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D3.14 Porto Value Case

Final demonstrator

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Acronyms

Acronyms	Explanation
B2C	Business-to-Consumer
CoP	Communities of Practice
COPERT	EU standard vehicle emissions calculator
CS-FLP	Charging Station – Facility Location Problem (model)
DoA	Description of the Action
DT	Digital Twin
DW	Logistics Service Provider's Dispatch Window
DV	Delivery Vehicles
EDV	Electric Delivery Vehicles
EIT	European Institute of Innovation and Technology
ETA	Estimated time of arrival
GHG	GreenHouse Gas
GitHUB	Web-based hosting service for software development projects
ICT	Internet Communication Technologies
INLE	INLE (Project partner)
KPIs	Key performance indicators
LL	Living Lab
LL6	Living Lab 6 (Porto)
LSP	Logistic Service Provider
MVP	Minimum Viable Product
O-D	Origin-Destination matrices
PI	Physical Internet
STAR	Sustainability Assessement of Mobility Projects
UDR	Unsuccessful Deliveries Rescheduling model (Use Case 3)
UPM	Universidad Politécnica de Madrid – Madrid Polytechnic University (Project partner)
WP	Work Package
ZLC	Zaragoza Logistic Centre (Project Partner)

Executive Summary

The LEAD Living Lab (LL) 6 is located in the Porto Metropolitan Area, Northern Portugal, with an estimated population of 1.7 million people, along 2.040 km^2 making it the second-largest urban area in Portugal, just behind of Lisbon Metropolitan area.

The Porto LL is led by MC Sonae, the food retailer leader in Portugal. MC Sonae offers a portfolio of multiformat business and Food Retail formats, including the e-commerce platform. The online sales channels are essential elements to support the omnichannel strategy, one of the strategic differentiating axes of the global and unique Value Proposition offered and provided by MC Sonae to its customers and general market.

Sonae`s Group has signed several pledges, such as the Paris Agreement and more recently announced its intention to anticipate the Paris Agreement by a decade to 2040. Taking into consideration that MC Sonae is the Portuguese food retailer leader, its fleet plays a crucial role to let this ambitioned carbon neutrality be achieved and anticipated.

Therefore, the main goals within the LL6 are oriented to support the upcoming electrification strategy of the Physical Internet (PI) Sonae`s Network through simulating, optimizing and testing it in real-life experimentation through a well-dedicated Digital Twin (DT) developed within the LEAD project, under three different scenarios, described in this deliverable.

Additionally, this document reports the related simulation environment, including the scenarios' modelling, the configuration of the DT, the data collection and anonymization, and the definition of modelling conditions accordingly. It is also detailed the created "what if" scenarios and its simulations and results as well.

The DT verification and validation through user acceptance are described and the final Key Performance Indicators (KPI) in an environmental, social, and economic perspective are compared with the baseline values. In the end, the lessons learnt, and recommendations are identified, which is concluded by a summary and outlook.

Within the LL6 it was possible to test the first-ever service based on electric mobility among all Sonae`s Group, directly to its customer`s homes through an electric motorbike, performing the rescheduling service and small deliveries in a much more flexible, quick and sustainable way, aligned with the on-demand economy concepts and LEAD project foundations.

The results of the pilot and simulations were positive and will support MC Sonae in the transition to the electric mobility. They will also be important for the Community of Practice (CoP) in the sense that it can be leveraged and escalated to another level, which leads to a higher impact for the society.

1 Introduction

1.1 Scope and objectives

This deliverable provides an updated and final version of the activities and results presented in D3.13 (Porto Value Case, v1) with the main goal to report the final release of the demonstrator including user acceptance, recommendations and lessons learnt from the implementation of the new business model and the DT. It also reports any updates that might have occurred in the meantime. Apart from it, it describes a set of explanatory simulation what-if scenarios demonstrating the potential of the DT in the decision-making process from different users/perspectives. One of the main outputs of the report is the user acceptance of the new business model and digital twin, which is supported by the assessment of the sustainability impact of the new business model by comparing the baseline of the defined KPIs with the final results.

Table 1 contains the deliverable adherence to LEAD LL objectives covered during the final phase.

Table 1 - Deliverable's adherence to LEAD objectives and Work Plan

LEAD GA Requirements	Section(s) of present deliverable addressing LEAD GA	Description
ST3.7.1 Preparation. MVP Specification and Modelling.	Chapter 2. Porto pilot description	This chapter contains a description of the scenarios in LL6 and an overall perspective how this approach brings effectively added value to a food retailer like MC Sonae. It is a concrete example for other internal LEAD partners and external stakeholders to learn from the experiments within LL6 in their operations and environments.
	Chapter 3.1 Scenarios Modelling and Chapter 3.1.2 Configuration of the DT	This section contains conceptual diagrams of the "as is" and "to be" scenarios following the MVP approach. It includes detailed descriptions of the specific models developed by the LL6 and the models configured from the Generic Reference Model Library.
ST3.7.2. Digital Twin Verification.	Chapter 3.2. and 5 Digital Twin Verification, Validation and user acceptance	This section describes the verification process for validating the simulation scenarios and validating the KPIs baseline measurements.

LEAD GA Requirements	Section(s) of present deliverable addressing LEAD GA	Description
ST3.7.3. Real-life implementation.	Chapter 3.1.3. Data collection and anonymization and Chapter 3.1.4. Definition of the modelling conditions	This Chapter reports the modelling conditions/ assumptions, the data sources and data ingested used for calculating the baseline KPIs measurements and verifying and validating the DT.
	Chapter 2.2. Physical pilot activities	This section reports all the activities taken in the field detailing the pilot activities, its challenges and barriers.
	Chapter 6 and 7. Learnings, recommendations, summary and outlook	Reports the implementation plan and concludes with learnings, findings and recommendations.
ST3.7.4 Evaluation/Impact Assessment.	Chapter 3.4 Scenarios results and Chapter 4. KPIs measurements and Chapter 5 validation and users' acceptance	These chapters include the KPIs measurements, users' acceptance evaluation and the validation of the LEAD strategies. Different scenarios defined by the CoP are further explored and documented.

1.2 How does this deliverable relate to other deliverables?

This report (Porto Value Case, final demonstrator) is the updated version of the D3.13 (Porto Value Case, v1) and contributes to the D3.2 (Living Labs monitoring, refinements and conclusions) and D3.15 (Impact Assessment, Solutions Validation and Learning Conclusions). It is achieved with the work carried out in WP2 (Digital Twin Model and Simulation Environment) as reported in D2.2 (Digital Twin Models Library).

1.3 Structure of the document

In this section, a description of the deliverable's structure is provided. This document is divided into seven main chapters:

- **Chapter 1:** provides the introduction and related information;
- **Chapter 2:** details the LL6 by summarizing its minimum viable product and its three different scenarios and updates the physical pilot activities;
- **Chapter 3:** describes the simulation environment, by summarizing the scenarios modelling, the configuration of the DT, the data collection and anonymization and the definition of the modelling conditions. It is also detailed the "what if" scenarios and its simulation and results;
- **Chapter 4:** describes the final KPIs and compares it with the baseline and targets;
- **Chapter 5:** includes the DT verification and its validation through user acceptance;

- **Chapter 6:** includes the lessons learnt and recommendations;
- **Chapter 7:** concludes through a summary and outlook.

2 Porto pilot description

This section of the document gives a high-level description of the LL6 and it's divided in (1) a brief summary of the minimum viable product with its three different scenarios detailed and (2) in an update of the physical pilot activities with its challenges and barriers.

2.1 Minimum viable product

MC Sonae's currently delivery strategy consists of Business-to-Customer (B2C) home delivery based on diesel vans (from specific preparation stores) carried out by external Logistics Service Providers (LSPs). MC Sonae manages the whole strategy and owns all the relevant data (particularly about the orders and its info - customer address, order details, stock availability, timings, etc.) and provides it daily to allow the external LSPs to timely perform the deliveries till the customer's home and/or Pick-up-Points.

Following MC Sonae's strategy for the upcoming years, the main goal of the Living Lab 6 (LL6) is to support the aimed electrification strategy of the Physical Internet (PI) Sonae's Network through simulations & optimizations with a customized DT developed within the LEAD project. Three scenarios were created, each one with a different objective and challenge, as can be seen in the Figure 1.

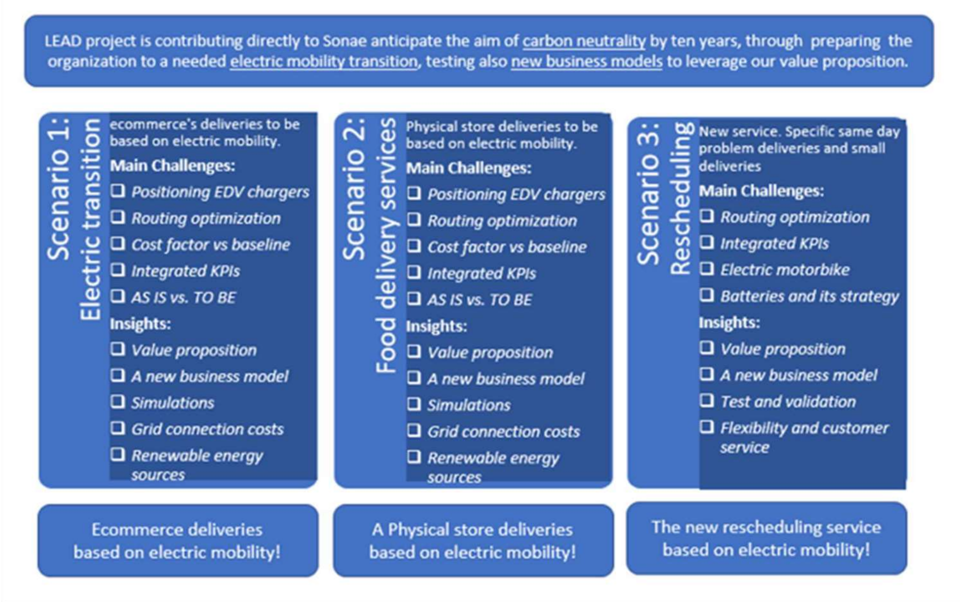

Figure 1 - Scenarios, details and visions (Source: (D1.4, 2021))

The first and second scenarios are about processing knowledge and data regarding MC Sonae delivery strategy mainly from four information blocks: stores locations and profiles, charging stations, fleet and orders. The third scenario, based on a real-life experiment, is about a new service called rescheduling, through an electric motorbike that was effectively tested.

2.2 Physical pilot activities

The third scenario, which has physically started on the 27th of January 2022 in one of the most relevant preparation stores in Porto Region (Arrábida), was the first concrete step by MC Sonae towards shifting to electric mobility, with a very specific business model – the rescheduling service. It is provided daily and directly to MC Sonae's customers, boosting the relevance of this real experiment. Following the Figures 2 and 3 represent respectively the map of the Porto Region and the electric motorbike used in the physical implementation.

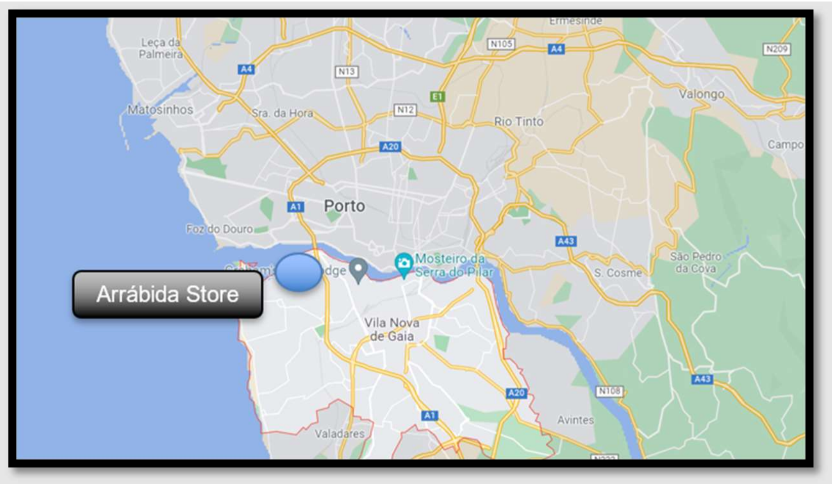

Figure 2 - Arrábida Preparation Store, location at Porto Region (Source: (D3.13, 2022))

Figure 3 - Electric Motorbike, overview (Source: (D3.13, 2022))

During its implementation and tests, we have seen a couple of challenges. A crucial one was the process to ensure that the food arrives at the destination in perfect conditions. Together with audits and food controlling teams we could control the process, but the acceptance of the possibility of transporting cold is still in progress – as of today it's still being studied due to the typification of the material used to guarantee the conditions of the food items (for example special boxes).

