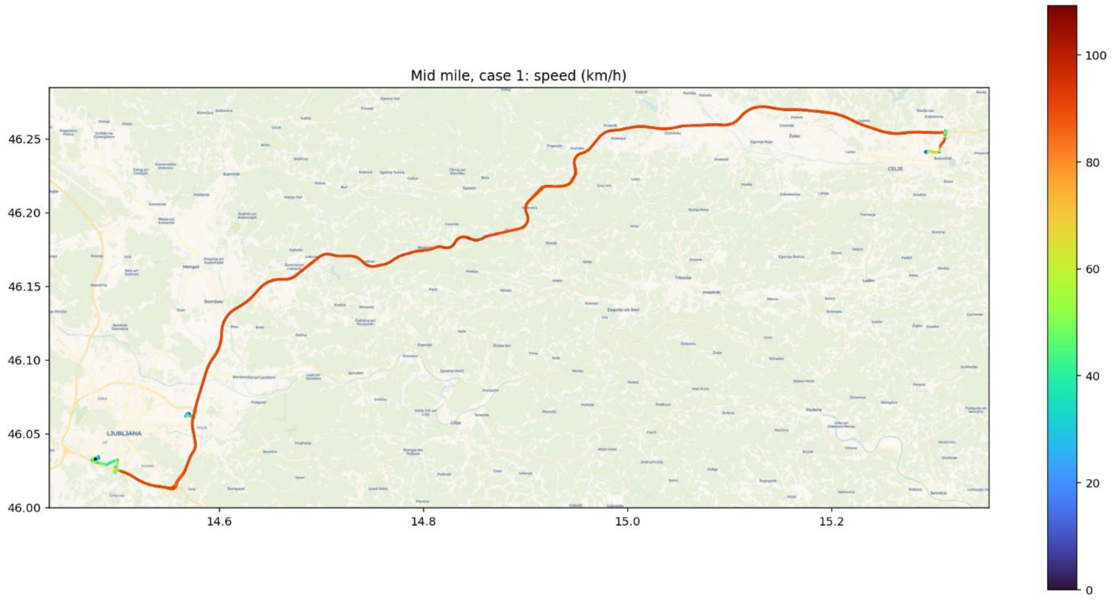

Figure 50. Mid-mile, case 1, speed vs. position

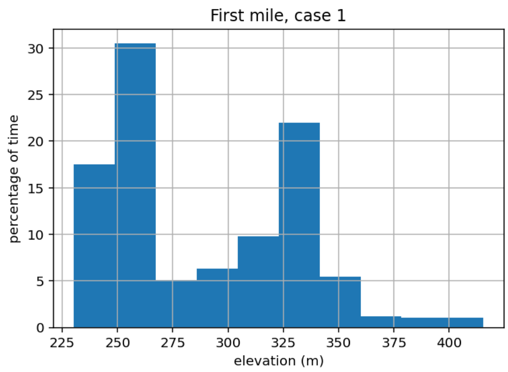

Figure 51. Mid-mile, case 1, elevation histogram

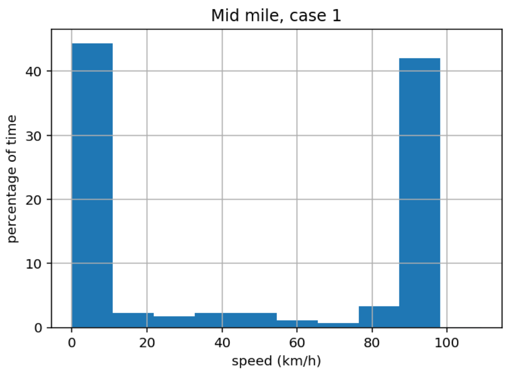

Figure 52. Mid-mile, case 1, speed histogram

Figure 53. Mid-mile, case 2, speed vs. position

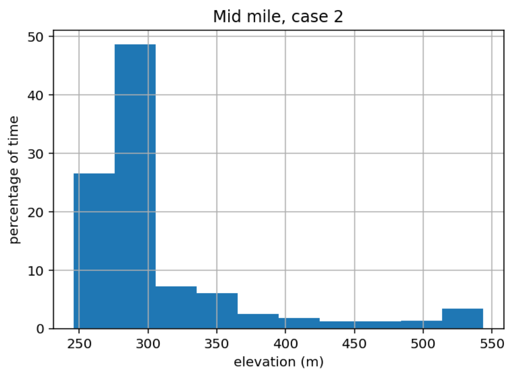

Figure 54. Mid-mile, case 2, elevation histogram

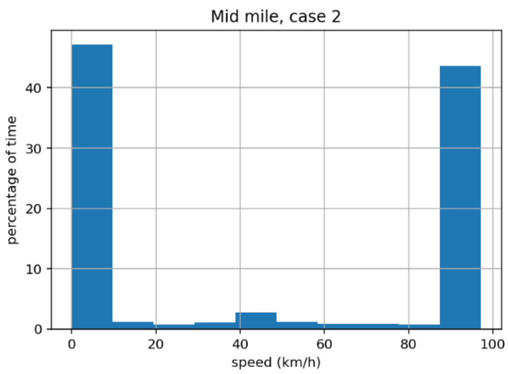

Figure 55. Mid-mile, case 2, speed histogram

Ljubljana - Zagreb (LJ – ZG) route – mid-mile measurements

In this subsection, two mid-mile measurements on the route Ljubljana – Zagreb are presented. The results obtained from measurements are presented in Figure 56, Figure 57, and Figure 58 for case 1 and in Figure 59, Figure 60, and Figure 61 for case 2.

From speed histograms it is evident that the route includes very steady driving at 80-100 km/h on motorways most of the time which is typical for heavy vehicles. Mild changes of elevations across the road were observed (between 100 and 450 m elevation).

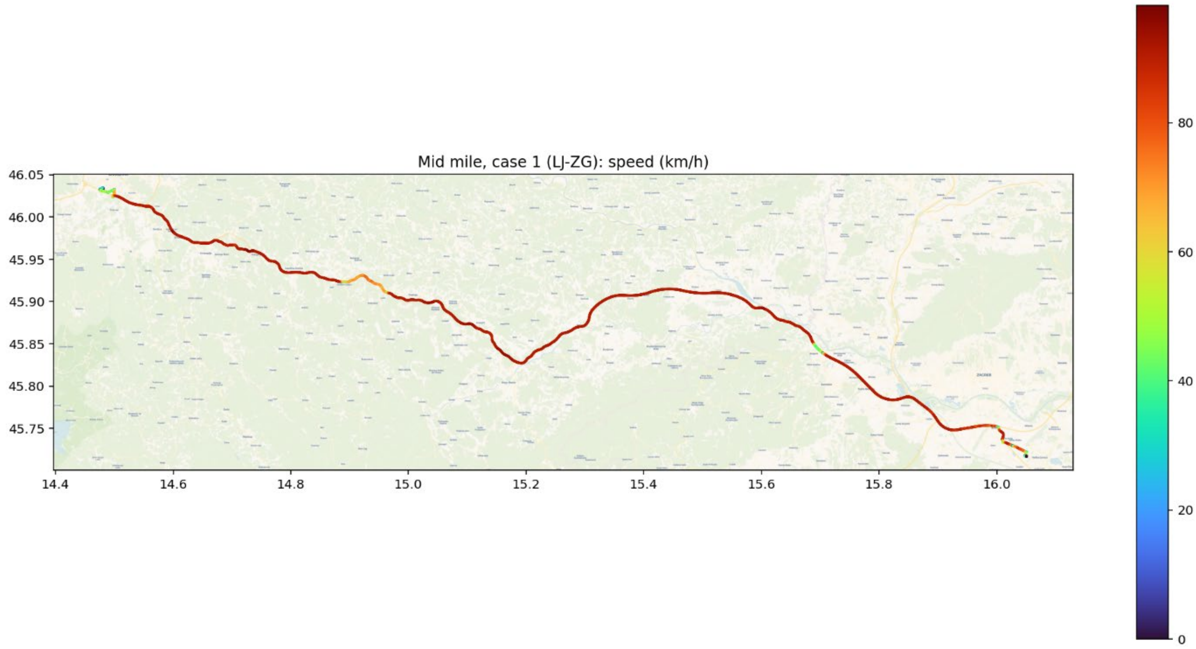

Figure 56. Mid-mile (LJ-ZG), case 1, speed vs. position

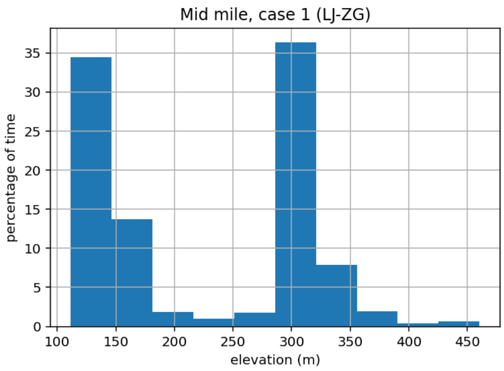

Figure 57. Mid-mile (LJ-ZG), case 1, elevation histogram

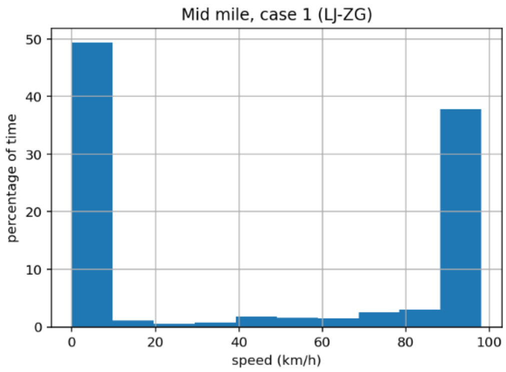

Figure 58. Mid-mile (LI-ZG), case 1, speed histogram

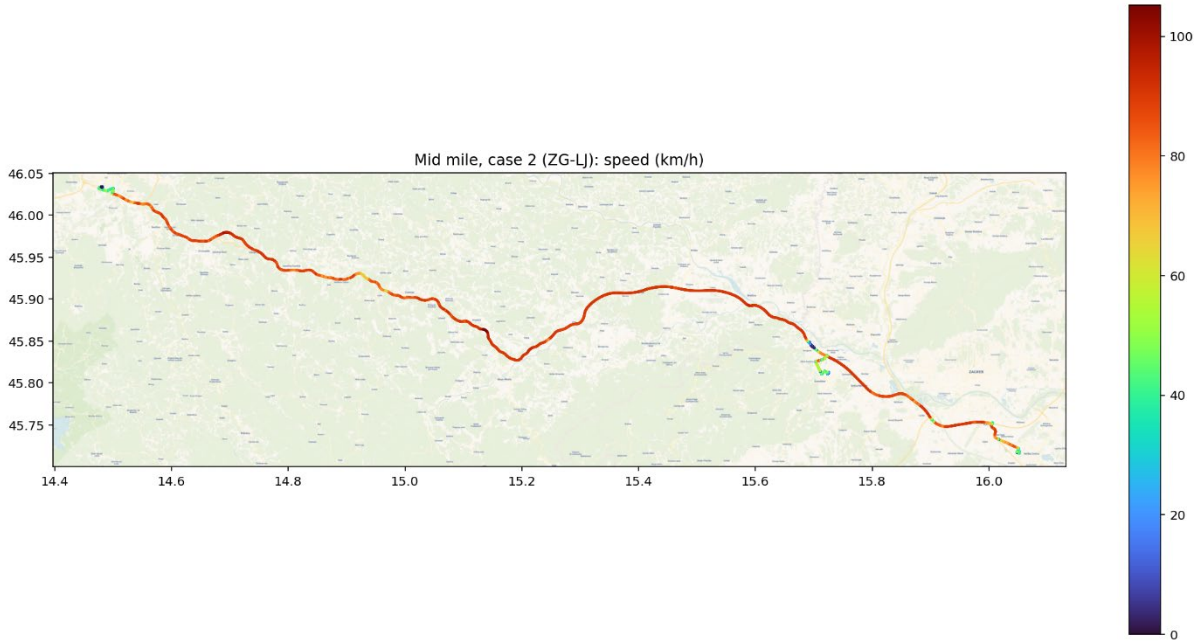

Figure 59. Mid-mile (ZG-LJ), case 2, speed vs. position

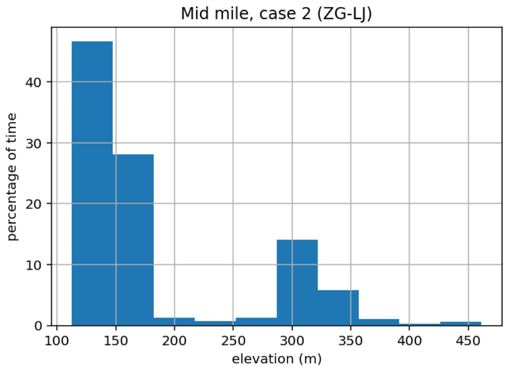

Figure 60. Mid-mile (ZG-LJ), case 2, elevation histogram

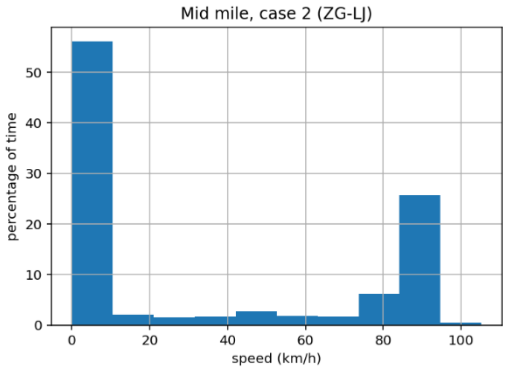

Figure 61. Mid-mile (ZG-LJ), case 2, speed histogram

Celje – Zagreb (CE – ZG) post-pilot route mid-mile measurements

In this subsection, two mid-mile measurements on the route Celje – Zagreb are presented. The results obtained from doing measurements are presented in Figure 62, Figure 63, and Figure 64 for Mid-mile case 1 and in Figure 65, Figure 66, and Figure 67 for Mid-mile case 3. From speed histograms it is evident that the route includes unsteady driving, mostly on extraurban roads with a lot of speed adjustments due to road curvature. Mild changes of elevations across the road were observed (between 100 and 250 m elevation).

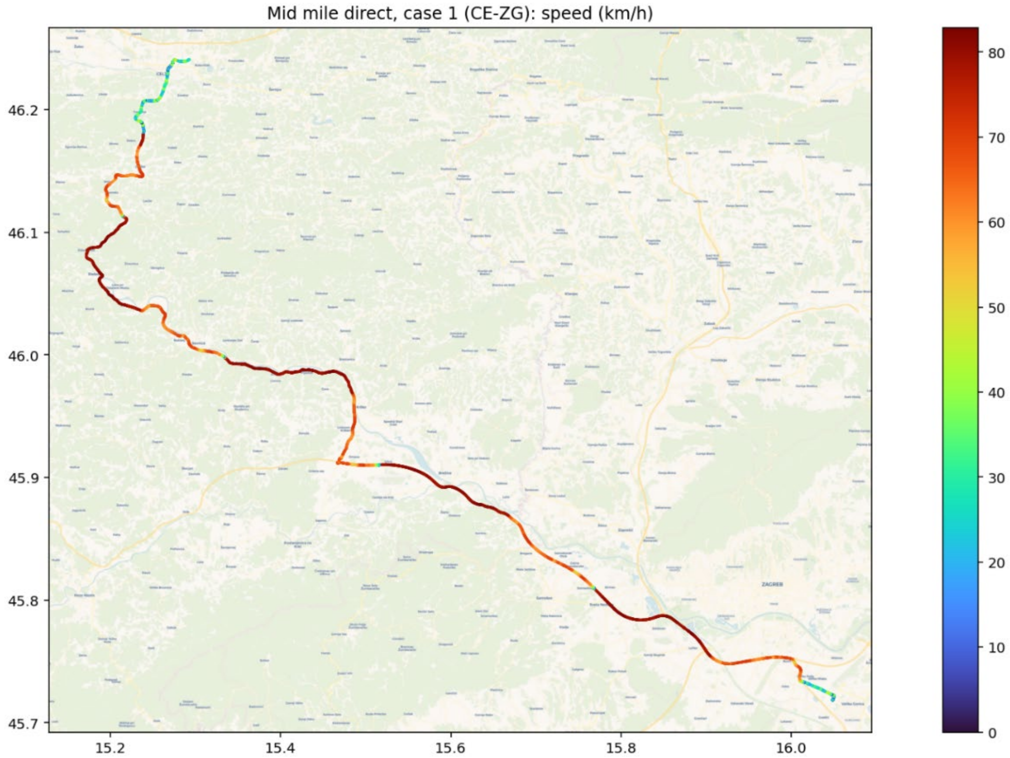

Figure 62. Mid-mile direct, case 1, speed vs. position

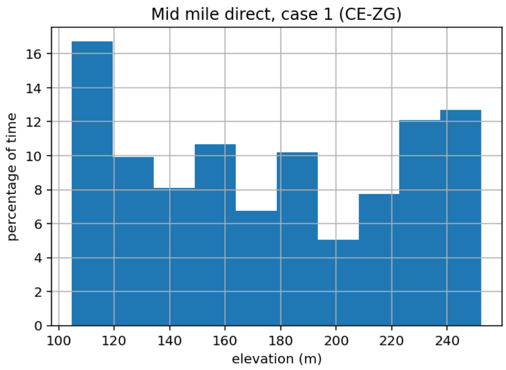

Figure 63. Mid-mile direct, case 1, elevation histogram

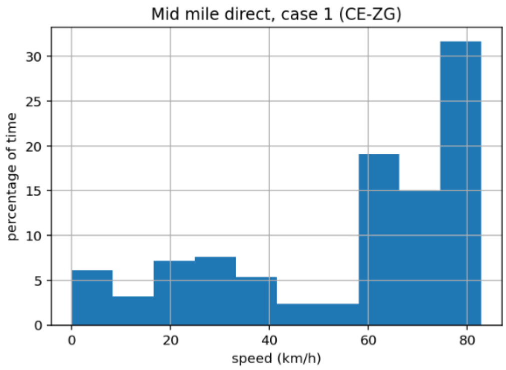

Figure 64. Mid-mile direct, case 1, speed histogram

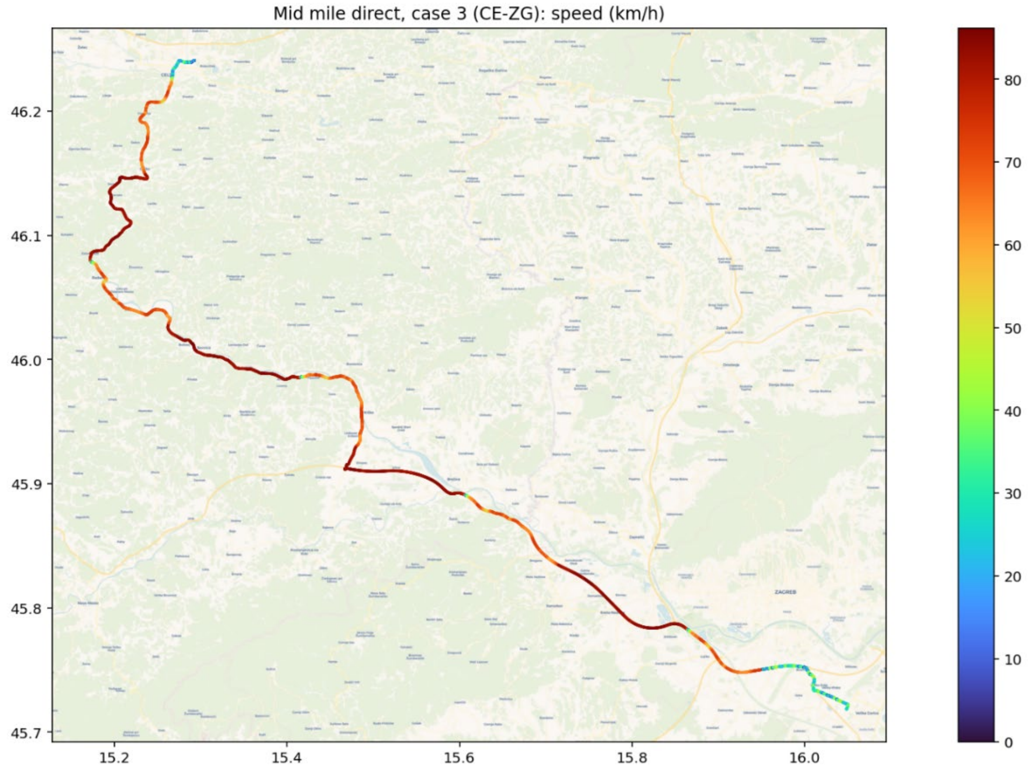

Figure 65. Mid-mile (LJ-ZG), case 3, speed vs. position

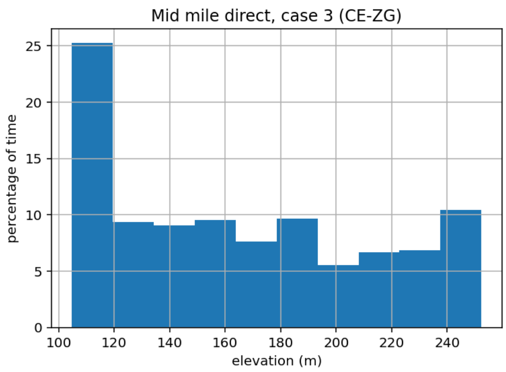

Figure 66. Mid-mile direct, case 3, elevation histogram

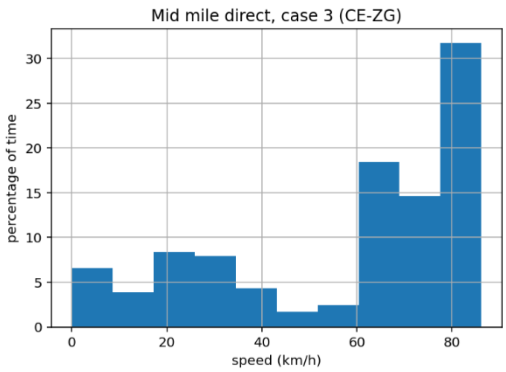

Figure 67. Mid-mile direct, case 3, speed histogram

Last-mile measurements

Last-mile measurements represent outsourced deliveries of packages in the Zagreb city area. Quite a high amount of accelerating and decelerating, and also quite high driving speeds, probably above the allowed speed limits, was observed (up to 90 km/h inside the city) is seen in the Figure 68 and Figure 71. Majority of the deliveries are at low elevations, characteristic of Panonian Basin where City of Zagreb is situated, however, some of the deliveries included ascending from around 100 m up to 350 m to the suburban settlements North of Zagreb (Figure 69 and Figure 72).

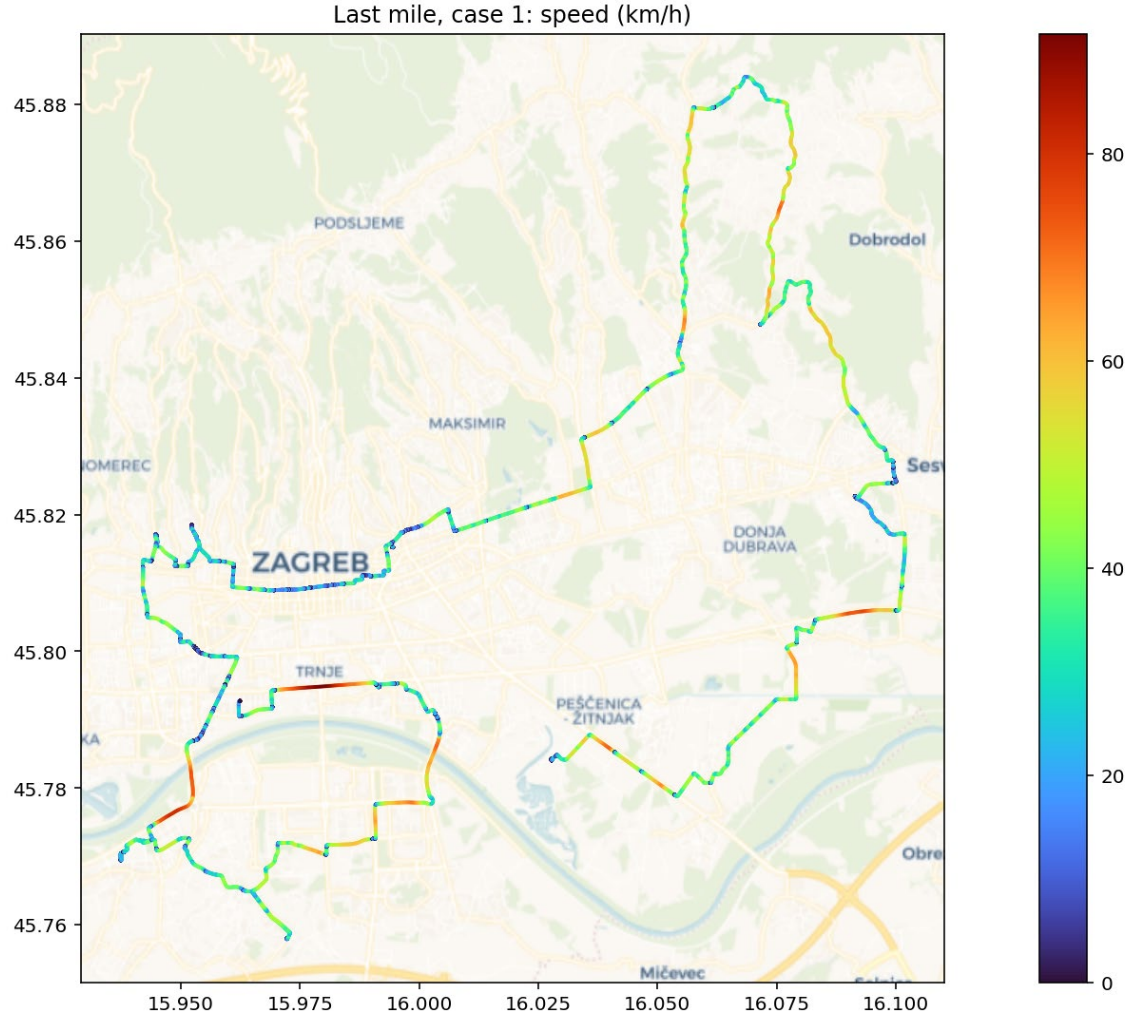

Figure 68. Last-mile, case 1, speed vs. position

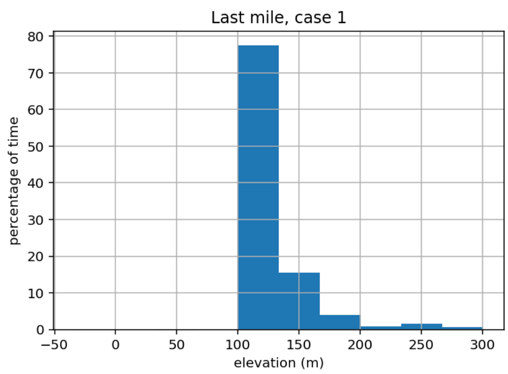

Figure 69. Last-mile, case 1, elevation histogram

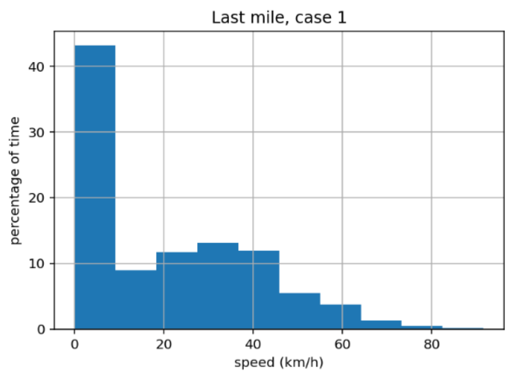

Figure 70. Last-mile, case 1, speed histogram

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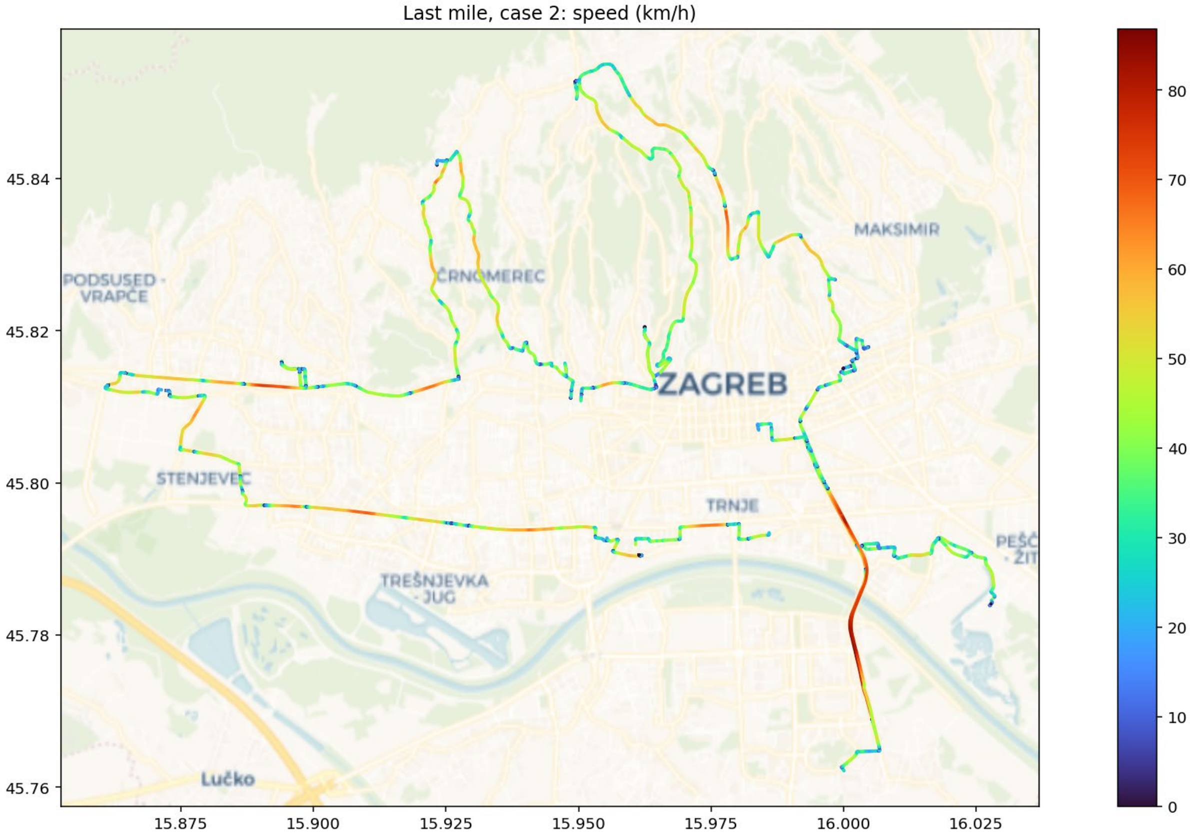

Figure 71. Last-mile, case 2, speed vs. position

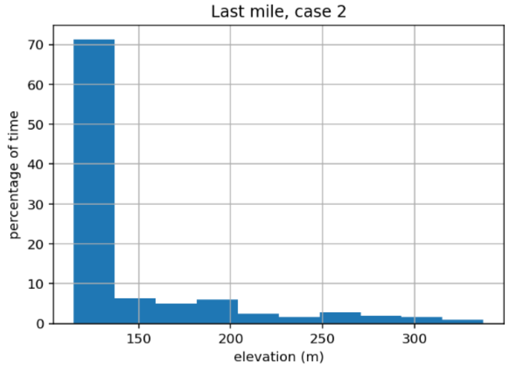

Figure 72. Last-mile direct, case 2, elevation histogram

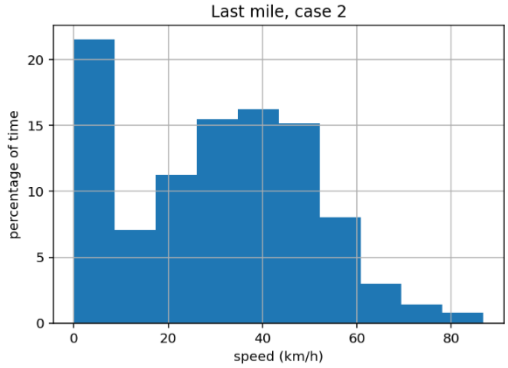

Figure 73. Last-mile, case 2, speed histogram

3.4.2 Vehicle trip data measurements summary

Tables 10 and 11 present the CO_2 emissions related to fuel consumption and average speed. Data are presented for the first-mile, mid-mile, and last-mile. Also, post-pilot data for the direct mid-mile case are added.

Table 10. Fuel consumption-distance and CO_2-related emissions

CASE	FUEL CONSUMPTION [l]	CO_2 [kg]	DISTANCE [m]
FIRST-MILE, CASE 1	32.5	83	100822
FIRST-MILE, CASE 2	33.5	85	111438
MID-MILE (CE-LJ-CE), CASE 1	43.0	109	178534
MID-MILE (CE-LJ-CE), CASE 2	38.6	98	176049
MID-MILE (CE-LJ-CE), CASE 3	39.1	99	176858
MID-MILE (CE-LJ-CE), CASE 4	39.8	101	175985
MID-MILE (CE-LJ-CE), CASE 5	39.3	100	178089
MID-MILE, CASE 1 (LJ-ZG)	33.1	84	147535
MID-MILE, CASE 2 (ZG-LJ)	43.4	110	159709
MID-MILE, CASE 3 (LJ-ZG)	32.5	82	147102
MID-MILE, CASE 4 (ZG-LJ)	42.2	107	158123
MID-MILE, CASE 5 (LJ-ZG)	32.0	81	147106
MID-MILE, CASE 6 (ZG-LJ)	42.7	108	168936
LAST-MILE, CASE 1	6.9	17	63202
LAST-MILE, CASE 2	7.1	18	68868
LAST-MILE, CASE 3	5.0	13	47223
MID-MILE DIRECT, CASE 1 (CE-ZG)	30.8	78	119565
MID-MILE DIRECT, CASE 2 (ZG-CE)	28.2	72	119561
MID-MILE DIRECT, CASE 3 (CE-ZG)	30.0	76	119564
MID-MILE DIRECT, CASE 4 (ZG-CE)	29.6	75	119561

Table 11. Average speed-acceleration and CO_2-related emissions

CASE	AVERAGE SPEED [km/h]	ABSOLUTE AVERAGE ACCELERATION [m/s²]	ENERGY (kJ)	RELATIVE CO_2 [g/km]
FIRST-MILE, CASE 1	19.7	0.31	368857	819
FIRST-MILE, CASE 2	18.6	0.27	379426	763
MID-MILE (CE-LJ-CE), CASE 1	44.9	0.27	487156	611
MID-MILE (CE-LJ-CE), CASE 2	43.9	0.20	437189	556
MID-MILE (CE-LJ-CE), CASE 3	46.7	0.23	442830	561
MID-MILE (CE-LJ-CE), CASE 4	46.1	0.24	451715	575
MID-MILE (CE-LJ-CE), CASE 5	49.2	0.25	445171	560
MID-MILE, CASE 1 (LJ-ZG)	41.9	0.21	375517	570
MID-MILE, CASE 2 (ZG-LJ)	33.6	0.31	491726	690
MID-MILE, CASE 3 (LJ-ZG)	43.6	0.21	368049	560
MID-MILE, CASE 4 (ZG-LJ)	29.6	0.29	478036	677
MID-MILE, CASE 5 (LJ-ZG)	40.0	0.20	363109	553
MID-MILE, CASE 6 (ZG-LJ)	24.1	0.19	483955	642
LAST-MILE, CASE 1	19.8	1.12	77918	276
LAST-MILE, CASE 2	30.1	1.40	80374	261
LAST-MILE, CASE 3	23.9	1.29	56692	269
MID-MILE DIRECT, CASE 1 (CE-ZG)	56.1	0.45	349440	655

CASE	AVERAGE SPEED [km/h]	ABSOLUTE AVERAGE ACCELERATION [m/s²]	ENERGY (kJ)	RELATIVE CO_2 [g/km]
MID-MILE DIRECT, CASE 2 (ZG-CE)	59.1	0.48	320211	600
MID-MILE DIRECT, CASE 3 (CE-ZG)	57.6	0.45	340714	638
MID-MILE DIRECT, CASE 4 (ZG-CE)	58.9	0.48	335260	628

3.4.3 Vehicle trip measurement data analysis

Emissions are calculated from trip trajectories sampled at a 1 Hz rate. As explained in previous chapters, the results obviously show that deliveries with a mid-weight truck show a lot more efficient driving, compared to the last-mile outsourced deliveries in the city, where drivers using personal vehicles drive quite aggressively (an abundance of accelerations and braking). See also the speed versus position charts (Figure 68 and Figure 71) in last-mile measurement previously presented in pages 94 to 96. Assuming an average load of personal vehicles and the number of trips conducted, it results in about 35% of total emissions (Table 12).