Also, we found some barriers during the implementation: we had initial difficulties in the adaptation to this type of business (rescheduling), as we carry out large volume deliveries and the vehicle's autonomy do not allow full optimization in the short term.

Furthermore, and as reported in D3.13 and adding to the previous point, we have seen that the autonomy of the electric mobility is one of the most challenging constraints to speed up the electric transition. In that sense, and in order to solve it, it was decided that the electric motorbike would have available two batteries to guarantee the minimum idle times during the charging period (plus one battery between routes). This way the motorbikes could perform more effectively a service like the rescheduling and small deliveries when compared to vans (as MC Sonae was previously performing it). Related assumptions in the digital modelling are included below in Section 3.1.4.

Last, but not the least, and after testing the electric motorbike for almost 1 year in Porto region, it was decided to test it in another and more demanding region, Lisbon - this way we could evaluate the impact of the volume of orders in the final results. Although the results are still being assessed and are not yet representative, qualitative feedback for our operations is telling us it is resulting in a much higher optimization of such vehicle.

3 Simulation environment

In this section of the document the simulation environment is given, including all the necessary parameters and decision points for the models employed that have defined the decision support that has been offered to SONAE in the context of LL6. Section 3.1 gives the description of models, including datasets used, modelling assumptions and verification process. Very central to the simulation environment is Section 3.3, including the "what-if" scenarios, and Section 3.4, that includes the results, and how they have been utilized for each 'what-if' scenario.

3.1 Digital twin: Scenarios modelling

3.1.1 Description of the LL6 Generic Models and connections

Table 2 - Summary of the generic models developed in the framework of LL6

Model	Description
Unsuccessful-and-Small-Deliveries-Scheduling/Rescheduling-algorithm (UDR) model	UDR is a last-mile logistics model that is based on Capacitated Vehicle Routing Problem with Time-Windows with Electric Delivery Vehicles (EDVs, e-C-VRP-TW). Within Porto LL it has been used to estimate the EDVs and Total kilometers traversed required to satisfy LSP's customer demand based on client's locations and network distances, as well as LSP's dispatch windows and client's required delivery windows. UDR can be run on both historical data and pseudo real-time/real-time data (enabling Digital Twining functionality) and can derive results that can support decision making regarding the establishment of a small orders and/or a rescheduling service by the LSP (in conjunction also with the required investments costs for EDVs). To solve sufficiently large instances of problems, UDR applies clustering and other pre-optimization techniques to reduce computational effort and provide heuristic solutions to real business problems. UDR can consider different types of Delivery Vehicles (DVs) based on their maximum range (i.e., battery capacity in case of an EDV), energy consumption and the EDV's load capacity.
CS-FLP model	A Charging Station Facility Location Problem (CS-FLP) model[1] has been developed in the context of the Porto LL to answer questions within Use Case 1. CS-FLP is based on a weighted-p-median model and its Mixed Integer-Linear Problem (MILP) formulation, and when solved with the OR-Tools library the solution can provide an answer about the best locations (i.e., where) to place Charging Stations on an LSP's network. The CS-FLP model is a newly implemented digital model and can be adjusted to the needs of different LSPs in Europe. It has been based on previous work by INLE in the Track&Know project[2]. The public repository of the previously elaborated algorithm can be found here: https://github.com/ibadkureshi/tnk-locationallocation. A formal description of the CS-FLP is: Given a set of locations N and given that the LSP wants to install CS at Y out of the N locations, a solution to the CS-FLP provides which of the N locations the CS should be placed to minimize operational cost according to distances and demand. The public GitHub, including the MILP model of a weighted-p-median model, and the Python implementation of the model, can be found here: https://github.com/dimrizo/CS-FLP.

[1] *Facility Location Problem, Wikipedia, https://en.wikipedia.org/wiki/Facility_location_problem*
[2] *Track&Know project: Big Data for Mobility Tracking Knowledge Extraction in Urban Areas, https://trackandknowproject.eu/*

Model	Description
Data preparation and demand clustering procedures (DP_clustering)	DP_clustering is a set of analytical procedures that pre-processes the data and cluster the delivery services on demand. Specifically, the DP_clustering procedures, first filters the data and corresponds the delivery latitude and longitude to code postal for specific regions. The procedure then clusters the delivery services based on clients' delivery services demand taking as input the clients' geographical locations (latitude, longitude) and return a clustering list for specific region.

Table 3 - Summary of the generic models integrated in the framework of LL6

Model	Description
Echelon	Echelon model estimates the resources needed (vehicles, drivers), total distance and delivery time per type of vehicle of 1-echelon network configuration or 2-echelon network configuration. The Echelon model is available on Horizon-LEAD/2echelon Github repository.
COPERT	COPERT model is the European standard vehicle emissions and energy consumption calculator. Specifically, in LL6 COPERT estimates the following: • Energy consumption, • GHG Emissions - CO_2-equivalent, • Air pollution – [PM; NOx; VoC]. More detailed information about the model can be found in (D2.2, 2022).
EVCO2	This methodology estimates the greenhouse gas emissions (GHG) from electric vehicles that is associated with the electrical mix used to produce electricity. The method estimates the electric vehicles' CO_{2eq} emissions based on the sum of the mean electricity consumed by each vehicle (kWh) and the carbon intensity -the CO_{2eq} emissions per energy unit- of the electricity generation system of each region or study area (gCO_{2eq}/kWh). The EVCO2 model is available on Horizon-LEAD/EV_EMISSIONS_UPM Github repository. More theoretic information about the model can be found in D2.2.

Table 4 - Summary of the LL6 model connectors

Model	Description
Echelon-Copert	It is a Python script that total distance and the number of vehicles needed filled to the input COPERT file/format.
UDR-EVCO2	UDR-EVCO2 is a Python script that calculates the energy consumption in Tera Joules based on the UDR outputs: the number of EDVs used and the total distance for delivery services. The model connector, UDR-EVCO2 is available on Horizon-LEAD/UDR-EVCO2_connector GitHub.
Echelon-EVCO2	Echelon-EVCO2 is a Python script that calculates the energy consumption in TJ based on the Echelon outputs: total distance and the number of vehicles needed for delivery services.

3.1.2 Configuration of the DT

The configuration of the DT and the respective models happened slightly differently as described in respective section D3.13. SONAE timely provided all data needed as described in Section 3.1.3 below, which have then been filtered to be able to be read by the models and analysis.

According to models' specification and documentation, models are now integrated on to the platform and respective datasets can be uploaded to rerun models. In the case of the Porto LL, UC2 and UC3 have been supported by the DT platform, with the UDR, 2-echelon, COPERT and EVCO2 models being integrated on to the platform. The necessary configuration of the model specification has been included in the platform which provides all the necessary inputs and outputs to the Digital Twin platform Simulation Execution engine on how the models should be run. Since 2-echelon configuration took place for the Madrid LL, the UDR configuration with EVCO2 and COPERT took place specifically for Porto LL. A high level representation of the configuration is given in Figure 4 below.

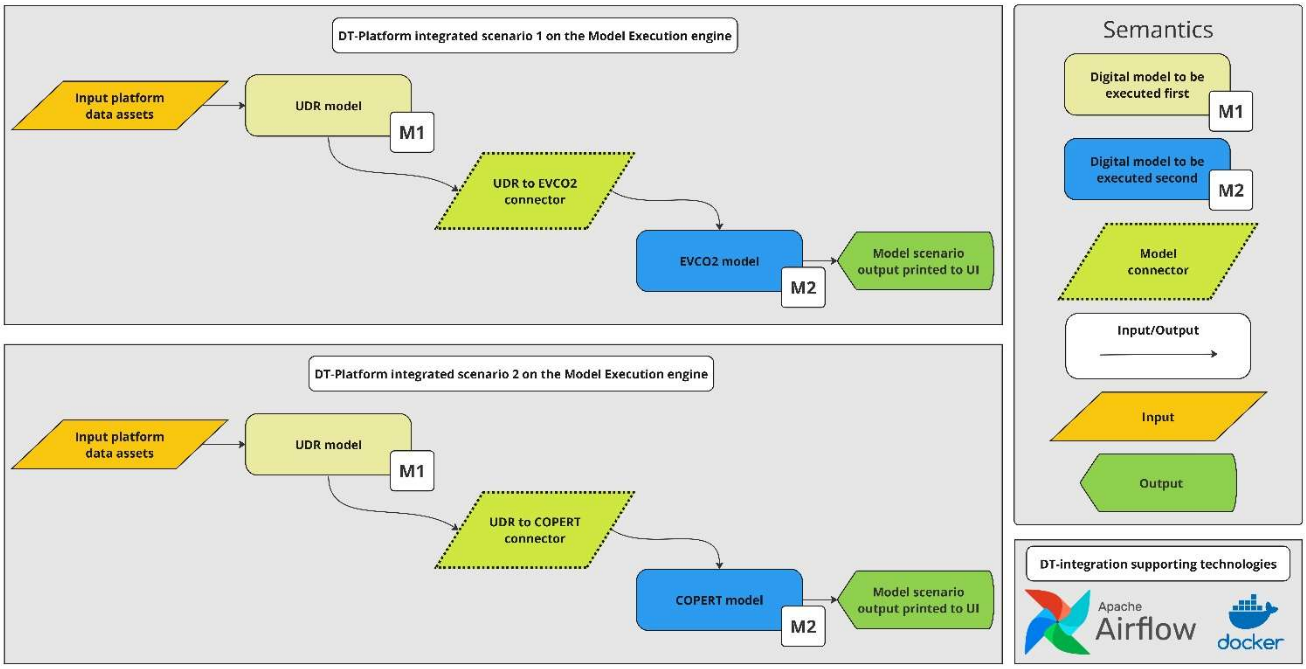

Figure 4 - High-level UDR configuration with the DT platform for Porto LL

Central to this discussion is the development of the necessary models' connectors that facilitated the execution of scenarios on the platform, as highlighted in Figure 4. Model connectors that were required for Porto LL6 are described in Table 4 above.

Finally, it is worth mentioning that UC1 and the CS-FLP model that supported it, has not been integrated in the platform since CS-FLP provides a static analysis of SONAE network and is not expected to support a dynamic Digital Twinning Use case.

3.1.3 Data collection and anonymization

As reported in the previous deliverable 3.13, in LL6 it was used store, order, fleet and working data, which were collected and provided by MC Sonae and/or LL6 partners based on the General Data Protection Regulation (GDPR). It was also used open-source data such as environmental, traffic and geolocation data.

Table 5 shows the LL6 data sources with its data type, description and dependencies. The data types are categorized as occasionally updated (OU), static (S) and real-time (R).

Table 5 - LL6 Data sources, data type, description, and dependencies with KPIs and models

Data source	Data type	Description	Dependencies (KPIs, models)
Store	S	MC Sonae's store information such as geographical locations, working hours, pick-up point/delivery service and relevant renewable energy source.	Echelon Model, COPERT, charging station location, Distributed Sub-Trajectory Clustering
Order	S	Historical daily deliveries carried out by the LSP of MC Sonae.	Echelon Model, Distributed Sub-Trajectory Clustering
Fleet	OU	Delivery vehicle specifications that are used for last-mile logistics by the LSP of MC Sonae.	Echelon Model, COPERT, charging station location, Distributed Sub-Trajectory Clustering
Working	S	Information related to work such as working hours/duration for both store and last-mile logistics employees.	2-Echelon
Vehicle	S	The vehicles that are used for scenarios 1 & 2 are diesel Iveco daily model.	2-Echelon, COPERT
Environmental	S	Environmental parameters such as humidity and temperature used for computing GHG emissions. URL open-source environmental data: • Climates to travel website • Porto climatemps website	COPERT
Traffic	S	Traffic information of the Porto region. URL open-source traffic and geographical data: • Tomtom website; • Traffic studies.	COPERT
URL with Portugal area	S	URL containing open-source geographic data of the city center of Portugal. Alternatively, for Porto region, Porto co-ordinates (latitude and longitude) are used.	2-Echelon Model

3.1.4 Definition of the modelling conditions

In general, several modelling conditions have been established for the models developed and used in the Porto LL. The general requirement to provide decision support for the transition to electromobility lead to considering the constraints that are introduced into the operations of the LSP. Firstly, range constraints must be considered as EVs have a limited range and require recharging at suitable locations to complete their route. The charging, battery swapping, or general refueling method is another significant factor as it can impact the total travel time and route selection. Different vehicle capacities have also been considered since they can affect how vehicles are assigned to clients.

Regarding Use Case 3, several specific assumptions had to be made in order to provide a realistic modelling of the small orders service and/or rescheduling service of SONAE MC. The list of assumptions is included below:

1) Data filtering: The deliveries file provided by SONAE has been filtered to include only small orders (<3 boxes) and rescheduling orders and in the scope of the analysis.
2) Three batteries are available per vehicle (2 onboard during delivery, one charging at depot), each providing a 70 km range per dispatch window: In order to provide realistic recharge conditions based on the vehicle type and based on SONAE's availability to recharge, a battery management strategy has been considered for the modelling, where given that SONAE utilized three batteries per Dispatch window:
    a. Kilometric range of 105.000 meters considered for the <u>first</u> dispatch window within each day where 1.5 (x) Scooter's EDV battery capacity has been considered (thus 70km + 35km = 105km),
    b. Kilometric range of 105,000 meters considered for the <u>second</u> dispatch window within each day where 0.5 (x) Scooter's EDV battery capacity has been left unused from the first dispatch window, plus one fully charged battery waiting at the depot (thus 70km + 35km = 105km),
    c. Kilometric range of 70.000 meters for the <u>third</u> dispatch window within each day, based on the availability of a recharged battery that has been utilized from the <u>first</u> dispatch window of each day.

    This battery management approach has been agreed with SONAE to achieve realistic results based on the fact that a full recharge is possible in just 3-4 hours via a 3-pin UK plug Super charger (so the third battery at the depot can be recharged while it is not being used). The three dispatch windows, in which SONAE groups the dispatch of deliveries, are 10:00-14:00, 14:00-18:00, 18:00-22:00.

3) Clients' maximum distance to enable feasible solutions of the model: Since the scooter EDVs considered can run for 70k per dispatch window, clients that are at maximum of 35 km of direct distance from the Arrábida deport were considered. This led to omitting from the deliveries data <1% of the clients. This assumption had to be made since some clients in the dataset are so far away from the store that not even single EDVs cannot reach them when used alone. It is considered that these few "outlier" clients will have to be handled by a conventional vehicle.
4) Heuristic rules employed: Clustering and temporal classification algorithms have been applied to the UDR approach in order to enable the solution of real-world problems leading to the solution of e-C-VRP-TW for each dispatch window and for each day.
5) A specific type of vehicle has been considered by the modelers, which is the SuperSoco CPX 125cc which can carry two batteries and has a capacity of 3 boxes per run.
6) Based on the initial deliveries' dataset, the total demand per boxes has been considered but not the different types of boxes (boxes at room temperature, positive cold, negative cold).

3.2 Digital twin: verification process

The verification of the models developed for the three scenarios of LL6 allowed the team to confirm that they were developed according to the requirements, apart from possible minor adjustments. The models represent the reality except the fact that real time data was not used – at this moment the models are using historical data. In order to give a step forward it would be needed to integrate our business databases with the LEAD platform. It is important to highlight that we saw different results for the same metric in different scenarios, which is explained by the different assumptions – it is indeed acceptable.

All models of the LL6 are developed (only one is not integrated into the platform) and the correct hypotheses and input values are currently ingested to the models that are part of the LL6 DT.

As mentioned before, the validation process allowed LL6 to confirm that the models developed for each scenario meets MC Sonae's needs. This process involved system testing and user acceptance tests, which led to a final workshop with the LL6 CoP and reported in Section 5.

For scenario 1, the charging station location model, which is essentially a location-allocation problem considering geographical, delivery and fleet information, the LL6 tested with static data and confirmed that the model can give us insights about the best rationale behind the best locations for the EV chargers.

For scenario 2, tor the sequence of the distributed sub-trajectory clustering, 2-echelon and COPERT models, validation required the involvement of the LSP of MC Sonae by comparing the simulated results for number of vehicles needed, vehicle distances and GreenHouse Gas (GHG) emissions and the values of the operator.

For scenario 3, for the rescheduling scenario, the verification of the business model was followed by the LL6 partners and its CoP in order to check if it works well and according to the initial expectations, which was confirmed.

3.3 Digital Twin: "What if" scenarios definition

3.3.1 First "What-if" scenario definition

In the first "What-if" scenario several questions have been attempted to be answered regarding the position of Charging Stations at SONAE's depot stores throughout the Porto area (see Figure 5 below). In more detail, after respective discussion two main questions were in focus:

- Based on past delivery demand, does SONAE need to place EDV chargers at all of its preparation stores in the PORTO area?
- Based on past delivery demand and real-world distances in between SONAE's depot in the PORTO area, what are the most suitable locations to add charging stations so that all depots are served with the minimum operational cost?

Both questions have been very important for MC Sonae in order to understand the investment costs for installing the charging stations throughout the last-mile delivery network and understand how their investment will affect the daily operations. More specifically, based on the daily delivery schedule, the EDVs usually have to perform a delivery route per dispatch window, starting at one of the depots and returning usually to the same deport after the delivery route is finished. If there are available charging stations at this same depot, then the EDV can recharge during the off times; otherwise, it would need to relocate to another depot that has available charging stations. This relocation of the EDVs can also take place due to shift in demand in-between days and depots, but when it happens solely for recharging purposes then it adds up to the operational cost of the LSP. For that reason, by utilizing respective decision support models and answering the questions above, a first step towards effective EDV recharging is aimed to be achieved.

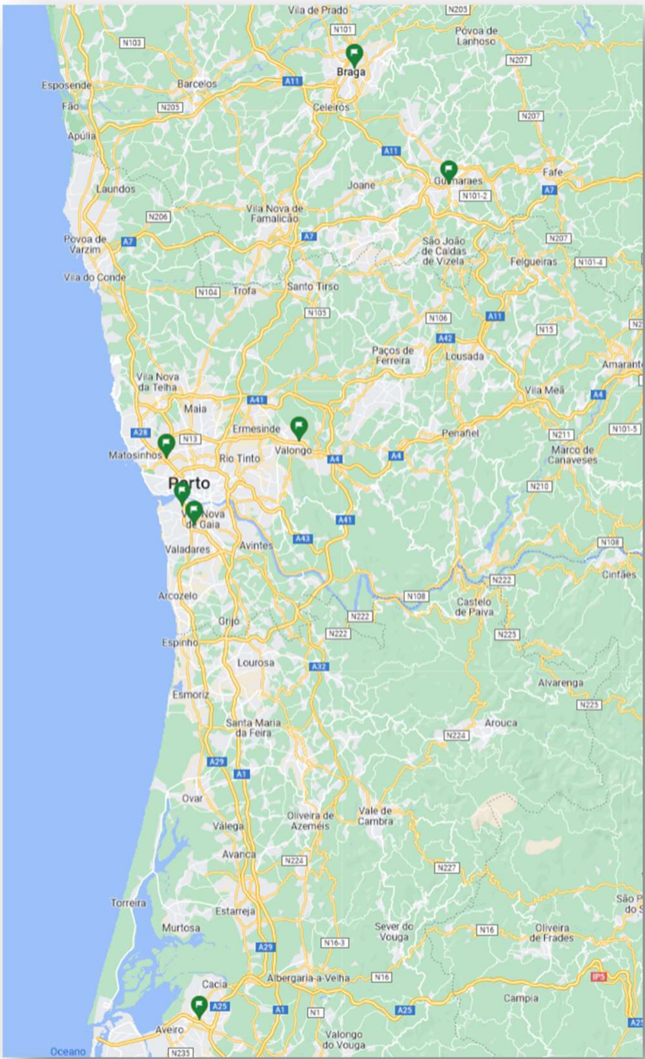

Figure 5 - A map depicting the seven preparation stores of SONAE in the Porto region (Google Maps)

3.3.2 Second "What if" scenario definition

The goal of the second "what-if" scenario is to investigate if EDVs can be used to the SONAE's instant food deliveries services. This second what-if scenario will provide SONAE with a clear understanding of the impacts of this new business value proposition, based on electric deliveries, to the preparation store, Sonae MC Continent Online Arrábida (COL Arrábida) store - the most relent in the Porto Region - that provides the delivery service (e-commerce channel), with a dedicated fleet.

In the context of Use Case 2, SONAE has posed the following business questions:

- What-if we deploy 25% diesel vans and 75% electric vans (what-if1)?
- What-if we deploy 50% diesel vans and 50% electric vans (what-if2)?
- What-if We deploy 75% diesel vans and 25% electric vans (what-if3)?

INLE modelling team translates the above SONAE's business questions into research and technical ones as follows:

- What type of data have to be considered?
- What data analysis techniques have to used?
- What is the difference between using a conventional vehicle and an electric delivery vehicle?
- How deliveries vehicles (conventional and electric ones) can be modelled in order to derive accurate estimations of the number of vehicles required and the total delivery distance (in kilometers)?
- How GHG emissions can be calculated for conventional and electric delivery vehicles?
- What programming language and software libraries should be used to implement the digital models that will be integrated with the Digital Twin Internet Communication Technologies (ICT) infrastructure.

INLE used the 2-Echelon model that was developed by ZLC. 2-Echelon model allows to estimate the number of vehicles required and the total distance traversed for SONAE's delivery services. In the LL6, we use the 1-echelon network configuration (Figure 6) as reported in D3.13, and the branch is the Sonae MC Continent Online Arrábida (COL Arrábida) store.

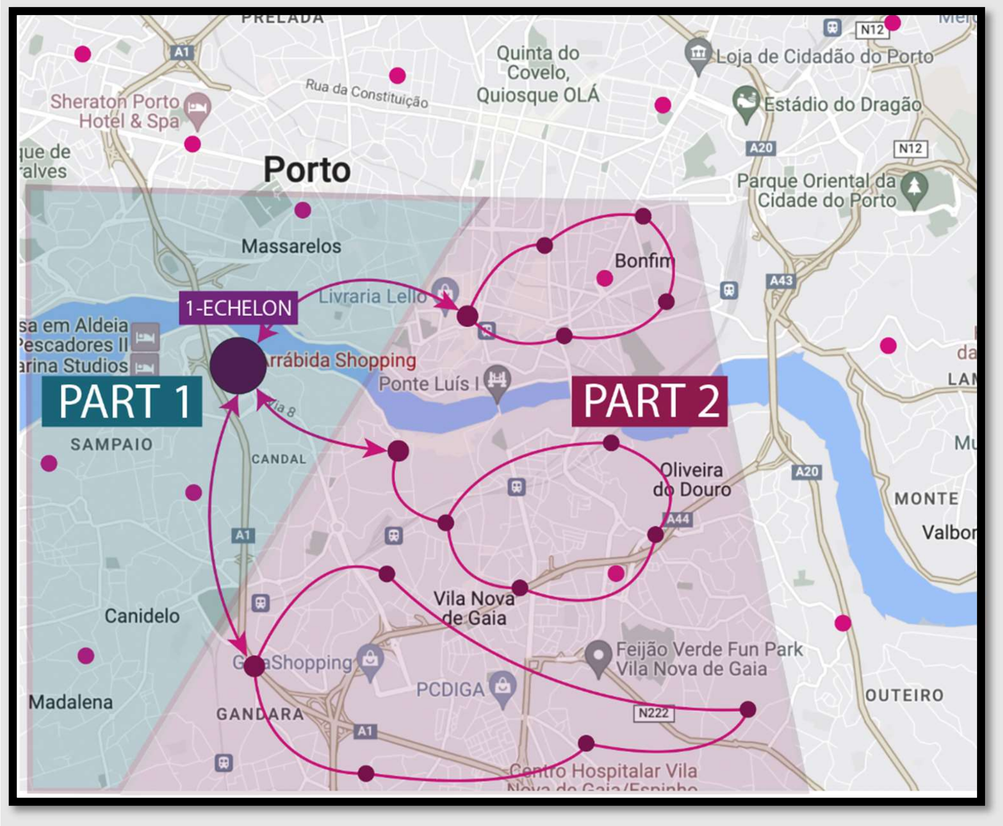

Figure 6 - 1-echelon network. Branch: Arrábida Store (Source: (D3.13, 2022))

The advantages of the 2-Echelon model, are presented as follows:

1. This model is useful when the user (LSP, shipper) aims to understand the impact of different scenarios.
2. It requires a low level of operational input data from the user and geographic data of the delivery zone to calculate the coordinates of a centric point within the delivery zone and the square meters of the polygon that defines the boundaries where the unloading operations take place.