Table 12. Shares of emissions per TCE

	Emissions		Share of emissions	
	pre-pilot	post-pilot	pre-pilot	post-pilot
First-mile	84	84	16 %	23 %
Mid-mile	293	151	54 %	42 %
Last-mile	161	128	30 %	35 %
Total	537	363	100 %	100 %

Calculation of CO_2e emissions (CE-LJ-ZG compared to CE-ZG)

The purpose of this analysis is to assess the reduction of CO_2 emissions using the direct route between Celje (CE) and Zagreb (ZG), bypassing Ljubljana (LJ). Implementation of the route was introduced in a way that the load of the trucks was similar to what was recorded before. Comparing emissions and distances travelled using direct connection shows that emissions for mid-mile deliveries are reduced by 48%, slightly less than the travelled distance (51% reduction) due to a more energy-consuming road that includes several windings and requires more variation in speed, as can be seen in Celje – Zagreb (CE – ZG) post-pilot route data in previous pages in tables 10 and 11. A summary comparing both cases is shown in Table 13.

Table 13. Emissions reduction through direct connection

	CE-ZG route	CE-LJ-ZG route
Average emissions per trip (kg)	151	293
CO_2 emissions reduction	**48 %**	**0 %**
Average distance per trip [km]	239	487
Distance reduction	**51 %**	**0 %**

3.4.4 LOPTA setup and methodology for testing the optimised plans

We defined multiple testing days covering three different time frames, each representing a typical number of postal service orders.

- High season (25.11. – 6.12.2024)
- Medium season (7.7. – 11.7.2025)
- Low season (7.4. – 11.4.2025)

The baseline covered the current situation. Currently a single 15-ton truck drives through all pickup locations and delivers in a single daily route. On mid-mile the truck starts from Celje and delivers the parcels to the PS Central Logistics Hub in Ljubljana and from there to Zagreb, which is a significant detour. On the last-mile the optimisation integrated to the Crowdsourcing App at the beginning of the ADMIRAL project, however now we can reliably track the emissions with the LOPTA-EC.

Here we were analysing three logistics chains, first-mile, mid-mile and last-mile.

Validation of the algorithms

In the First-Mile - LOPTA Optimisation algorithms are solving the following objectives:

- Optimising load factor
- Optimising distance
- Optimising CO_2 emissions
- Optimising costs

The developed algorithms were evaluated on the same test data and compared to the baseline.

In the LOPTA-FMO (First-Mile Optimization) we gave to the algorithm all available vehicles, which was in this case 1x 15-ton truck, and 1x 7.5-ton truck.

Table 14. LOPTA First-Mile Optimization (FMO) test vehicles

Vehicle	**15-ton truck**	**7.5-ton truck**
Truck acronym	15T	7T5
Fuel type	Diesel	Diesel
Fuel usage	0.2525 l / km	0.1825 l / km
Max Load Weight	7.8 t	3.8 t
Max Load Volume	35 m^3	60 m^3
Price per km	1.033 €	1.017 €
Emission intensity	0.191 $kgCO_2e$ / t-km	0.223 $kgCO_2e$ / t-km

Although the developed algorithm is using quite substantial set of constraints that can be weighted or enabled/disabled, we used a subset of them. This was dictated by the historical data from post operators, which contains only some of the fields that we could be using for optimization:

- Date_of_order
- Parcel_id
- delivery_location
- weight_of_parcel

One of the usual constraints is volume limits (space), which we could not use, because of the missing information about the volume of the parcels. This data is important not to overload the truck ad to correctly assign the parcels to the truck. After the analysis and discussions with PS, we figured out that weight-wise there is more space for the cargo on the truck than volume-wise.

To solve this issue, PS provided another piece of information, minimal and maximal size of the parcel for each of the customer. With this data we developed a calculation which **estimates the volume** of a parcel based on **the *weight_of_parcels*** parameter and **the minimal and maximal size of a parcel.**

Thus, for the lightest packages we assume the minimal size and for heavier packages we assume the bigger volume. Here we **assume** that the volume of parcels overshoots the actual volume, and to be on the safer side, we also decreased **the actual load** capacity of a vehicle to **98% of total capacity**.

The validation was done for the following LOPTA components.

- LOPTA – FMO (First-Mile Optimisation)
- LOPTA – EC (Emissions Calculation)

The process for the testing and validation is shown in the Figure 73 below.

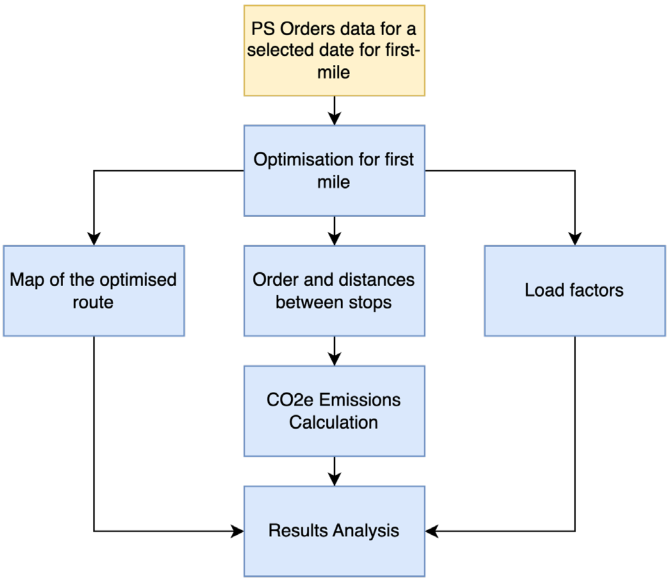

Figure 74. First-mile optimisation validation process

The parcel's data is inserted to the LOPTA-FMO algorithm where the optimization engine calculates the optimal pick-up plan. This results in:

- Maps (steps) of the optimised routes
- Order and distances between the stops
- CO_2e Emissions Calculation

3.4.5 LOPTA result analysis.

As part of the optimisation, the algorithm selects the best route and combination of the vehicle types based on estimated volumes and weights, load factors and CO_2 emissions. The result is a pickup plan for each vehicle (pickup order), and route map. Additionally, we provide the data for load factors for each trip in the plan which is used to calculate the load factors for the truck.

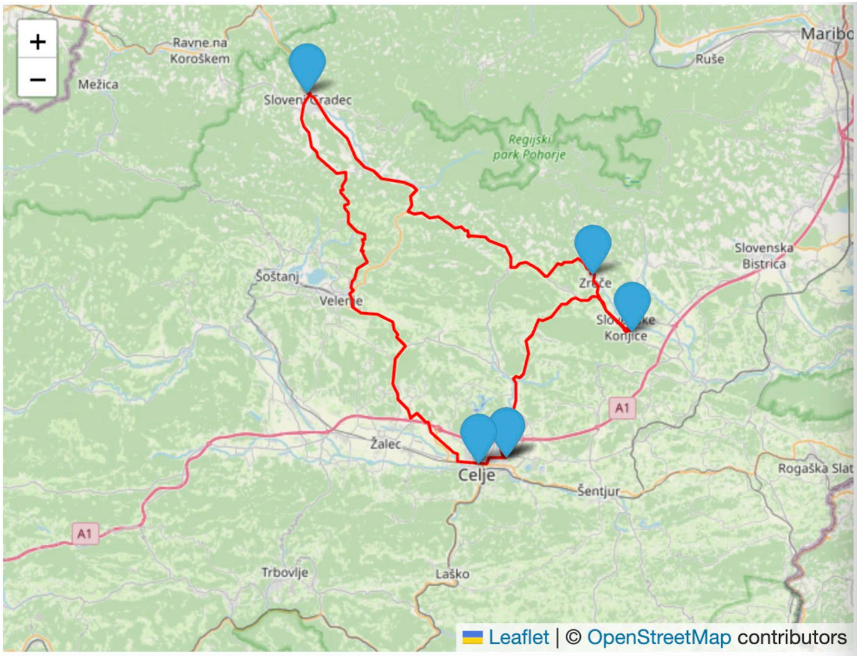

Figure 75. Optimised route map for orders from 29.11.2024 - 1st trip

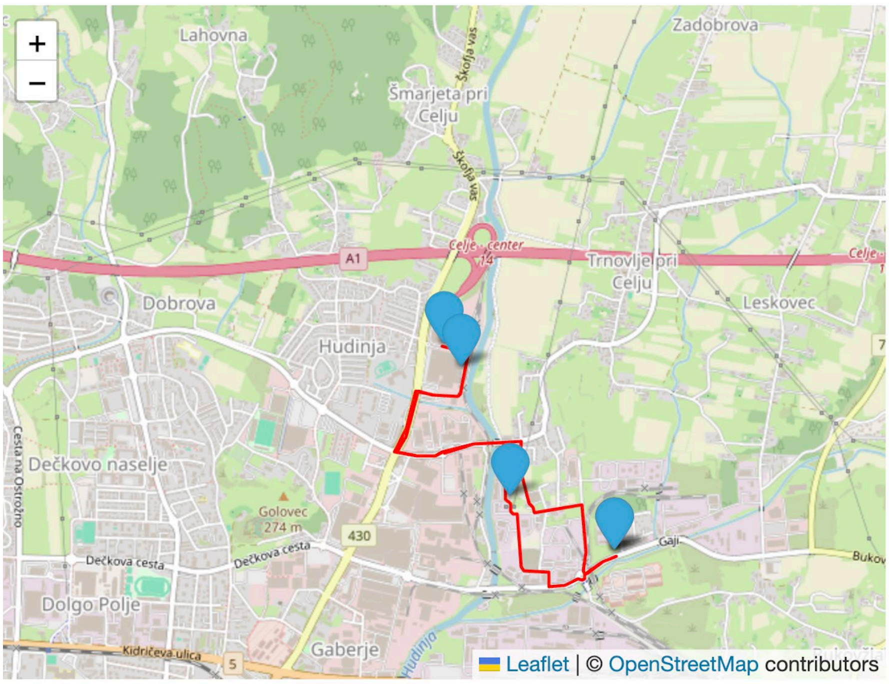

Figure 76. Optimised route map for orders from 29.11.2024 - 2nd trip

Together with the map, a route plan table is created, with distances between stops and a trip number shown in Table 15 below.

Table 15. Pickup plan with distances

Drive order	Trip number	Distance [km]	Loaded Weight [kg]	Loaded Volume [m^3]
PS Logistics Center Celje	1	0	0	0
Customer 1	1	2.8	0.715	0.041
Customer 2	1	49.4	931.573	27.016
Customer 3	1	36.6	1357.93	13.023
Customer 4	1	6.9	1256.67	14.655
PS Logistics Center Celje	1	24.7	0	0
Customer 5	2	3	120.51	16.976
Customer 6	2	0.3	1040.48	8.281
Customer 7	2	1.7	19.36	0.557
PS Logistics Center Celje	2	1.3	0	0

The **load factors** are calculated from the weight of the parcels and from the estimated volume. Calculating the load factors is important to correctly select the vehicle that pick-up of the parcels.

The **price per kilometre** for different type of truck is listed in the Table 14. The operating cost of PS trucks per kilometre are calculated as:

$$pricePerKilometre = truckPricePerKM \times numberOfKilometres \quad \text{(Eq.12)}$$

For the calculation of the **CO_2e emissions** we used the following formulas:

Empty run:

$$emissionsEmpty = averageFuelUsage \times dieselEmissionFactor \quad \text{(Eq. 13)}$$

Laded run:

$$emissionsLoaded = loadedWeight \times distance \times emissionIntensity \quad \text{(Eq. 14)}$$

Transshipment:

$$emissionsTransshipment = loadedWeight \times transshipmentEmissionsFactor \quad \text{(Eq.15)}$$

Emission intensities:

$$emissionIntensity = \frac{TotalEmissions_{WTW}}{\sum payloadWeigth \times ladenDistance} \quad \text{(Eq.16)}$$

Total emissions are the sum of all different emissions across each transport chain element.

The example of full results is shown in following Tables 16 and 17.

Table 16. Optimisation plan results for 29.11.2024

TCE	Location	Loaded Weight [kg]	Loaded Volume [m³]	Cumulative Weight [kg]	Cumulative Volume [m³]	Vehicle Used	Distance [km]	Run Type	Load Factor Weight	Load Factor Volume	Emissions Ton-km	Emissions [kgCO₂e]	Price [€]
0	HUB	0	0	0	0	15T		Empty	0.000	0.000	0.000	2.459	N/A
1	Customer 1	0.715	0.041	0.715	0.041	15T	2.8	Laden	0.000	0.001	0.035	0.007	N/A
2	Customer 2	931.573	27.016	932.288	27.057	15T	49.4	Laden	0.120	0.451	34.122	6.517	N/A
3	Customer 3	1357.93	13.023	2290.218	40.08	15T	36.6	Laden	0.294	0.668	15.803	3.018	N/A
4	Customer 4	1256.67	14.655	3546.888	54.735	15T	6.9	Laden	0.455	0.912	87.608	16.733	N/A
5	HUB	0	0	0	0	15T	24.7	TS	0.000	0.000	0.000	4.611	N/A
6	HUB					15T	0	Empty	0.000	0.000	0.000	2.634	N/A
7	Customer 5	120.51	16.976	120.51	16.976	15T	3	Laden	0.015	0.283	0.036	0.007	N/A
8	Customer 6	1040.48	8.281	1160.99	25.257	15T	0.3	Laden	0.149	0.421	1.974	0.377	N/A
9	Customer 7	19.36	0.557	1180.35	25.814	15T	1.7	Laden	0.151	0.430	1.534	0.293	N/A
10	HUB					15T	1.3	TS	0.000	0.000		1.534	N/A
Totals		**4727.238**	**80.549**				**126.7**					**38.191**	**130.8811**

Here In the Table 16 above the HUB (in the column Location) represents the PS Logistics Center Celje, and TS represents transshipment, TCE represents Transport Chain Element. The results show that a total of 4.7 tons of goods were transported over 126.7 km using a 15-ton vehicle, with total emissions of 38.19 kgCO_2e. The highest vehicle utilisation occurred after Customer 4, reaching 45% by weight and 91% by volume.

The cost of the first-mile can be calculated for the entire trip, while emissions are determined based on the Run Type. For example, the TCE 0 emissions represent the empty trip between TCE 0 and TCE 1. Once the truck is laden at TCE 1, emissions are calculated using the formula for laden runs. When the vehicle returns to the hub fully loaded and unloads the parcels at TCE 5, emissions are calculated for the transshipment phase.

The total emissions are obtained by summing the emissions from all TCE segments across the trip.

3.4.6 Comparing baseline plan with optimised Plan

In Table 17. Validation results of optimisation for the first-mile, below we present the comparison between the optimised plan and baseline data.

Table 17. Validation results of optimisation for the first-mile

Date	Vehicle Type	Total Weight [kg]	Distance [km]	b_ Distance [km]	diff_ Distance [km]	Emissions [kgCO₂e]	b_ Emissions [kgCO₂e]	diff_ Emissions [kgCO₂e]	Price [€]	b_ Price [€]	diff_ Price [€]
2024-11-25	15T	5911.1	181.5	161.1	-20.4	55.61	100.59	44.98	187.49	166.42	-21.07
2024-11-26	15T	4136.0	125.1	161.1	36.0	32.54	88.91	56.37	129.23	166.42	37.19
2024-11-27	15T	3942.0	168.7	161.1	-7.6	49.38	86.86	37.48	174.27	166.42	-7.85
2024-11-28	7T5	2834.2	156.8	161.1	4.3	44.18	85.18	41.00	118.70	166.42	47.72
2024-11-29	15T	4727.2	126.7	161.1	34.4	38.19	93.94	55.75	130.88	166.42	35.54
2024-12-02	15T	5787.8	161.9	161.1	-0.8	62.45	100.46	38.01	167.24	166.42	-0.83
2024-12-03	15T	4524.8	155.6	161.1	5.5	48.67	95.83	47.16	160.73	166.42	5.68
2024-12-04	15T	3840.4	126.7	161.1	34.4	30.36	94.21	63.85	130.88	166.42	35.54
2024-12-05	7T5	2824.5	226.3	161.1	-65.2	43.78	86.52	42.74	171.31	166.42	-4.89
2024-12-06	15T	6120.5	221.3	161.1	-60.2	95.54	112.31	16.77	228.60	166.42	-62.19
2025-04-07	15T	4329.2	128.9	161.1	32.2	37.45	94.21	56.76	133.15	166.42	33.26
2025-04-08	15T	3376.8	122.6	161.1	38.5	31.98	89.33	57.35	126.65	166.42	39.77
2025-04-09	15T	2941.8	122.9	161.1	38.2	29.66	85.28	55.62	126.96	166.42	39.46
2025-04-10	15T	3622.9	122.9	161.1	38.2	34.86	90.82	55.96	126.96	166.42	39.46
2025-04-11	15T	3808.6	125.1	161.1	36.0	33.41	89.72	56.31	129.23	166.42	37.19
2025-07-07	15T	3748.4	125.1	161.1	36.0	29.47	87.46	57.99	129.23	166.42	37.19
2025-07-08	7T5	3660.0	174.0	161.1	-12.9	45.19	87.73	42.54	131.72	166.42	34.70
2025-07-09	15T	3731.6	124.4	161.1	36.7	70.73	89.66	18.93	128.51	166.42	37.91
2025-07-10	15T	3655.2	122.9	161.1	38.2	31.52	89.66	58.14	126.96	166.42	39.46
2025-07-11	15T	6026.7	155.7	161.1	5.4	58.75	103.05	44.30	160.84	166.42	5.58

In the Table 17 we see the results from validation runs of LOPTA-FMO. The table shows the following columns:

Vehicle type: Which truck the optimisation algorithm used

TotalWeight: Total weight of the parcels.

Distance: Optimised distance

B_distance: Baseline distance

Diff_distance: Difference between baseline and optimised distance:

$$Diff\_Distance = b\_Distance - Distance \quad \text{(Eq.17)}$$

Emissions: Calculated optimised emissions in $kgCO_2e$. Calculation follows the same methodology (GLEC) as calculation for baseline emissions

B_Emissions: Baseline emissions

Diff_Emissions: Difference between baseline and optimised emissions

$$Diff\_emissions = B\_Emissions - Emissions \quad \text{(Eq.18)}$$

Price: Optimised price

B_Price: Baseline price

Diff_Price: Difference between baseline and optimised emissions

$$Diff\_Price = B\_Price - Price \quad \text{(Eq.19)}$$

Average improvement of the optimised plans is shown on the following table.

Table 18. Average improvement based one the difference between baselines and optimised trips

	Distance improvement	**Emissions improvement**	**Price improvement**
Absolute	12.3 km	47.4 $kgCO_2e$	20.44 €
Relative	8%	51%	12%

The results show consistent improvements across all aspects of the optimisation process. Most of the savings were achieved by **reducing the number of rides for the pick-up**. In the baseline scenario, parcel pick-up was performed along three static routes. The LOPTA-FMO component enables the flexibility to **create dynamic route plans** based on the real customer order data.

In practice, the analysis shows that three routes are often unnecessary. In most cases parcel pick-up can be completed using only two optimised routes. By reducing number of pick-up routes, we also increase vehicle load factor, improving both operational efficiency and sustainability.

Focusing on emission reduction we additionality calculated emission per kilometre for selected dates. Initially we intended to track emissions per parcel as it was written in the proposal. However, the emission per parcel is dependent on the characteristics of the parcels such as weight and volume. As the parcels in the Slovenian Croatian Pilot are highly heterogeneous, assessing the environmental impact through this metric can be misleading.

Emission per ton-kilometre provide more consistent and comparable measure of environmental impact.

Table 19. Comparing emission intensity

Date	Emission Intensity [kgCO_2e/t-km]	Baseline Emission Intensity [kgCO_2e/t-km]
2024-11-25	0.601	0.740
2024-11-26	0.282	0.933
2024-11-27	0.494	1.011
2024-11-28	0.533	1.007
2024-11-29	0.271	0.799
2024-12-02	0.430	0.695
2024-12-03	0.374	0.744
2024-12-04	0.286	1.112
2024-12-05	0.378	0.946
2024-12-06	0.507	0.550
2025-04-07	0.268	0.774
2025-04-08	0.118	0.870
2025-04-09	0.075	1.010
2025-04-10	0.105	0.835
2025-04-11	0.273	0.882
2025-07-07	0.289	0.968
2025-07-08	0.434	0.950
2025-07-09	0.617	0.879
2025-07-10	0.130	0.875
2025-07-11	0.400	0.659
Average	**0.343**	**0.861**
Improvement	**60%**	

We see that with LOPTA-FMO we can **improve emission intensities for 60%.** As the emission intensities (kgCO_2e/t-km) also take into account empty kilometres it is no surprise that the intensities show even better environmental impact.

For increasing load factors, the optimisation algorithms evaluate the total parcel volume per customer, determining the most efficient loading configuration and generate and optimised route plan accordingly. The table below presents a detailed analysis of load factor performance per route.

Table 20. Comparing baseline and optimised routes load factor performance

	Baseline vehicle	Baseline Route 1	Baseline Route 2	Baseline Route 3	Optimised vehicle	Optimised Route 1	Optimised Route 2	Optimised Route 3
2024-11-25	15T	0.571	0.978	0.344	15T	0.491	0.668	0.989
2024-11-26	15T	0.429	1.773	0.362	15T	0.791	0.959	/
2024-11-27	15T	0.210	0.454	0.351	15T	0.566	0.583	/
2024-11-28	15T	0.195	0.312	0.473	7T5	0.812	0.959	/
2024-11-29	15T	0.461	0.421	0.450	15T	0.912	0.430	/
2024-12-02	15T	0.420	1.111	0.916	15T	0.630	0.964	0.916
2024-12-03	15T	0.369	0.209	0.756	15T	0.974	0.369	/
2024-12-04	15T	0.245	0.580	0.339	15T	0.588	0.609	/
2024-12-05	15T	0.157	0.282	0.502	7T5	0.802	0.609	/
2024-12-06	15T	0.616	0.360	0.997	15T	0.964	0.916	/
2024-04-07	15T	0.553	0.218	0.411	15T	0.964	0.229	/
2024-04-08	15T	0.491	0.028	0.332	15T	0.854	/	/
2024-04-09	15T	0.301	0.163	0.365	15T	0.844	/	/
2024-04-10	15T	0.416	0.053	0.369	15T	0.860	/	/
2024-04-11	15T	0.447	0.289	0.319	15T	0.767	0.345	/
2024-07-07	15T	0.377	0.503	0.319	15T	0.696	0.668	/
2024-07-08	15T	0.326	0.375	0.392	7T5	0.997	0.881	/
2024-07-09	15T	0.462	0.372	0.332	15T	0.396	0.795	/
2024-07-10	15T	0.439	0.178	0.334	15T	0.964	/	/
2024-07-11	15T	0.781	0.314	0.344	15T	0.669	0.781	/

Average baseline load factor performance was 0.406 and average optimised load factor performance was 0.719. We can see the **improvement of 77% for load factor on the first-mile.**

The improvements, and the fact, that these **algorithms are now used in production** by two Admiral members (Posta Slovenije and Locodels (Hrvatska Posta), clearly shows, that the solution is worth to be disseminated to more logistic companies that want to improve the vehicle utilization and thus emission footprint and prices.

Mid-mile

In the mid-mile we compared the emissions from baseline route (Celje – Ljubljana – Zagreb) to the new improved route (Celje – Zagreb). The results are shown in the Table 21.

Table 21. Comparing mid-mile baseline and optimised routes

	Weight for Croatia [kg]	Volume [m³]	Distance Baseline [km]	Distance Pilot [km]	Emissions Baseline [kgCO₂e]	Emissions Pilot [kgCO₂e]	Volume Load Factor to Croatia [m³]
2024-11-25	1246.00	20.68	282.00	124.40	67.11	29.61	34%
2024-11-26	838.00	12.43	282.00	124.40	45.14	19.91	21%
2024-11-27	400.00	6.32	282.00	124.40	21.54	9.50	11%
2024-11-28	66.00	8.64	282.00	124.40	3.55	1.57	14%
2024-11-29	1025.00	13.98	282.00	124.40	55.21	24.35	23%
2024-12-02	1932.00	32.83	282.00	124.40	104.06	45.91	55%

	Weight for Croatia [kg]	Volume [m³]	Distance Baseline [km]	Distance Pilot [km]	Emissions Baseline [kgCO₂e]	Emissions Pilot [kgCO₂e]	Volume Load Factor to Croatia [m³]
2024-12-03	614.00	16.90	282.00	124.40	33.07	14.59	28%
2024-12-04	365.00	8.51	282.00	124.40	19.66	8.67	14%
2024-12-05	473.00	11.36	282.00	124.40	25.48	11.24	19%
2024-12-06	1428.00	30.86	282.00	124.40	76.91	33.93	51%
2025-04-07	1172.00	14.70	282.00	124.40	63.13	27.85	25%
2025-04-08	100.00	0.95	282.00	124.40	5.39	2.38	2%
2025-04-09	468.00	5.47	282.00	124.40	25.21	11.12	9%
2025-04-10	1385.00	12.02	282.00	124.40	74.60	32.91	20%
2025-04-11	342.00	6.18	282.00	124.40	18.42	8.13	10%
2025-07-07	516.00	11.82	282.00	124.40	27.79	12.26	20%
2025-07-08	144.00	2.42	282.00	124.40	7.76	3.42	4%
2025-07-09	511.00	6.71	282.00	124.40	27.52	12.14	11%
2025-07-10	501.00	5.80	282.00	124.40	26.98	11.90	10%
2025-07-11	385.00	4.81	282.00	124.40	20.74	9.15	8%
Average	**695.55**	**11.67**	**282.00**	**124.40**	**37.46**	**16.53**	**19%**

The volumes of parcels that were assessed and used in the first mile were also used in the same way in middle-mile. We used them to check whether it makes sense that the parcels are transferred through green corridor from Celje towards Zagreb.

The baselines tracked the emissions of parcels transported by 15-ton truck on the route Celje – Ljubljana – Zagreb. This transport leg included not only parcels originating from the pilot area, but also a large share of additional shipments from other regions of Slovenia, which were consolidated in Ljubljana before continuing towards Zagreb. Given the current state of digitalisation PS logistics processes, it is not yet possible to capture shipment weight data comprehensively across the entire Slovenian network. To solve the issue of comparison we calculated the emission based on the emission intensities for the known parcels on the truck from Celje to Ljubljana to Zagreb.

From the results (improvements due to direct route), we can see low load factors in case of daily transfer of parcels from Celje to Zagreb. The improvement can be achieved by grouping the transfers every 2 days. During the testing we validated: First group was formed by grouping the parcels from Fridays and from Monday, the second group was formed by grouping parcels from Tuesdays, Wednesdays and Thursdays.

Since we had data available only for the listed 20 days, we grouped together the first Monday and last Friday of each of the sample season for the validation purposes; we grouped parcels from 2024-11-25 with parcels from 2024-12-06.

Table 22. Grouping parcels in mid-mile route Celje to Zagreb

Grouping (15T)	Weight for Croatia [kg]	Distance Pilot [km]	Volume [m³]	Emission Pilot [$kgCO_2e$]	Volume Load Factor Grouping
2024-11-25	2674.00	124.40	51.54	63.54	86%
2024-11-26	/	/	/	/	/
2024-11-27	/	/	/	/	/
2024-11-28	1304.00	124.40	27.39	30.98	46%
2024-11-29	/	/	/	/	/
2024-12-02	2957.00	124.40	46.81	70.26	78%
2024-12-03	/	/	/	/	/
2024-12-04	/	/	/	/	/
2024-12-05	1452.00	124.40	36.77	34.50	61%
2024-12-06	/	/	/	/	/
2025-04-07	1514.00	124.40	20.88	35.97	35%
2025-04-08	/		/	/	/
2025-04-09	/		/	/	/
2025-04-10	1953.00	124.40	18.44	46.40	31%
2025-04-11	/	/	/	/	/
2025-07-07	901.00	124.40	16.63	21.41	28%
2025-07-08	/		/	/	/
2025-07-09	/		/	/	/
2025-07-10	1156.00	124.40	14.93	27.47	25%
2025-07-11	/	/	/	/	/
AVERAGE	**1738.88**	**124.40**	**29.17**	**41.32**	**49%**

In the Table 23 we show the comparison between baseline scenario, pilot scenario and pilot with grouping scenario.

Table 23. Summary of mid-mile improvements

Mid-mile results	Total distance [km]	Distance improvement [%]	Average emissions [$kgCO_2e$]	Average emissions improvement	Average volume Load Factor
Baseline	5640.00	/	749.27	/	19%
Pilot	2488.00	56%	330.53	56%	19%
Pilot - Grouping	995.2	82%	330.53	56%	49%

The results clearly demonstrate a significant improvement in transport efficiency following the implementation of the green corridor.

In the baseline scenario, total transport distance amounted to 5,640 km, resulting in 749.27 kgCO_2e of emissions and an average load factor of 19%. This baseline highlights underutilised vehicle capacity and high operational emissions.

During the Pilot phase, the total distance was reduced to 2,488 km, representing a 56% improvement compared to the baseline. Correspondingly, average **emissions decreased by 56%** to 330.53 kgCO_2e, while the load factor remained constant at 19%. These results indicate that route optimisation alone can halve total travel distance and emissions, even without changes in vehicle loading efficiency.

Analysing environmental impact through emissions intensities did not show any improvements. Main reason being unavailable data of the weight of the parcels on the route Celje – Ljubljana – Zagreb. Since we used the same calculation for emissions (through emission intensities), the calculated emission intensities in both cases, baseline as well as pilot, **0.191 kgCO_2e/t-km.** Another factor for the identical intensities is also that in mid-mile scenario we do not have any empty miles.

In the Pilot – Grouping scenario, additional optimisation through shipment grouping and consolidation achieved further distance reduction to 995.2 km, corresponding to an 82% improvement over the baseline. Emissions remained stable at 330.53 kgCO_2e, but the average volume load factor increased substantially to 49%, demonstrating a much more efficient use of vehicle capacity.

Last-Mile

The last-mile delivery is performed by Locodels, which operates in the Zagreb region. Deliveries are carried out using light delivery vans, as larger vehicles would face manoeuvring constraints in urban areas. The vehicle characteristics used for emission calculations are presented in the Table 24 below.

Table 24. Van details for last-mile delivery

Characteristics	Detail
Acronym	VAN
Fuel type	Diesel
Fuel usage	0.119 l / km
Emission intensity	0.793 kgCO_2e / t-km

Data of parcels from Celje is sent to Locodels' Crowdsourcing app with integrated LOPTA-LMO. The application determines which parcels can be delivered by Locodels (Zagreb region) and which by Hrvatska Pošta (rest of the parcels). Then the app determines how many vans are needed for the delivery of goods around Zagreb. The LOPTA-LMO then optimises the routes over the given delivery addresses.

An example for the delivery on 26.11.2024 is shown in Figure 77.

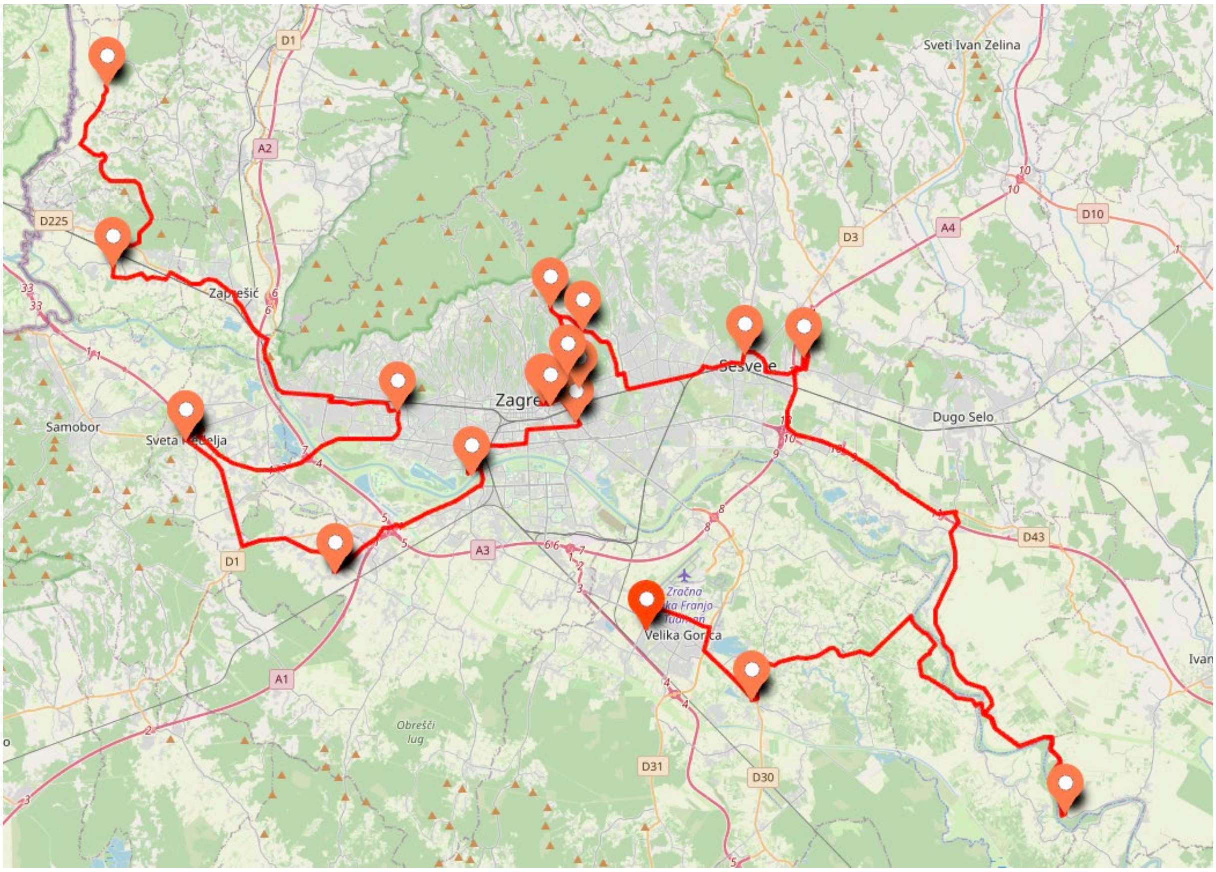

Figure 77. Last-mile route in Zagreb for 26.11.2025

The example for calculations for results for 26.11.2024 can be seen in the Table 25:

Table 25. Example results for emissions calculation

Location	Vehicle Type	Distance [km]	Total Weight [kg]	Volume [m³]	Emissions [kgCO₂e]	Ton-Kilometre
HUB-Zagreb	VAN	0	79.028	2.146	0.103	0.643
Customer1	VAN	8.136	73.928	0.130	0.510	1.910
Customer2	VAN	25.837	72.568	0.064	1.515	2.318
Customer3	VAN	31.937	70.048	0.084	1.838	0.337
Customer4	VAN	4.807	54.668	0.310	0.267	0.565
Customer5	VAN	10.34	54.608	0.041	0.448	0.112
Customer6	VAN	2.06	29.768	0.477	0.089	0.139
Customer7	VAN	4.67	29.718	0.041	0.110	0.053
Customer8	VAN	1.77	27.378	0.081	0.042	0.048
Customer9	VAN	1.74	27.333	0.041	0.038	0.019
Customer10	VAN	0.70	27.233	0.042	0.015	0.070
Customer11	VAN	2.58	25.793	0.065	0.056	0.208

Location	Vehicle Type	Distance [km]	Total Weight [kg]	Volume [m³]	Emissions [kgCO₂e]	Ton-Kilometre
Customer12	VAN	8.08	24.665	0.060	0.165	0.254
Customer13	VAN	10.32	18.335	0.151	0.202	0.000
Customer13	VAN	0.00	17.335	0.057	0.000	0.196
Customer14	VAN	11.33	14.195	0.095	0.156	0.000
Customer14	VAN	0.00	9.875	0.116	0.000	0.130
Customer15	VAN	13.15	7.025	0.090	0.103	0.132
Customer16	VAN	18.78	6.33	0.052	0.105	0.082
Customer17	VAN	12.97	0	0.151	0.065	0.000
HUB-Zagreb		46.32			19.169	
Totals		215.51	79.028	2.146	24.994	3.463

The calculated emission intensities for this ride are 3,46 kgCO_2/t km.