In the specific case of LL6, we define the geographic coordinates of each delivery zone based on the postal codes around the store locations. The identification of clusters can change based on the orders, consequently the geographical data of delivery zone change. Finally, to calculate GHG emissions for conventional and electric delivery vehicles, INLE uses COPERT and the Porto-adapted version EVCO2 (see Figure 7 below) respectively.

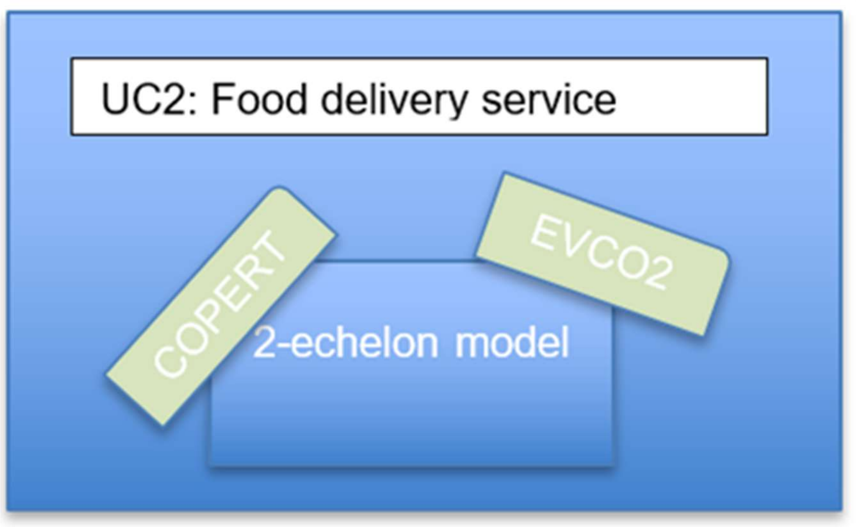

Figure 7 - UC2 Food delivery services. 2-echelon model for resources, COPERT & EVCO2 to calculate GHG respectively

3.3.3 Third "What-if" scenario definition

The goal of the third "what-if" is to test if a specific electric motorbike type can be utilized for the SONAE's small orders service or a potential rescheduling service, deeply aligned with the market needs (flexibility and quickness to solve identified intra-days problems) and the expectations from the society (at environmental, social and economic levels) regarding SONAE's high-impact operations and innovative culture.

For a matter of context, the rescheduling policy applies when something must be modified or should be corrected or even postponed, as follows, based on same potential/typical reasons:

1. The customers ask for a change on the time slot (they wouldn`t be at home in the slot previously submitted though continente.pt);
2. There is nobody in the house when MC Sonae went to customers` home as initially requested through continente.pt;
3. The MC driver did not find the address for any reason:
4. The driver could not get the address point (e.g., traffic);
5. Payment issues (e.g., the system did not work when the order was delivered);
6. Out-of-stock products;
7. Forget MC Sonae stamps for handling further discounts;
8. SONAE postpones the order because there is the danger of delivery failure.

The rescheduling service though the electric motorbike applies to all the orders that suit the motorbike capacity and time slots optimization. The rescheduling is guarantee by our contact centers when any reason described above happen, from MC side or customers' side.

In the context of Use Case 3, with a focus on the Arrábida store, SONAE has posed the following business questions:

- We expand the use of electric vehicles to all eligible rescheduling services?

- We expand the use of electric motorbikes for small deliveries?

Based on these questions the task of the INLE modelling team has been to translate these questions into research and technical questions which will have to be answered to derive business value to SONAE. These research and technical questions were:

- What type of data have to be considered?
- What data analysis techniques have to used?
- What is the objective of the LSP and what insights can be offered to support decision making?
- What type of modelling approaches have worked in the past and what are some insightful examples from the literature?
- What is the difference between using a conventional vehicle and an electric delivery vehicle?
- How EDVs can be modelled to derive accurate estimations of the number of EDVs required and the kilometers that they will traverse?
- What programming language and software libraries should be used to implement the digital models that will be integrable with the Digital Twin ICT infrastructure?

Based on these questions INLE has decided to approach the problem based on a well-established and well-known approach the Vehicle Routing Problem (VRP)[3] and more specifically its extension the C-VRP-TW which utilizes the Mixed Integer Linear Programming (MILP) approach to answer the questions above. However, the state-of-the-art literature is attempting to solve the version of C-VRP-TW, so INLE had to focus on somehow including the EDVs as proposed by SONAE. This step has been the main challenge on the modelling side, and then the algorithm had to account for some the business aspects of SONAE like dispatch windows, current EDVs refueling options as well spatial allocation of deliveries, and temporal classification of time-windows required by the customers. The algorithm that has been elaborated for UC3, and respective “what-if” scenarios and business questions is called the “Unsuccessful Deliveries Rescheduling (UDR)” algorithm that is based on a e-C-VRP-TW algorithm that can run on SONAE real world data (delivery demand dataset, stores locations, fleet, Porto road network, etc.) – See Figure 8 below. The algorithm can be used in under two UCs:

- Historical data UC: Estimation of EDVs required, as well as kilometers traversed and environmental impact, based on daily dispatch window historical data,
- Digital Twin UC: Real-time (or pseudo real-time) estimation of EDVs required to satisfy customer demand based within daily timeframes, when supported by the Digital Twin ICT system.

[3] *Vehicle Routing Problem definition, Wikipedia, https://en.wikipedia.org/wiki/Vehicle_routing_problem*

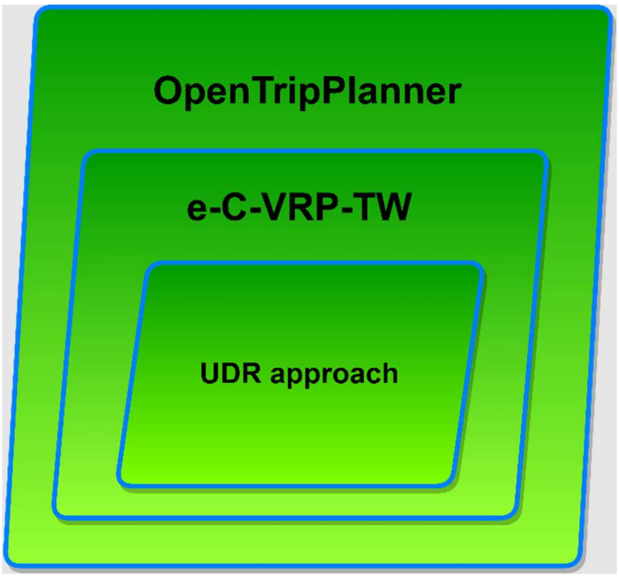

Figure 8 – UDR model's subcomponents, the e-C-VRP-TW model and the OpenTripPlanner routing engine

Due to the complexities of refueling EDVs, including the consideration of vehicle energy consumption, battery capacity, number of batteries included per vehicle, and spare batteries, a solution is needed to efficiently schedule and reschedule deliveries. An algorithm, such as UDR, including all necessary EDV modelling, that has been introduced in the context of Porto LL, is required that addresses this problem by providing cost reductions through efficient scheduling and routing of unsuccessful deliveries within short timeframes (i.e., LSP's dispatch windows within a single day). At a larger scale, the use of such an algorithm is expected to bring additional benefits to fleet management and market reach of the SONAE's operations, by estimating the exact number of EDVs required in order satisfy customer demand.

This algorithm is one of the first to address the challenge of the scheduling of small and/or unsuccessful deliveries within last mile logistics systems when EDVs are used (considering consumption and real-world distances to satisfy demand). As this is an emerging problem, this algorithm attempts to account for parameters that are unique to EDV scheduling and routing and were not necessary for conventional gasoline vehicle fleets. Based on this algorithm, SONAE can estimate the number of EDVs required to implement their small orders and/or rescheduling orders service in the Arrábida store.

Central to the analysis of UC3 has been the identification of rescheduling orders and small orders. According to SONAE's input rescheduling orders have been the orders that exist within the initial dataset with two or more times (i.e., indicated by the same order ID) and the small orders have been the ones with a total box demand of three boxes or less. Based on the data analysis by INLE, in the six-month period of analysis by SONAE:

- The number of small orders has been 24.890 entries in the initial deliveries file;
- The number of rescheduling orders has been 126 unique deliveries have been performed, out of 279 rescheduling delivery attempts to deliver the orders;

- The number of deliveries that have been both “small deliveries”, as defined SONAE, but also rescheduling deliveries, have been 32;
- The total demand of rescheduling deliveries has been 842 boxes in the six-month period, and the total demand for small deliveries has been 51455 boxes. The total delivery demand in the six-month period has been 1.877.832 boxes;
- The total demand for rescheduling orders has been less than 0,1% of the overall deliveries, and the demand for delivery of small order is ~12% of SONAE’s orders.

This data analysis has been very important because it enabled the modelers to understand the prioritization of the different tasks in the analysis. Based on the statistics presented above, it has been more important to develop a modelling approach that will analyze small deliveries rather than rescheduling ones. INLE has developed a model to tackle both, but the results that will be included here will mainly refer to small orders since one can easily understand from above that the demand for small deliveries much higher (12%) than the demand for rescheduling orders (less than 0.1%).

3.4 Digital twin: “What if” scenarios simulation and results

This section touches upon several topics concerning the application of the models and the results that have been offered to the LSP. It connects to Section 3.3, the use cases definition, and Section 3.1, where the models that are used within this deliverable are defined. Specifically, it elaborates:

- Input data,
- Models used,
- Results of the model,
- Some reasoning link to the results to respond to the research question formulated in the section above.

3.4.1 “What if” Scenario 1: Simulation and results

1. Data and models used

For the first Use Case, two of the available datasets were used. The demand dataset for deliveries in the period of January 2022 to June 2022, as well as the depot locations (seven depots according to excel spreadsheet provided by the LSP). UDR model has been used to answer the first question within UC1, and the CS-FLP model has been used to answer question two. For the first question a specific type of EDV vehicle has to be considered for the simulation through the use of the Vehicle Routing Problem execution, which has been considered to have a capacity of 150 boxes (based on fleet specification provided) and a total range of 250 kilometers per full charge. The MILP model[4] for the CS-FLP used for questions 2, is given in the Tables 6 to 8 below:

[4] Definition of Mixed-Integer Linear Programming (MILP) Algorithms, MathWords, https://www.mathworks.com/help/optim/ug/mixed-integer-linear-programming-algorithms.html

Table 6 - Parameters and variables of the CS-FLP MILP formulation

Parameters	
i, j	*Indices are used to indicate facilities.*
N	*The number of available facilities in the last-mile network.*
P	*The maximum number of depots at which charging stations can be installed.*
D_i	*Demand at depot I (measured in number of boxes).*
W_i	*Demand weight at depot i, based on a normalization of demand at depot i comparing to the total demand at all depots.*
$C_{i,j}$	*The transport cost from i to j (expressed in meters).*
Variables	
$X_{i,j}$	*A binary variable that is equal to 1, if facility is assigned to facility j, when j has CS available.*
y_j	*A binary variable that is equal to 1, if depot j is selected for the CS installation.*

Table 7 - Constraints of the CS-FLP MILP formulation

Constraints	
$\sum_{j=1}^{N} X_{i,j} = 1, \forall\, i \in N$	*Every depot i has to be served by exactly one depot j.*
$\sum_{j=1}^{N} y_j \leq P$	*The sum of all variables y_j has to be less or equal to P, meaning that we may have charging stations at maximum P out of N depots.*
$X_{i,j} \leq y_j, \forall\, i, j \in N$	*In order for a facility i to be served by a facility j ($X_{i,j} = 1$), then we would need to have charging stations established there ($y_j = 1$).*

Table 8 - Objective functions used for the two types of solution of the CS-FLP

Objective functions for the CS-FLP	
$MINIMIZE \sum_{i=1}^{N} \sum_{j=1}^{N} X_{i,j} * C_{i,j}$	*Distance-based objective function minimizing distances-to-be traversed by EDV trucks performing delivery tours in depots with no charging stations, to depots with charging stations.* $C_{i,j}$ is the transportation cost in meters, thus the objective function takes the value of meters.
$MINIMIZE \sum_{i=1}^{N} \sum_{j=1}^{N} (X_{i,j} * C_{i,j} * W_i)$	*Demand-weighted distance-based objective function minimizing distances-to-be traversed by EDV trucks performing delivery tours in depots with no charging stations, to depots with charging stations. The final values of the objective function are in (demand percentage at depot) x (meters).*
$W_i = \frac{D_i}{\sum_{j=1}^{N} D_j}, \forall\, i \in N$	*Formula for the calculation of the demand relative weight at depot i, based on the total demand across all depots.*

2. Results for the first question utilizing UDR model

SONAE wanted to verify if it is or not necessary to place charging stations at all of the depot location in its Porto network. To answer this question the UDR model has been used in order to simulate past delivery demand by making use of the "simulation by optimization" concept. But before presenting the results of this analysis it is important to consider the topography of the last-mile network of SONAE, and the distances in between depots, which can be found in Table 9 below.

Table 9 – Asymmetric Distance Matrix between SONAE's depot locations based on real-world routing (i.e., O-D matrix for the CS-FLP)

Distance from/to (m)	COL Arrábida	COL Matosinhos	COL Gaia	COL Aveiro	COL Valongo	COL Guimarães	COL Braga
COL Arrábida	0	7.632	5.734	67.440	22.665	58.677	60.768
COL Matosinhos	7.315	0	10.923	72.629	19.251	55.616	57.707
COL Gaia	5.259	9.786	0	63.533	22.524	58.536	60.627
COL Aveiro	71.558	75.673	66.818	0	85.324	121.336	123.427
COL Valongo	21.643	20.708	22.992	84.610	0	31.128	58.143
COL Guimarães	57.615	55.688	58.964	120.582	57.052	0	24.433
COL Braga	60.889	58.962	62.238	123.855	60.325	25.175	0

Based on Table 9 above (and Figure 5), one can notice that the Arrábida stores is very close to Matosinhos and Gaia stores, and the two stores that are further away are Aveiro and Braga that are approximately 123 kilometers away from each other. Even the latter case of 123 km distance and given that CS only existed at one of these stations, the scenario of performing a relocation of the EDV fleet in order to recharge is possible, given modern EDVs range (>250km). However, of course in such a scenario the EDV would need to perform delivery trips that are at maximum 120-130km per run/dispatch window. In a more realistic scenario, where CS would be located the Arrábida store, an EDV truck would need to travel for 5,734 km at minimum (from COL Gaia) and 67.440 km at maximum from the Aveiro store. It is evident from this table that scooter EDVS examined in UC3 are highly unlikely to be used with recharging relocation tours since their range is 70km per battery.

Based on these insights the UDR model has been run for the first week of May 2022 for all the preparation stores in the dataset. Given the computational resources available for solving the Capacitated-VRP-TW module of UDR, several EDV trajectories have been attempted to be simulated resulting in simulations of full-truckload trips in the Porto region for EDVs with 250 km maximum range and 150 boxes of maximum capacity. Based on simulation results it seems that the capacity of the vehicles limits the range covered per delivery run to less than 100km per run per dispatch window, with few outliers' exceptions being run for over 100km per delivery trip.

All in all, from the quantitative analysis included for this first section, it can be concluded that, to achieve a transition from a conventional truck fleet to a modern EDV truck fleet (i.e., with a range of at least 250km at full charge, and at least 150 boxes of capacity), SONAE doesn't need to establish CS at every preparation store. By installing some of them at locations of the network (based on the CS-FLP model), SONAE can cover the recharging needs of an EDV trucks when necessary. A next step for this study is to find optimal *number and locations* of charging stations based on a direct integration of UDR model and CS-FLP model.

3. Results for the second research question utilizing CS-FLP model

To answer the second question INLE has developed an individual Charging Stations Facility Location model (CS-FLP), which can provide decision support regarding the placement of CS at the locations of SONAE's network. To make the application of this model as realistic as possible, two criteria have been considered for the positioning of the Charging Stations (CS), the distances between the depots and the total demand at each depot.

The CS-FLP model can answer the following question: Given a set of locations N and given that the LSP wants to install CS at Y out of the N locations, at which of the N locations the CS should be placed to minimize operational cost according to distances and demand? Since in the Porto LL, we have seven facilities, in our problem we have *N=7,* we need to execute the model seven times for the different values or execute the model seven times for the different values of *Y = [1,6].* The scenario where *Y=7* is excluded from the experiments since in this case all locations have their own chargers, and there is no need for EDVs recharging transfer in between them. The results are presented in Table 10 below:

Table 10 - Experiments results of the application of CS-FLP model to the case of Porto LL

Results for the facility location of EV chargers				
Value of Y = Maximum number of locations to install *EV* chargers	Facilities to establish CS stations when **distance** is considered	Objective Function Value (m)	Facilities to establish CS stations when **demand-weighted distance** is considered	Demand-weighted Objective Function Value (Percentage of demand at depot) x (meters)
Y = 1	COL Arrábida	224.279	COL Arrábida	12.907
Y = 2	COL Arrábida, COL Braga	130.208	COL Arrábida, COL Braga	7.927
Y = 3	COL Arrábida, COL Braga, COL Aveiro	58.650	COL Arrábida, COL Braga, COL Aveiro	5.065
Y = 4	COL Arrábida, COL Braga, COL Aveiro, **COL Guimarães**	34.217	COL Arrábida, COL Braga, COL Aveiro, **COL Valongo**	2.900
Y = 5	COL Arrábida, COL Braga, COL Aveiro, **COL Guimarães, COL Valongo**	12.574	COL Arrábida, COL Braga, COL Aveiro, **COL Valongo, COL Gaia**	1.270
Y = 6	COL Arrábida, COL Braga, COL Aveiro, **COL Guimarães, COL Valongo, COL Matosinhos**	5.259	COL Arrábida, COL Braga, COL Aveiro, **COL Valongo, COL Gaia, COL Guimarães**	293

Based on the analysis offered by the CS-FLP model, we can see in Table 10 the prioritization of depots based on the number of depots that we select to install charging stations to. From Table 10 it is evident that COL Arrábida, COL Braga, and COL Aveiro are the locations that are the most important for both when only distances are considered, and when demand is considered in the objective function of the model. Then from the experiment results in Table 10, we can see that when the model can establish charging stations up to four locations the prioritization changes: when only distance is considered COL

Guimarães is selected but when demand is considered COL Valongo is selected (along with COL Arrábida, COL Braga, COL Aveiro). Then one the differentiation is further augmented for *Y = 5* and *Y = 6* in both cases, with the distance-based CS-FLP leaving COL Gaia as the last facility to be included in the *Y = 6* case, and in demand-weighted experiments leaving out COL Matosinhos. These results can be further understood when one considers the spatial distribution of depots in Figure 5 and the demand weights at Table 11 below:

Table 11 - Demand weights per SONAE depot (percentage of demand compared to whole demand at all depots)

	COL Arrábida	COL Matosinhos	COL Gaia	COL Aveiro	COL Valongo	COL Guimarães	COL Braga
Demand weight	0.41	0.04	0.31	0.04	0.1	0.04	0.06

3.4.2 "What if" Scenario 2: Simulation and results

1. Data and models used

For the simulation results of the Use case 2, we use historical last-mile deliveries data for the months January 2021 to September 2021 for SONAE's COL Arrábida store located in the Porto area. Moreover, fleet specification, configuration data (e.g., stop time, handling time), corresponding centroid points for the preparation store are used. A detailed list of data is included in D3.13. A high-level overview of the scenario is presented in Figure 9 below.

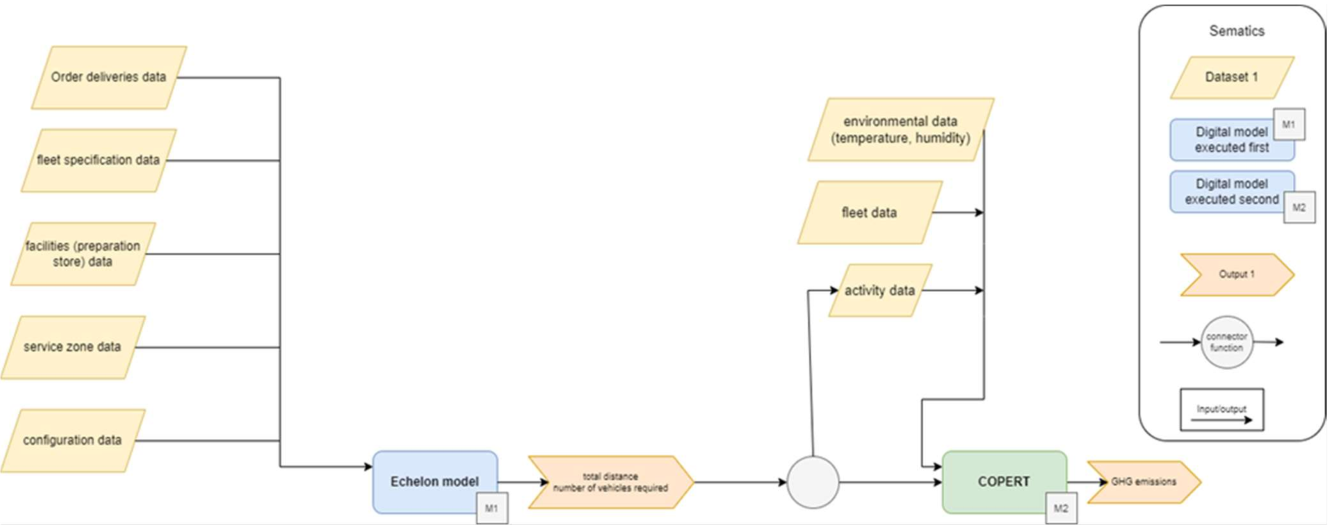

Figure 9 - Food delivery services models overview including connector

To simulate SONAE's instant food deliveries services and to investigate if Electric Deliveries Vehicles and in which percentage can be used for their establishment and operation, we create two scenarios:

- 1st scenario: Food deliveries using diesel fleet: Echelon model to compute first total distance and number of vehicles needed and COPERT to calculate GHG emissions for diesel vehicles (see Figure 10 on the left),
- 2nd scenario: Food deliveries using EDVs: Echelon model to compute first total distance and the number of vehicles needed and Porto-adapted EVCO2 to calculate emissions for EDVs (see Figure 10 on the right).

In both scenarios, the echelon model takes as inputs the facilities, orders, and deliveries zones, and configuration information. The COPERT takes as inputs the Portugal weather information, the total distance, and the number of vehicles needed that are the echelon outputs. Finally, the EVCO2 takes as input environmental factors for the Portugal region, the number of vehicles needed, and the energy consumption given the total distance for a specific number of orders.

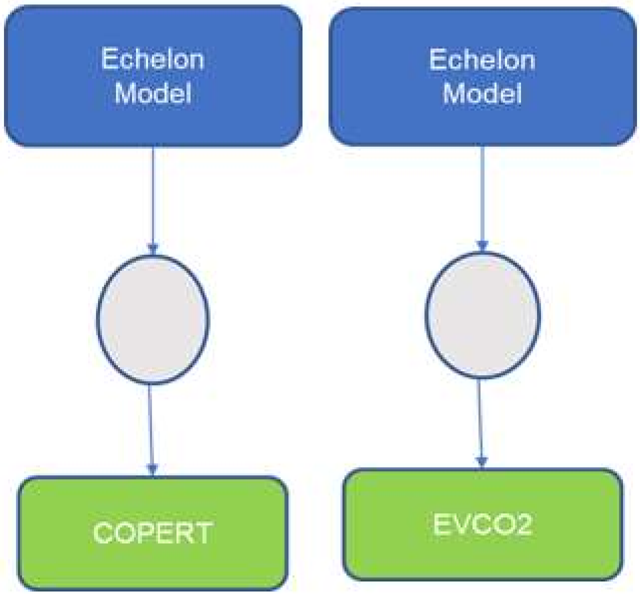

Figure 10 - Scenario 1: Food deliveries Diesel fleet (on the left) & Scenario 2: Food deliveries EDVs (on the right)

In the case of the LL6, the diesel fleet consists of Iveco Daily diesel refrigerated vans. More technical information on vehicles is presented in Table 12. However, the COPERT database contains passenger vehicles and not freight vehicles. Hence, the diesel vehicle selected from COPERT is a EURO VI Diesel classified as Category N1 (vehicles intended to transport freight with a maximum weight equal or less than 3.5 tons available in the COPERT database).

Table 12 - SONAE fleet technical specifications

Type	Engine	Brand	Model	Capacity (m3)	Capacity (kg)	Battery capacity (kWh)	Autonomy (kms)	Consumption (lts)
Refrigerated van	diesel	Iveco	Daily	12	760	n.a.	n.a.	16,5
Refrigerated van (eletrical)	eletrical	Maxus	eDelivery 9	9	785	88	250	n.a.
Motorbike	eletrical	Super Soco	CPX 125cc	0,14	30	n.a.	30-40 (per battery)	n.a.