We tested the last-mile for 12 days covering different load as show in the Table 26 below.

Table 26. Last-mile test for 12 days

Last-mile test	No. of vans	Distance [km]	Total Weight [kg]	Volume [m³]	Emissions [kgCO₂e]	Emission Intensity [kgCO₂e/t-km]
2024-11-25	1	215.51	79.028	2.146	24.994	3.463
2024-11-26	1	130.53	70.375	1.715	9.515	3.175
2024-11-27	1	186.26	229.037	2.224	43.880	1.438
2024-11-28	2	123.58	130.4	3.724	26.033	7.400
2024-11-29	2	329.06	153.781	2.844	38.329	2.035
2024-12-02	5	503.99	614.585	9.317	127.063	1.855
2024-12-03	3	483.51	124.507	3.864	66.553	11.711
2024-12-04	1	110.04	136.805	3.251	15.373	2.192
2024-12-05	2	204.06	165.595	3.748	36.081	6.132
2025-04-07	2	138.31	499.786	5.888	48.672	1.949
2025-04-11	1	41.25	160.386	3.576	8.293	3.266
2025-07-07	1	31.56	84.69	2.208	7.666	5.701

The optimisation algorithm requires specific constraints, as urban routing demands a higher level of adaptability. Some of the key constraints in LOPTA-LMO address travel time and the balanced distribution of routes across the city of Zagreb when multiple vehicles are deployed.

For example, on 2 December 2024 (Figure 78), five vehicles were required for parcel delivery. The LOPTA-LMO system generates a plan that evenly distributes vehicles across the city, minimising route overlap while ensuring that all deliveries are completed within the defined time windows.

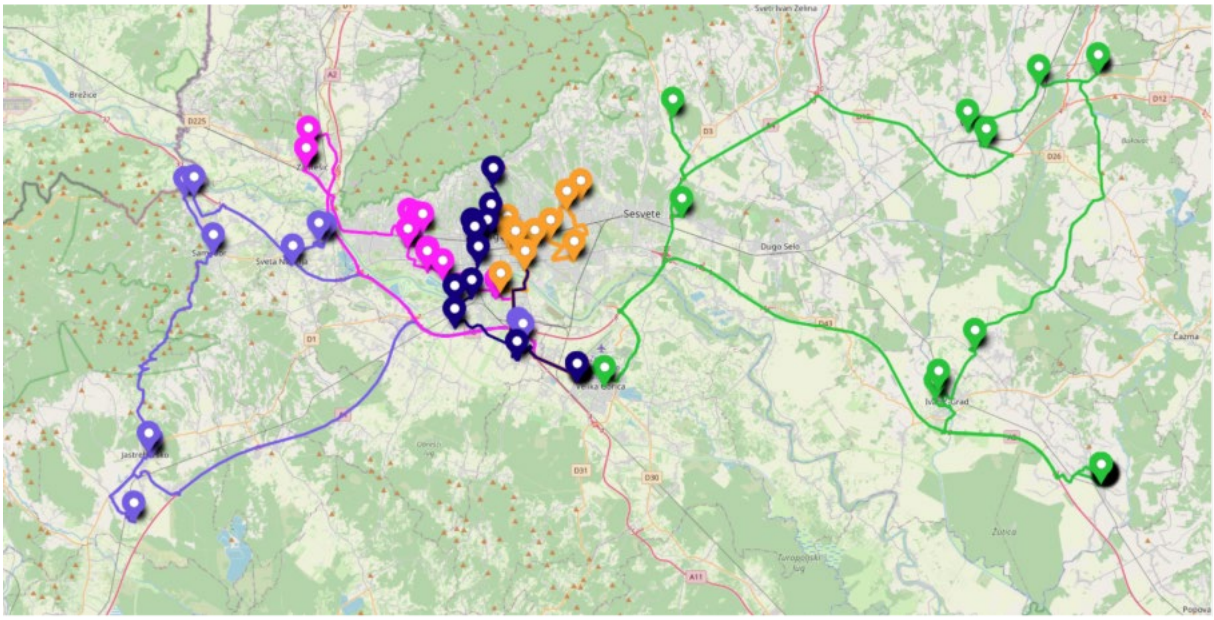

Figure 78. Last-mile routes for five vehicles on 2 December 2024

From an environmental perspective, the data show that emissions and emission intensities are significantly more variable in the last-mile than in the first-mile. This variability results from the highly dynamic nature of urban routes, as illustrated in Figure 78. In addition, most deliveries must be completed before noon, which creates narrow operational time windows. These constraints can lead to empty kilometres for longer-distance deliveries, thereby increasing total emissions (as observed on 3 December 2024).

The LOPTA-LMO is in use from the early stages of ADMIRAL project and is already used in production for two different use cases. With this test we confirmed that the LOPTA-LMO is prepared for pilot demonstration.

Pilot demonstration results

In pilot demo we showcased the complete logistics chain: First-mile in Slovenia on 18.8.2025, Middle-mile with transferring packages from Celje to Zagreb on 21.8.2025 and the Last-Mile with delivery of parcels in the Zagreb region on 22.8.2025.

In the first-mile we obtained the following route plan and emissions (Table 27):

Table 27: Slovenian - Croatian pilot demonstration – first-mile results 18.8.2025

Location	Cumulative Weight [kg]	Cumulative Volume [kg]	Vehicle Type	Distance [km]	Run Type	Load Factor	Emission [kgCO₂e]	Price
HUB - Celje	0	0	15T	0	Empty	0.000	0.814	
Customer 1	19.22	0.75	15T	1.3	Laden	0.013	0.012	
Customer 2	383.67	7.57	15T	3.3	Laden	0.126	0.022	
Customer 3	573.73	11.45	15T	0.3	Laden	0.191	4.975	
Customer 4	1012.31	31.49	15T	45.4	Laden	0.525	7.077	
Customer 5	1637.77	42.13	15T	36.6	Laden	0.702	2.158	
Customer 6	2915.27	57.80	15T	6.9	Laden	0.963	13.753	
HUB - Celje	2915.27	57.80	15T	24.7	TS	0.963	3.790	
Total				118.5			32.601	122.41

The emission intensity for the first-mile for pilot demonstration is 0,121 $kgCO_2e/t$ km

Map of the optimised route is shown on the following Figure 79.

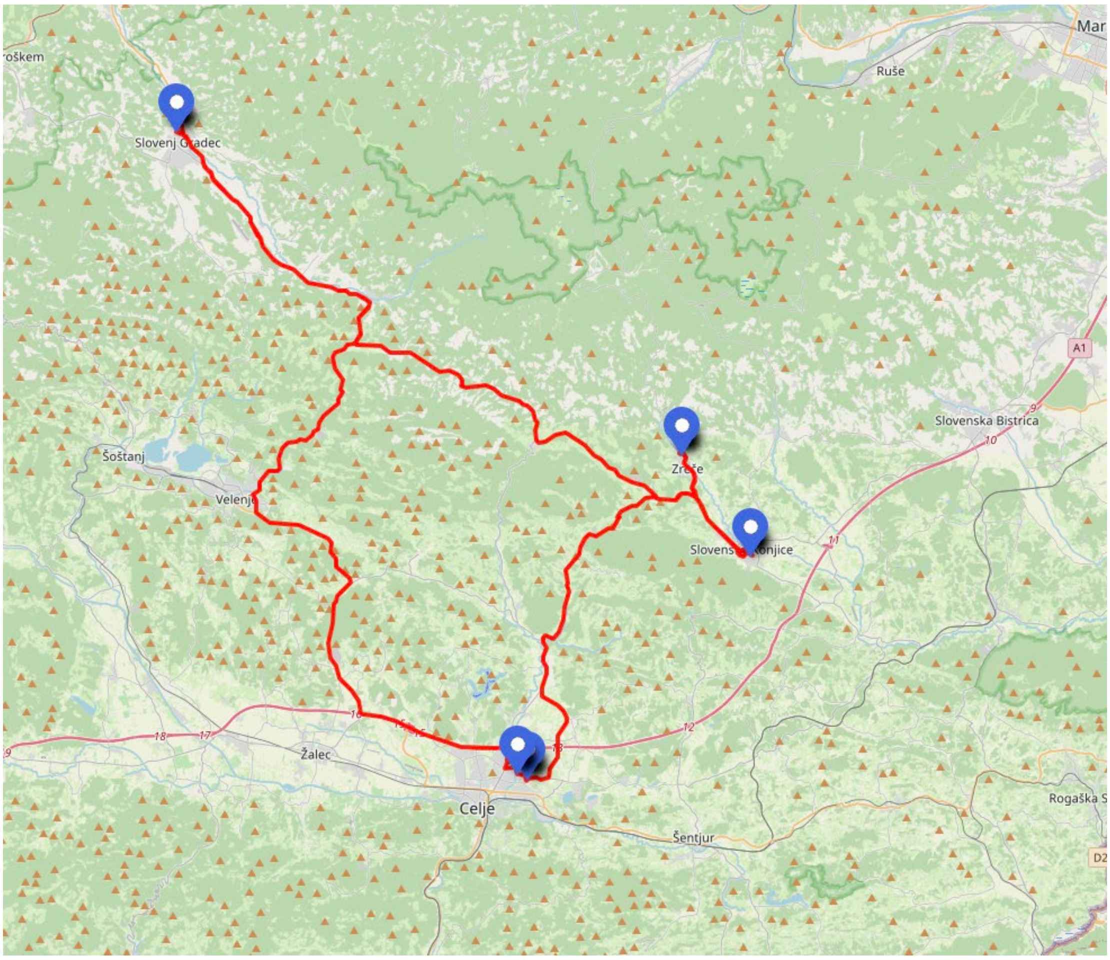

Figure 79. Slovenian – Croatian Pilot Demonstration - Route map for First-mile 18.08.2025

Table 28 shows the results obtained for the mid-mile:

Table 28. Slovenian – Croatian pilot demonstration – Mid-mile results 18. -22.082025

Date	Weight for Croatia [kg]	Volume [m³]	Volume Load Factor	Distance Pilot [km]	Emissions Pilot [kgCO₂e]
2025-08-18	500.50	5.78	10%	124.40	11.89
2025-08-19	510.03	11.03	18%	124.40	12.12
2025-08-20	143.91	2.41	4%	124.40	3.42
2024-08-21	510.65	6.71	11%	124.40	12.13
2025-08-22	1025.00	13.98	23%	124.40	24.35

We observed that during the pilot demonstration period, the number of orders was relatively low. As mentioned in section 3.3.3 we had to wait until 21 August 2025 to accumulate a sufficient number of parcels for the middle-mile transfer to become viable, achieving a 43% load factor (Table 29).

Table 29. Slovenian – Croatian pilot demonstration – Mid-mile grouping 18. – 21.08.2025

Grouping (15T)	Weight for Croatia [kg]	Distance Pilot [km]	Volume [m³]	Emission Pilot [kgCO₂e]	Volume Load Factor
2025-08-18	/	/	/		
2025-08-19	/	/	/		
2025-08-20	/	/	/		
2024-08-21	1665.09	124.40	25.94	39.56	43%

On the last-mile we got the following results (Table 30):

Table 30. Slovenian – Croatian pilot demonstration – Last-mile results 22.08.2025

Location	Cumulative Weight [kg]	Vehicle Type	Distance [km]	Run Type	Emission [kgCO₂e]
HUB - Zagreb	105.65	VAN	0	TS	0.137
Customer 1	81.72	VAN	15.88	Laden	1.330
Customer 1	66.76	VAN	0.00	Laden	0.000
Customer 1	66.66	VAN	0.00	Laden	0.000
Customer 1	66.66	VAN	0.00	Laden	0.000
Customer 2	49.93	VAN	3.93	Laden	0.208
Customer 2	33.33	VAN	0.00	Laden	0.000
Customer 3	16.60	VAN	7.89	Laden	0.208
Customer4	0.00	VAN	6.87	Laden	0.090
HUB - Zagreb	0.00	VAN	16.54	Empty	6.844
Totals			51.1		8.818

We calculated emission intensity for the last-mile: 2,2415 $kgCO_2e$/t-km.

Below is the route of the optimised last-mile, illustrated in Figure 80:

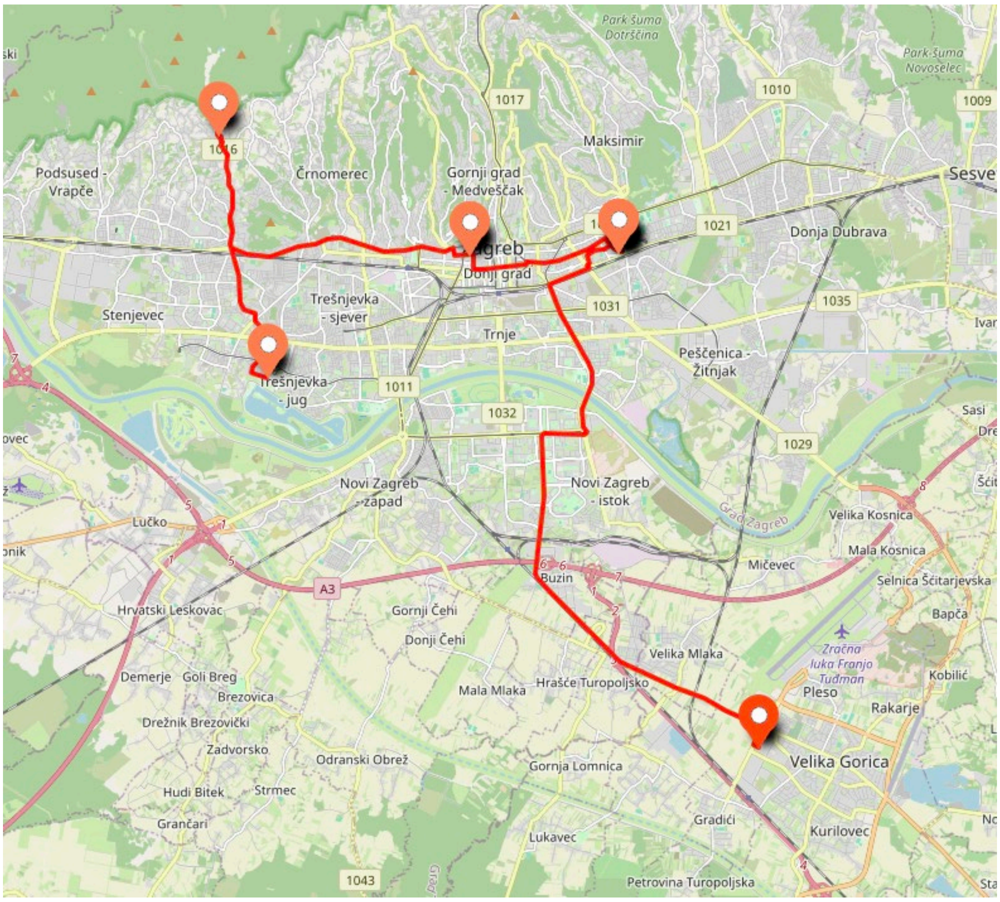

Figure 80. Slovenia-Croatia Pilot Demonstration - Last-mile

This pilot demonstrated an optimised and environmentally sustainable logistics workflow covering the complete delivery chain — from parcel pick-up in the Celje region, through middle-mile transfer to Zagreb via a designated green transport corridor, to the last-mile delivery to customers in Zagreb.

The pilot aimed to validate the integration of LOPTA optimisation modules (First-Mile Optimisation, Middle-Mile Optimisation, and Last-Mile Optimisation) within a real operational environment. The system applied green optimisation principles to dynamically plan routes, consolidate shipments, and maximise vehicle utilisation.

Key results include:

- **Improved load factors** specifically for first-mile and middle-mile transfers.
- First-mile load factor improvement: from 40.6% to 71.9% -> 77% improvement.
- Middle-mile load factor improvement: from 19% to 49% -> 61% improvement
- Significant **reduction in travel distance** compared to baseline operations, leading to measurable CO_2e emission reductions.
- Travel distance reduction on first-mile: from 161.1 km to 148.8 km -> 8% improvement

- Travel distance reduction on middle-mile: from 5640 km to 2488 km (995.2 km in case of grouping) -> 56% reduction
- CO_2e emissions reduction for first-mile (normalised per ton kilometre): from 0.861 kgCO_2e/t-km to 0.343 kgCO_2e/t-km -> 60% improvement
- CO_2e emissions reduction for middle-mile (total emissions): from 759.27 kgCO_2e to 330.53 kgCO_2e -> 56% improvement
- **Adaptive routing capability**, allowing real-time adjustment to order volumes and delivery constraints.
- **Operational feasibility of cross-border parcel logistics** between Slovenia and Croatia under sustainable transport conditions.

Overall, the pilot successfully showcased how data-driven route optimisation and cross-border coordination can **increase efficiency, reduce environmental impact**, and support the **transition towards greener logistics operations** in the Central European region.

3.5 Summary of the pilot

Slovenian-Croatian pilot activities focused on developing a logistics optimization tool for postal services including CO_2 emissions calculation, CO_2 emissions reporting data, CO_2 emission prediction and the integration of a custom logistics AI tool. Different CO_2 emissions calculation approaches and data sources have been tested and compared in terms of measurement accuracy, also taking into account factors such as road elevation. For last-mile delivery, different trajectories for the delivery vehicle have been simulated to obtain information on according energy consumption.

Summary of technology developed in this pilot

Crowdsourcing tool, target TRL 8

- Pilot 2) Green Logistics: Optimizing Postal Sustainability Across Borders (Slovenia-Croatia), has developed Crowd-shipping tool, the Locodels platform, which has qualified in real operational environment, and **is production-ready, current TRL 8.**

Logistics planning tool, target TRL 8

- Pilot 2) Green Logistics: Optimizing Postal Sustainability Across Borders (Slovenia-Croatia), has developed LOPTA - Logistics Optimisation Planning Tool or ADMIRAL, with following service components:
  - Routing engine
  - First-Mile Postal Optimisation services – LOPTA FMO
  - Last-Mile Postal Optimisation services - LOFTA LMO
  - CO_2 emissions calculation services – LOPTA-EC
- Development has been qualified in real operational environment, **current TRL 8**
- CO_2e tracking system with onboard measurement devices, the additional development, **this is at TRL 7, tested in real life, operational environment**

CO_2 emissions reduction

The goal of the pilot was to develop solutions that enable better utilization of current assets and existing infrastructure to decrease energy use and emissions without significant investment needs.

- Railway-based freight transfer was not feasible due to lack of traffic toward Zagreb and high operational costs—especially for one operator like Pošta Slovenije. Significant investment would be needed to shift freight from road to rail, contradicting the "no major investment" premise.
- Instead, a road-based cross-border corridor was created, bypassing Ljubljana's Exchange Office and reducing mileage for certain flows. Concept of asymmetric corridors introduced, allowing better use of local hubs and fleet—mainly viable for postal operators with decentralized infrastructure.

Develop and pilot solutions that have altogether energy and emission reduction potential higher than 30%

- **Projected emission reduction targets are achieved especially due to corridor-level solutions.**
  - Bypassing the Office of Exchange (OE) in Ljubljana significantly reduces mileage and emissions.
  - Operational optimization of cross-border flows aligns with the goals of greener infrastructure use without needing new assets.
- Position established to comfortably reach 25–30% CO_2 reductions, validating the initial objectives through smarter routing and asset use.

The integration with the ADMIRAL marketplace, see Section 6.2

4 GREEN ROUTE: EMISSION AWARE LOGISTICS MANAGEMENT PILOT (*LITHUANIA*)

4.1 Overview of the pilot

4.1.1 Pilot environment

Road transport is a key component of the Lithuanian economy, supporting both domestic and international logistics. As sustainability becomes an increasing priority, the transport sector must evolve to meet green transition goals – road transport emissions in 2022 were 73.2% from total emissions from transport sector (European Environmental Agency, 2024[6]). Despite high climate impact, road transport is essential: in EU, road transport ensures movement of 77% of freight (Eurosender, 2025[7]). The share of freight road transport using alternative fuels in the EU is currently under 4% of the total fleet, with diesel trucks representing about 96% of all heavy-duty vehicles (The European Automobile Manufacturers' Association, 2024[8]). Impact of road transport must be addressed by deploying alternative measures, such as optimizing transport operations. One of the most effective ways to enable large scale optimization is by enhancing data sharing among logistics organisations—particularly through digitisation at the network level.

Currently, digital tools and data collection are mainly used within individual organisations to support internal operations. However, data exchange between companies remains fragmented and still relies heavily on manual processes or direct communication channels. This limits opportunities for real-time information sharing and coordinated decision-making.

To address this gap, the Lithuanian pilot *"Green Route: Emission-Aware Logistics Management"* focuses on strengthening digital cooperation among logistics network members. The pilot brings together a major freight transport company, a transport hub, a transport management system provider, and solution developers to establish integrated digital links for seamless exchange of transport-related data. The pilot was tested with two end users:

- **Klaipeda Free Economic Zone (KFEZ):** a strategically located logistics and industrial hub adjacent to the Port of Klaipeda. KFEZ brings together a broad spectrum of logistics operators and infrastructure providers, enabling efficient supply chain and industrial operations;
- **CargoGO:** an international cargo transportation company headquartered in Vilnius. CargoGo focuses on digital logistics, technological innovation, and data-driven operations and played a key role in the development and validation of digital tools designed to enhance collaboration and information exchange among supply chain stakeholders.

The key ambition of the pilot was to identify approaches for data exchange between logistics network participants and to improve regular road transport operations without additional investment in vehicles or infrastructure. End users – KLEZ and CargoGo – were essential partners to provide insights on common practices in the industry, as well as data and insights on impact of digital tools.

[6] https://www.eea.europa.eu/en/analysis/publications/sustainability-of-europes-mobility-systems
[7] https://www.eurosender.com/en/resources/freight-transport-statistics
[8] https://www.acea.auto/figure/share-of-alternatively-powered-vehicles-in-the-eu-fleet-per-segment/

Co-funded by the European Union

Figure 81. End users engaged in Green Route: Emission Aware Logistics Management pilot - CargoGo base and KFEZ

4.1.2 Challenge and purpose of the pilot

Transport is one of the least digitalized sectors in the EU. There are multiple technical and operational challenges for broader digitalization:

- Lack of interoperability between different systems for operation management, such as transport management systems (TMS), enterprise resource planning systems (ERP), fleet management systems, freight information exchange, transport operation, and hub scheduling tools. The majority of these systems were not originally intended to exchange data among themselves, and standards for data quality are not properly implemented.
    1. High costs for adopting digital tools and upskilling staff. The expense of upgrading, digitizing legacy workflows, and training staff is a barrier, especially for SMEs;
    2. Lack of trust. Concerns over misuse of shared data, accidental loss of sensitive information, or its being used for competitive advantage discourage openness and collaboration.
- Digitalizing business processes and emission reporting requirements. Transport operations are complex and dynamic, while ICT systems require structure and standardization. Structuring logistic processes and data flows in a way that is fully compliant with regulations has been difficult for both public and private entities;
    3. Limited use of data for decision-making and optimisation. Data is collected in individual systems, but is not analysed at the network level for broader improvements either due to interoperability or confidentiality issues;

4. Restricting regulatory environment. The opportunity to improve overall logistics network efficiency is not realised due to limited use of compatible digital tools and documents, as competent authorities are only able to accept paper documents.

Green route: emission aware logistics management pilot aimed to address these challenges by identifying information to be exchanged between supply chain participants when planning transport service. This pilot aimed to identify practical digital solutions for the automatic calculation of CO_2 emissions, with a targeted reduction of at least 20%. To achieve this, the Lithuanian pilot raised the following objectives:

1. Identifying approaches for logistics data exchange, that enable better understanding of climate impact and support operation planning with CO_2 reduction as criteria;
2. Proposing data exchange approaches and demonstrating the impact of digital connectivity among logistics network stakeholders to improve coordination and data flow;
3. Demonstrating the potential of ADMIRAL marketplace to share emission related information and promote choices to reduce emissions.

By integrating tools such as eCMR, CO_2 calculator, and Estimated Time of Arrival (ETA) into the ADMIRAL Marketplace, the initiative promotes greater transparency, collaboration, and operational efficiency in road transport. These efforts are essential for optimising resource utilisation, fostering sustainability, and accelerating the digital transformation of the logistics sector.

Green Route: Emission-Aware Logistics Management pilot is developing digital tools that enable better supply chain participant collaboration and information exchange. Specific contributions from each of technical solutions developed in the pilot:

- **Transport scheduling tool** (dock management, loading and unloading schedules) allows to plan more efficient routes, reduce waiting with ignition on and to reduce movement around hub while looking for loading dock;
- **Digital bill of lading** (digital documentation and signature) reduces amount of time and miles wasted on transporting paper documents;
- **CO_2 calculation methodology**, digital tools and data exchange increases awareness of emissions created as well as improved accountability for emissions related to each parcel. This technical result is associated with Digital bill of lading, as methodology was developed for the tool specifically.

4.1.3 Partners involved and their roles

The Lithuanian Pilot is implemented by a team of diverse partners, each bringing specific expertise to support the successful implementation of pilot activities:

- **Transport Innovation Association (TIA)** – Lithuanian Pilot Coordinator. TIA is responsible for the overall coordination and implementation of pilot activities in Lithuania, including the development of training materials, stakeholder engagement, and leading communication and dissemination tasks.
- **TREVIO** – a digital solution developer tasked with designing and developing digital tools, representing industry knowledge, and ensuring active stakeholder engagement.

- **CSign** – software solution provider focused on digitising logistics processes. CSign integrates the eCMR into the marketplace and calculates CO_2 emissions based on eCMR data, contributing to paperless and more sustainable logistics.
- **CargoGo** – an industry partner providing operational insights, facilitating pilot testing in real-life logistics operations, and contributing data for tool validation. CargoGo supports stakeholder engagement and provides expertise in eco-driving practices.
- **Klaipeda Free Economic Zone (KFEZ)** – an industry partner contributing infrastructure and operational knowledge. Klaipeda FEZ supports piloting through access to real-life conditions, connects local businesses, and addresses digital transformation and data-sharing challenges.

Responsibilities and contributions for each of the partners are summarized in Table 31 below.

Table 31. Green route: emission aware logistics management pilot (Lithuania) partner KERs and individual outputs

Partner	Partner responsibilities and expected results	Delivery of expected results
Transport Innovation Association (TIA)	• Pilot coordination; • stakeholder engagement and communication framework; • dissemination and knowledge-transfer methods linking ADMIRAL with EU policy agendas (eFTI, Scope 3 reporting, EU Strategy for the Baltic Sea Region - EUSBSR)	• Ensured timely delivery of pilot milestones, cross-WP alignment, and direct involvement of industry stakeholders. • Strengthened replication and exploitation potential by embedding pilot results into EU and Baltic Sea Region policy processes. • Disseminated ADMIRAL in transport logistics innovation communities.
TREVIO	Applicable KERs: Transport service order management tool, Transport scheduling tool Technical objectives: • Develop ETA scheduling tool for high-accuracy real-time arrival predictions; • Have easy and industry-standard integration with telematics and ERP systems; • Contribute to reduction of idle times and emissions through better ramp management.	• Developed planned digital tools. • Tested digital solutions under real-life conditions with CargoGo logistics operations. • Piloted scheduling, order management, data integration, and information exchange tools. • Demonstrated potential for CO_2 emission reduction through initial results. • Advanced integration with the AWAKE Marketplace.
CSign	Applicable KERs: CO_2 calculation methodology, digital tools and data exchange Technical objectives: • Ensure eFTI-compliance of eCMR solution, designed for transport and logistics companies and their customers; • Create and implement ISO 14 083 compliant CO_2 Emission Calculation approach using eCMR data; • Develop emission calculation based on routing provided by ADMIRAL Marketplace	• Developed planned digital tools. • Validated tool accuracy through benchmarking with CargoGo telematics data, confirming close alignment with fuel-based calculations. • Developed APIs for eCMR data sharing and integration with other systems like AWAKE Marketplace, TMS, ERP etc. • Enhanced Scope 3 reporting capacity by upgrading functionalities and embedding a dual-method CO_2 calculator into the AWAKE Marketplace.

Partner	Partner responsibilities and expected results	Delivery of expected results
CargoGo	Applicable KERs: CO_2 calculation methodology, digital tools and data exchange Technical objectives: • Operational validation of ETA tool with real operational data and in operational conditions; • Enabling API-based telematics data sharing for CO_2 calculation; • Structuring and developing digital tool for eco-driving programme; • Route optimisation using AndSoft, PTV, Power BI.	• Developed planned digital tools. • Demonstrated measurable efficiency gains; • Demonstrated measurable CO_2 savings. • Internal systems proven compatible with ADMIRAL tools; • Demonstrated strong basis for scaling.
Klaipeda Free Economic Zone (KFEZ)	Objectives: • Feasibility study for digital customs checkpoint; • Pilot deployment of Trevio scheduling tool within KFEZ community; • Stakeholder engagement on digital adoption.	• Completed study, that confirmed potential of digital customs checkpoint for reducing unnecessary customs-related trips and emissions. • Identified barriers in pilot (data-sharing reluctance, cybersecurity needs) while confirming demand for digital solutions under trust conditions.

4.2 Tested scenarios

4.2.1 Approach to piloting and explored scenarios

The **ADMIRAL pilot in Lithuania** aimed to analyse existing data from freight delivery operations and identify interaction points between logistics network members where digital solutions can deliver the highest impact. The pilot project methodology was structured to examine typical operational improvements within the Lithuanian freight transport sector, deliberately excluding complex exception scenarios to focus on core digitalization benefits that represent the majority of daily operational activities.

This approach aligns with established pilot project principles, emphasizing controlled testing of standard operational procedures before addressing complex outlier situations. The implementation was designed within the European Union regulatory framework, particularly considering Lithuania's strategic position in Baltic logistics networks and emerging EU digitalization initiatives such as the Electronic Freight Transport Information (eFTI) regulation.

The pilot is structured around two key scenarios:

1. **Optimisation of road transport carrier operations** – focusing on improving routing, fuel efficiency, and operational coordination for freight carriers through digital tools. This pilot scenario targeted optimization of road transport carrier operations within Lithuania's competitive freight market, focusing on three critical operational dimensions: route optimization, fuel efficiency enhancement, and operational coordination improvement. Lithuania's logistics sector, which generates approximately 12% of the country's GDP (more than double the EU average), provides an optimal environment for testing such digitalization

interventions. The pilot implementation involved a large Lithuanian logistics operator representing the scale and operational complexity characteristic of major European freight carriers: CargoGo is also advanced with adoption of digital tools to manage and optimize transport operations;

2. **Optimisation of road transport hub operations** – targeting enhanced coordination, data exchange, and process efficiency within logistics hubs and industrial zones. The implementation strategy involved two technology providers working to create digital coordination platforms enabling standardized interactions between multiple stakeholders operating within the same operational environment. This approach aligns with Lithuania's broader digital transformation initiatives in the transport sector, where companies are increasingly implementing smart transport management systems and automated warehouses to increase efficiency and reduce operational costs. The pilot design focused on standard cargo handling procedures, routine coordination activities, and typical data exchange protocols that represent the majority of hub operations.

In **Optimisation of road transport carrier operations scenario**, the digitalization intervention concentrated on implementing integrated platforms capable of real-time data exchange and collaborative planning, addressing the fundamental challenge identified in Baltic transport digitalization literature regarding system fragmentation and the need for seamless information flow across transport chains. The approach reflects Lithuania's advanced position in implementing automated and digital solutions, leveraging the country's professional workforce and technology investment capabilities. The pilot specifically excluded multimodal scenarios or exceptional operational circumstances, maintaining focus on typical daily operations that constitute the bulk of freight activities for Lithuania's extensive road transport network, which handles approximately 77% of total inland freight transport in the Baltic region.

In **Optimisation of road transport hub operations scenario,** the implementation strategy involved two technology providers working to create digital coordination platforms enabling standardized interactions between multiple stakeholders operating within the same operational environment. This approach aligns with Lithuania's broader digital transformation initiatives in the transport sector, where companies are increasingly implementing smart transport management systems and automated warehouses to increase efficiency and reduce operational costs. The pilot design focused on standard cargo handling procedures, routine coordination activities, and typical data exchange protocols that represent the majority of hub operations, deliberately avoiding complex exception handling scenarios.

Both of the piloting scenarios followed the same structure:

- Methodology development (choosing CO_2 emission assessment approaches and frameworks): overviewing CO_2 calculation frameworks for freight transport service based on upcoming requirements; defining calculation data points. Preliminary list of calculation methodologies and guidelines analysed.
- CO_2 calculation experiments: collecting data samples for different automation scenarios (minimal accuracy vs. high accuracy).

- CO_2 calculation experiments: calculating transport CO_2 emissions using different datasets.
- Integration and automation experiments (development of new features in CSign products) investigating results of automation experiments (accuracy, reliability, outcome dependence on inputs and chosen methodology).
- Assessment of optimisation and CO_2 saving opportunities.

The pilot also planned close collaboration with AWAKE marketplace, to demonstrate:

- Data exchange integration capabilities.
- Demonstrate practical application of existing and emerging logistics data exchange standards.
- Demonstrate the importance of integrating stand-alone logistics solutions to achieve network-wide objectives.

4.2.2 Preparation and testing inputs

Piloting activities performed by Green route: emission aware logistics management pilot technical partner CSign, TREVIO, CargoGo and KLEZ were implemented individually, and where applicable, in collaboration between a few of the pilot partners.

CSign – Digital bill of lading (digital documentation and signature) for emission-aware eCMR and CO_2 calculation methodology, digital tools and data exchange

As part of the Lithuanian pilot "Green Route: Emission-Aware Logistics Management", the task to develop a robust methodology for CO_2 emissions assessment was carried out by CSign in close collaboration with NORM. CO_2 calculation methodology, digital tools, and data exchange are an integral part of CSign emission-aware eCMR tool.

The goal was to define standardized, practical, and automated approaches for calculating transport-related CO_2 emissions, particularly aligned with emerging Scope 3 reporting requirements. During the ADMIRAL proposal development stage, pilot partners planned to develop their own CO_2 calculation approaches. However, the ADMIRAL implementation coincided with the release of CO_2 calculation guidelines, including the GLEC Framework by the Smart Freight Centre and ISO 14 083. These guidelines served as key inputs in developing CO_2 calculation approaches as well as data assessment approaches.

Additionally, implementing acts with requirements for Electronic Freight Information (eFTI) regulation implementation were released, providing technical requirements for structuring logistics data and data exchange between businesses and authorities. eFTI does not regulate or harmonize additional business services that may be provided using eCMR and eFTI platforms, creating new opportunities for logistics digitalization with expected mass adoption of eFTI.

Significant effort has been made by NORM and CSign to explore new requirements for Scope 3 emission reporting and possible automation approaches. A total of five guidelines were analysed to understand possible differences and calculation implications (Figure 82 and 83):

- ISO 14083:2023. Greenhouse gases. Notably, ISO 14083:2023 is based on Global Logistics Emissions Council (GLEC).