Regarding the meteorological and traffic circulation data, they were collected and reported in D3.13.

In LL6, for the UC2 – the food delivery service, SONAE uses the electrical vans, Maxus eDelivery 9 (for technical information see Table 12) that consume 29.44 to 31.06 kWh/100km. For UC2 simulations, for the electrical vans' consumption, we use 30.23 kWh/100km.

To estimate CO_2 emissions from the delivery operations from Electric Delivery Vehicles in UCs 2 and 3 an adaptation of UPM's EVCO2 methodology has been utilized. Ideally, in the case of LL6, the suitable values for the electricity production have to be found in regard to two aspects:

- The participation of primary energy sources for the production of electricity in Portugal, and if possible, in the Porto region,
- Secondly, the estimated CO_{2eq} emissions for the electricity per source.

These are two sets of values that are proposed by the EVCO2 methodology and respective equation modelling in order to estimate the CO_{2eq} from delivery activities. In the Porto LL, and based on the information that researchers were able to find based on a report from Entidade Reguladora dos Serviços Energéticos (ERSE) [4] from 2021, the following sources have been included:

- Natural Gas: 31%
- Wind Energy: 28%
- Hydroelectric Power: 28%
- Solar Energy: 4%
- Biomass: 7%
- Coal: 1%

The ERSE report states 1% from "Other sources", which has been considered to have minimal effect for the adaptation. This report, that stated the participation of each source in the electricity production mix in Portugal for 2021, has been considered the main cornerstone for the adaptation of EVCO2 for LL6. However, the researchers were not able to find related information for the Porto region or Portugal's average emission intensity. According to several sources, the following hypothetical values are included in Table 13. Values in Table 13 average to a carbon intensity of ~250 gCO_2 per kWh on average which is inline the only source found for 2019 values[5].

The hypothetical values used for the emission factors (energy sources and electricity production) in Porto are presented in Table 13. For the utilization of this approach a Python implementation of the adapted EVCO2 methodology has been developed, which will be uploaded to the LEAD GitHub repository until the end of the project. With the approach developed it is expected that the estimations will reach realistic values, but the modelling of CO_2 emissions is not at the ideal level, as in the case where the exact values for the Porto region were available. The EVCO2 adaptation is expected to be further developed in the next few years including more detailed emission factors as well as the effect of elevation on consumption which can be done with NASA's Shuttle Radar Topography Mission (SRTM) data[6] through our already integrated OpenTripPlanner routing engine (with UDR model).

Table 13 - Emission factors in Porto

	gCO_2/kWh
Natural Gas	320
Wind Energy	11
Hydroelectric Power	24
Solar Energy	41
Biomass	230
Coal	911

2. Results from the analysis of SONAE's delivery services

In this section, we analyze results for a representative day of 2021. We run simulations for the AS-IS and what-if scenario. For the what-if scenarios, we split the orders based on the corresponding percentages of orders that have been delivered by diesel and electric vans respectively. To compute GHG emissions for diesel fleet, we use COPERT and for EDVs the EVCO2 model.

[5] Portuguese Renewable Energy Association (APREN), PORTUGUESE RENEWABLE ELECTRICITY REPORT, December 2019, https://www.apren.pt/contents/publicationsreportcarditems/portuguese-renewable-electricity-report-dec-19-vf.pdf

[6] Shuttel Radar Topography Mission data by Nasa, https://www2.jpl.nasa.gov/srtm/

Figure 11 shows the total number of orders per day for the months January 2021 to September 2021. We observe that an increase in orders during the COVID period. Hence, we focus on a normal period without exceptional circumstances, that is the last two months August and September 2022. To pick a representative day for our simulations, we compute the average of orders for months August and September and we choose a day that corresponds to that average value. This day is the September 29th and number of orders is 361.

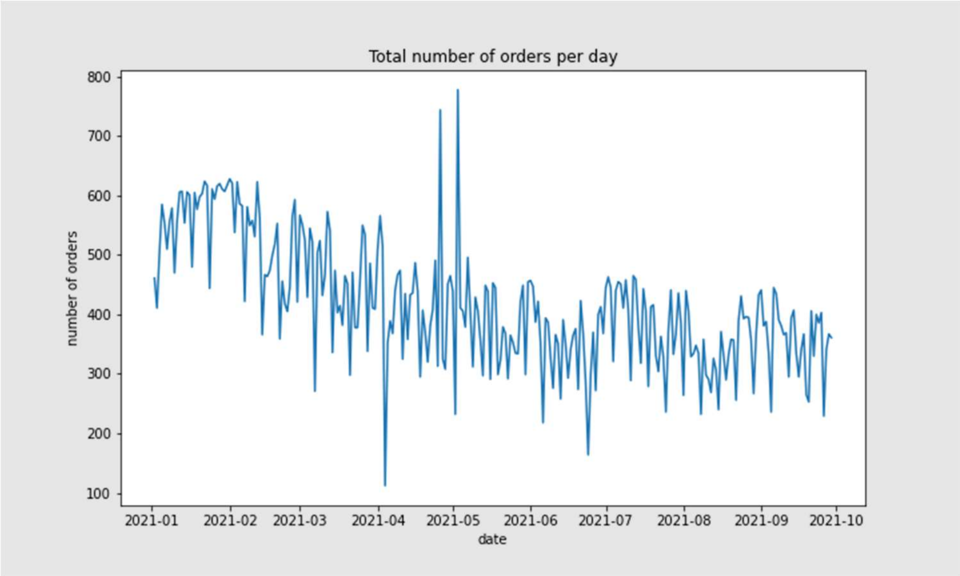

Figure 11 - Total number of orders per day from January 2nd, 2021, till September 30th, 2021

Figure 12 depicts the total number of orders per slot (client time-windows) for the 29th of September 2021. As observed, most orders are delivered either during morning or night. SONAE delivers three times per day in specific dispatch windows. The correspondence of the client time-windows to the dispatch windows (DW) is reported in Table 14. As described in Section 3.1.4 with the modelling conditions and assumptions, the three dispatch windows, in which SONAE groups the dispatch of deliveries, are 10:00-14:00, 14:00-18:00, 18:00-22:00.

Figure 12 - Total number of orders per slot on 29th September 2021

Table 14 - Client time-windows to dispatch windows

Slot	Dispatch Window
00:00 - 11:45	Morning
00:00 - 15:45	Morning
08:00 - 10:00	Morning
08:00 - 20:00	Morning
10:00 - 12:30	Morning
10:00 - 14:00	Morning
10:00 - 14:30	Morning
12:00 - 14:30	Morning
14:00 - 16:30	Afternoon
14:00 - 18:30	Afternoon
16:00 - 18:30	Afternoon
18:00 - 20:30	Night
18:00 - 22:30	Night
20:00 - 22:30	Night
21:30 - 23:30	Night
22:45 - 23:45	Night

Table 15 - Number of orders delivered by diesel or electrical fleet per dispatch window for all scenarios (AS-IS and what-if for UC2)

Scenario	DW0	DW1	DW2
AS-IS	130 orders	105 orders	126 orders
What-if1	33 orders (diesel) 97 orders (electric)	26 orders (diesel) 79 orders (electric)	31 orders (diesel) 95 orders (electric)
What-if2	65 orders (diesel) 65 orders (electric)	52 orders (diesel) 53 orders (electric)	63 orders (diesel) 63 orders (electric)
What-if3	97 orders (diesel) 33 orders (electric)	79 orders (diesel) 26 orders (electric)	95 orders (diesel) 31 orders (electric)

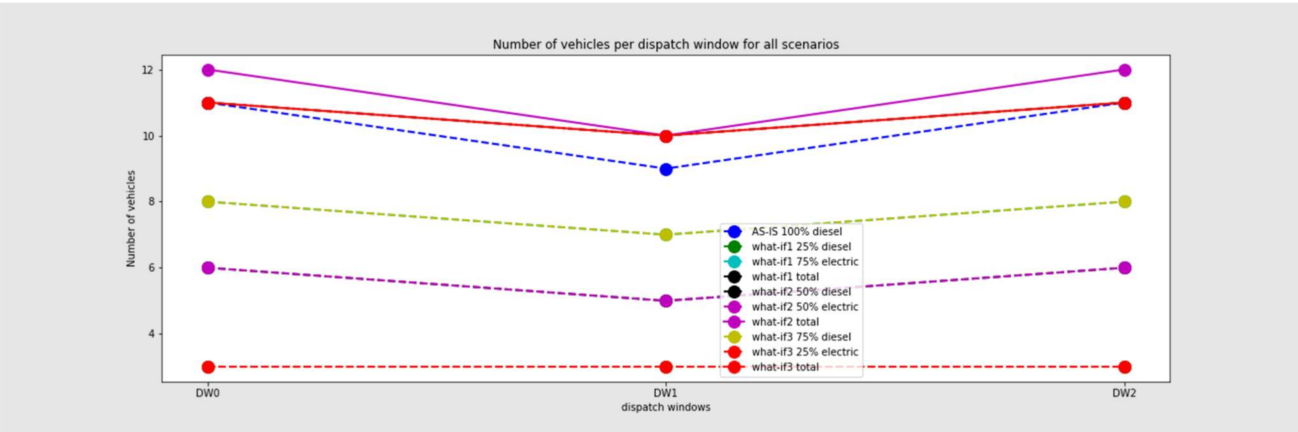

Figure 13 - Number of vehicles used per dispatch window for all scenarios

Table 16 - Number of vehicles per dispatch windows for all scenarios

	DW0	DW0_total	DW1	DW1_total	DW2	DW2_total
AS IS	11	11	9	9	11	11
What-if 1 (diesel)	3	11	3	10	3	11
What-if 1 (electric)	8		7		8	
What-if2 (diesel)	6	12	5	10	6	12
What-if2 (electric)	6		5		6	
What-if3 (diesel)	8	11	7	10	8	11
What-if3 (electric)	3		3		3	

Figure 13 presents the total number of vehicles needed per dispatch window for all scenarios and specifically the number of diesel and electric vehicles per what if scenarios. In all cases, we observe that during DW0 (morning) and DW2 (night) more vehicles needed to serve the deliveries. This can be explained by most of orders delivered either during morning or night as shown in Table 15. We also notice that in some cases such as what-if scenario 2 where 50% of the orders delivered by diesel fleet and 50% of the orders by EDVs, one more vehicle needed in total (see Annex 1) per DW to serve all the deliveries. This happens due to the smaller capacity (capacity m3) of the EDVs in comparison to the diesel fleet (see Table 12).

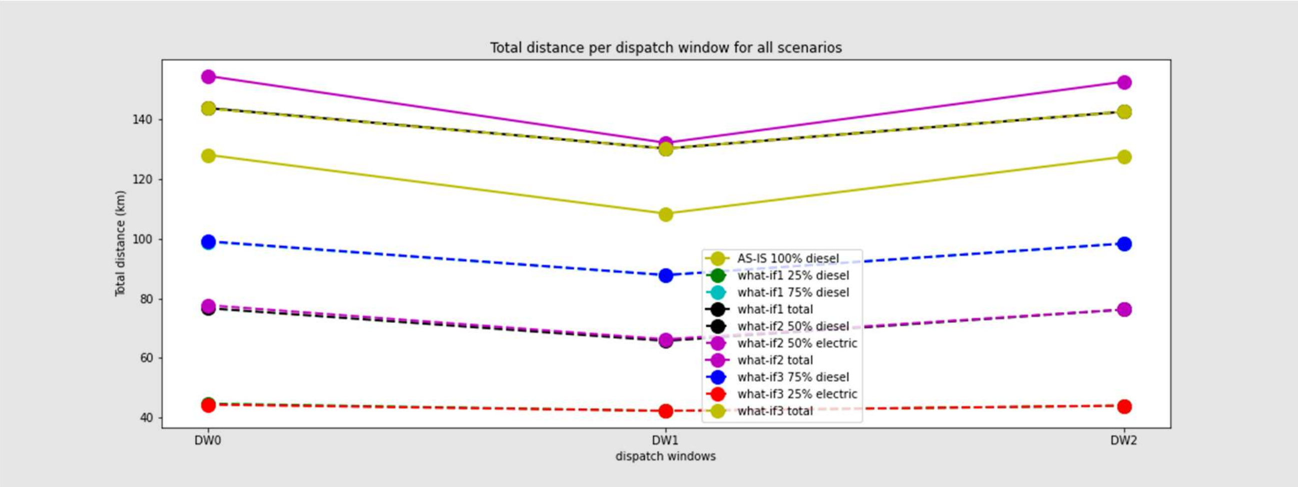

Figure 14 - Total distance traversed per dispatch window for all scenarios

Figure 14 shows the total delivery distance per dispatch window for all scenarios and the total delivery distance that the diesel and electric vehicles traversed per what if scenario. We note that the total delivery distance is larger during DW0 and DW2. This can be explained by the number of orders and the clients' geolocation data. Moreover, the delivery distances for the what-if scenarios are larger than AS-IS scenarios (see Appendix 1) because more vehicles are usually used due to the EDVs capacity as explained above. This implies that the extra vehicles that are used to serve the deliveries, might visit the same neighborhoods/regions as other vehicles from the fleet. Hence, the distance traversed of the extra vehicle(s) is added to the total one.