- Global Logistics Emissions Council (GLEC) Framework (2025)
- GHG Protocol for Calculating Scope 3 Emissions v1.0 (2013)
- DIN EN 16258:2013 Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers)
- French decree No. 2011-1336 (2011)

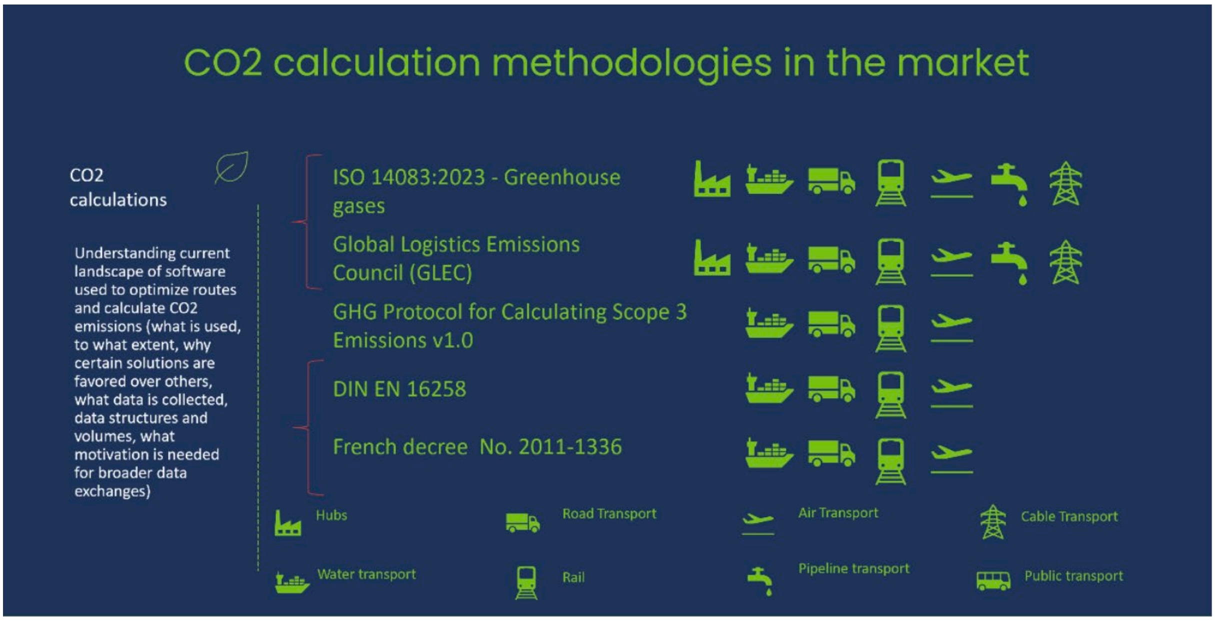

Figure 8282. Overview of emission calculation tool analysis and presentation (1)

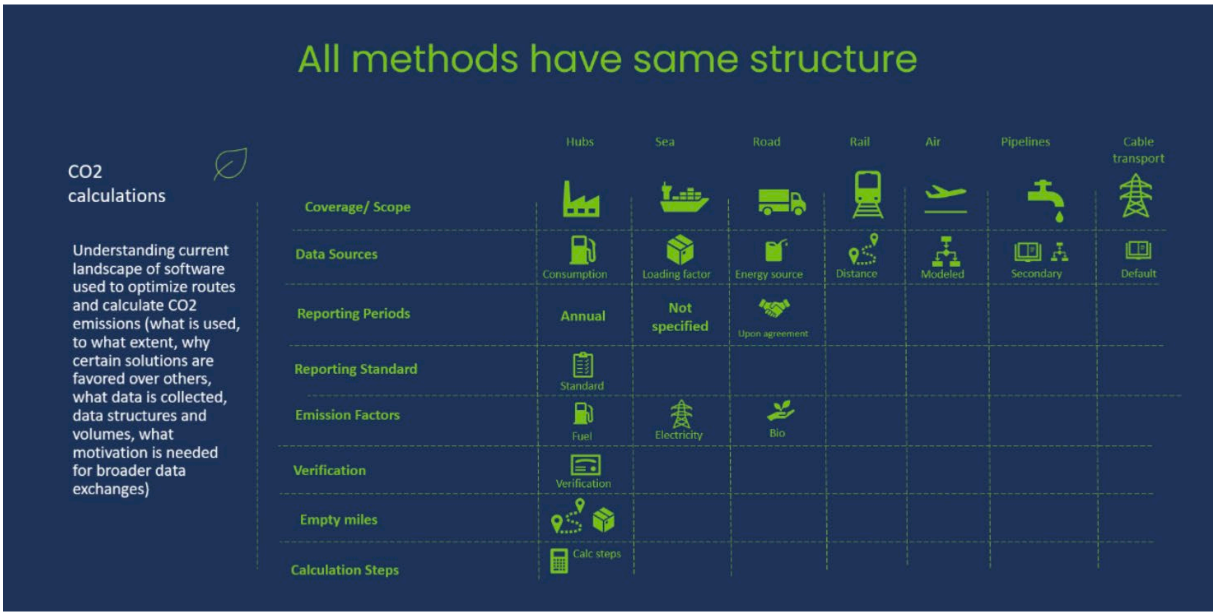

Figure 8383. Overview of emission calculation tool analysis and presentation (2)

Each calculation methodology was analysed considering:

- **Application scope**: modes of transport included, types of operations covered, requirements for data, geographies covered.

- **Potential for automated calculation:** using existing data from logistics platforms, such as origin and destination of delivery, weight of goods transported, fuel consumption.
- **Technical implementation:** availability of data exchange APIs, maturity of digital logistics tools, engagement of all relevant parties to receive full scope of data needed.
- **Standardization potential:** in a sense, calculation methodologies deliver similar content and are competing. Analysis also considered which methodologies are likely to become industry standard and achieve widest adoption.

Intermediary results were regularly presented in ADMIRAL meetings to receive insights and feedback from research community and other practitioners from ADMIRAL pilots. Emission estimation and emission reduction potential have been a shared interest, allowing constructive discussions and perspectives for different modes of transport, types of operation.

The analysis concluded, that following the release of ISO 14083:2023 as formal standard, it constitutes the only viable methodology for emission-related estimations in the Pilot. Further research focused on practical implications of standard application in real-life conditions. Analysis performed also contributed to research in WP3 Business models for sustainable transports and data exchange concepts for WP4 Multimodal marketplace development.

Interest in emission reporting has been driven by regulation. Upcoming mandatory Scope 3 reporting has been identified as a significant driver for monitoring and reducing CO_2 emissions for businesses. Following discussions with industry partners in ADMIRAL, it was agreed that technical solutions should be universal and adhere to accepted CO_2 calculation standards, ensuring broader applicability rather than being tailored to specific economic operators. This approach aligns with the expected functionalities of the Multimodal Marketplace developed under WP4.

Based on these findings, the Pilot partners agreed that the CSign solution prototype must be upgraded with features that allow the estimation of CO_2 emissions. These estimates are essential to set a baseline for emissions in a supply chain or transport network. Baseline may be used to identify operations that stand out with their emissions and to identify more specific activities where transport operations can be optimized, and CO_2 emissions could be realistically reduced.

A detailed mapping exercise was conducted to align eCMR data fields with the inputs required by the selected CO_2 calculation methodologies. Key assumptions used to develop the calculation methodology are summarized below:

- Applicable to full truck load consignments.
- Applicable to consignments transported within EU.
- Journey start and journey end points are mandatory to fill fields in the eCMR (also mandatory fields for assessment of empty miles). Round trip approach is used, assuming that all clients use eCMR. Distance adjustment factor (DAF) of +5% is applied.
- Applicable to diesel vehicles.

The following boundaries are applicable to CO_2 emission calculations using CSign:

- Applicable to freight road transport.
- Supports diesel consumption CO_2 calculations.
- Applicable to full truckload transport operations only.
- Empty miles are assigned to transport operator [9].
- Hub operation category (HOC) emissions are not included.

CSign tool can contribute to:

- Well-to-wheel (WTW) GHG emission calculations by enabling calculations of transport activities in the transport chain. The tool is not intended and does not provide data for full WTW calculation.
- Carbon intensity calculations.

Distance

Approach to calculating distances is based on knowledge of origin and destination, that are inputs in eCMR. The distance of transport activities is quantified in km and stretches from consignor to consignee. Shortest feasible distance (SFD) estimation approach is used. Values for the SFD are sources from publicly available route planning application.

Emission calculations include a + 5% distance conversion to correct possible difference between actual and shortest feasible distance.

Shipment mass and transport activity

For the calculation of transport activity, actual mass in tons is to be used based on eCMR inputs. If provided in eCMR, mass calculations include the product and the packaging provided for transport by the shipper.

Based on these assumptions and requirements, data sources were selected and matched with ISO 14083 requirements (Table 32).

[9] As per GLEC v3.1 guidance, "to ensure the consideration of empty operations and the accounting of the related emissions, the use of vehicles in transport chains is based on a round-trip approach, both for calculation of emission intensities and for the allocation of emissions to consignments in shared transport. Therefore, the necessary return of a vehicle is included, even though freight is usually moved from consignor to consignee in one direction only. This ensures that all emissions related to a transport operation are included."

Table 32. Data used in CSign tool

Type of data	Data description	Data source	Data category as per ISO 14083
Data for distance	Distance is calculated between origin and destination using route planning tool. +5% are added to compensate possible deviations of actual route taken	eCMR inputs	Secondary data
Data for weight	As provided by shipper (weight of goods and packaging)	eCMR inputs	Primary data
Data for fuel	Default fuel consumption per vehicle category	European fuel emission factors	Default data
Data for vehicle (emissions)	Default emission data per fuel consumption	European fuel emission factors	Default data

Data requirements have been passed to CargoGo, to evaluate the practical availability of necessary data and to extract data samples for further calculation experiments. The final data structure and calculation outputs are summarized in Table 33.

Table 33. Emission aware eCMR outputs

Type of data	Data description	Data source	Data category as per ISO 14083	Data schema
Empty CO_2	Calculated using eCMR data and Empty distance estimate	Calculated	Secondary data	Number
Loaded CO_2	Calculated using eCMR data for cargo weight and Loaded Distance estimate	Calculated	Secondary data	Number
Total CO_2	Sum of Empty CO_2 and Loaded CO_2		Secondary data	Number
Total Distance	Sum of Empty Distance and Loaded Distance. Estimated using route planning tools (Google Maps or equivalent).	Calculated	Secondary data	Integer
Empty Distance	Distance driven between last point of unloading and point loading. Estimated using route planning tools (Google Maps or equivalent).	eCMR inputs	Secondary data	Integer
Loaded Distance	Distance driven with cargo, between point of loading and unloading.	eCMR inputs	Secondary data	Integer

This approach ensured that the digital tools developed could automatically extract necessary data (e.g. route, vehicle type, freight weight) for accurate emissions estimation with manual input only where data is not accessible in realistic scenarios.

For the **emission aware hub scheduling tool,** stakeholders were engaged to evaluate:

- Current systems used in transport hubs and data exchanged in between involved stakeholders. Identified challenges are lack of common standards and limited interoperability between existing systems. While standards such as UN/CEFACT Multimodal transport do exist, they are not always considered when custom systems are developed for companies or when ecosystems of digital tools are created intentionally locking clients in the ecosystem.
- Digital and physical enablers needed to improve management of hub operations. Digital solutions may require infrastructure components, such as monitoring cameras or sensors to detect vehicles, as well as ensuring sufficient connectivity (coverage and speed) for smart infrastructure.
- Data availability from hub operators, companies operating in hubs and logistics operators. Lack of trust between partners – if data is not stored at source, there must be sufficient trust in data manager, as well as other participants of exchange environment.

Data samples were received from CargoGo and modelled in initial versions of the tool to evaluate performance of the tool and create iterations. During the Lithuanian pilot, several operational scenarios were tested with stakeholders by TREVIO to evaluate how digital solutions can optimize logistics workflows and reduce CO_2 emissions. Activities were performed in close collaboration with KLEZ, which both provided their insights on hub operations and also facilitated dialogue with companies operating in their hub.

For the development of the **eco-driving tool**, CargoGo formed a team in ADMIRAL hackathon. The team explored available data, driver eco-performance indicators, and developed an initial concept for digitalizing calculations. The tool concept was based on insights from its long-standing eco-driving programme, which calculates an "Eco Score" based on telematics parameters including speed, braking behaviour, RPMs, idle time, and use of cruise control. These data requirements became the basis for further experiments.

While not a digital tool itself, **the study for improving information exchange between hub members and third parties** provided valuable inputs to understanding optimization potential. KFEZ explored two integration scenarios:

- establishing a dedicated "green corridor" between its territory and the Port of Klaipėda;
- establishing digital customs checkpoint within the KFEZ territory.

The scenarios are based on real operational constraints in Lithuania, however challenges are replicable in other circumstances where non-EU countries are involved in freight operations.

4.2.3 Development of new standards and IPR

Green Route: Emission-Aware Logistics Management pilot developed the following digital tools for transport under ADMIRAL:

- Transport service order management tool
- Transport scheduling tool
- Digital bill of lading
- Data Exchange structures and solutions
- CO_2 calculation methodology

The digital tools are intended to contribute to other systems or to integrate with other existing systems. For this reason, tools must follow existing common specifications and standards, to provide inputs that are compliant.

As of the submission date of this report, technology developers have not planned to apply for IPR protection.

4.3 Tested systems

This chapter presents the digital solutions piloted and validated by ADMIRAL partners during the Lithuanian pilot. It highlights the development and testing of emission-aware eCMR and CO_2 calculator by CSign as well as emission-aware hub scheduling tool and eco-driving optimisation by TREVIO, all integrated with partner data from CargoGO and KLEZ, and supported by methodological input from NORM.

CSign – emission aware eCMR

CargoSign (CSign) is a software solution provider specialising in digital transport and logistics documentation. Its flagship product, the electronic consignment note (eCMR), replaces paper-based workflows with a fully digital process, streamlines logistics operations, and integrates an automated CO_2 calculator to support sustainable freight transport.

Emission-aware eCMR

The system developed and tested by CSign during the ADMIRAL pilot is a robust, production-ready electronic consignment note (eCMR) solution, designed to streamline freight transport documentation, support regulatory compliance, and enable automated emissions tracking. The system architecture includes core eCMR management functionality, modern API integrations, and an intuitive user interface, all built on open standards to ensure scalability and interoperability within the European logistics ecosystem.

The system supports full lifecycle management of electronic consignment notes in compliance with the UNECE (United Nations Economic Commission for Europe) eCMR data standard. Key features include:

- Creation, editing, and validation of eCMRs based on structured templates.

- Role-based access for transport operators.
- Secure digital signatures and status tracking throughout the transport process.
- Archiving and export capabilities to support audit and compliance requirements.

The CSign tool was piloted as a digital freight documentation solution designed to fully digitalise eCMRs and ensure compliance with the upcoming eFTI regulation. A key feature is its automated CO_2 reporting functionality, enabling emissions data to be shared directly with logistics service providers and beneficial cargo owners.

The pilot addressed several challenges: identifying which eCMR data fields can reliably support CO_2 calculations, determining complementary data sources, and developing appropriate algorithms. To achieve this, the team mapped eCMR data to UNECE standards, researched and validated CO_2 calculation methodologies, collected sample datasets, conducted calculation experiments, and verified the concepts against international standards.

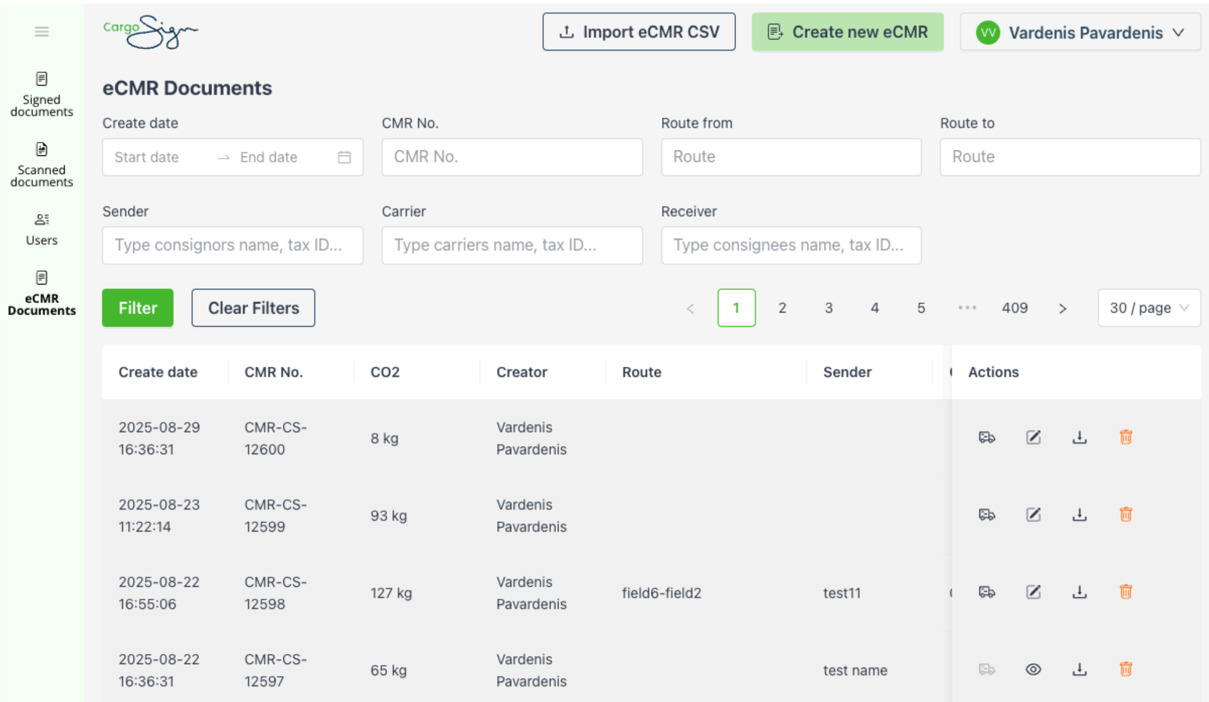

Figure 84. User interface for CSign eCMR

CO_2 Calculator

One of the key innovations in CSign's system is the automated CO_2 calculator. It uses shipment data (such as route, vehicle type, and freight weight) extracted directly from the eCMR and applies calculation logic aligned with ISO 14083 and the GLEC Framework. This enables standards-compliant Scope 3 emissions reporting while also helping logistics operators and transport buyers to evaluate and reduce the environmental footprint of their shipments.

The calculator is based on a hybrid data approach and can operate in two modes:

- Route-based: using eCMR addresses, vehicle parameters, freight weight, and routing via Google Maps API.
- Distance-based: using pre-defined empty and loaded distances from external systems (e.g. ADMIRAL Marketplace) combined with vehicle and cargo specifications.

These modes enabled flexible testing under different operational contexts and integration levels. Validation confirmed that the calculator delivers reliable, accurate, and standards-compliant estimates for road freight operations using real transport data.

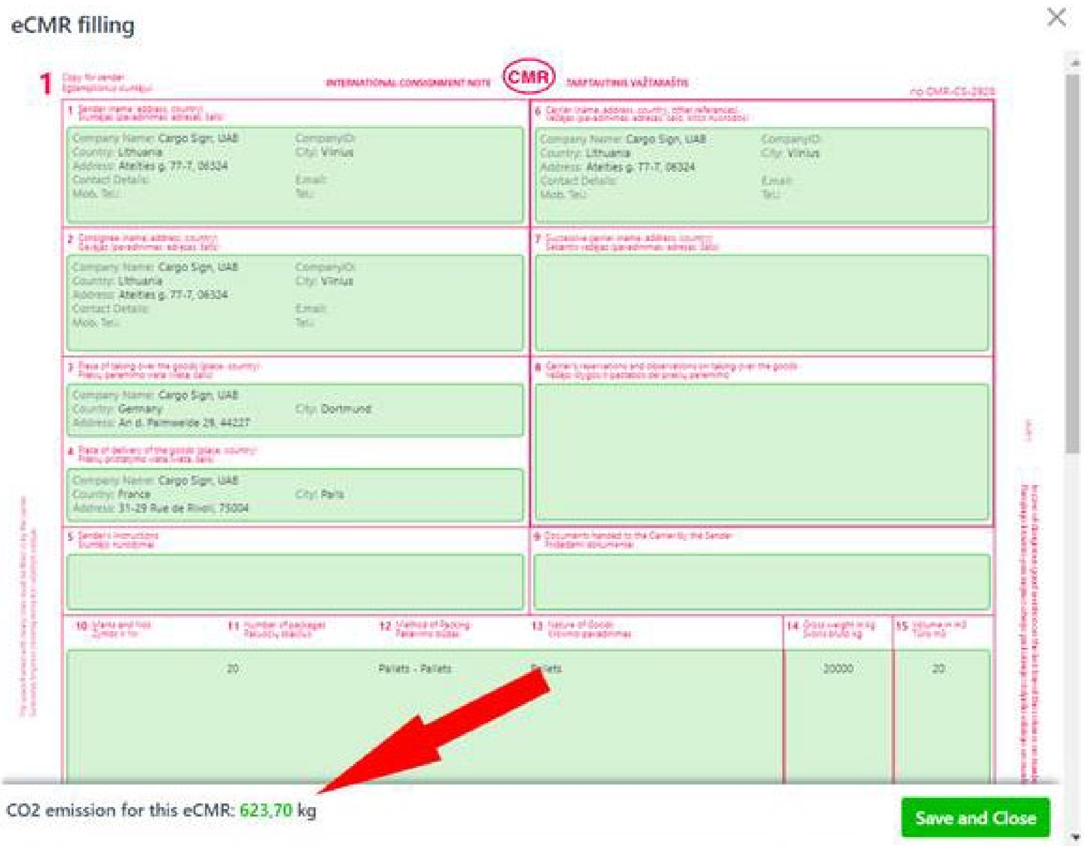

Figure 85. eCMR example, including CO_2 calculation for the transport operation

To support interoperability and digital workflows, the system includes a comprehensive set of RESTful APIs. These cover all eCMR management functions (creation, editing, retrieval) and additional methods for CO_2 emissions calculation. Importantly, the calculator API allows external systems to generate CO_2 predictions even before an eCMR is created. This capability enables seamless integration with platforms such as the ADMIRAL Marketplace and allows logistics partners to exchange documentation and emissions data in real time, significantly improving transparency and supporting data-driven, sustainable decision-making.

According to Eurostat data, with eCMR digitalisation, reducing empty freight runs by just 1% could save ~3.8 Mt CO_2 annually (≈1.3% of freight emissions), while a 20% reduction could save up to ~60 Mt CO_2

annually (≈20% of freight emissions). This corresponds to ~0.5% to ~7.9% of total EU road transport emissions.

TREVIO – Emission-Aware Hub Scheduling Tool

TREVIO is a Lithuanian digital solutions provider focusing on logistics automation and scheduling tools. Within the Lithuanian pilot, TREVIO tested and integrated several operational scenarios and systems to demonstrate how digital solutions can optimise workflows, improve coordination, reduce CO_2 emissions, and enable seamless data exchange in logistics processes. In ADMIRAL Pilot, TREVIO developed two innovative systems/tools: Transport Service Order Management Tool and Transport Scheduling tool.

- **Transport Service Order Management Tool**

The Transport Service Order Management Tool acted as the starting point of the workflow. Orders were created and assigned to drivers in the carrier's ERP system, ensuring structured task management and workflow initiation.

Once a task was generated in the ERP, it was transmitted to the CargoGo telematics system (Fleethand API), which continuously collects operational data such as location, speed, fuel consumption, ignition time, and other driving parameters. This system ensured that driver tasks were transferred correctly and that real-time operational data was linked to specific events.

The ERP and telematics data were then synchronised with the TREVIO ETA scheduling and notification tool, which provides real-time arrival predictions to warehouses. The ETA system displayed arrival information on warehouse dashboards and distributed notifications via email, allowing cargo receivers to prepare for upcoming deliveries in advance. This functionality reduced waiting times at loading/unloading zones, minimised engine idling, and improved workflow efficiency (Figure 86).

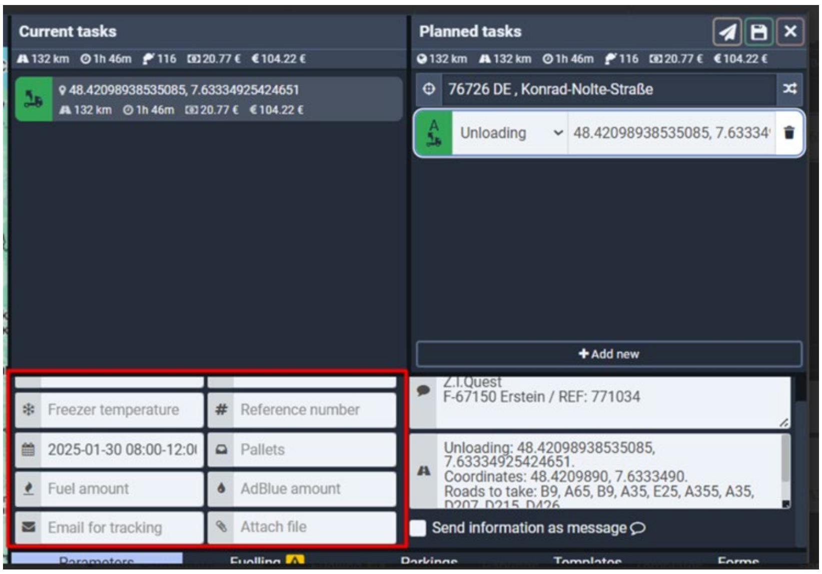

Figure 86. Carrier ERP system and tasks for drivers (email for tracking)

- **Transport scheduling tool -Estimated Time of Arrival (ETA) tool**

The ETA (Estimated Time of Arrival) tool was integrated with the telematics system, enabling real-time truck arrival notifications to be sent directly to cargo receivers. This information was displayed on the warehouse's arrival board and distributed via email notifications. This advance visibility allowed warehouses to prepare unloading areas before truck arrival, reducing congestion at loading zones. The result was: shorter waiting lines, less truck idling with engines running, more efficient cargo handling, and lower CO_2 emissions (Figure 87 and 88).

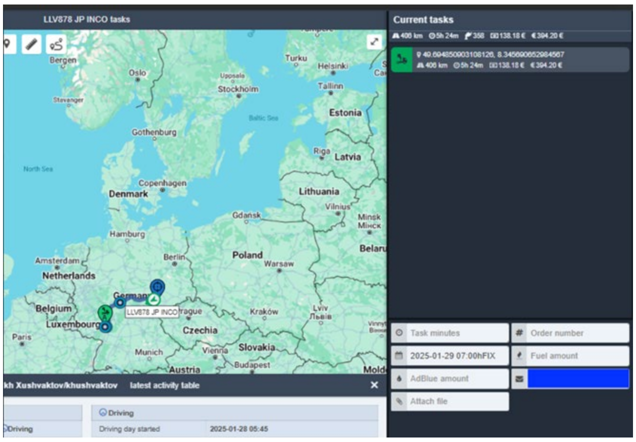

Figure 87. Integrated & automated solution for planning trucks arrival (1)

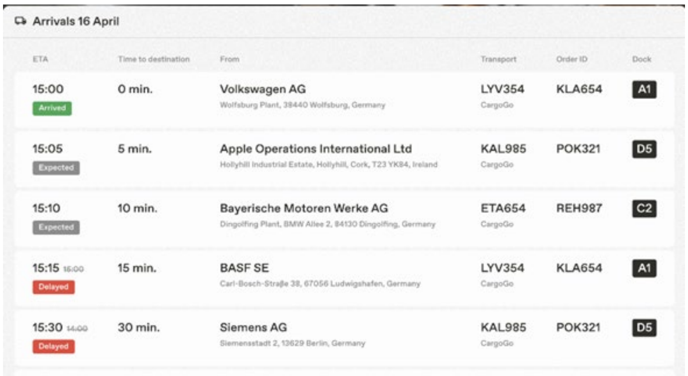

Figure 88. Integrated & automated solution for planning trucks arrival (2)

Tr.pr	Data	Atvykimo laikas	Dokumentų pridavimo laikas	Krovimo pradžia	Krovimo pabaiga	Mechanizuota/ Rankinė krova	In/Out	Konteineris/ Paletės	Palečių / konteinerių kiekis
PVZ	2024-02-20	15:25	15:40	16:00	16:45	M	Out	P	10
PVZ	2024-02-22	09:05	09:10	09:15	11:15	R	In	K	1
1	03:04	14:00	14:05	14:15	14:40	M	I	P	2
2	03-04	14:05	14:10	14:30	14:50	M	O	P	3
3	03-05	13:10	13:15	13:15	13:20	M	I	P	1
4	03-05	16:20	16:25	16:25	16:35	M	I	P	3
5	03-07	08:15	08:25	08:25	08:35	M	O	P	2
6	03-07	14:15	14:15	14:20	15:00	M	I	P	2
7	03-08	07:30	08:05	08:15	09:00	M	O	P	2
8	03-12	9:25	9:30	9:45	9:55	M	I	P	1
9	03-13	15:00	15:15	15:15	15:30	M	I	P	3
10	03-14	10:50	10:55	10:55	11:00	M	I	P	1
11	03-14	13:15	13:30	13:45	13:55	M	O	P	3
12	03-15	14:35	15:00	15:00	17:00	M	O	P	7
13	03-18	9:10	9:10	9:15	9:20	M	I	P	1
14	03-18	11:00	11:30	11:45	12:30	M	I	P	6
15	03-18	13:20	13:20	13:25	14:10	M	I	P	5

Figure 89. Initial scheduling and planning tool at Klaipėda LEZ company UAB Roteksas

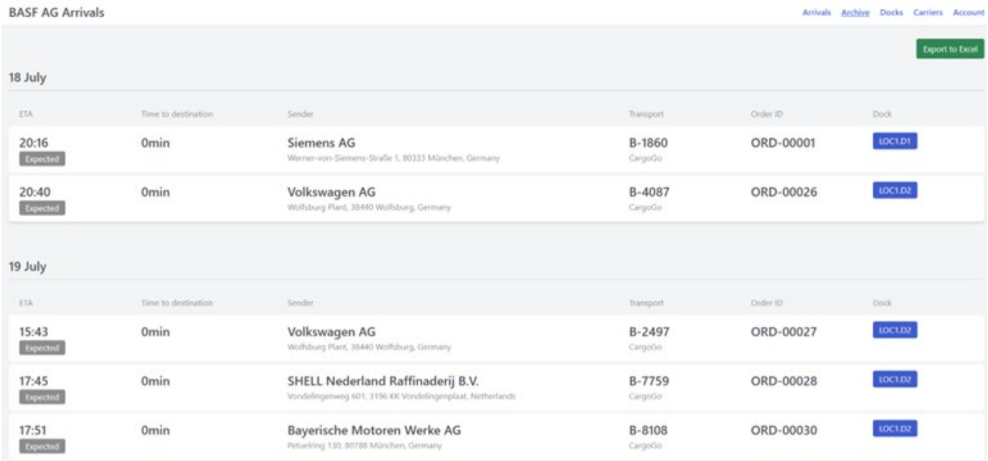

Figure 90. Dashboard with manual input of arrival time

To expand functionality, TREVIO applied telematics data (location, speed, fuel use, ignition-on time, RPMs) to assess the relationship between eco-driving scores and CO_2 emissions during loading/unloading operations. Analysis of 500 routes and 38 drivers confirmed that higher eco-driving scores correlated with shorter ignition-on times and reduced emissions.

Drivers with higher eco-scores emitted less CO_2 in loading/unloading areas.

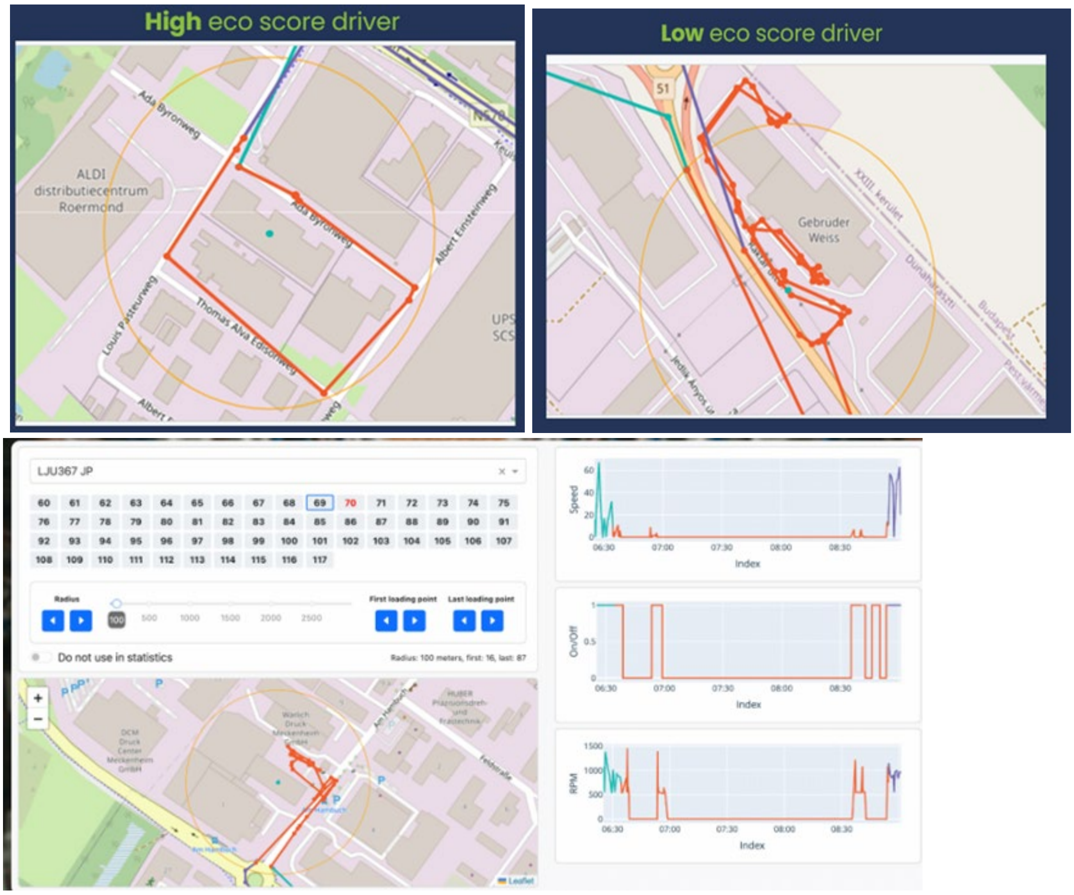

Figure 91. Functionality of telematics trip analysis tool - visualization of truck travel data on maps

This evidence confirmed that driver behaviour is a critical factor in emissions reduction and can be effectively improved through monitoring and feedback. By comparing the top five best-performing drivers with the lowest-performing ones based on their ECO score, it becomes evident that using ETA and eco-driving can lead to savings of around 31.5% in CO_2 emissions (Figures 92-93).This means that if all drivers reached the ECO score level of the TOP 5 performers, CO_2 emissions would be reduced significantly.

Co-funded by
the European Union

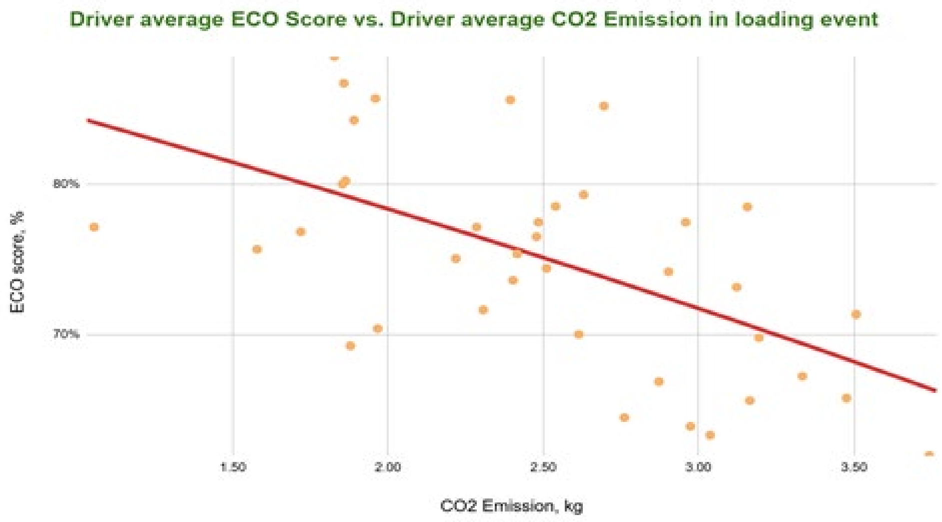

Figure 92. Driver average ECO score vs CO_2 emissions in loading

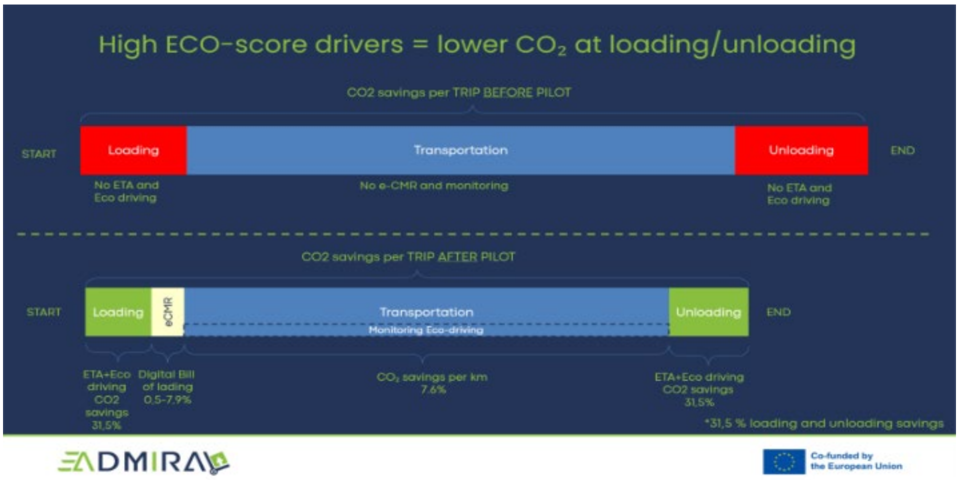

Figure 93. CO_2 saving before and after piloting

CargoGo - demonstrating potential of digital solutions for logistics in operational environment

Within the Lithuanian Pilot, CargoGO tested and validated several digital systems in cooperation with Lithuanian partners (TREVIO, CSign). The central focus was on route optimisation, Estimated Time of Arrival (ETA) planning, eco-driving, and CO_2 monitoring, aiming to improve operational efficiency and deliver measurable emission reductions.

CargoGO has developed a Power BI dashboard that monitors eco-driving performance using real-time Fleethand telematics data. The system tracks **key sustainability indicators such as Eco Score** (based on speed, RPM, braking, idling, cruise control), **fuel consumption per 100 km relative to load**, stops and braking events, engine load, and idle time.

The data provided a real-world emissions baseline based on actual driving patterns, allowing for more accurate calculation and validation of CO_2 estimation tools (e.g., eCMR-based calculators). Behavior-based metrics (Eco Score, braking, cruise usage) supported ADMIRAL in developing standardized performance indicators (PIs) across pilots. Drivers receive tailored feedback, and the dashboard supports training, route optimization, and emissions reduction. This tool directly supports ADMIRAL goals by enabling accurate CO_2 baseline tracking, validating emissions calculators, and offering a replicable model for monitoring sustainability KPIs. Its API-accessible data can be integrated into the ADMIRAL Marketplace for Scope 3 reporting, operational benchmarking, and eco-driving impact assessment.

Figure 94. Dashboard that monitors eco-driving performance

Piloting the ETA Scheduling Tool (developed by TREVIO and integrated with Fleethand telematics), the system automatically communicated the estimated time of arrival to the receiver once a vehicle was within 50 km of its destination. The receiver could assign ramps and adjust schedules directly in the system, while both parties were notified of any changes via automated emails. Integration with CargoGO's existing telematics platform enabled seamless use without additional manual input. This functionality improved real-time visibility, reduced idle times during unloading, and enhanced coordination between dispatchers and customers.

Driver behaviour was analysed to assess the potential for fuel efficiency improvements. Telematics-based monitoring allowed comparison between the highest- and lowest-scoring drivers in terms of eco-driving performance. By combining monitoring results with targeted driver training, CargoGO was able to show measurable fuel savings and corresponding CO_2 reductions, proving the strong impact of eco-driving practices on sustainability outcomes.

The red line in Figure 93 shows the regression trend: as eco-driving score increases, CO_2 emissions per km decrease. Moving from the lowest eco-driving score (60) to the highest (100) results in about a 7.6% reduction in CO_2 emissions per km.

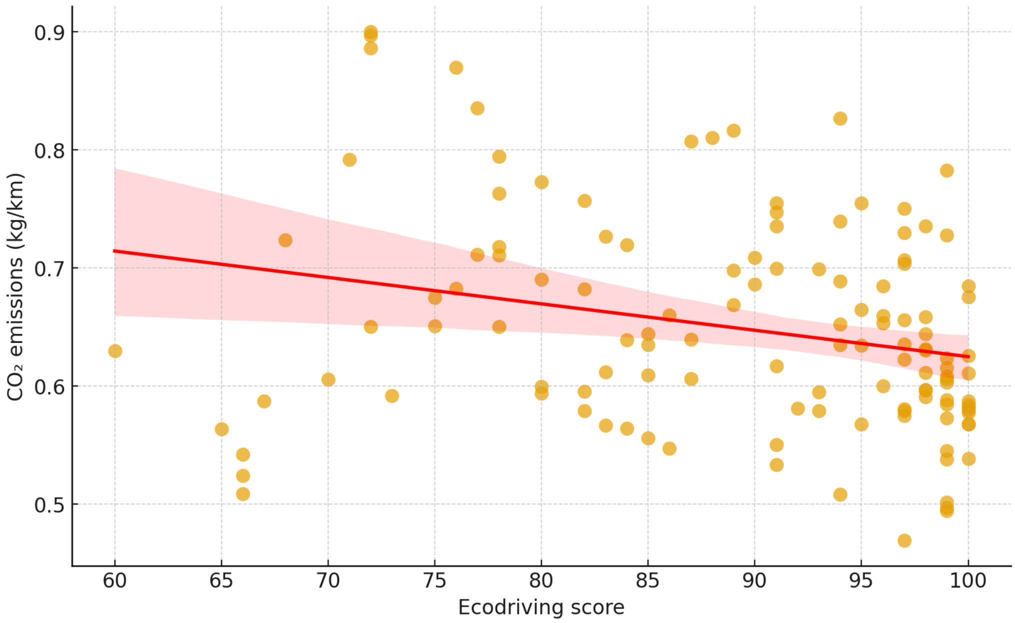

Figure 95. Correlation between ecodriving score and CO_2 emissions per km

KFEZ – improving information exchange between hub members and third parties

The tested systems within the KFEZ pilot environment focused on digital scheduling tools, customs integration concepts, and supporting digital infrastructure. Within the pilot, KFEZ and its partners tested two main systems:

- **KFEZ piloted TREVIO technology in partnership with CargoGO**

In collaboration with TREVIO and CargoGO, KFEZ piloted a digital tool to explore its applicability for hub-level coordination. The tool aimed to provide advance visibility of truck arrivals, reduce congestion, and enable more efficient use of loading ramps within the zone.

The pilot confirmed technical feasibility but also revealed significant adoption barriers. Companies were reluctant to share logistics data, even in anonymised form, highlighting the need for transparent governance and secure data handling. Scaling digital tools requires stronger cybersecurity, compliance with EU data protection standards, and investments in local infrastructure. Effective deployment also depends on seamless interoperability with customs, port systems, freight forwarders, and ERP platforms, supported by robust APIs and tailored integration. As systems scale, advanced user and access management—such as role-based access, audit logging, and monitoring—will be essential to ensure resilience and maintain trust.

Despite these barriers, the pilot confirmed strong interest among companies in solutions that support eco-driving, scheduling efficiency, and emissions reduction.

- **Digital customs checkpoint concept**

In parallel, KFEZ carried out a feasibility study for establishing a digital customs checkpoint within its territory. This assessment analysed customs declarations and logistics statistics, company surveys, and expert interviews, and benchmarked against existing private customs posts.

The number of re-export declarations significantly exceeds the number of export declarations, but it is characterized by a decreasing trend, therefore, the assessment of the total number should be based on data from the first half of 2024. Feasibility study findings confirm the strategic role of Klaipėda FEZ in Lithuania's external trade. Concentrated export and re-export activity through nearby posts demonstrates both the existing integration of FEZ companies into international value chains and the capacity to expand. This underlines Klaipėda FEZ's potential to strengthen its logistics, port-related services, and customs clearance advantages, positioning it as a cornerstone for further trade growth and investment attraction (Figure 96).

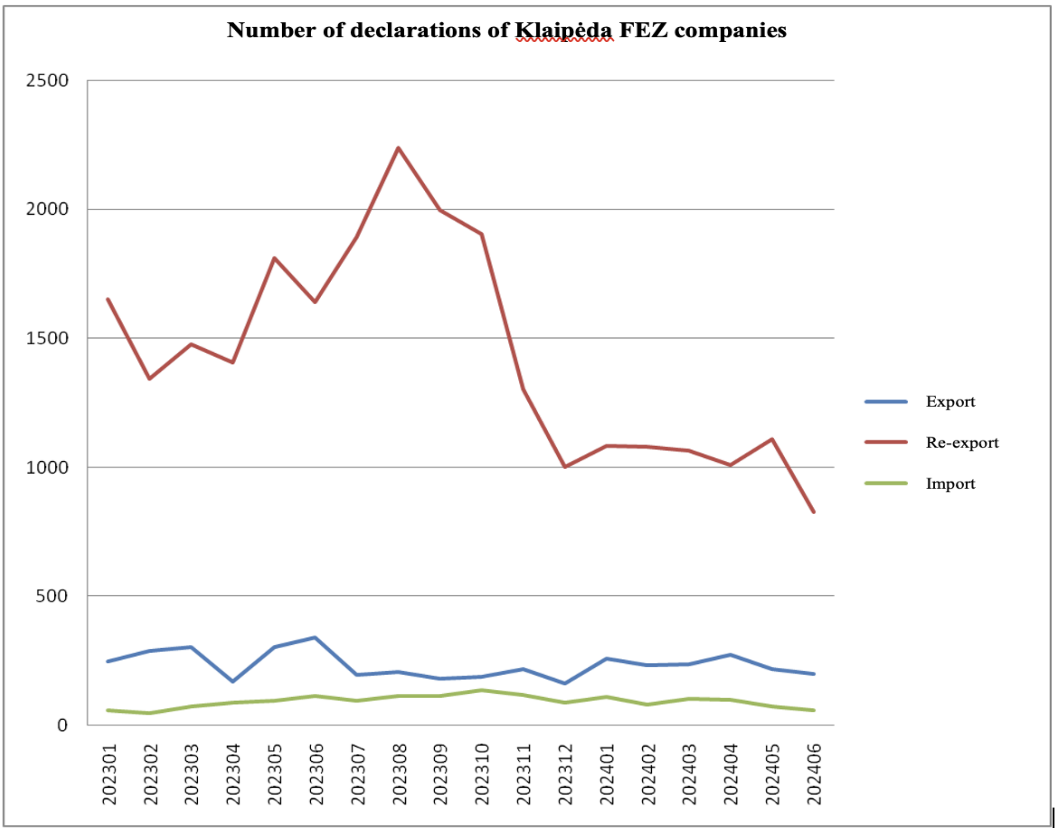

Figure 96. Number and type of customs declarations of Klaipėda FEZ companies

The findings demonstrated clear opportunities:

- An on-site customs checkpoint would streamline processes, reduce redundant trips to off-site customs posts, cut CO_2 emissions, and strengthen KFEZ's attractiveness for existing and prospective tenants.
- Integrating customs processing with eco-driving and green logistics initiatives would amplify sustainability benefits by promoting fuel efficiency and smarter transport practices.

The concept also considered different business models, positioning the checkpoint not only as a potential revenue source but also as a value-added service to attract new companies. A targeted design would prioritise export declarations, where goods are loaded within KFEZ, making local customs clearance particularly valuable.

Exports in Lithuania are handled through 16 customs posts, with Klaipėda playing the central role due to its port. The Malkų įlankos Seaport Post is the largest, processing 27.25% of all export declarations in 2023 and 33.1% in the first half of 2024, mainly for sea shipments but also road transport. The Klaipėda Cargo Post, focused on land transport, accounted for 21.3% in 2023 and 20.7% in early 2024. Pilies Marine Seaport's share has been declining, from 13.6% in 2023 to 8.0% in 2024. Additionally, Klaipėda FEZ companies actively use the Gollner Spedition customs control point at Klaipėda Cargo Post (Figure 97).

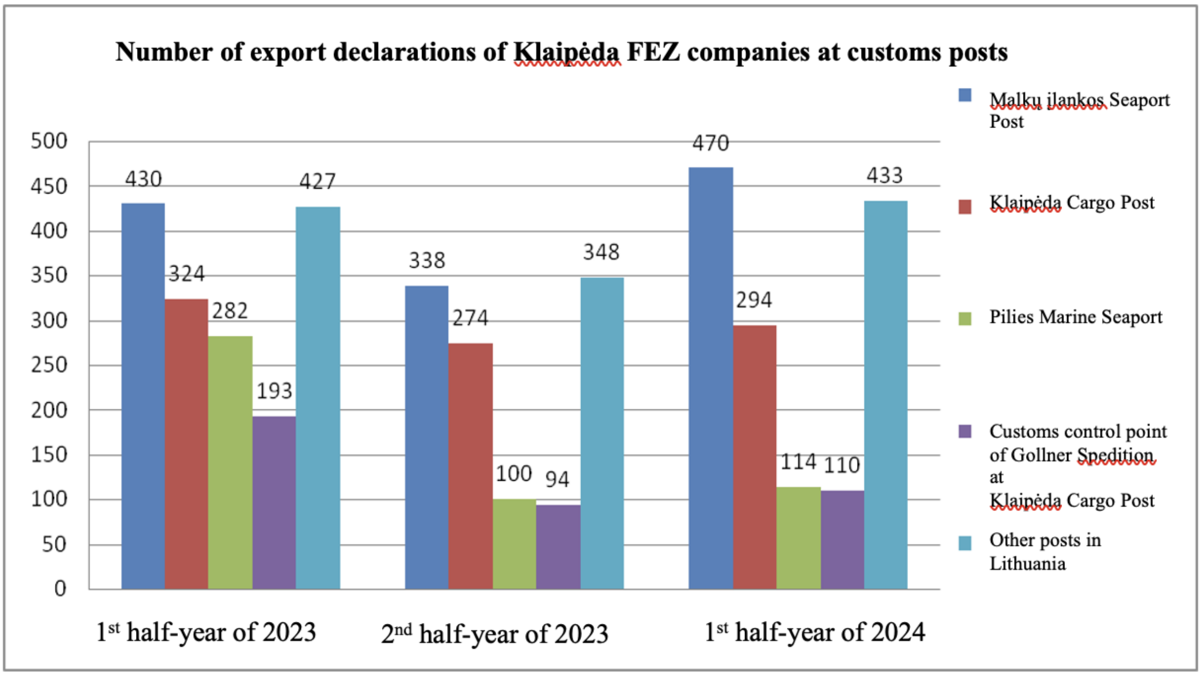

Figure 97. Number of export declarations of Klaipėda FEZ companies at custom control points

4.4 Results of test

The Lithuanian Pilot – Green Route: Emission-Aware Logistics Management was designed to identify realistic and practically applicable digital solutions that would enable the automatic calculation of CO_2 emissions while at the same time improving operational efficiency in road transport. The ultimate goal was to demonstrate how digitalisation can directly support measurable reductions of CO_2 in daily logistics operations.

As a result, **the pilot achieved a significant advancement of digital tools, moving from early concepts and prototypes (TRL3–5) to validated demonstrations in operational environments (TRL6–7).** Within the Lithuanian Pilot, the following digital tools were developed and demonstrated first as stand-alone applications and subsequently integrated into the AWA Multimodal Marketplace:

- **Digital Bill of Lading (eCMR)**

The eCMR solution was based on a document signing system previously used in the healthcare sector. This platform had already demonstrated secure document handling workflows in a real environment (TRL5). The goal within ADMIRAL was to adapt the core system to logistics-specific requirements, including structured transport data models and compliance with eCMR standards and eFTI. During the project, solution reached **TRL7/8**, which includes a redesigned UI/UX, supports integration via APIs and iFrame embedding, and implements the UNECE-compliant eCMR data structure. Demonstrations with logistics stakeholders validated the tool's usability and compliance. Additionally, the eCMR solution was successfully integrated with the **Awake Multimodal Marketplace** and a few other transport management systems outside the Admiral project, enabling seamless creation, editing, and retrieval of eCMR documents via API. This integration confirms interoperability between the eCMR system and external logistics platforms and lays the groundwork for broader adoption within the digital transport ecosystem.

- **CO_2 calculation methodology**

The CO_2 calculator initially existed only as a theoretical concept (TRL3). The idea was to build it on top of an existing document-signing platform prototype, evolving it into an eCMR-based solution capable of calculating emissions from structured logistics data. With no implementation or methodology in place, the starting TRL was 3. Within ADMIRAL, the calculator was integrated into the Marketplace with two operational API methods. It is now functioning in a real pilot environment, where emissions estimates support transport planning and decision-making, thus meeting the criteria for demonstration in relevant conditions (**TRL7**).

- **Transport scheduling tool (ETA)**

The ETA scheduling tool started at TRL5 as a conceptual truck arrival scheduling solution, developed and validated outside operational systems, demonstrating its potential to save time. A prototype was then built and tested in a relevant sender–carrier–receiver environment, simulating real operational conditions. Core functions, including arrival tracking and notifications, were successfully validated without full-scale deployment, using real data from CargoGo and a telematics system provider (**TRL6**). After integration with AWAKE, the tool will be made widely available to end-users, reaching **TRL7.**

- **Transport service order management tool (TMS)**

The TMS initially existed only as a theoretical concept (TRL3). In parallel, the ETA tool was developed and validated. Both, were combined into a full TMS focused on reducing CO_2 emissions. Within this system, Trevio manages arrival planning and shipper–carrier–recipient integration, while the AWA Multimodal Marketplace platform provides order management and additional functionalities. The ETA tool, as a core TMS component, was developed to connect sender, carrier, and receiver, reaching TRL6. A prototype was successfully tested and integrated with AWAKE, achieving **TRL7.**

- **Data Exchange structures and solutions**

All developed tools evolved from initial theoretical concepts (TRL3) to validated prototypes in relevant environments (**TRL6**). From the beginning, they were built to be interoperable and compatible with other systems, not as stand-alone applications. APIs and data models were aligned with European standards (eFTI, eCMR, customs/port integration), ensuring seamless interaction with external platforms.

Finally, **the core outcome of the Lithuanian Pilot** was to demonstrate that the automated CO_2 footprint solutions could achieve **at least a 20% reduction in CO_2 emissions** when applying the developed tools (transport service order management and scheduling solutions, digital bill of lading, and eco-driving). The pilot results confirmed this expectation.

- **The ETA scheduling tool**: validated its potential to cut waiting times and reduce idling, demonstrating CO_2 savings of up to 31.5% in loading and unloading areas when combined with eco-driving
- **Digital Bill of Lading (eCMR):** with eCMR digitalisation, reducing empty freight runs by just 1% could cut CO_2 emissions by ~3.8 Mt per year (≈1.3% of freight emissions), while a 20% reduction could achieve ~60 Mt (≈20% of freight emissions). This corresponds to ~0.5% to ~7.9% of total EU road transport emissions.
- **Eco-driving monitoring:** regression analysis confirmed 7.6 % CO_2 savings per kilometre by improving driver behaviour.

4.5 Summary of the pilot

Lithuanian pilot activities have been mainly dedicated to the development of a Transport Scheduling Tool, and identifying a suitable CO_2 emissions calculation methodology and data sources for road transport. Regarding the Transport Scheduling Tool, an automated tool for planning truck arrival (ETA) has been tested to reduce truck idling time and thereby potentially reduce CO_2 emissions. Another focus was on analysing different market approaches to CO2 calculation, whereby eCMR data has been identified and tested as a promising data source. For the calculator, eCMR data has been complemented by modelled data on fuel consumption.

Summary of technology developed in this pilot

Transport service order management tool (including integration with the marketplace), target TRL 7

- Pilot 3) Green Route: Emission Aware Logistics Management (Lithuania), has developed Transport Service Order Management Tool (TMS). It has been demonstrated in operational environment, and integrated to Awake.AI Marketplace, current **TRL 7**.

Transport scheduling tool (dock management, loading and unloading schedules), target TRL 7

- Pilot 3) Green Route: Emission Aware Logistics Management (Lithuania), has developed Transport scheduling tool, Estimated Time of Arrival (ETA) tool, currently TRL6, after integration to Awake.AI Marketplace, will reach TRL 7. TREVIO - Emission -Aware Hub Scheduling tool, has been demonstrated in operational environment, current **TRL 7**

Digital bill of lading (digital documentation and signature), target **TRL 8**.

- Pilot 3) Green Route: Emission Aware Logistics Management (Lithuania), has developed CSign – emission aware eCMR with CO_2 Calculator. It has been integrated to Awake.AI Marketplace. Current TRL 7/8

Data exchange structures and solutions, target TRL 6

- Pilot 3) Green Route: Emission Aware Logistics Management (Lithuania), has developed data exchange structures and solutions, which are demonstrated, current **TRL 6**

CO_2 calculation methodology, digital tools and data exchange, target TRL 6

Pilot 3) Green Route: Emission Aware Logistics Management (Lithuania), has developed CO_2 calculation methodology. It has demonstrated in relevant conditions, current **TRL 7**

CO_2 emissions reduction (see also more details in previous pages)

- ETA scheduling tool shows up to 31,5 % CO_2 saving in loading/unloading areas
- Digital Bill of Lading (eCMR) shows 1-20% fewer empty runs,
- Eco-driving monitor shows 7.6 % CO_2 savings per km

The integration with the ADMIRAL marketplace is described in Section 6.3

5 AI-BASED OPTIMIZATION OF LOGISTICS FOR SUSTAINABILITY PILOT (FINLAND)

5.1 Overview of the pilot

5.1.1 Pilot environment

The Port of HaminaKotka consists of multiple terminals, including the Hietanen RoRo Terminal, which is the primary pilot location managed by Steveco Oy.

This terminal processes approximately 2.4 million tons annually, with exported forest products such as paper, pulp, and sawn timber accounting for 80% of this volume. Export products are primarily transported to the port warehouses by rail, although a substantial amount of cargo also arrives by truck. The terminal offers around 130,000 square meters of warehouse space and 67,700 square meters of storage area. It utilizes a customized IT system (FLOW) that is integrated with customer IT systems.

The principal customers of the Hietanen RoRo Terminal have their own logistical solutions, and aligning the objectives of all partners—including customers, trucking companies, port authorities, and railway operators—will enhance the overall efficiency of the logistical system. Steveco has implemented the Truck Appointment System (TAS), resulting from previous projects, which provides better insight into incoming truck schedules.

5.1.2 Challenge and purpose of the pilot

This pilot, AI-Based Optimization of Logistics for Sustainability, aims to improve the efficiency of cargo flows through the port and specifically to optimize the use of workers, equipment, warehouse space and minimize total driving distances within the terminal and to reduce GHG emissions of operations.

Currently all relevant operational decisions are made by managers, foreman and workers themselves, including berth allocation planning, directing trains and trucks to specific warehouses, selecting transport units for cargo, allocating warehouse space for cargo and transport units, and scheduling workers, vehicles and equipment. Planning time frame varies from months to days and hours. Due to the reliance on human decision making, the warehouse operations are based on heuristic rules, decision makers experience, (skills and human factors) and do not fully consider all the information that is already available in the different port information systems.

The scope of the pilot is to test a solution that increases data sharing, digitalization and includes a standalone AI-tool replacing some of the cargo flow planning processes currently done by humans. AI-based planning tool should help to offer more even quality of cargo handling services, which is less based on the workers "artistic view".

Two specific port operational decisions were initially targeted by the AI-based cargo planning tool implementation in the pilot:

- ***Warehouse train scheduling:*** the tool will propose in which warehouse to drive each incoming train from the adjacent railyard. If there are more trains than can be immediately processed, the tool will also propose which trains to unload first.

- ***Intelligent order placement:*** the tool will propose in which transport units or storage locations to place each order of cargo on each day. The tool will similarly plan where to put transport units carrying each order on each day. The proposals will be provided via the VTS system to warehouse foremen.

The decisions of the tool will be treated as proposals, and people are free to deviate from them, in which case the tool needs to update its plans in real time.

The pilot aims for the following improvements in operational efficiency:

- Unloading time of truck or train will be reduced by 15% in port.
- Current warehouses allow passage of 15% more cargo.
- Current Steveco workers and port equipment can handle 20% more cargo in a same time in the operations of unloading truck or train, warehousing, and loading a vessel.
- Due to higher productivity, emissions of working machines will be reduced by approx. 15%.

This pilot demonstrates the benefits of a newly developed AI-based tool for cargo handling operations optimized planning and sustainability. The AI-tool receives input from Steveco TOS (terminal operating system) called (FLOW), that will enable it to give instructions and suggestions for the workers to unload rail wagons and trucks to the most optimal location in the terminal (including different warehouses and locations inside the warehouse). The tool also brings GHG emissions related data such as type of fuels to be used and related GHG emissions for the decision-making process. The expected reduction of GHG emissions will be 15-20%.

5.1.3 Partners involved and their roles

The Finnish pilot at Hietanen ro-ro terminal involves two stakeholders from the ADMIRAL consortium, one subcontractor and two outside stakeholders, each bringing specific expertise to support the successful implementation of pilot activities:

- **Steveco**: The pilot partner, working as terminal operator and testing the standalone AI-tool.
- Envare Solutions Oy is the subcontractor for Steveco, offering GHG emission related KPIs at the port terminal.
- **VTT:** Providing the scientific support and developing AI technology, data collection and simulation.

Outside the consortium:

- VR, Finnish Railways, will provide and receive information from railway logistics operations.
- Finnish forest industry companies' order data will be used and additional integration opportunities will be tested in simulation and discussed in stakeholder workshops.

5.2 Tested scenarios

In the spring of 2025, real-life testing was performed (related also to the WP 6. Assessment of Solutions and Impact Assessment), to obtain Baseline data including driving distances (km), tons handled and GHG emissions (g/ton) in warehouse operations, following current manual planning procedures.

The following KPIs were used to measure overall terminal performance and the improvements achieved by the pilot over current practice.

- Average train unloading time, min/train. Includes the time from train arrival to terminal to the time all the railcars are ready to be retrieved.
- Average truck unloading time, min/truck. Includes the time from truck arrival to terminal to the time the truck is free to leave.
- CO_{2e}, CO, NO_x, PM and SO_2 emissions of port vehicles in warehouse work, g per ton of cargo. Derived from vehicle driving data according to vehicle type.
- Maximum cargo throughput with current workers and port equipment, ton/year.
- Maximum cargo throughput with current warehouses, ton/year.

The performance of AI planning was evaluated and compared to the baseline in Phase 1 simulation testing, using operational data collected from the period January-September 2025. During simulation testing, advance data about upcoming ships, trucks, trains and their cargo was sent gradually to the AI planning tool, so that at any time the planning system had only as much data as was available in reality, including inaccuracies in expected arrival times. Actions outside the terminal, i.e. ship, truck and train arrivals and departures, were simulated exactly according to historical data. Actions inside the terminal were simulated under the guidance of the AI tool, in particular where to unload cargo and where to move transport units.

To prepare for Phase 2 production testing, the AI tool has been developed further and during September 2025, repeat monitoring has been performed to get baseline results that can be used to compare with the results obtained from when AI-tool is used in real world production environment.

The next steps will be to have a Demonstration of intelligent order placement and Demonstration of AI-based cargo planning.

5.3 Tested systems

The focus of this pilot is the AI-based cargo planning tool, which is implemented as an online service with no user interface of its own. The AI Planning tool receive updates to relevant data, prepare plans in the background, and send updated plans to the FLOW and VTS (Vessel Traffic System) systems of the port operator. The users of FLOW and VTS will see the decisions proposed by the cargo planning AI service and may deviate from the proposals at their discretion. The final user decisions and actions will be sent immediately to the cargo planning AI service as data updates, signalling the service to update plans.

Emission data is currently collected by the port operator in the Ensio energy monitoring system at the port terminal level. Energy monitoring is extended to track activities in specific phases of the work process in warehouses by specific vehicles, so that the scope 1 and 2 emissions impact of the AI-based cargo planning tool can be measured and linked to specific railcars and trucks.

Development and the initial user validation of the decision support tool is implemented in VTT's PORTMOD simulation environment, with results presented off-line to pilot users.

Basic data in AI-planning includes:

- type of machines/engines
- used fuel (diesel) and consumption
- distance data between warehouses (including inside warehouses), sheds and berth places of vessels
- information of handled cargoes from Steveco TOS (FLOW) including tons, pallets, reels and cargo units

The information is stored inside the operator's databases (FLOW and ENSIO, Envare Emission Software).

The tested development version of the AI tool fully implements the order placement features and the integration API (application programming interface) for connection with the Steveco TOS. The here reported results reflect the current status of the software, which continues to be developed.

The data was collected from Steveco TOS (FLOW and ENSIO) and manual recordings.

1) ENSIO emissions collecting software (g/ton) historical information
2) Operational and cost data (handled tons and €/ton etc).

5.4 Results of test

The baseline results are based on average realized GHG emissions for different working machine groups. These results will be updated in follow-up testing.

Phase 1: Manual monitoring during autumn 2025, these results will be compared to the second, more sophisticated version of AI-tool

Phase 2: Manual monitoring if needed, before the AI-tool will be tested in port operations

Baseline data, emission g/ton vs terminal vehicle and unit costs €/ton are shown in Table 34.

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Table 34. Baseline data, emissions and cost vs terminal vehicle

Emissions g/ton vs terminal vehicle			
Emissions g/ton	**3 ton (stage III B)**	**8 ton (stage IV)**	**Terminal tractor**
CO	0,6161	0,8246	7,6873
NOX	0,4929	0,0662	0,8771
PM10	0,0027	0,004	0,052
PM25	0,0027	0,004	0,052
CH4	0,0057	0,0075	0,0975
N2O	0,0016	0,0021	0,0279
HC	0,0864	0,0314	0,4158
SO2	0,0004	0,0005	0,0065
CO2	99,8563	131,0614	1711,1919
CO2eq	100,4476	131,8375	1721,3244
Historical Unit Cost (€/ton) vs terminal vehicle			
	3 ton (stage III B)	**8 ton (stage IV)**	**Terminal tractor**
€/ ton	0,0409	0,0537	0,7017
Historical Delivery Reliability (%)			
Reliability%		>99%	
Existing Stakeholder Satisfaction score (if available)			
Satisfaction Score		n/a	
Systems Integrated Prior to ADMIRAL (Yes/No)			No

Fuel consumption and emission information based on observations 10.9.-24.9.2025 at Hietanen RoRo. Figure 98 illustrates comparison for every forklift using LFO (Light Fuel Oil also known as regular diesel), or HVO (Hydrotreated Vegetable Oil also known as Renewable Diesel), and the use of AI-based planning.

The emissions of machines using HVO-diesel are up to 90% lower compared to regular diesel (Diezemann et al. 2025). Currently, renewal diesel is more expensive, the fuel price increase about. + 25% / ltr.

	Paper reels (8 ton)			
	avg Consumption l/h	avg CO2eqv [kg]/ton	Workhours	tons
LFO	4,71	0,1805	175	11 605
HVO	4,71	0,0098	175	11 605
AI-optimization	*4,71*	*0,1763*	*175*	*11 605*

	Paper Pallets (3 ton)			
	avg Consumption l/h	avg CO2eqv [kg]/ton	Workhours	tons
LFO	2,65	0,2872	73	1 607
HVO	2,65	0,0247	73	1 607
AI-optimization	*2,65*	*0,2805*	*73*	*1 607*

	Timber (18 ton)			
	avg Consumption l/h	avg CO2eqv [kg]/m3	Workhours	m3
LFO	11,58	0,3137	8	754
HVO	11,58	0,0247	8	754
AI-optimization	*11,58*	*0,3063*	*8*	*754*

	Plywood (18 ton)			
	avg Consumption l/h	avg CO2eqv [kg]/ton	Workhours	tons
LFO	13,08	0,2436	13	1 915
HVO	13,08	0,0210	13	1 915
AI-optimization	*13,08*	*0,2379*	*13*	*1 915*

Figure 98. Consumption and emission information for different type of cargo

The key performance indicators of the current development version of the AI tool are shown in Table 35, compared to the baseline results from the current manual planning procedures for the period from January to September 2025. The results indicate that the current AI tool version is barely better than the baseline in terms of operational costs (2.8% improvement) and emissions (3.9% improvement). AI planning reduced truck unloading time by 4.8% and increased train unloading time by 1.2%.

The main issue is that AI planning ended up putting packages more often on floor storage before transport units than the baseline, resulting in 4% more forklift moves, but the AI planning compensated by reducing transport unit moves by 27%: this was not enough to offset the increase in forklift operations, since the latter are more numerous.

The planning algorithm is still under development and improved results are expected before pilot testing in production is completed.

Table 35. KPI's of AI cargo planning in simulation compared to historical baseline

Description	Baseline	Simulation	Change
Operational expenses (€/ton)	3.01	2.92	-2.83%
CO_2 equivalent emissions (kg/ton)	0.498	0.479	-3.92%
Total number of packages transported to ship on period	756388	753836	-0.34%
Total cargo tons transported to ship on period	774292	771878	-0.31%
Total number of transport units shipped on period (only unit types managed by AI tool)	24441	22825	-6.61%
Total terminal vehicle worktime (min/ton), averaged by shipped tonnage	1.98	1.94	-2.34%
Average truck unloading time (min) including forklift unloading packages from truck, and terminal tractor fetching units for loading	47.0	44.7	-4.80%
Average train unloading time (h) including forklift unloading packages from railcars, and terminal tractor fetching units for loading	12.2	12.3	1.17%
Average number of times a cargo package is moved by forklift	1.17	1.21	3.75%
Average number of times a cargo package is moved on transport unit	3.97	2.89	-27.25%
Average distance (km) a cargo package moves by forklift, averaged by tonnage	0.086	0.057	-33.34%
Average distance (km) a cargo package moves on transport unit, averaged by tonnage	1.34	1.21	-9.17%
Observed cargo throughput (Mt/a) in test scenario	1.04	1.03	-0.31%
Maximum cargo throughput (Mt/a) with current workers, assuming that available worktime is the bottleneck	1.36	1.39	2.39%
Maximum cargo throughput (Mt/a) with current warehouses, assuming that floor storage capacity of either cargo or units is the bottleneck	1.72	1.79	4.43%

5.5 Summary of the pilot

Finnish pilot activities have so far focused on testing a simulation model for basic order placement in the port of Hamina Kotka to identify how terminal operations can be optimized and thus CO_2 emissions reduced. Current activities include integration of AI features in the warehouse work planning system that is used daily by warehouse foremen in the port. Simulation data on cargo handling as well as terminal operations data are used to drive the development of the AI tool for cargo unloading operations. Real-world testing of the AI-based planning tool is planned to commence later before end of the project.

Summary of technology developed in this pilot

AI-based cargo planning tool, target TRL 7. Development in WP4 and WP5

- Pilot 4 - AI-Based Optimization of Logistics for Sustainability (Finland), has developed AI-based cargo planning tool. Development is not yet fully demonstrated in operative environment. Development and testing is on-going. Current TRL 6, will be TRL 7 after testing in operative environment.

CO_2 emissions reduction

Current emissions reduction with AI-planning in test was 3.9 %. The planning algorithm is still under development and improved results are expected before end of the project.

Higher emission reduction is achieved using biofuels instead of regular diesel, but with extra cost. Service buyers are offered option to use biodiesel as shown in Section 6.4, see Figure 106.

The integration with the ADMIRAL marketplace, see Section 6.4

6 Integration to the ADMIRAL Marketplace

The ADMIRAL Marketplace is build on top of existing Awake.AI Marketplace operated by AWA (also known AWA Multimodal marketplace), as show in previous sections. The ADMIRAL Service Catalogue is integrated to the Awake.AI Marketplace as show in Section 2. The services developed in pilots are shown in the ADMIRAL Service Catalogue. The solutions developed in Pilot 2 and 3 are integrated to the Awake.AI Marketplace. The marketplace is one of the key outcomes of the ADMIRAL project.

The pilot solutions have undergone testing and planning both as standalone implementations and as integrated components within the ADMIRAL Marketplace. The pilot initiatives clearly demonstrate emerging opportunities for inter-company collaboration, including cross-border partnerships such as those between Portugal–Spain and Slovenia–Croatia. Further testing of real-life pilot solutions in connection with the ADMIRAL Marketplace was used to provide demonstration of its capability to disseminate the developed logistics solutions across. The integration with the ADMIRAL Marketplace supports ADMIRAL project to focus on the integration and harmonization of previously closed, independent logistics networks, as well as clusters of interconnected networks, to enable seamless collaboration and improved efficiency across heterogenous supply chain stakeholders. These implemented solutions encourage companies to shift their approach to more sustainable supply chain management—from focusing primarily on minimizing transport and logistics costs to prioritizing the reduction of emissions and energy consumption. By displaying the emission levels associated with different service alternatives, the ADMIRAL Marketplace (Figure 99) incentivizes both service providers and buyers to place less emphasis on price and instead concentrate on minimizing environmental impact.