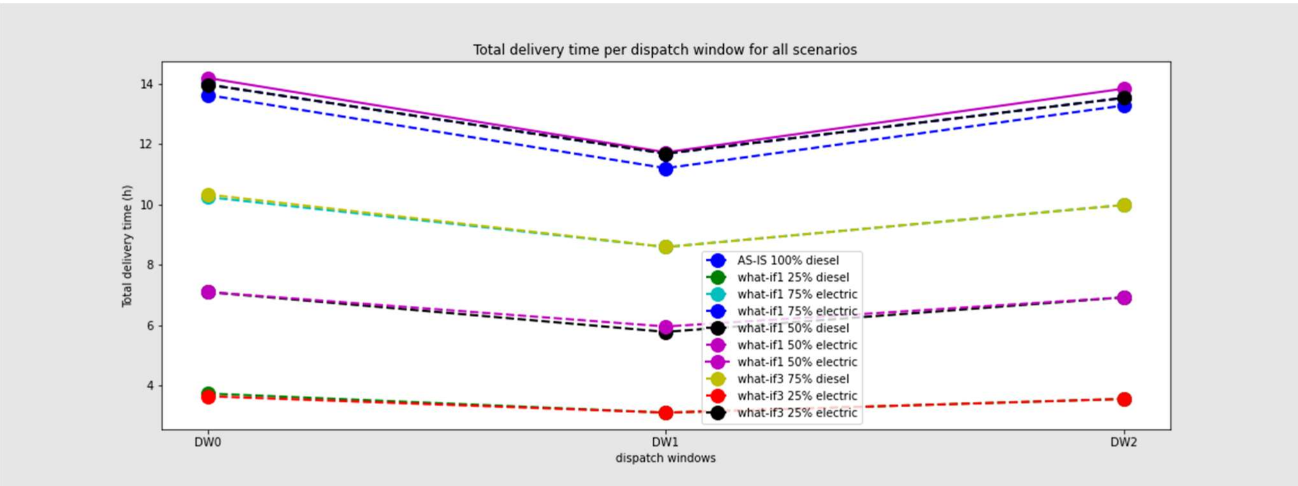

Figure 15 - Total delivery time per dispatch window for all scenarios

Figure 15 illustrates the total delivery time per dispatch window for all scenarios and the total delivery time that the diesel and electric vehicles needed per what if scenario. Same here, the total delivery time is longer during DW0 and DW2 as expected due to the DW duration: the DW0 is 14.5hours and the DW2 is 5.75hours and the number of vehicles and orders and the distance that traversed the extra vehicles. The values of total delivery time per dispatch window for all scenarios are also presented in Appendix 1.

Figures 16-19 shows the GHG emissions for total NO2, VOC2, PM2.5 and, CO_2 respectively. We notice that in the AS-IS scenarios the emissions are more than the others three what if scenarios. The higher percentage of the orders that are delivered by diesel fleet, the more NO2, VOC2, PM2.5, CO_2 are emitted as expected. The values of NO2, VOC2, PM2.5 and CO_2 are also reported in Appendix 1.

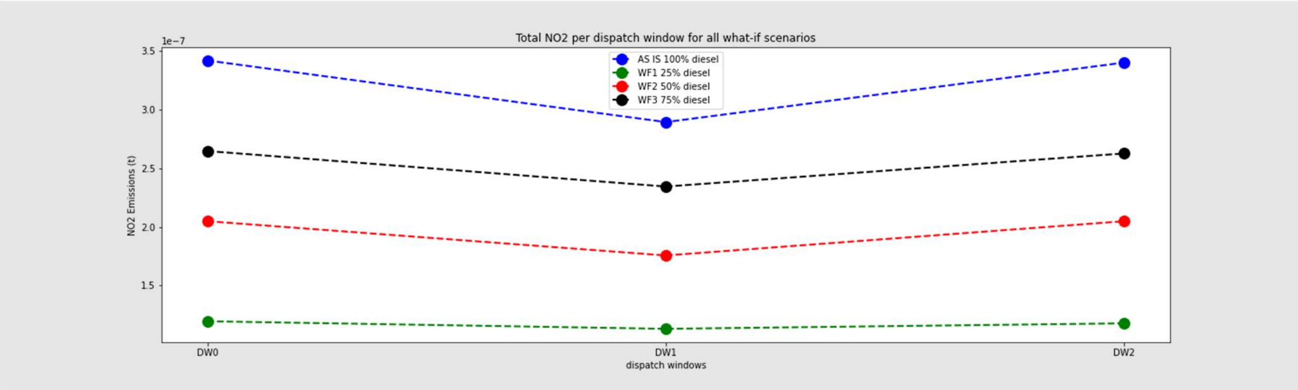

Figure 16 - Total NO2 per dispatch window for all scenarios

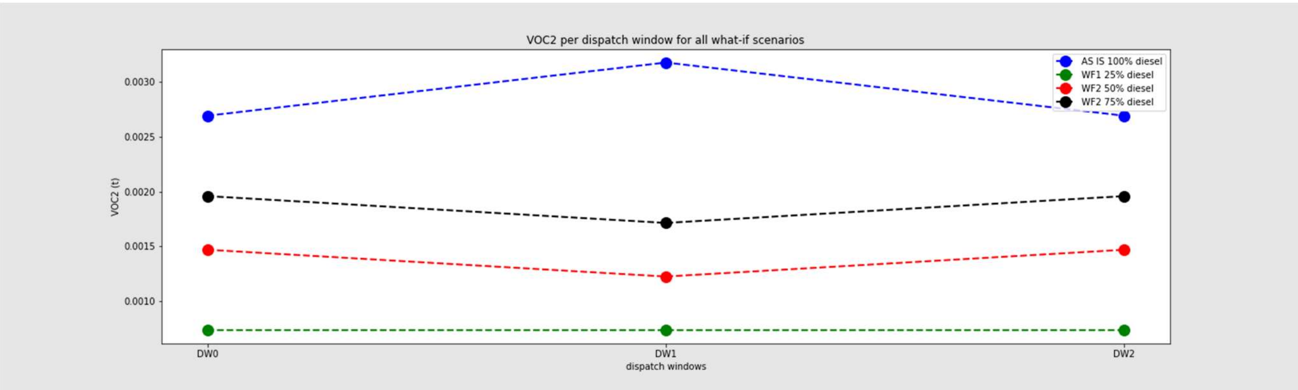

Figure 17 - Total VOC2 per dispatch window for all scenarios

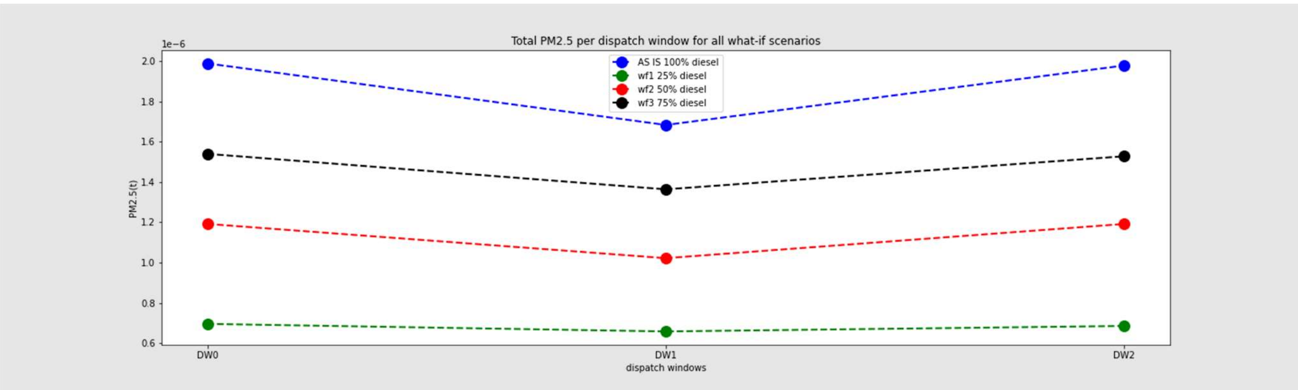

Figure 18 - Total PM2.5 per dispatch window for all scenarios

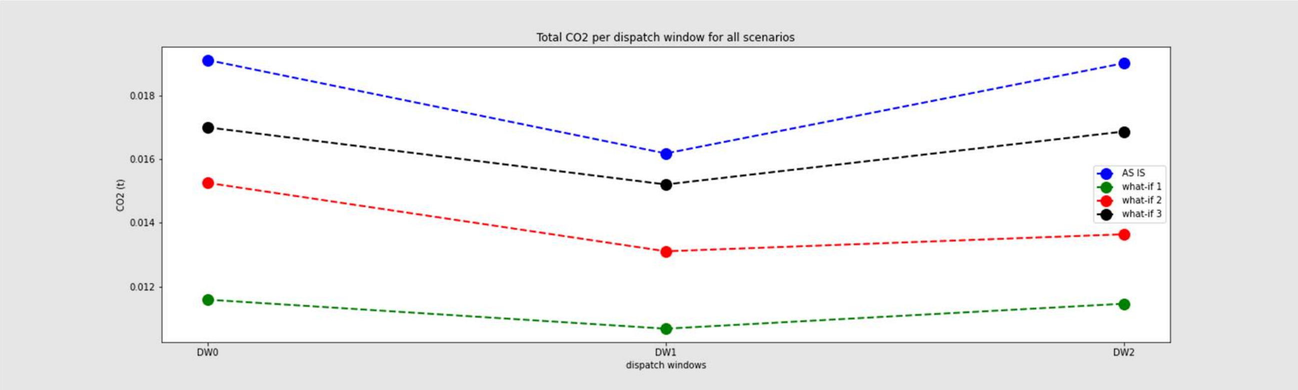

Figure 19 - Total CO_2 per dispatch window for all scenarios

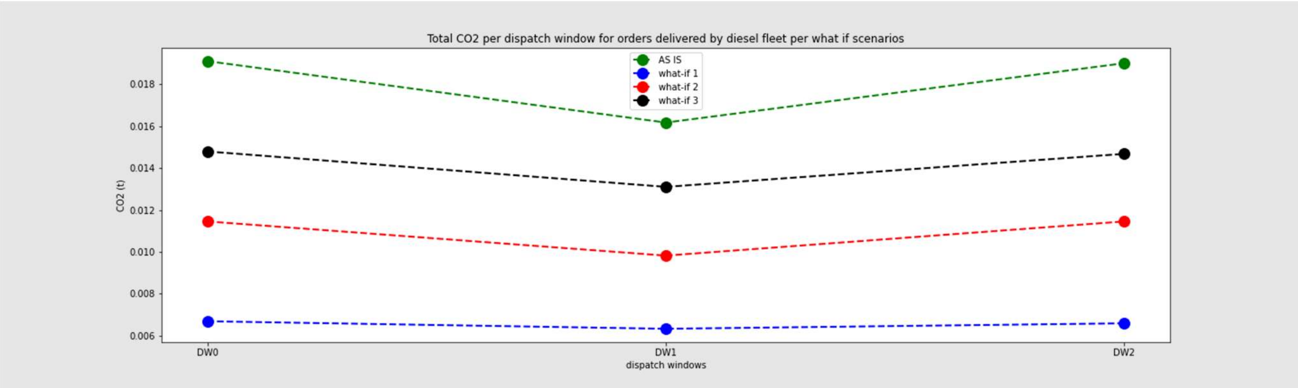

Figure 20 - Total CO_2 per dispatch window for orders delivered by diesel fleet per what if scenarios