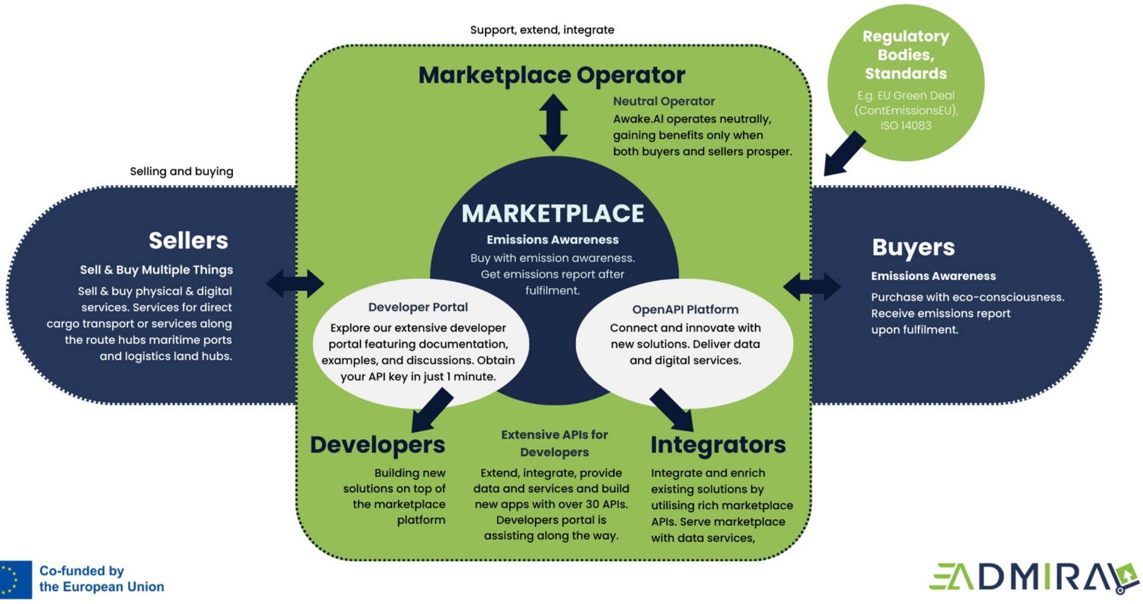

Figure 99. ADMIRAL Marketplace

The ADMIRAL Marketplace represents a unique commercial logistics solution that integrates services along with physical and digital products into a unified platform encompassing sea, port, and hinterland operations for both import and export cargo flows, except for air cargo. To remain competitive, logistics platforms must evolve beyond mere networking and collaboration, advancing toward comprehensive planning and execution workflow capabilities. Initially, ADMIRAL Project defined that the primary criterion for the marketplace's success will be the volume of completed and verifiable operations conducted by multiple buyers and sellers around Europe. Consequently, its development has been closely aligned with four pilot projects and their piloted solutions, each of which will introduce specific requirements to ensure practical applicability and scalability. The user stories developed for each pilot serve as key inputs guiding the design and implementation of the initial applications within the ADMIRAL Marketplace. Subsections 6.1 – 6.4 of this Deliverable D5.3 are proving further details of the Marketplace integrations with the individual pilots and their piloted solutions.

6.1 Digital & Green Multimodal corridor

Pilot 1) Digital & Green Multimodal corridor (Portugal-Spain) has developed integration methods for the ADMIRAL Service Catalogue. The developed methods enable:

- User (login, user and company management)
- Integration with NEXUS/JUL
- Service Offers and Availability creation and configuration
- Connection to ADMIRAL Marketplace, able to connect others

Some development steps continue until end of the project.

See section 2.4- 2.5 for detailed presentation on ADMIRAL Service Catalogue.

6.2 Green Logistics: Optimizing Postal Sustainability Across Borders

Pilot 2) Green Logistics: Optimizing Postal Sustainability Across Borders (Slovenia-Croatia), see section 3 for details of standalone test results.

Within development in the pilot framework, it was identified that the **ADMIRAL Marketplace** can benefit from the following solution components:

- Routing Engine
- First-Mile Postal Optimisation Service (LOPTA-FMO)
- Last-Mile Postal Optimisation Service (LOPTA-LMO)
- CO_2 Emissions Calculation Service (LOPTA-EC)

These services, individually or combined, provide flexible methods for optimising road transport logistics - from simple use cases to more complex, granular challenges. Except for generic routing services, such optimisation functionalities are largely absent from existing logistics marketplaces. Their successful integration requires domain expertise. The cooperation between three postal operators

(**Pošta Slovenije, Hrvatska Pošta, Locodels**), an IT company specialising in logistics optimisation (**Solvesall**), and a research and education institution (**University of Ljubljana**) provided a strong foundation for developing and testing of these services.

Routing Engine

The routing engine forms the backbone of all pick-up and delivery operations. It processes addresses and generates the most efficient sequence of stops using custom optimisation algorithms for the Vehicle Routing Problem (VRP). The selection of appropriate vehicle type is handled by cost function which maximises the load factor of the selected vehicle as well as the cost function which minimises the number of vehicles for pickup. Additionally, constraints are set which (if possible) reduces the empty miles as well as cost functions that minimises the number of kilometres. By reducing travel distances, the routing engine directly supports both economic objectives (lower costs) and sustainability objectives (reduced CO_2 emissions). The specificity of the approach is, that we can enable/disable some constraints, for example:

- How similar new solution is to the baseline (to not cause too big confusion to the drivers)
- Driving CO_2 emissions (prefers electric vehicles) - this is not completely finished yet, as we only have ranges to the first fuelling/charging - Time constraints
- CO_2 emissions due to inclinations (emptier trucks uphill)
- Detours

First- and Last-Mile Optimisation Services

These services build upon the routing engine by incorporating:

- Pre-processing (parcel data analysis, address verification, hub mapping, vehicle definitions).
- Constraints (time windows, vehicle capacity, operational rules).
- Post-processing (selection of appropriate vehicle types, consolidation strategies).

Well-defined constraints are critical to ensuring meaningful optimisation results. They enable higher load factors, route efficiency, and further improvements in sustainability.

CO_2 Emissions Calculation Service

This service calculates emissions in line with the **GLEC Framework**, accounting for vehicle type, route characteristics, and each element of the transport chain. For postal operations, this provides a precise understanding of environmental impact across first-, mid-, and last-mile activities. To validate the specified LOPTA components (LOPTA-FMO, LOPTA-LMO, LOPTA-EC) we isolated each of the components from the LOPTA and defined the testing parameters to ensure the end products would be usable in scope of the ADMIRAL Marketplace.

Following Figures 100 and 101 illustrates the Postal services, Recurring packet handling service integration to the ADMIRAL Service Catalogue.

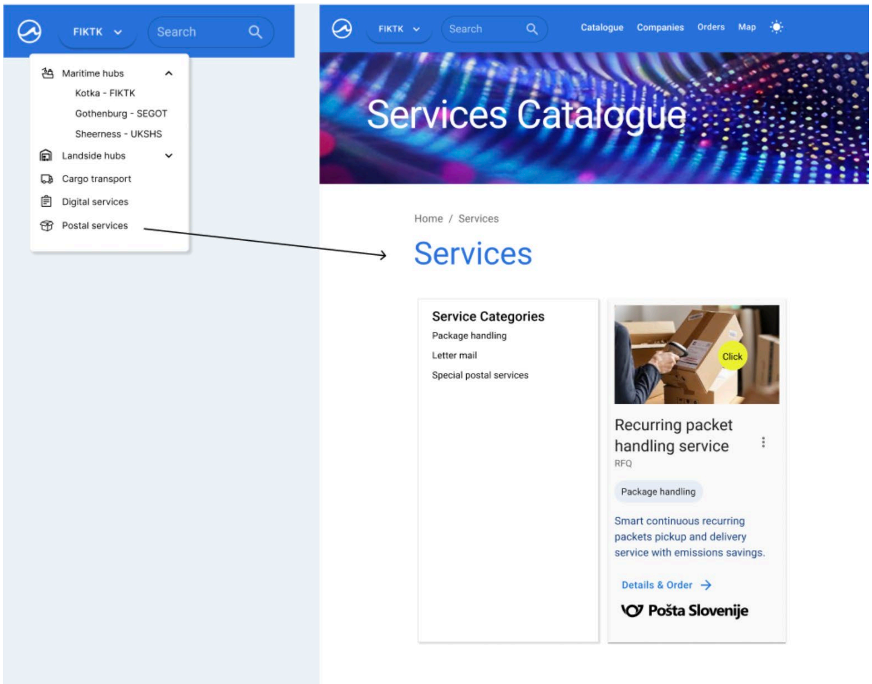

Figure 100. Recurring packet handling service in ADMIRAL Marketplace.

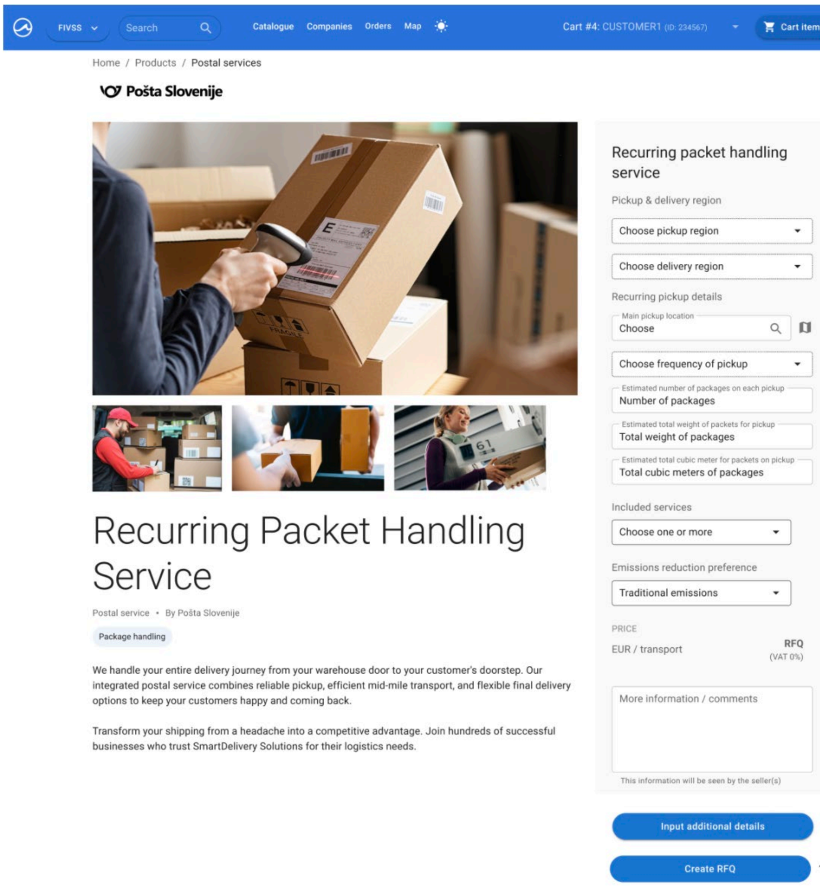

Figure 101. Recurring packet handling service details.

6.3 Green Route: Emission Aware Logistics Management

Pilot 3) Green Route: Emission Aware Logistics Management (Lithuania), see section 4 for details of standalone test results.

ADMIRAL Marketplace (Awake.AI Marketplace, AWA Multimodal marketplace), is one of the key outcomes of the ADMIRAL project. Green route: emission aware logistics management pilot solutions have close cooperation with the Marketplace due to overlap in addressed transport modes, ambition to reduce emissions and focus on logistics data exchange improvement. Over ADMIRAL implementation, the Lithuanian Pilot and AWA collaborated to:

- Exchange knowledge and approaches for development of digital tools for logistics.
- Insights and approaches for stakeholder validation, improved market acceptance.
- Practical insights on logistics operations and how these practicalities may be reflected in digitalization.

As Green route: emission aware logistics management pilot develops multiple individual technical solutions, integration and common activities are described separately for each partner.

As part of the Lithuanian pilot, CSign has successfully completed all the planned testing activities related to digital emissions tracking and system integration. A key focus was on the integration of CSign's CO_2 emission calculator module (developed as part of its eCMR solution) with the ADMIRAL Marketplace operated by AWA.

CSign also collaborated with the ADMIRAL Marketplace development team to initiate the integration of the eCMR solution into the broader multimodal platform. This effort began with technical discussions aimed at identifying feasible integration points and establishing a shared understanding of system interoperability. Through these discussions, both parties agreed on the primary integration scenario, focusing on enabling the marketplace to create eCMR document, retrieve structured eCMR data to support shipment visibility, documentation compliance, and emissions tracking. Based on this alignment, CSign prepared a detailed integration guide for the ADMIRAL Marketplace team. The guide outlines the data exchange model, describes key API methods to be implemented, and provides step-by-step instructions for enabling system-to-system communication. It includes specifications for eCMR data structure, authentication procedures, and recommendations on when and how the marketplace should invoke CSign's APIs to create, retrieve or update eCMR related data. This integration enables emissions-awareness in freight transport operations by enabling automated carbon emission calculations using easily accessible data. Following calculation scenarios are implemented:

CO_2 Emission Calculation Based on Route Geometry from eCMR. In this scenario, the eCMR system calculates the shortest feasible distance using the Google Maps API based on provided address inputs. This allows for accurate routing and emissions estimation within the eCMR system without depending on marketplace-side routing. It is suitable for standalone usage where routing data is not sourced from the ADMIRAL platform or any other system that would be integrated and would use this API for CO_2 emission calculation. To support this use case, CSign developed API, which uses the following input parameters:

- Starting position – Address of vehicle starting point. Can be `null` or not sent at all. In such case, `empty$CO_2$` value will be `0`.
- Loading position – Address of vehicle starting point when loaded.
- Unloading position - Destination address.
- Truck type – value from vehicle type classification.
- Freight weight - loaded vehicle weight in kilograms.

The Google Maps API is used to determine the most efficient route based on these inputs. The eCMR system then uses this distance and transport characteristics to calculate estimated CO_2 emissions. This ensures emissions data is readily available before the transport operation start and supports compliance with standards such as ISO 14083 and GLEC.

Emission Calculation Based on Routing Provided by ADMIRAL Marketplace or any other system. In the second scenario, the route and distance data are generated by the ADMIRAL Marketplace or any other system that is using the API method. The eCMR system retrieves this data and performs the emissions calculation based on the supplied distances and transport parameters. To support this integration, CSign developed API, which uses the following input parameters:

- Empty distance – empty vehicle driven distance in meters.
- Loaded distance – loaded vehicle driven distance in meters.
- Truck type – value from vehicle type classification.
- Freight weight – loaded vehicle weight in kilograms.

This scenario enables system to system interoperability and data exchange between CSign's eCMR system and ADMIRAL Marketplace or any other system, allowing users to base emissions estimates on routes proposed by the marketplace. Solution enhances accuracy and estimation consistency for customers using both tools in tandem.

Both scenarios were successfully tested during the reporting period, validating the flexibility and robustness of the emission calculator module. These integrations form a critical foundation for enabling transparent, standardized, and scalable CO_2 reporting within ADMIRAL's multimodal logistics ecosystem.

The CSign solution has successfully delivered full eCMR digitalisation and CO_2 emissions calculation functionalities. The system is operational: it allows creating, updating and digitally signing eCMR documents, while automatically transferring data to external platforms. CO_2 emissions are calculated both via eCMR routing and marketplace routing options, ensuring accurate and comparable results across use cases. Built on UNECE-aligned data models and open APIs, the solution is already fully interoperable with external platforms and technically ready for cross-border data exchange as well as integration into broader logistics digitalisation ecosystems (Figure 102).

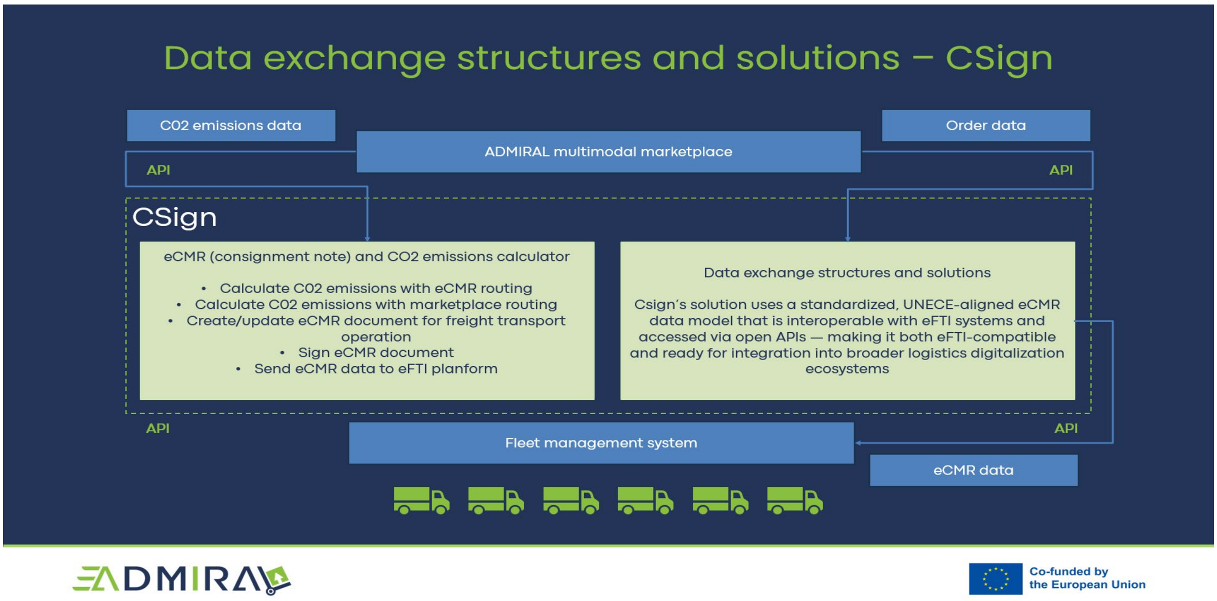

Figure 102. Data exchange structures and solutions developed by CSign

In collaboration, **TREVIO and AWA developed a structured plan for the integration of ETA handling through the AWAKE API**. The plan outlined a step-by-step integration pathway:

- Finalisation of API endpoints and permissions
- Clarification of carrier information retrieval and developer account setup.
- Adjustment of login/authentication flow (likely via OAuth2/Keycloak).
- Fallback logic for missing ETA values.
- Pilot demonstration of seamless ETA tracking and notification between AWAKE and TREVIO ETA.

Within the Green route: emission aware logistics management pilot, freight receivers and carriers were integrated through the TREVIO ETA solution, utilizing dedicated API credentials to enable the automated transfer of order-related data (carrier and ETA) from AWAKE. Automated notification functionalities were deployed to request carriers to confirm or update the ETA prior to arrival (Figure 103).

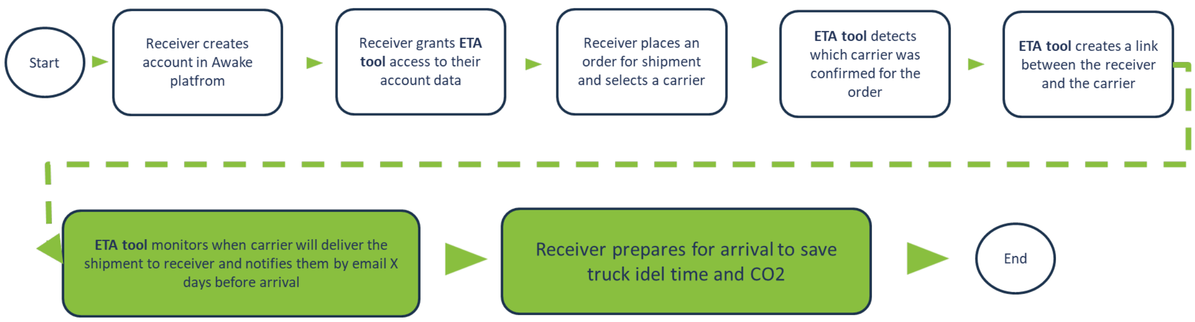

Figure 103. TREVIO ETA solution process

In addition, the Lithuania pilot examined mechanisms related to authentication, permission management, and company linkage, in alignment with the specifications outlined in the API documentation.

The TREVIO solutions demonstrated how digital scheduling tools can reduce inefficiencies in logistics operations. It integrated dock management, loading/unloading schedules, and transport service order management with the ADMIRAL multimodal marketplace (Figure 104).

- A visual interface provides senders, carriers, and receivers with real-time shipment status and ETA notifications.
- Through APIs, ETA and order data are automatically exchanged with the marketplace and fleet management systems.
- The tool enables synchronisation of operations and prevents bottlenecks, directly supporting emission reduction through fewer delays and optimised resource use.

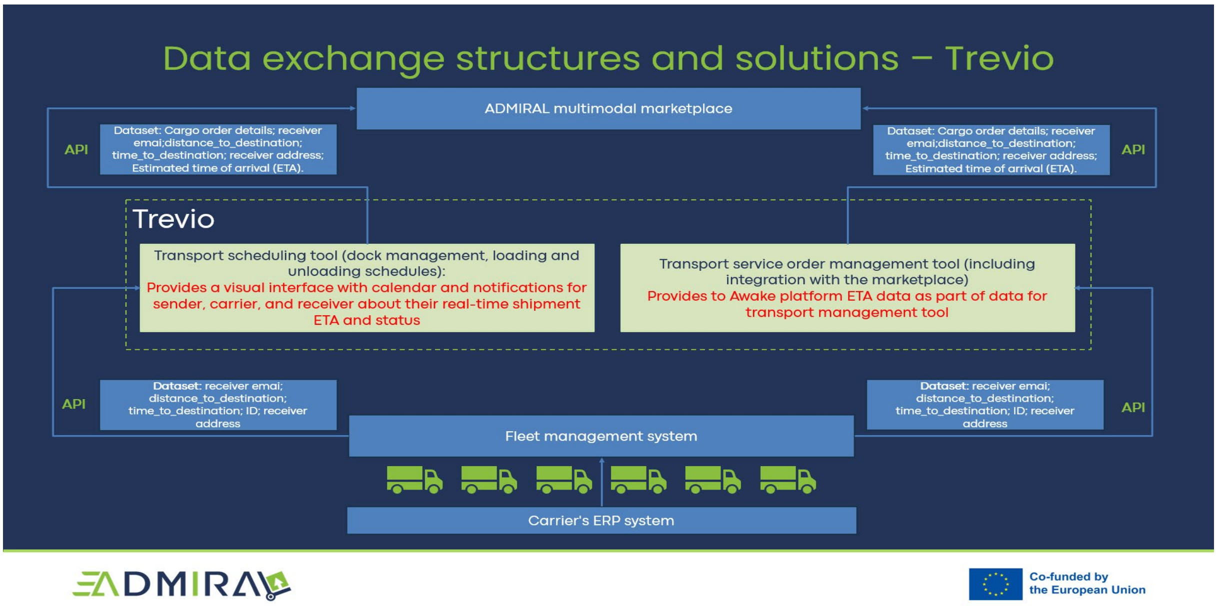

Figure 104. Data exchange structures and solutions developed by TREVIO

6.4 AI-Based Optimization of Logistics for Sustainability

Pilot 4) AI-Based Optimization of Logistics for Sustainability (Finland), see section 5 for details of standalone test results.

The Finnish Pilot tests the ADMIRAL Service Catalogue concept (Portugal-Spain pilot) and is integrated to the ADMIRAL marketplace. Steveco collects machine-specific data on the unloading of trucks and railcars. The data collected provides the initial data for emissions information (for RoRo operations) to the Service Catalogue and ADMIRAL Marketplace. When Steveco acts as a Service Provider, the customer can choose the emission level of their services based on their products (reels/pallets). The elements affecting emissions are type of fuel, regular diesel or HVO (Renewable diesel) or AI-based planning. The emissions of machines using HVO-diesel are up to 90% lower compared to regular diesel (Diezemann et al. 2025). The price increase about. + 25% / ltr.

The Finnish Pilot is integrated to ADMIRAL Marketplace as follows:

- Providing real world emission data to the Marketplace emission calculations (g/ton) from terminal- and port operations in Hietanen Terminal of Port of HaminaKotka. Data to be provided by API from pilot software.
- Participating in Marketplace as Buyer and Seller of Logistics services (Freight forwarding and Port Operations), see Figure 105.
- Terminal operations service listing enables to choose low emissions service, low emission fuels such as HVO diesel instead of ordinary diesel, see Figure 106 and 107
- Choose AI-optimized Terminal operations service or manual planning (for demonstration purposes) see Figure 106.

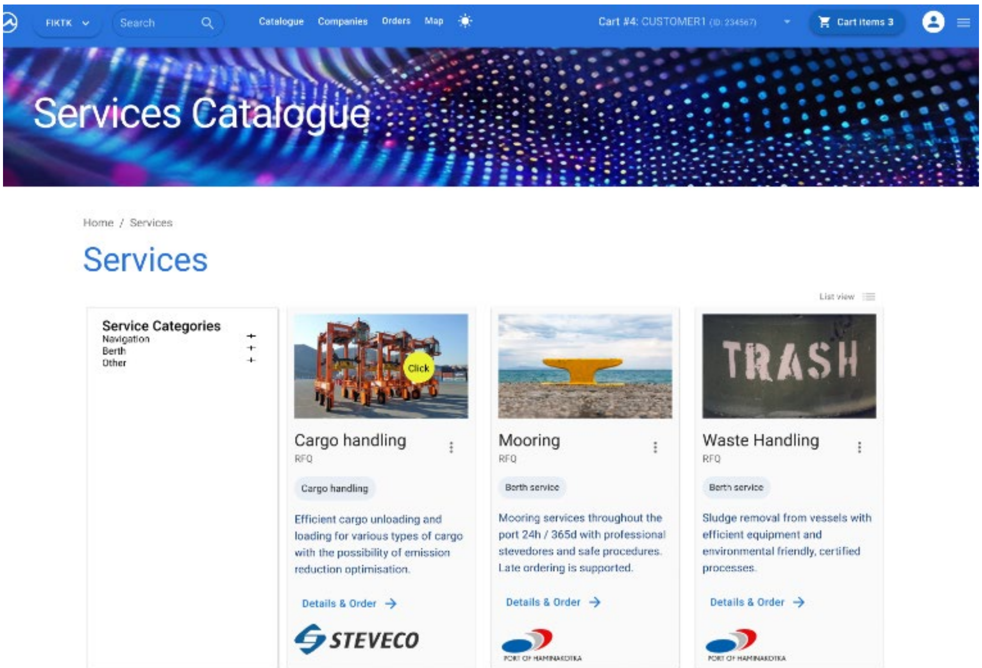

Figure 105. Cargo Handling and other port Services in the Service Catalogue

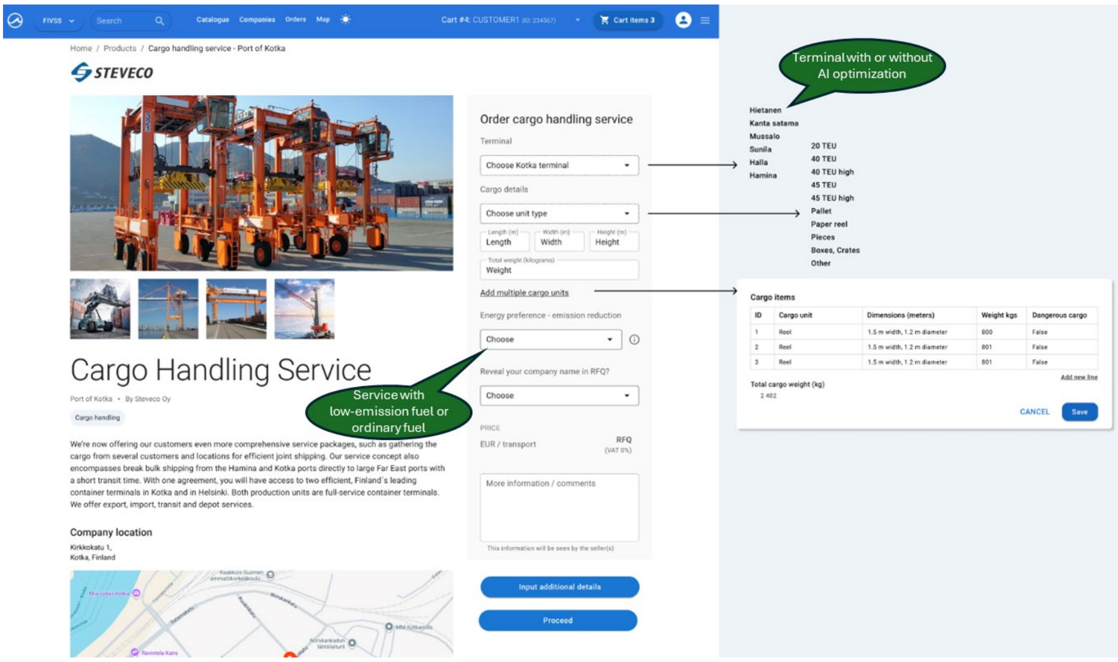

Figure 106. Cargo Handing Service with GHG emission reduction option

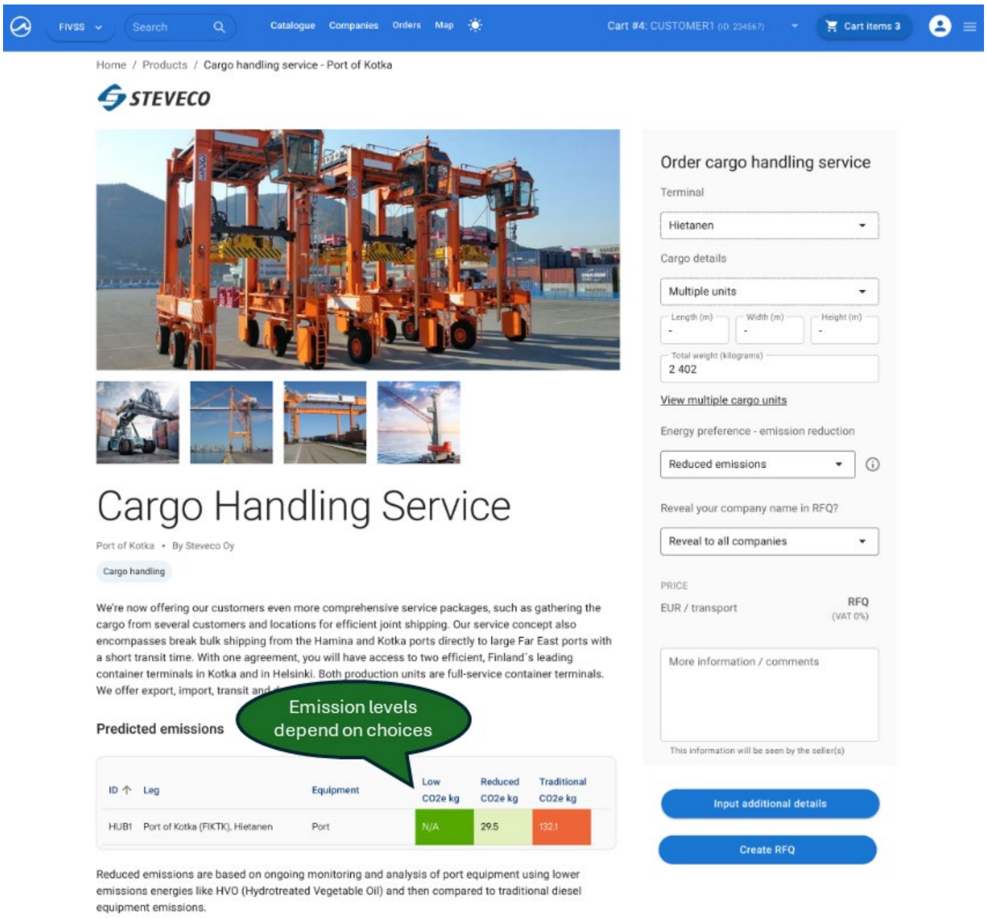

Figure 107. Cargo Handing Service – predicted CO_2e emissions

6.5 Summary of pilot's integration to the ADMIRAL Marketplace

ADMIRAL Marketplace (build on Awake.AI Marketplace, AWA Multimodal marketplace), is one of the key outcomes of the ADMIRAL project. Pilot results have been integrated to the ADMIRAL Marketplace as services to the ADMIRAL Service Catalogue and solutions to the Awake.AI Marketplace:

- **Pilot 1:** NEXUS and JUL ecosystem integration, the ADMIRAL Service Catalogue, integrated to the ADMIRAL Marketplace.
- **Pilot 2:** Recurring Packet Handling Services visible at the marketplace, ADMIRAL Service Catalogue. Recurring Packet Handling services are using LOPTA (Logistics Optimisation Planning Tool or ADMIRAL), with following service components: Routing engine, First-Mile Postal Optimisation services – LOPTA FMO, Last-Mile Postal Optimisation services - LOFTA LMO, CO_2 emissions calculation services – LOPTA-EC. Crowd-shipping tool, the Locodels platform is used for last-mile postal deliveries. Developed solutions are also integrated to the ADMIRAL Marketplace.
- **Pilot 3.** Developed tools are integrated to the ADMIRAL Marketplace: Transport Service Order Management Tool (TMS); Transport scheduling tool -Estimated Time of Arrival (ETA) tool; TREVIO - Emission -Aware Hub Scheduling tool; CSign – emission aware eCMR with CO_2 Calculator.
- **Pilot 4:** Cargo Handling Service is visible at the marketplace, ADMIRAL Service Catalogue. Cargo Handling Services can use the developed AI-based cargo planning tool, embedded to the service operator systems, in operations planning.

7 Collaboration between pilots

Increasing collaboration among diverse logistics networks and strengthening partnerships between heterogeneous supply chain stakeholders across Europe is a cornerstone of ADMIRAL's mission to achieve policy-driven decarbonisation goals. The ADMIRAL project recognizes that no single actor can meet these ambitious targets alone; instead, success depends on creating interconnected, cooperative ecosystems that span geographical boundaries (within ADMIRAL's geographical coverage) and different operational contexts.

ADMIRAL facilitates this transformation through several key mechanisms:

- **Cross-Pilot Collaboration:** Solutions developed and validated in one pilot region are systematically tested in other geographical areas and slightly different operational contexts. This approach demonstrates the adaptability and scalability of standalone innovations, ensuring that they are not limited to local conditions but can contribute to a pan-European logistics framework.
- **Interoperability and Knowledge Exchange:** By promoting open standards, shared data platforms, and collaborative governance models, ADMIRAL enables seamless integration of technologies and processes across multiple networks. This fosters trust among stakeholders and accelerates the adoption of sustainable practices.
- **Policy Alignment and Decarbonisation Synergy:** ADMIRAL acts as a bridge between industry and policy, ensuring that collaborative logistics solutions align with EU sustainability objectives. This includes harmonizing operational strategies with regulatory frameworks and leveraging incentives for carbon reduction.
- **Innovation Through Diversity:** Bringing together heterogeneous stakeholders—ranging from transport operators and technology providers to regional authorities—creates a fertile environment for collaborative innovation. ADMIRAL leverages this diversity to co-develop solutions that address real-world challenges such as multimodal transport optimization, energy efficiency, low emission services and digitalization.

Through these efforts, ADMIRAL demonstrates that collaborative logistics is not only feasible but essential for building resilient, efficient, and environmentally responsible supply chains across Europe. All pilots share goals of promoting emissions reductions and increasing the sustainability of transport operations.

7.1 Digital & Green Multimodal corridor

The Portugal-Spain pilot collaborated with other ADMIRAL pilots through knowledge exchange and mainly through integration of developed services and solutions to the ADMIRAL Service Catalogue.

Collaboration with Slovenia–Croatia Pilot: Green Logistics – Optimizing Postal Sustainability Across Borders

The Recuring Packet Handling Services is integrated to the catalogue of low-emission services developed in the Portugal-Spain pilot and are presented on the ADMIRAL Service Catalogue.

Collaboration with Lithuania Pilot: Green Route: Emission Aware Logistics Management

The dedicated tools such as CO_2 emission calculation developed by the Lithuanian pilot, are integrated to the ADMIRAL Marketplace and could be used in Portugal-Spain pilot, ADMIRAL Service Catalogue as discussed in section 2.6.

Collaboration with Finland Pilot: AI-Based Optimization of Logistics for Sustainability

Finnish pilot services, Cargo Handling Services are integrated to the catalogue of low-emission services developed in the Portugal-Spain pilot and are presented on the ADMIRAL Service Catalogue

The AI-based cargo planning tool developed (Finnish Pilot) was planned to be tested with offline data in the context of the Portugal-Spain pilot. Potential scenario was to use the layout of the Sines multipurpose terminal, available parking spaces, and existing handling equipment to simulate the best handling and parking of wind blades for the wind energy industry. This scenario had challenges due the different characteristics of the two facilities, in Portugal and Finland, as well as the lack of data available on the Portuguese infrastructure that is necessary to implement a test. This scenario did not progress to implementation during the reporting period.

7.2 Green Logistics: Optimizing Postal Sustainability Across Borders

The Slovenia-Croatia pilot collaborated with other ADMIRAL pilots through knowledge exchange. There was also closer collaboration with Portugal-Spain and Lithuanian pilots as show here.

Collaboration with Portugal–Spain Pilot: Digital & Green Multimodal Corridor

The Slovenia-Croatia pilot tests the ADMIRAL Service Catalogue concept (Portugal-Spain pilot) and acts as service provider integrated to the ADMIRAL Service Catalogue.

Planned collaboration on train transportation was not activated due several reasons, such as cargo volume in rail between Slovenia-Croatia was too low to be economically feasible, the pilot focused on road transportation of postal cargo. Secondly the building of new rail infrastructure in Portugal-Spain was delayed.

Collaboration with Lithuania Pilot: Green Route: Emission Aware Logistics Management

The **Lithuanian pilot (**Green Route: Emission Aware Logistics Management) placed a strong emphasis on the **development of CO_2 emission estimation methodologies**, which quickly proved to be pivotal not only for their activities but also for the **Slovenian–Croatian pilot (**Green Logistics: Optimizing Postal Sustainability Across Borders). At the **beginning of the project**, we realized that **emission-related reporting** was becoming increasingly important for both **regulatory compliance** and **customer transparency**. This recognition created a strong motivation to **cooperate closely with the Lithuanian pilot from an early stage**, ensuring that the methodologies under development would be **tested, validated, and adapted** for other business-logistics environments, particularly within the **postal industry**, which follows its own operational logic.

Through this cooperation, we were able to establish a **systematic transfer of knowledge** from the Lithuanian pilot. Based on their **guidance and methodological expertise**, our consortium identified and adopted the **most appropriate CO_2 estimation methodologies for postal operations**. This included adapting **predictive models** (for forward-looking decision support) as well as **retrospective estimation methods** (for transparent reporting and validation). The Lithuanian team provided us with critical **frameworks, calculation logics, and best practices**, which we then **tailored to the realities of postal logistics services** such as **last-mile delivery**, **cross-border transport**, and **parcel consolidation**. The process was characterized by **continuous dialogue, testing in live environments**, and **joint alignment of methodological standards** across both pilots.

As a result, the Slovenian–Croatian pilot reaped **substantial benefits**. We successfully developed a **robust CO_2 reporting framework**, enabling us to **assure compliance with upcoming EU regulations** and **enhance transparency toward customers** by providing reliable emission information for each shipment. Furthermore, this cooperation allowed us to **align with broader project objectives**, reinforcing the **green and sustainable dimension of postal logistics**. The joint effort not only improved the **accuracy of our emission reporting** but also increased the **credibility and competitiveness** of our services, laying a foundation for **future scalability across other markets** and creating lasting value for both partners and end users.

Collaboration with Finland Pilot: AI-Based Optimization of Logistics for Sustainability

Collaboration was focused on knowledge transfer.

7.3 Green Route: Emission Aware Logistics Management

The Lithuanian pilot collaborated with other ADMIRAL pilots mainly through knowledge exchange on CO_2 emission estimation methodologies and their practical application in different logistics environments.

Collaboration with Slovenia–Croatia Pilot: Green Logistics – Optimizing Postal Sustainability Across Borders

The closest cooperation was with the Slovenian–Croatian pilot. From the beginning of the project, both teams recognised that emission-related reporting was becoming increasingly important for regulatory compliance and customer transparency. This created a strong motivation to work closely together and ensure that the methodologies developed in Lithuania could be tested, validated, and adapted for postal operations, which follow their own specific logic.

The collaboration involved systematic knowledge transfer during joint ADMIRAL activities, joint conference calls and the ADMIRAL hackathon. Guided by the Lithuanian pilot, the Slovenian–Croatian team identified and adopted suitable CO_2 estimation approaches for postal processes, adapting both predictive models for forward-looking decision support and retrospective methods for transparent reporting. During these exchanges, both pilots discussed challenges and requirements related to applying ISO 14083, the GLEC Framework and national legislation on sustainability.

Continuous dialogue, live testing and joint alignment of methodological standards characterised the cooperation. For the Lithuanian pilot, this validated that its methodologies can be successfully applied in other business-logistics environments, including postal networks.

Collaboration with Portugal–Spain Pilot: Digital & Green Multimodal Corridor

Collaboration with the Portugal–Spain pilot consisted of knowledge exchange on data structuring and platform integration over joint conference calls and joint ADMIRAL activities.

7.4 AI-Based Optimization of Logistics for Sustainability

The Finnish pilot collaborated with other ADMIRAL pilots mainly through knowledge exchange.

Collaboration with Portugal–Spain Pilot: Digital & Green Multimodal Corridor

The Finnish Pilot tests the ADMIRAL Service Catalogue concept (Portugal-Spain pilot) and acts as service provider integrated to the ADMIRAL Service Catalogue.

Steveco collects machine-specific data on the unloading of trucks and railcars. The data collected provides the initial data for emissions information (for RoRo operations) to the Service Catalogue and ADMIRAL Market place. When Steveco acts as a Service Provider, the customer can choose the emission level of their services based on their products (reels/pallets). The elements affecting emissions are (see Figures 106-107):

- LFO (Light Fuel Oil), also know as regular diesel
- HVO (Hydrotreated Vegetable Oil), also known as Renewable Diesel
- AI-based planning (embedded to service provider planning systems)

The emissions of machines using HVO-diesel are up to 90% lower compared to regular diesel (Diezemann et al. 2025). The price increase about + 25% / ltr.

The original plan was to test the AI tool in Sines port in Portugal. This scenario did not realise during reporting period, due challenges in getting the relevant facility and cargo information needed for set-up and testing.

Collaboration with Slovenia–Croatia Pilot: Green Logistics – Optimizing Postal Sustainability Across Borders and with Lithuania Pilot: Green Route: Emission Aware Logistics Management

Collaboration was intensive knowledge exchange.

The following Table 36 summarises key results of each pilot, collaboration activities between pilots. Diagonal cells show the main results of the pilots. The matrix is symmetric.

Table 36. Pilots collaboration matrix

	Digital & Green Multimodal corridor (Portugal-Spain)	**Green Logistics: Optimizing Postal Sustainability Across Borders (Slovenia-Croatia)**	**Green Route: Emission Aware Logistics Management (Lithuania)**	**AI-Based Optimization of Logistics for Sustainability (Finland)**
Digital & Green Multimodal corridor	Integration of NEXUS and JUL. Service catalogue integration, processes to add users, and configure services, search services, …			
Green Logistics: Optimizing Postal Sustainability Across Borders	Originally planned rail transport collaboration was not feasible during pilot Service added to the ADMIRAL Service Catalogue	LOPTA; Routing, First-mile, Last-mile optimisation, CO2 emission calculation services, and Crowdsourcing tool Recurring Packet Handling Services		
Green Route: Emission Aware Logistics Management	Knowledge exchange on data structures and platform integration Developed tools integrated to the ADMIRAL Marketplace	CO2 emission calculation methods, C02 reporting framework	Transport Service Order Management Tool (TMS), Transport scheduling tool -Estimated Time of Arrival (ETA) tool, TREVIO - Emission - Aware Hub Scheduling tool, CSign – emission aware eCMR with CO_2 Calculator Data exchanges structures	
AI-Based Optimization of Logistics for Sustainability	Testing of the development with suitable off-line data, discussion on going Service added to the ADMIRAL Service Catalogue	no-direct collaboration activities, focus on knowledge transfer	no-direct collaboration activities, focus on knowledge transfer	AI based Optimisation for cargo handling, intelligent order placement, warehouse train scheduling Cargo Handling Services

Co-funded by
the European Union

8 Conclusion

This deliverable presents the status of the pilots in ADMIRAL project, tested methods, solutions and test results at end of October 2025. This deliverable is the compilation of documentation from each pilot received during September – October 2025. In each pilot the developed solutions are tested as standalone as shown in sections 2 to 5. The developed solutions are integrated to the ADMIRAL Service Catalogue and ADMIRAL Marketplace as presented in section 6.

The common purpose of the pilots is to reduce CO_2 emissions and increase the visibility of emissions of supply chain operations. These emissions will become visible in the ADMIRAL Marketplace and will impact decision-making of service buyer.

All pilots had external stakeholders' groups such as cargo service providers or transport service buyers. These actors provided valuable feedback. Pilot also collected logistic, transport data for baseline as well for scenario assessment. Technology development was focused on tools and methods for logistic operation planning and assessment of CO_2e emission calculation. Standalone tests in pilots are shown in detailed way in previous sections. The comparison of baseline and optimised operations do show remarkable improvement regarding CO_2e emissions, up to 60 % reduction. Partially solution tests continue, even the piloting activities have ended in WP5 Pilots in October 2025. The services and tools integration to ADMIRAL Marketplace continues until end of the project as part of WP4.

ADMIRAL Marketplace (Awake.AI Marketplace, AWA Multimodal marketplace), is one of the key outcomes of the ADMIRAL project. Pilot results have been integrated to the ADMIRAL marketplace as shown in Section 6, either as services integrated to the ADMIRAL Service Catalogue or developed tools integrated to the ADMIRAL Marketplace operated by AWA.

All pilots did have collaboration as shown in Section 7.

8.1 Technology Solutions TRL achieved

Table 1 in Introduction section, presented technologies and solutions to developed in the ADMIRAL project. Following text summaries all the pilots and solutions development done as well achieved TRL in the pilots.

Technology Solutions TRL per pilot

Marketplace, target TRL 7. The main development in done WP4 Multimodal marketplace development by AWA.

- **Pilot 1)** Digital & Green Multimodal corridor (Portugal-Spain), has developed the service catalogue integration (inclusion of energy-efficient and multimodal services to Awake.AI Marketplace).
    - Each pilot integrates the suitable services or tools to the ADMIRAL Service catalogue: Pilot 2 integrates Recuring Packet Handling Services, Pilot 3 integrates its digital solutions into the ADMIRAL Marketplace. Pilot4 integrates Cargo Handling Services.
- Current TRL 7

Integration tool, target TRL 7.

- **Pilot 1)** Digital & Green Multimodal corridor (Portugal-Spain), has developed the service catalogue integration
    - API integration with JUL/Nexus Open Data (two-way integration)
    - API integration with Awake.AI Marketplace, development continues in WP4 until end of the project
- Current TRL 7

Crowdsourcing tool, target TRL 8

- **Pilot 2)** Green Logistics: Optimizing Postal Sustainability Across Borders (Slovenia-Croatia), has developed Crowd-shipping tool, the Locodels platform, which has qualified in real operational environment, and is production-ready, current TRL8

Logistics planning tool, target TRL 8

- **Pilot 2)** Green Logistics: Optimizing Postal Sustainability Across Borders (Slovenia-Croatia), has developed LOPTA - Logistics Optimisation Planning Tool or ADMIRAL, with following service components:
    - Routing engine
    - First-Mile Postal Optimisation services – LOPTA FMO
    - Last-Mile Postal Optimisation services - LOFTA LMO
    - CO_2 emissions calculation services – LOPTA-EC
- Development has been qualified in real operational environment, current TRL 8
- CO2e tracking system with onboard measurement devices, the additional development, this is at TRL 7, tested in real life, operational environment.

Transport service order management tool (including integration with the marketplace), target TRL 7

- **Pilot 3)** Green Route: Emission Aware Logistics Management (Lithuania), has developed Transport Service Order Management Tool (TMS). It has been demonstrated in operational environment, and integrated to Awake.AI Marketplace, current TRL 7.

Transport scheduling tool (dock management, loading and unloading schedules), target TRL 7

- Pilot 3) Green Route: Emission Aware Logistics Management (Lithuania), has developed Transport scheduling tool -Estimated Time of Arrival (ETA) tool, currently TRL6, after integration to Awake.AI Marketplace, will reach TRL 7. TREVIO - Emission -Aware Hub Scheduling tool, has been demonstrated in operational environment, current TRL 7

Digital bill of lading (digital documentation and signature), target TRL 8.

- Pilot 3) Green Route: Emission Aware Logistics Management (Lithuania), has developed CSign – emission aware eCMR with CO_2 Calculator. It has been integrated to Awake.AI Marketplace. Current TRL 7/8

Data exchange structures and solutions, target TRL 6

- Pilot 3) Green Route: Emission Aware Logistics Management (Lithuania), has developed data exchange structures and solutions, which are demonstrated, current TRL 6.

CO2 calculation methodology, digital tools and data exchange, target TRL 6

- Pilot 3) Green Route: Emission Aware Logistics Management (Lithuania), has developed CO2 calculation methodology. It has demonstrated in relevant conditions, current TRL 7

AI-based cargo planning tool, target TRL 7. Development in WP4 and WP5

- Pilot 4) AI-Based Optimization of Logistics for Sustainability (Finland). Has developed AI-based cargo planning tool. Development is not yet demonstrated in operative environment, tests are planned, early 2026. Current TRL 6, will be TRL 7 after testing in operative environment.

Table 37 summarizes the TRL achievements.

Table 37. Solutions developed in the ADMIRAL project and their aimed TRL-levels.

Technology / Solution	planned TRL		TRL
	from	to	achieved
Marketplace	5	7	7*
AI-based cargo planning tool	5	7	7**
Transport service order management tool (including integration with the marketplace)	3	7	7
Transport scheduling tool (dock management, loading and unloading schedules)	5	7	7
Digital bill of lading (digital documentation and signature)	6	8	8
Data exchange structures and solutions	3	6	6
CO_2 calculation methodology, digital tools and data exchange	3	6	7
Logistics planning tool	5	8	8
Crowdsourcing tool	5	8	8
Integration tool	3	7	7

*) Multimodal logistic marketplace development continues until end of the project.
**) AI-based cargo planning tool prototype was not fully demonstrated in operational environment during reporting period

The higher TRL results are in operative use by the pilot partners.

8.2 CO_2 emission reduction

ADMIRAL's objectives include shifting the industry focus towards emission reduction along the whole supply chain, developing a digital marketplace for multimodal logistics, and reducing emissions by 20%. Pilot achievements regarding reduction of CO_2 emissions, based on comparison of baseline and optimised scenarios are shown in a detailed way in previous pilot section 2,3,4 and 5. CO_2e calculation methodology is based on ISO 14083:2023. Greenhouse gases — Quantification and reporting of greenhouse gas emissions arising from transport chain operations and Smart Freight Centre (2025). Global Logistics Emissions Council Framework for Logistics Emissions Accounting and Reporting.

Pilot 1 Portugal-Spain

During the reporting periods the API for CO_2e for marketplace was in development.

Baseline values estimation and CO_2e emissions average and evolution through time based on (see traffic analysis, section 2.2.2):

- Types of vehicles
- Types of cargo
- Routes
- Fuel type / energy

Future scenarios shows that rail remains the most effective near-term decarbonisation lever, capable of absorbing additional volume with modest infrastructure upgrade. Emission intensity estimates, well-to-wheel, reveals that electric rail emits 0.28 tons CO2e per twenty-foot equivalent unit (TEU) versus 0.60 tons CO2e/TEU for diesel trucks.

Pilot 2 Slovenia-Croatia

Goal of the pilot was to develop solutions that enable better utilization of current assets and existing infrastructure to decrease energy use and emissions without significant investment needs. Railway-based freight transfer was not feasible due to lack of traffic toward Zagreb and high operational costs—especially for one operator like Pošta Slovenije. Significant investment would be needed to shift freight from road to rail, contradicting the “no major investment” premise. Instead, a road-based cross-border corridor was created, bypassing Ljubljana’s Exchange Office and reducing mileage for certain flows. Concept of asymmetric corridors introduced, allowing better use of local hubs and fleet—mainly viable for postal operators with decentralized infrastructure.

Develop and pilot solutions that have altogether energy and emission reduction potential higher than 30%.

- Projected emission reduction targets are achieved especially due to corridor-level solutions.
- Bypassing the Office of Exchange (OE) in Ljubljana significantly reduces mileage and emissions.
- Operational optimization of cross-border flows aligns with the goals of greener infrastructure use without needing new assets.
- Position established to comfortably reach 25–30% CO_2 reductions, validating the initial objectives through smarter routing and asset use.

Pilot 3 Lithuania

The Lithuanian Pilot demonstrated how digitalisation can directly reduce CO_2 emissions in everyday road-transport operations. A full set of digital solutions was developed and integrated into the

ADMIRAL Marketplace (AWA Multimodal Marketplace), ensuring practical applicability for logistics stakeholders.

Developed and demonstrated solutions:

- Digital Bill of Lading (eCMR) – adapted to logistics needs, with a redesigned UI/UX, a UNECE-compliant data model, and integration via APIs and iFrame embedding.
- CO_2 Calculation Methodology – implemented as an operational tool using structured logistics data.
- Transport Scheduling Tool (ETA) – supporting arrival planning, tracking and notifications based on real operator data.
- Transport Service Order Management (TMS) – combining ETA and order-management functions to support CO_2-aware planning.
- Data-exchange structures and interoperability components – aligned with eFTI, eCMR and customs/port standards.

Confirmed CO_2 reduction potential:

- ETA scheduling tool → up to 31.5% CO_2 savings in loading and unloading areas when combined with eco-driving.
- eCMR digitalisation → 20% fewer empty runs, resulting in a 7.9% reduction of total EU road-transport CO_2 emissions.
- Eco-driving monitoring → 7.6% CO_2 savings per kilometre.

Overall, the Lithuanian Pilot demonstrated that integrated digital tools can enhance operational efficiency and achieve measurable CO_2 reductions in road transport, with an overall decrease of at least 20% confirmed by the pilot results.

Pilot 4 Finland

Current CO_2e emissions reduction with AI-planning in the test was 3.9 %. The planning algorithm is still under development and improved results are expected before end of the project. Use of fuel has big impact, fossil fuels such as regular diesel vs biodiesel. Use of biodiesel can reduce emissions up to 90 %, but currently with additional cost.

8.3 Next steps

The ongoing integration with ADMIRAL Marketplace (based on AWA Multimodal Marketplace) provides access to those above mentioned and developed services. The developed service integration to the ADMIRAL Marketplace, service catalogue continues in WP4 until end of the project. Tools developed in the pilots are also integrated to the ADMIRAL Marketplace.

The pilots impact assessment will be done in parallel WP6 (Assessment of Solutions and Impact Assessment) and reported in the public deliverable D6.3. Overall Impact Assessment of Project Results and Cross-Analysis of Pilots (M36).

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Annexes

Annex 1 – Paper presented at the XVI Conference on Transport Engineering – CIT 2025 18-20 June 2025, Zaragoza, Spain

José Pedro Antunes, Elisabete Arsenio, Rui Henriques (2025). Data-centric models for the sustainable development of the multimodal Sines-Madrid transport corridor. Transportation Research Procedia 00 (2025) 000–000. XVI Conference on Transport Engineering, CIT2025 (Open Access).

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Natalia Sobrino, José Manuel Vassallo, Elisabete Arsenio, Sofía Cerqueira (2025). *Exploring the potential of the multimodal low-carbon freight corridor Port of Sines – Madrid. Transportation* Research Procedia 00 (2025) 000–000. XVI Conference on Transport Engineering, CIT2025 (Open Access).

Annex I

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Data-centric models for the sustainable development of the multimodal Sines-Madrid transport corridor

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Abstract

The multimodal freight transport planning on strategic transnational corridors often neglects critical sustainability criteria. This observation is corroborated by the generalized lack of optimization principles for the carbon-aware allocation of transport modes. This work introduces a prospective study of freight transport along the Sines-Madrid multimodal transport corridor, proposing data-centric models to guide its sustainable growth. The Sines-Madrid corridor represents a critical section in the Trans-European Transport Network Atlantic Rail Freight Corridor. The research explores road-rail transport scenarios until 2030 by: i) consolidating data provided by the Port of Sines and other institutional statistical sources, such as Eurostat, for modelling freight transport.; ii) developing uncertainty-aware time series models to analyze freight trends and forecast demand for road and rail modes in the corridor; and iii) conducting a sensitive analysis of various scenarios for freight transport, namely increasing rail-to-road split ratios to reduce carbon emissions, and their potential impacts. The acquired results from the proposed scenario-based modelling offer stakeholders insights to promote sustainable freight transport strategies. The 2030 horizon is selected to align with the European Union's (EU) climate and transport goals. The explored scenarios account for the impact of road and rail modal split, as well as road fleet configurations, on emissions and costs. These findings, conducted in the context of the Advanced Multimodal Marketplace for Low Emission and Energy Transportation (ADMIRAL) project, provide a blueprint for similar corridors, guiding EU policy and investment toward sustainable transport solutions.

Keywords: Data-centric models; Time series; Sines Madrid corridor; Freight forecasting; CO_2 emissions; Modal shift.

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1. Introduction

The EU goal of climate neutrality by 2050 has placed the transport sector at the center of sustainability efforts. Transport, accounting for a significant share of greenhouse gas (GHG) emissions, approximately 23%, and energy consumption, must undergo fundamental shifts towards low-carbon and efficient multimodal solutions. In this context, rail transport is a key enabler of sustainable logistics, offering lower emissions per ton-kilometer compared to road transport. However, it remains underutilized in critical multimodal corridors, requiring further strategic planning and investments to achieve greener road-to-rail modal shifts.

This study is conducted as part of the ADMIRAL project, a Research and Innovation (R&I) initiative focused on integrating green and digital logistics solutions. This work specifically targets the Sines-Madrid multimodal corridor, a key segment of the TEN-T Atlantic Rail Freight Corridor, connecting the Port of Sines in Portugal with Madrid in Spain, to support efficient, low-emission freight transport across the Iberian Peninsula and beyond. The project aligns with the EU targets for climate neutrality by 2050, focusing on reducing direct and indirect emissions from logistics and transport. Ensuring its sustainable growth aligns with the European Green Deal and the Fit for 55 package, reinforcing the role of strategic corridors in decarbonizing freight transport.

The sustainable development of the Sines-Madrid corridor should account for prospective railway and roadway changes, including those driven by the Plano Ferroviário Nacional (National Railways Plan – PFN), which outlines a roadmap for modernizing and expanding Portugal's railway infrastructure, including the Évora-Elvas high-speed link to improve cross-border freight capacity and reduce congestion. The role of data-driven decision tools to optimize modal shifts and emissions reduction strategies is critical to maximize the potential of the mentioned railway investments.

Transitioning to a low-carbon and efficient freight transport system requires data-driven insights for strategic decision-making. This research aims to model road and rail freight traffic patterns along the Sines-Madrid multimodal corridor for assessing how different modal shift scenarios contribute to emission reductions and sustainability goals. To achieve this, the study sets the following research questions:

- How will freight traffic patterns evolve along the corridor up to 2030 under different forecast scenarios?
- What is the environmental impact (CO_2 emissions) of the freight transport choices?
- How do different modal shift scenarios influence emissions levels?

The objectives align with the ADMIRAL project and broader EU climate goals, offering a data-centric approach to support policymakers, logistics operators, and infrastructure planners in developing sustainable freight strategies.

This study provides a data-driven analysis of freight transport along the Sines-Madrid multimodal corridor, leveraging real-world data from the Administração dos Portos de Sines e do Algarve (APS). By analyzing cargo movements in TEUs (Twenty-foot Equivalent Units) entering and leaving the Port of Sines, this research applies a capacity-aware time series approach to forecast freight trends up to 2030 in the corridor. Various scenarios are considered by placing feasible assumptions to create optimistic and conservative forecasts.

This study further assesses the environmental impact of different freight distribution patterns by quantifying CO_2 emissions associated with projected transport flows. To evaluate modal shift potential, a sensitivity analysis is conducted by varying the percentage of total cargo transported by road and rail, framing emission reduction opportunities and aiding subsequent policy actions.

2. Related Work

Freight transportation forecasting is a critical tool in supply chain management and infrastructure planning, aiding the prediction and optimization of the movement of goods across road, rail, and maritime networks (Patil and Sahu, 2016). Forecasting techniques for freight transportation range from classical statistical models, such as Multiple Linear Regression (MLR) and Autoregressive Integrated Moving Average (ARIMA), to more advanced machine learning approaches, including Neural Networks (NNs). More recently, deep learning architectures have demonstrated superior predictive accuracy in highly dynamic environments (Zhong, 2021). Table 1 summarizes key applications in freight transportation. Despite these advancements, essential challenges remain: i) quantifying uncertainty in freight predictions, ii) ensuring sensitivity to multiple levels of seasonality (daily, weekly, yearly), and iii) incorporating domain knowledge to guide scenario creation. Addressing these problems is critical for developing robust and actionable forecasting models for freight transport planning.

Sustainability in freight transport has gained increasing attention, with studies focusing on strategies such as modal shifts, fleet electrification, policy interventions, and intermodal optimization to reduce GHG emissions and improve energy efficiency (Arsenio et al., 2024). A key challenge is the reliance on road transport, which remains dominant despite growing efforts to shift towards more sustainable modes such as rail and maritime transport.

Henke et al. (2024) analyzed the Italian road transport sector under the "Fit for 55" framework, emphasizing that current policies are insufficient to meet the 2030 climate targets. Their study highlights the importance of electrification and energy efficiency measures in achieving sustainability goals. Similarly, Mishra et al. (2024) focused on India's freight sector, showing that road electrification has the highest potential for emissions reduction, complemented by fleet modernization and efficiency-driven policies. Manzanedo et al. (2024) examined sustainability disparities among EU countries, identifying that some nations have successfully decoupled transport demand from economic growth, while others remain heavily reliant on road freight. In Turkey, Temizerci and Kara (2024) proposed a bi-objective optimization model integrating machine learning to enhance intermodal efficiency, though their findings indicate that intermodal transport remains underutilized due to infrastructure and policy gaps. In Sweden, Johansson et al. (2024) explored modal shifts through Swedish national freight transport model simulations (SAMGODS), demonstrating that shifting freight to rail and sea can reduce emissions but only if energy sources are decarbonized. Their study underscores the importance of coupling modal shifts with clean energy investments rather than treating them as standalone sustainability measures. Collectively, these works emphasize that sustainable freight transport must account for technological transitions, policy effectiveness, and real-world transport constraints, requiring a shift towards more adaptive models.

Table 1. Forecast and sustainability studies overview.

Author(s)	Analysis Year(s)	Region	Mode	Approaches	Key Findings
Patil and Sahu (2016)	2014-2018	India	Seaport	Multivariate Regression; Time Series Models (ARIMA)	Inbound cargo will grow at a rate similar to GDP and Outbound cargo will grow at a slower pace. Multivariate models performed better than univariate ones. Time-series models had lower forecasting error compared to regression models.
Zhong (2021)	2010-2019	China	Seaport	Time Series Forecasting plus BPNN	BP neural networks were applied to predict monthly port cargo volume, achieving small errors.
Wei et al. (2022)	2014-2020	China	Seaport	Seasonal ARIMA; Impact Index Calculation	COVID-19 had significant impacts on transportation. Freight volumes for highway and railway transport were severely affected.
Tran and Takebayashi (2015)	1995-2014	Vietnam	Seaport	ARIMA; Time-Series Analysis	Port planning must account for exogenous shocks (financial crises, trade agreements) as they significantly impact trade volumes.
Henke et al. (2024)	2005-2030	Italy	Road	Scenario Analysis; Avoid-Shift-Improve (ASI) approach; Tank-to-Wheel and Wheel-to-Wheel	Current Policies are insufficient to meet 2030 climate targets. Road transport must shift to electrification and efficiency measures.
Mishra et al. (2024)	1970-2050	India	Road	ARIMAX Forecasting; Policy impact analysis	Road electrification has the highest emission reduction potential. Fleet modernization & efficiency-driven policies are also effective.
Manzanedo et al. (2024)	2010-2025	EU	Road	SARIMA Forecasting; Decoupling analysis	EU countries vary in sustainability progress. Some have decoupled transport

				economy vs. energy consumption	from economic growth, while others remain road-dependent.
Temizceri and Kara. (2024)	2023	Turkey	Road, Rail and Ship	Bi-Objective Optimization; Machine Learning	Machine learning optimizes modal shift efficiency. Intermodal transport remains underutilized despite sustainability benefits.
Johansson et al. (2024)	2017-2040	Sweden	Road, Rail and Ship	SAMGODS Model Simulations; Policy Assessment	Shifts to rail/sea reduces emissions yet only if energy sources are decarbonized. Electrification remains key.

3. Methodology

3.1. Case study

The Sines-Madrid corridor integrates road, rail, and maritime transport, connecting the Port of Sines to Madrid and the broader European market. The road network connecting Sines to Madrid is a vital component of the corridor, offering multiple route options, with the A-5 highway serving as the primary road connection, linking Madrid with Badajoz at the Spanish-Portuguese border. From there, freight traffic flows into Portugal via major highways leading to the Port of Sines.

The railway segment of the corridor plays a crucial role in promoting a shift towards more sustainable freight transport. However, its current capacity is limited, primarily due to insufficient connectivity. This issue is being addressed through the construction and modernization of railway lines, enhancing both efficiency and capacity, as in Arsenio et al. (2024). A key example is the Évora–Elvas connection, which will shorten the route by approximately 140 km and travel times by 3 hours, significantly improving freight transport.

The dataset provided by APS contains information on the goods transported by road and rail at the Port of Sines, offering valuable insights into freight transport activities along the Sines-Madrid corridor. Containerized cargo entering and leaving the Port of Sines is monitored (including type, timestamping, number of TEUs, allocated transport), serving as a key indicator of cargo flows. The dataset has a daily granularity, covering the period from October 2021 to June 2023, providing an aggregated view of freight transport activities and enabling the identification of key trends and patterns over time.

3.2. Uncertainty-bounded modelling freight demand

The dataset presents varying levels of detail for different transport modes. Railway data includes origin-destination information with critical stations, allowing a detailed assessment of cargo flows up to the Entroncamento station hub. As freight movements beyond this hub, particularly towards Spain and Madrid, are not captured, the share of rail freight continuing to Madrid is estimated using cargo proportions at Entroncamento and APS insights. Similarly, for road transport, historical trends and industry data were used to approximate the proportion of cargo reaching Madrid. These parameterizable adjustments enhance the understanding of freight flows along the corridor despite the dataset's restrictions.

Building on this enriched data foundation, a time series forecasting model is proposed to analyze historical freight trends and project future transport demand along the Sines-Madrid corridor. Given the dataset's daily granularity and the distinct characteristics of road and rail freight flows, the model was designed to incorporate trend analysis, multi-level seasonality adjustments, and uncertainty quantification to generate robust freight transport forecasts.

To predict future transport volumes, a regression model is applied to estimate the underlying growth trend in freight demand. However, given the complexity of real-world logistics systems, simple trend extrapolation is insufficient. To enhance forecast accuracy, seasonality adjustments are incorporated, allowing the model to reflect periodic demand fluctuations. Additionally, historical noise from the series is introduced to account for transport variability, ensuring that the forecast represents a range of possible outcomes rather than a single deterministic prediction. Figure 1 illustrates the forecasted TEU volumes in rail outbound transport, showing both the original time series data, the estimated trend line, and the forecasted values up to 2030.

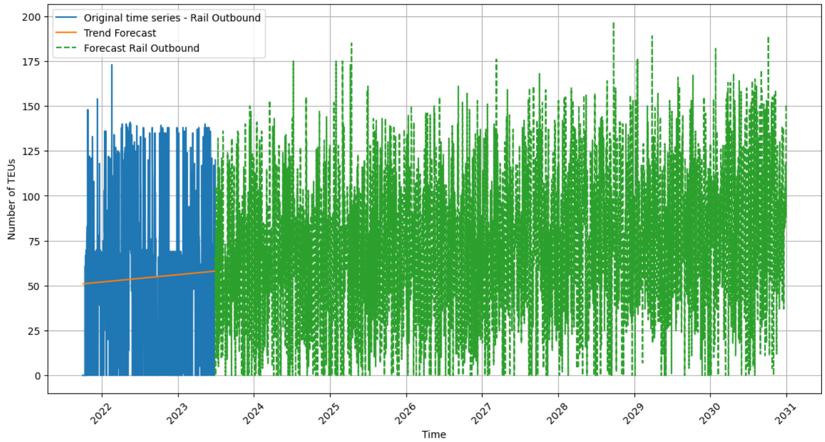

Fig. 1. Forecasted TEU volumes in rail outbound transport with time series analysis.

Recognizing the uncertainty inherent in forecasting freight transport, a Monte Carlo simulation approach is suggested to generate multiple forecast values. By randomly sampling from historical residuals and simulating 100 different potential outcomes, the model is able to provide probabilistic confidence intervals for future freight movements.

3.3. Capacity-aware pathway analysis

To further explore potential freight transport developments along the Sines-Madrid corridor, three distinct forecasting scenarios were developed to assess the impact of different growth patterns and modal shifts. These scenarios allow for a comparative evaluation of future freight trends under varying conditions, considering both historical trends and external factors. The assumptions and projections in these scenarios are corroborated by data from Eurostat, Pordata, and National Institute of Statistics (INE), ensuring consistency with broader freight transport trends and macroeconomic indicators.

The first scenario, referred to as the baseline scenario, maintains the existing trend observed in the dataset. It assumes that freight transport volumes continue evolving at the same rate as in the historical data, without any significant shifts. This scenario offers a reference point for understanding the progression of freight demand in the absence of major interventions.

The second scenario considers a 2.8% annual increase in freight transportation. This projection reflects expectations of moderate growth, accounting for factors such as economic expansion, trade demand, and infrastructure enhancements that could contribute to increased freight movement along the corridor. This scenario helps estimate the potential rise in cargo volumes if demand continues to expand at a steady rate.

The third scenario adopts a more sustainable perspective, emphasizing the transition from road to rail transport. Arsenio et al. (2024) indicate the corridor's capacity to accommodate such a shift, assuming that 20% of the TEUs predicted for road transport will be transferred to rail. This reflects a feasible effort to sustainability goals, reducing greenhouse gas emissions and improving freight efficiency by leveraging the increased railway capacity provided by recent infrastructure investments.

3.4. Carbon emissions estimates

For evaluating the environmental impact of freight transport along the Sines-Madrid corridor, the emissions of the forecasted TEU volumes were estimated through life cycle analysis of both direct and indirect emissions. To this end, the online EcoTransIT calculator, a state-of-the-art digital tool for modeling carbon emissions for different transport modes along specific routes, was selected based on comprehension, feasibility of direct and indirect carbon estimates, and customization capacity (e.g., energy sources, vehicle capacity, routing details). It is then possible to determine the emissions associated with freight movement between the Port of Sines and Madrid, both for road and rail transport routes.

A key aspect of emissions analysis is the adoption of Well-to-Wheel (WTW) emissions as the primary metric. Well-to-Wheel emissions encompass both Well-to-Tank (WTT) emissions, which include energy production, refining, and transportation of fuel, and Tank-to-Wheel (TTW) emissions, which account for the direct emissions produced during vehicle operation. This holistic approach provides a more accurate and comprehensive assessment of the total environmental impact of freight transport, policies and modal shifts since it reflects the entire life cycle of energy use rather than focusing solely on tailpipe emissions.

4. Results

Figure 2 illustrates the forecasted monthly TEU volumes for road and rail transport in 2030 under the 2.8% annual growth scenario, revealing important trends regarding freight movements along the Sines-Madrid corridor. A notable finding is that inbound freight volumes consistently exceed outbound volumes across both transport modes.

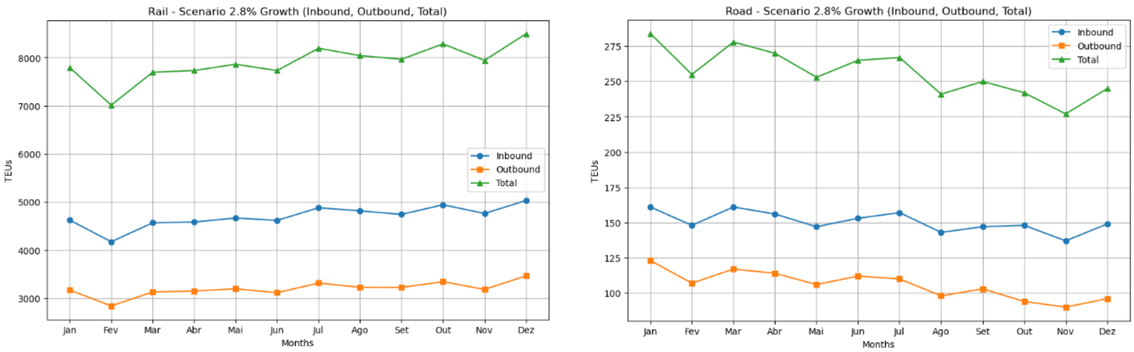

Fig. 2. Forecasted TEU volumes for road and rail transport under growth scenario.

The carbon emissions along the corridor using the EcoTransIT calculator were estimated at 0.6 tons of CO_2e per TEU for road transport (diesel-based) and 0.28 tons of CO_2e per TEU for rail transport. These values reveal a significant difference in carbon intensity, highlighting the potential for emissions reduction through modal shift strategies. Figure 3 presents the sensitivity analysis of CO_2e emissions for 2030, illustrating how total emissions vary depending on the proportion of TEUs transported by road and rail. If all freight were transported by rail, total emissions would amount to approximately 27,398.84 tons of CO_2e, whereas if all freight were transported by road, 58,711.8 tons of CO_2e. This severe contrast underscores the environmental benefits of increasing rail transport share within the corridor.

A new scenario was created considering potential changes in the composition of the road transport fleet by 2030, and an alternative sensitivity analysis was conducted, incorporating a mixed road fleet scenario. This scenario, based on statistical sources, assumes that by 2030, 81% of road transport will be powered by diesel, 8% by liquefied natural gas (LNG), 6% by hydrogen fuel cells (FCEV), and 5% by battery electric vehicles (BEVs). The emission factors for these alternative fuels are 0.66 tons of CO_2e per TEU, 0.69 tons of CO_2e per TEU and 0.18 tons of CO_2e per TEU, respectively.

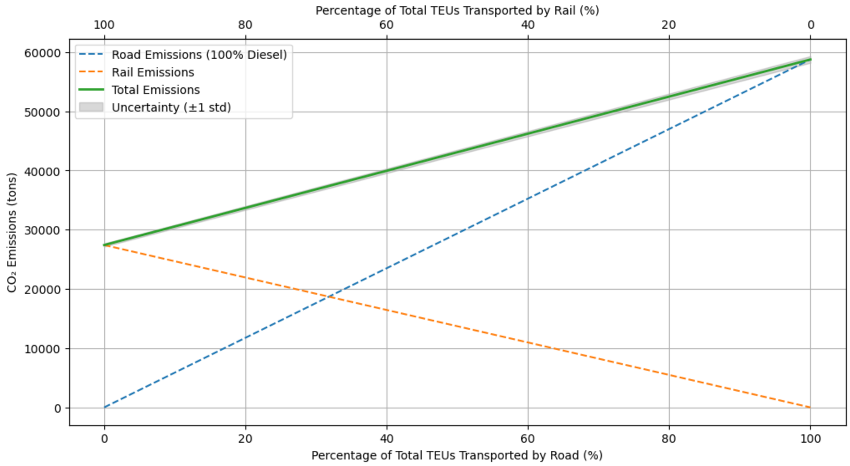

Fig. 3. Sensitivity analysis of CO_2e emissions for different modal shares in 2030.

Although LNG and FCEV have lower TTW emissions compared to diesel, their WTW emissions remain higher, highlighting that decarbonizing road transport requires not only a shift in vehicle technology but also significant advancements in energy production and distribution systems. This underscores the fact that simply transitioning to alternative fuels is insufficient if the underlying energy sources remain carbon-intensive, and highlights the importance of considering full life-cycle emissions rather than focusing solely on direct tailpipe emissions when assessing the sustainability of alternative fuels. The only road transport alternative with a substantially lower WTW emissions profile is BEVs.

Figure 4 depicts the sensitivity analysis of CO_2e emissions for 2030 under different transport allocation scenarios. Total emissions from railways remain unchanged, while in a mixed road fleet total emissions amount to 57,654.99 tons CO_2e. This represents only a small reduction, of approximately one thousand tons, compared to the scenario when road transport relies entirely on diesel. The marginal difference highlights that simply diversifying fuel types within the road fleet does not significantly mitigate emissions, reinforcing the need for a stronger modal shift towards rail and the widespread adoption of fully renewable energy sources in road transport to achieve meaningful reductions.

Assuming a new road scenario where the road transport fleet is composed of 81% diesel and 19% BEVs. Compared to the previous scenario where multiple alternative fuels were considered, this configuration results in total road emissions of 50,903.13 tons of CO_2e, reflecting a more substantial reduction in emissions. The result reinforces the notion that transitioning to BEVs within road freight can provide more notable emission reductions.

Figure 5 presents a comparative analysis of CO_2e emissions for 2030, evaluating scenarios where the total road transport is made by different fuel types and their impact on total emissions. Results highlight the significant differences in emission outcomes depending on the energy source used for road transport, reinforcing the importance of selecting sustainable alternatives. A key observation is that LNG and FCEV exhibit higher total emissions than diesel. In contrast, BEVs emerge as the most sustainable road transport option, producing significantly lower emissions than diesel, LNG, or FCEV. BEVs can even outperform rail transport in terms of emissions reduction. However, achieving a full BEV transition for the projected freight volumes presents significant operational and infrastructural challenges. The deployment of a fully BEV-based freight fleet capable of handling the total TEUs predicted for 2030 would require an investment in a substantial number of new vehicles, making large-scale electrification of road transport a complex and resource-intensive process.

5. Conclusion

This research introduced a data-driven methodology to model freight transport along the Sines-Madrid multimodal corridor, focusing on eligible modal shifts according to capacity constraints, uncertainty-bounded forecasts of carbon emissions, and sustainability strategies.

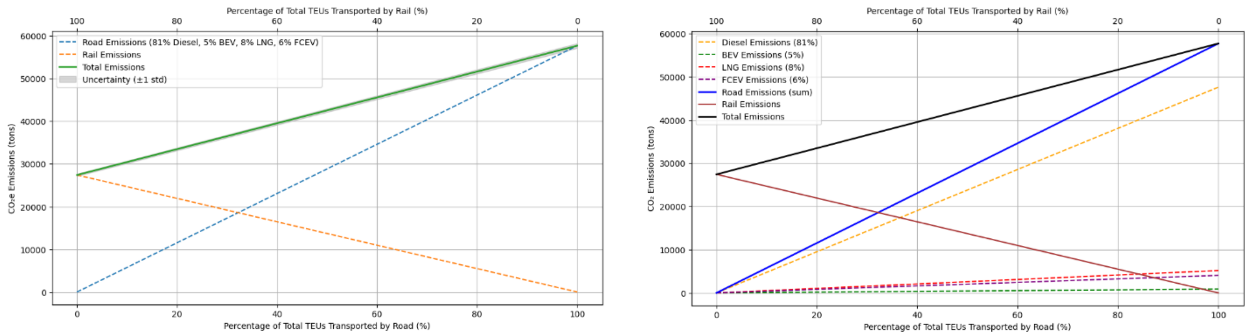

Fig. 4. Sensitivity analysis of CO_2e emissions for different modal shares in 2030 with mixed road fleet. Aggregated estimates (a) and their fleet-based disaggregation (b).

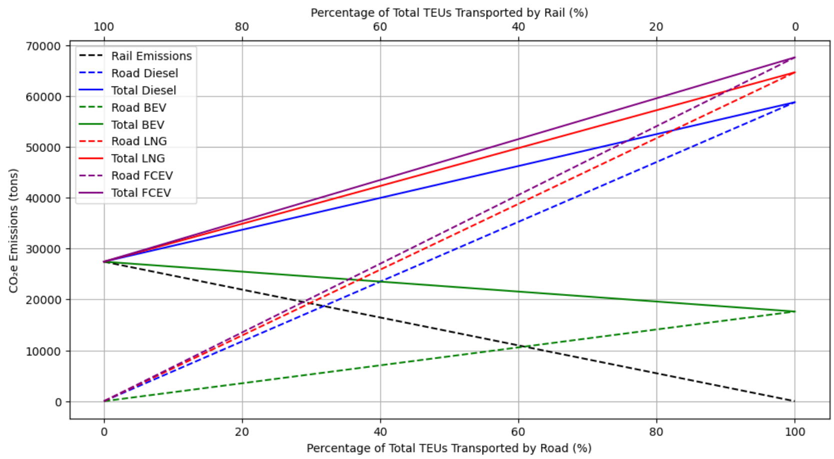

Fig. 5. Sensitivity analysis of CO_2e emissions for different modal shares in 2030 with different road fuels for the total road fleet.

The results confirm that rail transport remains the most effective option for reducing emissions, with a CO_2e emission factor of 0.28 tonnes per TEU, significantly lower than road transport, associated with 0.6 tonnes per TEU when fully diesel-powered. Alternative road transport fuel scenarios were also examined, considering a mixed fleet of LNG, FCEV, and BEVs. The results indicate that while LNG and FCEV exhibit lower direct emissions (TTW), their full WTW emissions remain higher than diesel, questioning their sustainability benefits. In contrast, BEVs show the most promising emissions reduction potential, with an emission factor of 0.18 tonnes CO_2e per TEU, making them the most sustainable road transport alternative. However, achieving large-scale BEV adoption for freight would require significant fleet expansion and infrastructure investments, making rail transport the most immediate and scalable decarbonization strategy.

Despite the potential of BEVs, rail transport remains the lowest-emission mode across all scenarios. The results show that rail consistently achieves the lowest CO_2e emissions per TEU, regardless of the share of freight shifted from road, reinforcing its role as an effective decarbonization strategy. Even with increased BEV adoption, rail transport offers an immediate and scalable solution for reducing emissions, particularly for long-haul freight, without requiring a drastic transition in vehicle technology.

In conclusion, while electrifying road freight with BEVs presents a promising long-term strategy, shifting freight transport from road to rail remains the most effective and feasible approach to reduce emissions in the short term. Additionally, the reliance on LNG and FCEV does not provide meaningful sustainability benefits unless the production and distribution systems for these fuels transition toward renewable energy sources.

These findings highlight the urgency of integrated transport policies that prioritize rail expansion while supporting targeted investments in rail electrification along with using renewable energy sources to power traction.

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Annex II

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Exploring the potential of the multimodal low-carbon freight corridor Port of Sines - Madrid

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Abstract

Freight transport contributes significantly to greenhouse gas (GHG) emissions in Europe, primarily due to the reliance on fossil fuels and road transport. With increasingly interconnected supply chains and rising cargo volumes, direct (Scope 1) and indirect (Scopes 2 and 3) GHG emissions are expected to increase unless proactive and effective measures are implemented. European transport policy has emphasized a shift to eco-friendly transport modes, such as rail and inland waterways, to reduce the dominance of road transport and consequently mitigate impacts on climate change. Within the framework of the ADMIRAL Horizon Europe project, this study conducts a detailed analysis of the multimodal freight corridor between the Port of Sines (Portugal) and Madrid (Spain), part of the Atlantic corridor promoted by the European TEN-T initiative. The study characterizes the existing and future rail and road infrastructure of the Sines-Madrid corridor, and analyses the cargo moved between Sines and Madrid by transport mode, estimating the share of the modal freight that the multimodal corridor could potentially capture and evaluating the reduction of GHG emissions. Additionally, feedback from key stakeholders was collected in a workshop with the aim of exploring their interests in this multimodal solution. The results of the analysis indicate that investment in infrastructure and interoperability is crucial for the viability and success of the service, particularly with regard to the possible development of rail motorways. The traffic analysis suggests that approximately 10% to 30% of current cargo could be transferred to rail, leading to significant reductions in emissions. This work enhances understanding of the sustainability challenges and the extended traffic-related changes necessary to greening transport within the Sines-Madrid corridor and its hinterland.

Keywords: TEN-T corridor; freight transport; modal shift; GHG emissions

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1. Introduction

Freight transport and logistics are essential for connecting goods, markets, and consumers, but the current model has significant environmental and health impacts. In Europe, transport is one of the main sources of greenhouse gas (GHG) emissions, representing 29% of the total in 2022 (EEA, 2025), and remains heavily reliant on oil-derived fuels (92.7%) (EC, 2024). Road transport dominates inland freight (75%), contributing 22% of total transport emissions (EEA, 2025). To address these challenges, EU policies focus on clean technologies, efficient logistics, and sustainable transport infrastructure, notably through the Trans-European Transport Network (TEN-T). This article examines the Port of Sines-Madrid corridor—part of the Atlantic Corridor—as a case study in low-carbon freight transport.

The shift from road to rail transport has been widely explored as a strategy to reduce the environmental impact of freight logistics. Numerous studies highlight the environmental benefits of modal shift, particularly in terms of reducing GHG emissions and improving energy efficiency (Bask & Rajahonka, 2017). Furthermore, rail transport is more energy efficient than road transport, with the potential to reduce carbon emissions by up to 70% for long-distance cargo movements (Doll et al. 2021). Studies have also pointed to the importance of identifying *shiftable* freight that can be feasibly transferred from the road to rail without compromising efficiency. Several authors have used different methods to assess modal shift potential, such as market segmentation methods (i.e. Zimmer & Schmied, 2008; Jonkeren et al. 2023), decomposition analysis (i.e. Jonkeren et al. 2019), agent-based transport model (i.e. Mommens et al. 2020) and modal choice models (i.e. Regmi & Hanaoka, 2015; Boehm et al. 2021). However, a crucial issue is that data availability (data of freight volumes, transport distance, cargo type, infrastructure data, etc.) conditions the use of one method or another.

Research on the Port of Sines–Madrid corridor has been limited, despite its strategic role in the Iberian Peninsula, where road transport dominates and rail services remain scarce. This study explores opportunities to shift freight from road to rail and intermodal options to enhance sustainability and reduce emissions. It also examines stakeholder interest in this multimodal approach. The article outlines the case study, methodology, findings, and implications for future freight transport in Europe.

2. Case study: Freight transport between Port of Sines and Madrid

The Port of Sines (Portugal) is a deep-water port included in the core transport network of the Trans-European Transport Network (TEN-T). Located 150 kilometers away from Lisbon, it is the main energy supply port in Portugal, and it is already positioned as an important deep-sea container hub and cargo gateway for the Ibero-Atlantic front. The Port of Sines occupies the fifteenth place among the ports in Europe, behind the Ports of Algeciras, Valencia, and Barcelona, handling more than 39 million tons in 2023 (Eurostat, 2024a). The Port of Sines lays on the cross of the main international maritime routes – East-West and North-South. Its hinterland comprises all the South and midland part of Portugal. In terms of extended hinterland concerns, the Port of Sines has a competitive position in relation to the Extremadura region and the area of Madrid in Spain, see Figure 1.

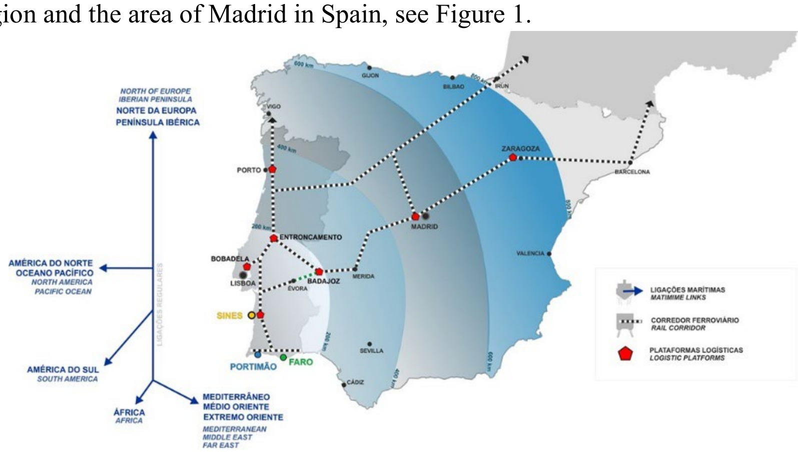

Fig. 1. Port of Sines and its connections. Source: APS (2025).

The Madrid region has a high volume of foreign trade, with imports (83.6 billion euros) exceeding exports (45.5 billion euros) (IE, 2021). Key sectors include textiles, chemicals, and agriculture, with Europe as the main trade partner. Extremadura's exports have grown significantly, reaching 2.98 billion euros in 2022 (CES, 2023), led by the agri-food, metal, and automotive sectors. Imports mainly involve equipment goods, semi-manufactures, and foodstuffs. The Port of Sines–Madrid corridor, part of the Atlantic TEN-T, is strategic due to its multimodal potential. A twin-track freight rail line from Sines to Badajoz will improve connections to Madrid and Lisbon (EU 2024/1679).

2.1. Road transport infrastructure

As part of the Atlantic TEN-T, the road corridor between Port of Sines and Madrid runs from Madrid along the Southwest Highway (A5), which belongs to the Spanish State Road Network. It is primarily a dual carriageway with two lanes in each direction, except for a three-lane section in the Madrid region. Once in Badajoz, in the cross-border until Port of Sines, there are different options to get to the Port of Sines, depending on the type of road the user chooses, using main road itineraries (subject to tolls) or choosing complementary itineraries and other national roads. The total length of the corridor is 667 km, with an estimated 6.5 hours for heavy vehicles. No tolls apply on the Spanish side, but fees on the Portuguese side range from €0 to €33, depending on the route.

2.2. Rail transport infrastructure

The Atlantic Rail Freight Corridor is a crucial part of the TEN-T, which seeks to improve infrastructure connections between the different countries of the EU. The Port of Sines-Madrid freight railway corridor under the expected Atlantic rail freight corridor is 709km long and undergoing significant upgrades, with electrified completion expected by 2030-2035. The Madrid-Talayuela section (200 km) is projected for 2033-2034, while Talayuela-Plasencia (68.8 km) will see partial completion by 2025 and full electrification by 2028. The Plasencia-Cáceres-Badajoz section (150 km + 18 km) is operational with hybrid trains, though the stations are still under construction. On the Spanish side, the Badajoz-Portuguese border link (>11 km) is on hold, while Portugal has completed the Elvas-Caia section (11 km). The Elvas-Évora line (100 km) will allow for 750m trains at 250 km/h and is expected to be completed by mid-2025. The modernisation of Évora-Poceiro (86.3 km) and Poceirão-Ermidas-Sado (80.1 km) will allow for 750 m trains, with Ermidas-Sado to Port of Sines (50.7 km) set to complete by early 2025, ensuring seamless connectivity across the corridor. The connection between Spanish and Portuguese networks of the corridor takes place in the borders of Elvas/Caia-Badajoz. The track gauge is the same (Iberian gauge - 1,668 mm wide).

2.3. Intermodal terminals

The main land-based intermodal terminals along the freight railway corridor are 3 in the Madrid region, 3 in Extremadura region and the Container Terminal at the Port of Sines on the Portuguese side. The *Abroñigal Intermodal Terminal*, located in central Madrid and operated by ADIF, consists of *Santa Catalina* (16 electrified tracks, 145-710 m) and *Abroñigal* (19 electrified tracks, 124-560 m), offering services like shunting, intermodal unit handling, and 24/7 operations. Nearby, the *Vicálvaro Terminal Logistics Centre*, also managed by ADIF, is under construction and is expected to open in 2025, featuring nearly 40 tracks (600-750 m) and similar services. The *Coslada Dry Port*, operated by ConteRail SA under Cosco Shipping Ports, provides intermodal services, container repair, customs and warehousing, extending its reach to Spain's main seaports. In addition, intermodal freight terminals in *Navalmoral and Mérida*, managed by Extremadura Avante and MEDWAY, are under development. The *Southwest European Logistics Platform in Badajoz*, initiated in October 2024, connects Portugal and Spain with five initial train frequencies, offering storage for 720 TEUs, processing up to 376,000 TEUs/year, and enabling 4.5-hour connections to Sines and 6-hour connections to Madrid.

3. Research framework and data sources

This research seeks to analyze -in a preliminary stage- the potential of the modal shift from road to rail in the Port of Sines – Madrid corridor and assess the potential environmental benefits of such shift. The research is part of

ADMIRAL project which aims to develop AI-driven solutions to manage logistics supply chains and reduce transport and logistics emissions. The research framework is displayed in a three-phase framework (see Figure 2). Phase 1 comprises the identification of the freight transport infrastructure along the corridor which has been already described in Section 2 and the freight traffic analysis (see Section 4.1). Phase 2 addresses the analysis of the modal shift from road to rail and the evaluation of the environmental benefits in terms of GHG emissions reduction (see Section 4.2). Finally, in Phase 3, a workshop is held with the main stakeholders of the corridor to get their opinions on the potential modal shift (see Section 4.3). The data and methodologies used in the phases are described below.

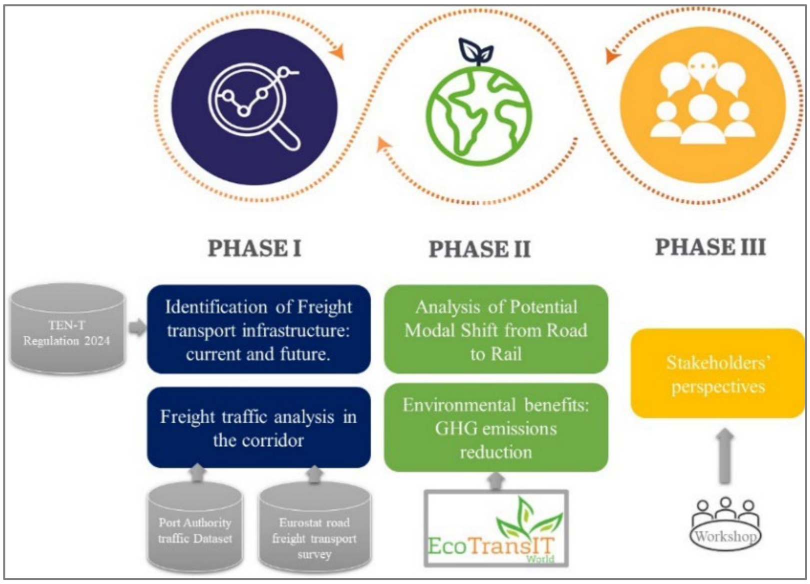

Fig. 2. Research framework

3.1. Freight traffic datasets

The Port of Sines Authority (APS) collects data for daily freight volumes by transport mode (road and rail) entering or exiting the Port of Sines. These data are also disaggregated by type of cargo and type of goods. The following Table 1 contains the type of data in the APS dataset. For rail transportation the visibility of the cargo journey is limited. The last rail terminal recorded before the cargo reaches the Port of Sines is Entroncamento, which means that any preceding locations in Spain are not captured. For road transportation it is not possible to perform a comprehensive analysis of road traffic based on this database to analyze modal shift.

Table 1. APS traffic dataset characteristics

	Road	Rail
Scale ID	No	yes
Origin Date	Only departures in the port of sines	yes
Destination Date	Only arriving in the port of Sines	yes
Mode Origin (Port/Terminal/Country)	Only departures from the port of Sines	yes
Mode Destination: (Port/Terminal/Country)	Only arriving in the Port of sines	yes
Location – starting point of cargo	Not applicable	yes
Location – destination point of cargo	Not applicable	yes
Transshipment	Not applicable	Not applicable
Hazardous cargo indicator	Yes	yes
Volume in Tons	Yes	yes
Volume in TEUS	Yes	yes

By its part, Eurostat collect data of goods transported by road between EU regions (Eurostat, 2024b). The survey is applicable to all goods transport vehicles registered in an EU member state, except military, agricultural, and public administration vehicles. The flows are aggregated at the NUTS2 region level. This means that for the Madrid – Port of Sines, there are 3 NUTS2 regions that are under our scope: the Alentejo Region (PT1C), Extremadura region (ES43), and Madrid region (ES30). This study uses data with origins and destinations between the Alentejo region and the regions of Madrid and Extremadura for the years 2021 and 2022 (Eurostat, 2024b).

3.2. Modal shift analysis, environmental benefits and stakeholders' perspectives

The modal shift analysis, developed in the second phase of the study, follows the approach by Zimmer & Schmied (2008), which identifies the potential for shifting container transport from road to rail for distances greater than 300 km. This approach assumes that long-distance container transport is, in principle, transferable to rail or inland waterways. The estimation focuses on theoretical potential, acknowledging that real-world conditions may limit the extent of this shift.

Greenhouse gas (GHG) emissions are estimated using the GLEC framework v3.1 (Smart Freight Centre, 2024), aligned with ISO 14083 standards. The EcoTransIT World tool (Ecotransit, 2025) applies a bottom-up, energy-based approach to calculate emissions based on fuel type, route parameters, vehicle characteristics, freight weight, and load factors. The methodology involves defining route segments, setting relevant parameters, and aggregating emissions for each section of the corridor.

Finally, to complement the technical analysis, a stakeholder workshop was conducted in Madrid in November 2023. The workshop brought together 17 participants, including infrastructure managers (Port of Sines Authority – APS, ADIF), logistics and transport operators (such as Combiberia and Medway), public bodies, a vehicle manufacturer (Faprove-VTG), a transport think tank, a trade association, and academic institutions. Participants discussed the corridor's strategic importance, the main barriers to multimodal transport, responsibilities of key actors, and challenges for implementing a successful modal shift.

4. Explanatory analysis of modal shift in the corridor

4.1. Freight traffic analysis in the corridor

Figure 3 shows cargo inflows and outflows at the Port of Sines (in TEUs) via rail and road from October 2021 to June 2023, with rail consistently exceeding road volumes (Arsenio et al. 2024). Figure 4 highlights the main rail terminals—Leixões, Bobadela, and Entroncamento—classified by hazardous and non-hazardous cargo. Hazardous goods account for about 1.54% of inflows and 3.08% of outflows.

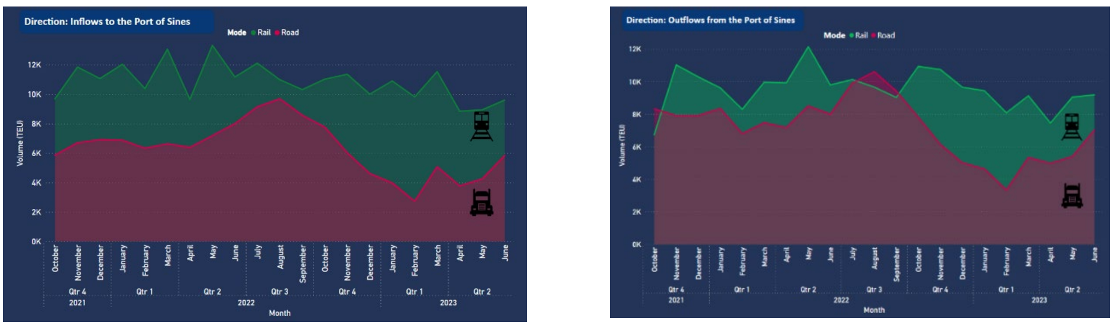

Fig. 3. Comparison of freight cargo volume (1000 TEU) transported by rail and road over time (year/quarter/month), entering the Port of Sines

Freight rail transport in the Port of Sines to Madrid is almost non-existent. Freight rail activity between Madrid and Extremadura is minimal, with only four trains per day. Movements along the corridor include: Madrid–Mérida (4 trains/week), Mérida–Sines (6 trains/week), and Badajoz–Sines (2 trains/week). Transported goods include agricultural products, steel, aluminium, and wood. However, detailed data on total freight volumes transported are unavailable.

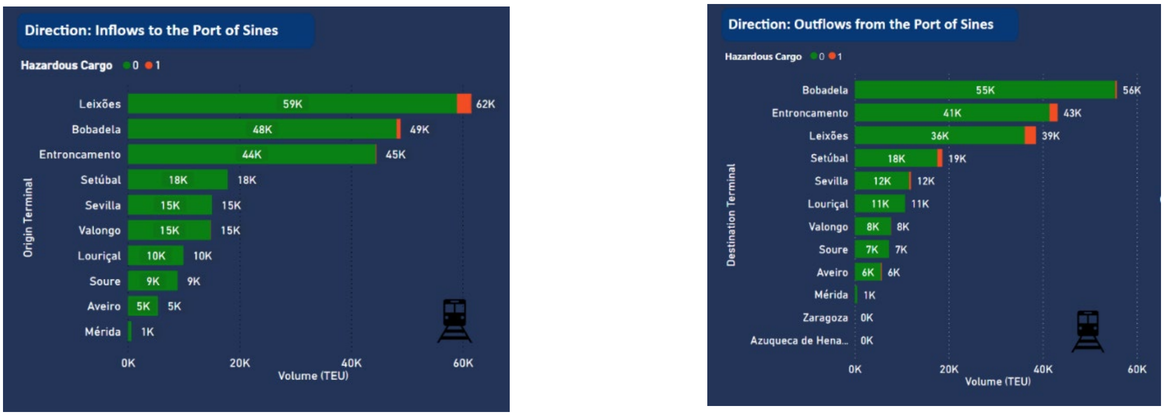

Fig. 4. Cargo inflows and outflows from the Port of Sines by rail transport between October 2021 and June 2023, by cargo type and by rail terminal destination.

Road transport dominates freight movement along the Port of Sines–Madrid corridor due to its flexibility and direct access. According to Eurostat (2024b), Table 2 shows how freight volumes between Alentejo and Spanish regions rose by 17%, and journeys increased by 9.7%, although average distance decreased, leading to a 2.2% drop in ton-kilometers. The average vehicle age also decreased, suggesting partial fleet renewal.

The main goods transported include mining products, agriculture, and food, followed by chemicals, metals, and nonmetallic minerals. In 2022, metal ores led with 30.54% of the volume, followed by food-related goods (18.53%) and agricultural products (15.85%). Containerised cargo from Alentejo to Extremadura declined (11.7%), while it rose toward Madrid (27.6%). Bulk solids and large containers decreased overall, while palletised and liquid goods increased, reflecting evolving supply chain patterns.

Table 2. Road freight traffic data: Alentejo region from/to Extremadura and Madrid regions

Year	**2021**			**2022**		
OD	Alentejo ↔ Extremadura	Alentejo ↔ Madrid	**TOTAL**	Alentejo ↔ Extremadura	Alentejo ↔ Madrid	**TOTAL**
Total goods (t)	1,131,220	52,751	1,183,971	1,293,680	91,374	1,385,054
Total goods tonnes-km	204,186,393	31,164,215	235,350,608	171,015,791	59,031,920	230,047,711
Total journeys (No.)	117,981	3,418	121,399	128,430	4,703	133,133
Average journey distance (km)	139.90	636.96	153.89	128.69	641.29	146.80
Average degree of loading capacity (%)	40.0%	59.9%	40.5%	45.7%	73.9%	46.7%
Average veh-km loaded (%)	56.3%	92.3%	57.3%	61.3%	93.7%	62.5%
Empty running (%) veh-km	43.7%	7.7%	42.7%	38.7%	6.3%	37.5%
Average vehicle age (years)	8.44	4.15	8.32	7.72	5.61	7.65

4.2. Assessment of potential modal shift and environmental benefits

Using the approach described in Section 4.2, the potential modal shift in the corridor will correspond to the road transport of containers with a distance longer than 300 km. This traffic is considered as shiftable to the rail. Table 3 shows that there was an upward trend in long-distance freight transportation, especially with increased use of freight containers. Overall, in 2022, freight containers over 300 km accounted for 5.32% of total goods, showing a significant increase compared to 2021 (0.33%). This indicates that the share of long-distance transportation, particularly using freight containers, increased substantially during the year.

Table 3. Potential transfer of freight containers from road to rail in the corridor

Year	OD	Total goods (t)	Total freight containers >300km (t)	Freight container percentage of total goods (%)
2021	Alentejo ↔ Extremadura	1,131,219.56	0.00	0.00%
	Alentejo ↔ Madrid	52,750.58	3,868.00	7.33%
	Total	**1,183,970.14**	**3,868.00**	**0.33%**
2022	Alentejo ↔ Extremadura	1,293,679.57	48,433.31	3.74%
	Alentejo ↔ Madrid	91,374.54	25,254.65	27.64%
	Total	**1,385,054.11**	**73,687.95**	**5.32%**

The Ecotransit tool is used to estimate GHG emissions from shifting freight containers from road to rail, comparing a baseline (diesel trucks) with two rail scenarios: Scenario 1 (via Entroncamento, current infrastructure) and Scenario 2 (via Elvas, expected by 2030). Table 4 shows emissions reductions of 4.42% in Scenario 1 and 5.00% in Scenario 2. The Alentejo–Madrid route sees the greatest benefit, with an 18.96% reduction in Scenario 2, while Alentejo–Extremadura shows smaller gains due to shorter distances. Overall, the analysis confirms the environmental benefits of shifting long-distance freight to rail, especially with improved infrastructure and supportive policies.

Table 4. Analysis of freight transport GHG emissions scenarios in the corridor

	Total freight by road (t)	Total freight by rail (t)	Distance by road (km)	Distance by rail (km)	Total GHG emissions tCO2e WtW	GHG emissions reduction (%)
Scenario 0 – Actual	**1,385,05.11**				**39,616.98**	
ALENTEJO ↔ EXTREMADURA	1,293,679.57		326.7		34,629.75	
ALENTEJO ↔ MADRID	91,374.54		667.4		4,987.23	
Scenario 1 – Freight containers by rail actual	**1,311,366.16**	**73,687.95**			**37,867.28**	**4.42%**
ALENTEJO ↔ EXTREMADURA	1,245,246.26	48,433.31	326.7	519.2	33,74664	2.55%
ALENTEJO ↔ MADRID	66,199.90	25,254.65	667.4	943.0	4,120.64	**17.38%**
Scenario 2 – Freight containers by rail 2030	**1,311,366,16**	**73,687.95**			**37,637.10**	**5.00%**
ALENTEJO ↔ EXTREMADURA	1,245,246.26	48,433.31	326.7	296.61	33,595.35	2.99%
ALENTEJO ↔ MADRID	66,199.16	25,254.65	667.4	709.39	4,041.75	**18.96%**

4.3. Point of view of stakeholders

The workshop gathered 17 stakeholders who agreed that the Port of Sines–Madrid corridor is crucial for freight transport and GHG reduction. They noted the lack of direct trains and slow infrastructure progress. Emphasis was placed on viewing the corridor as a network serving various cargo types, including containers and rail motorways. Some suggested extending it beyond Madrid to Central Europe due to Sines' strategic role in Atlantic traffic. Major challenges include inadequate rail infrastructure and cross-border interoperability issues between Portugal and Spain, with solutions expected after 2026. Stakeholders highlighted the need to involve cargo owners and logistics companies from regions like Extremadura and stressed that while road operators resist losing business, they favor rail motorways for lower investments. To boost intermodality, government incentives are needed to reduce costs by at least 10%. Success depends on improving infrastructure, collaboration, and ensuring economic and environmental benefits.

5. Discussion and conclusions

This research analyses the potential modal shift from road to rail in the Port of Sines–Madrid corridor, focusing on environmental benefits. It highlights the importance of reducing GHG emissions in line with EU climate goals and the 2024 TEN-T revision. Using data from the Port of Sines, Eurostat, and the EcoTransIT tool, the study shows that more than seventy-three thousand tons of containerized cargo over 300 km could shift to rail. The shift could reduce emissions significantly, With a reduction of more than 37,000 tons of CO_{2e} annually on the Alentejo-Madrid route with the 2030 infrastructure. However, achieving this requires technological upgrades, strong policy support, and stakeholder coordination. Slow rail infrastructure development, especially for intermodal transport, remains a major barrier that must be addressed to make rail a more attractive alternative. While environmental benefits are clear, the economic viability of the modal shift relies on strategic investments to improve rail connectivity, interoperability, and incentives for stakeholders. Future research should explore cost-effective ways to enhance rail efficiency and reduce emissions further. Additionally, studies could assess the broader sustainability impacts, including social and economic effects like job creation and changes in regional logistics. In conclusion, the Port of Sines–Madrid corridor holds strong potential to reduce GHG emissions and support EU climate goals, but success depends on overcoming technical and economic challenges through collaboration.

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