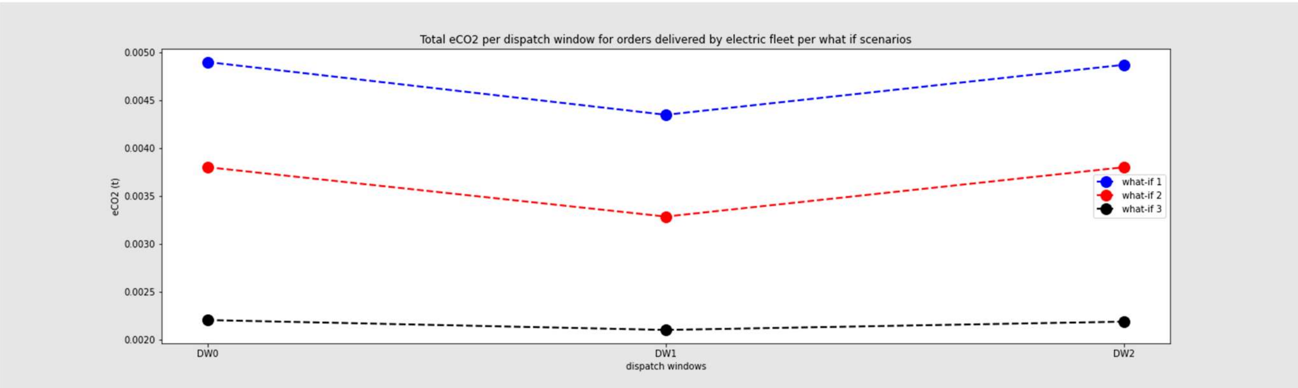

Figure 21 – Total CO_2 per dispatch window for orders delivered by electric fleet per what if scenarios

Moreover, Figure 22 shows the total energy consumption per dispatch window for all scenarios. We note that in the AS IS scenario more energy is consumed than the other three scenarios and as more electric fleet is used as less energy is consumed. Figures 23-24 illustrate the energy consumption per dispatch window for orders delivered by diesel or electric fleet respectively. We observe that the energy consumption is less in what-if scenarios than AS IS scenarios as expected since the electric vehicles use less energy than diesel ones. The values of energy consumption for diesel and electric vehicles and in total per dispatch windows for all scenarios are detailed in Appendix 1.

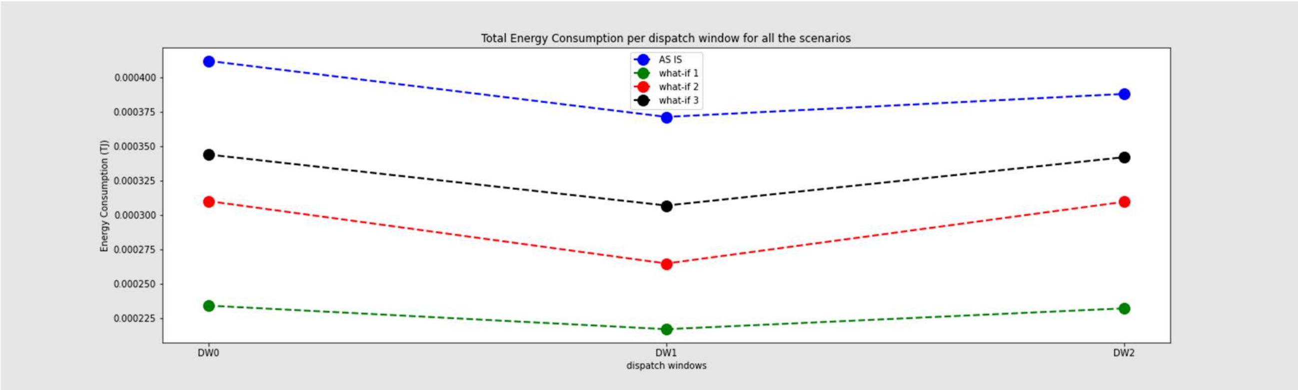

Figure 22 - Total Energy Consumption per dispatch window for all what if scenarios

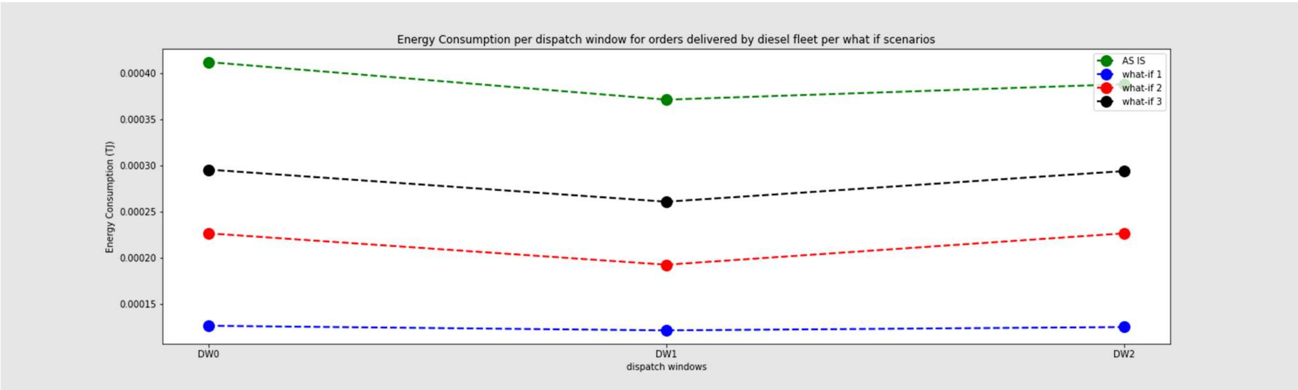

Figure 23 - Total Energy Consumption per dispatch window for orders delivered by electric fleet per what if scenarios

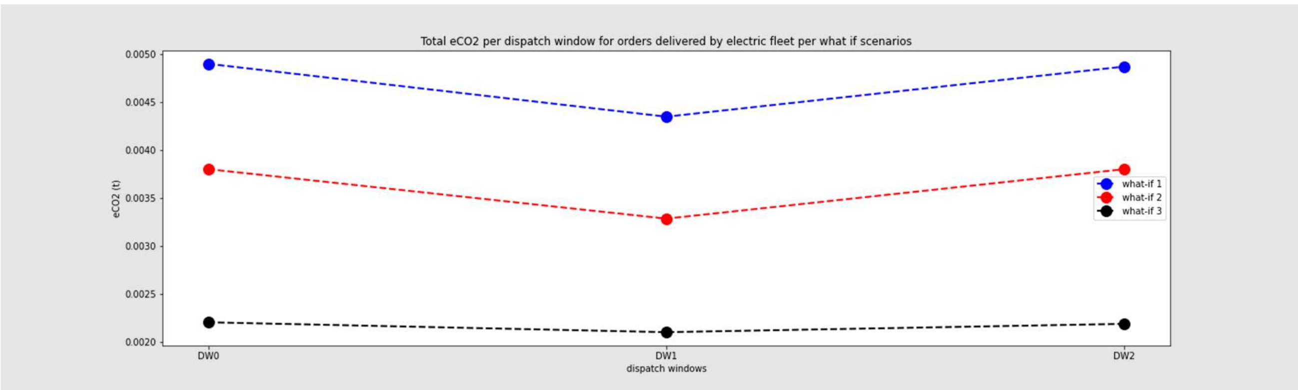

Figure 24 - Total Energy Consumption per dispatch window for orders delivered by electric fleet per what if scenarios

3.4.3 "What if" Scenario 3: Simulation and results

1. Data and models used

For the simulation results of the UDR algorithm, we used mainly historical last-mile deliveries data for the months January 2022 to June 2022 for SONAE's Arrábida store located in the wider Porto area. Other datasets used have been the Porto area's list with corresponding centroid points, the depot data, as well as the fleet specification data. A high-level overview of the model can be seen in the Figure 25 below.

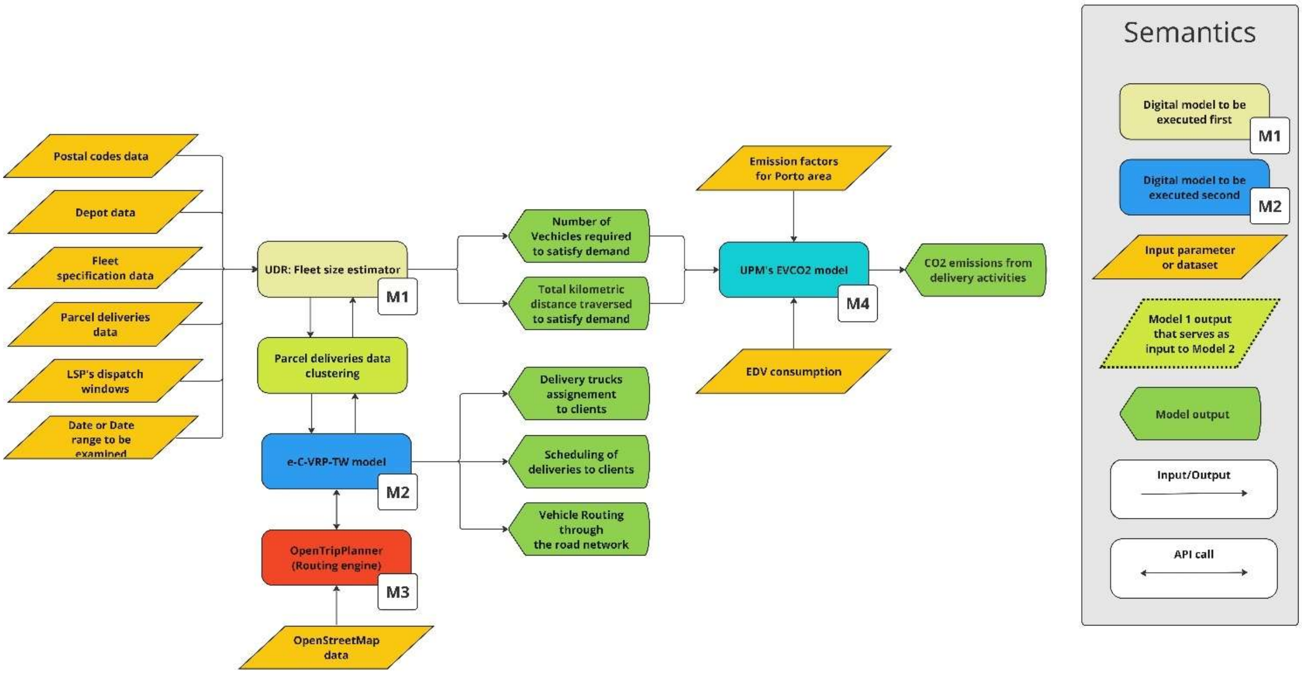

Figure 25 - UDR models overview including the three main submodels

Central to the development of the UDR model has also been OpenTripPlanner routing engine [1] and the related OpenStreetMap dataset [2] that have been utilized for the dynamic calculation of the Origin-Destination (O-D) matrices upon which the e-C-VRP-TW calculations has been based. As discussed above, the UDR model can be used in two ways: 1) One is through the Digital Twin platform in order to assess the number of EDVs required to satisfy customer demand in the upcoming demand window on a daily basis, and 2) To utilize it on historical data in order to have an estimate of EDVs required based on previous needs and seasonal patterns. This section will focus on the second use case for the UDR model.

Before proceeding with the results section, let us also make a reference to UPM's EVCO2 model that has been utilized in order to calculate emissions from the usage of scooter EDVs utilized for the deliveries. As described above, EVCO2 has been adapted to the Porto case by utilizing the data for energy production in Portugal in 2021 based several sources [3], [4]. The results about CO_{2eq} emissions from the small orders service and the rescheduling service can be found in sections below. Based on the sources the following values have been considered for the energy sources and electricity production in Porto:

- For the gCO_{2eq}/kWh, previously in Table 13 numbers have been detailed;
- And for the participation of each energy source to electricity production in 2021 [4]:
    - Natural Gas: 31%
    - Wind Energy: 28%
    - Hydroelectric Power: 28%
    - Solar Energy: 4%
    - Biomass: 7%
    - Coal: 1%

2. Results from the analysis of SONAE's potential small-orders service

The UDR model has been run for each one of the six months that the LSP has provided to the modelling team focusing only on small order demand that existed within the three time-windows of each day in the dataset. While results for all six months are included in Appendix 1, in this section we will analyze results for January and February 2022, the first two months out of the six that have been under study. Based on UDR's application to the dataset, the following results are included.

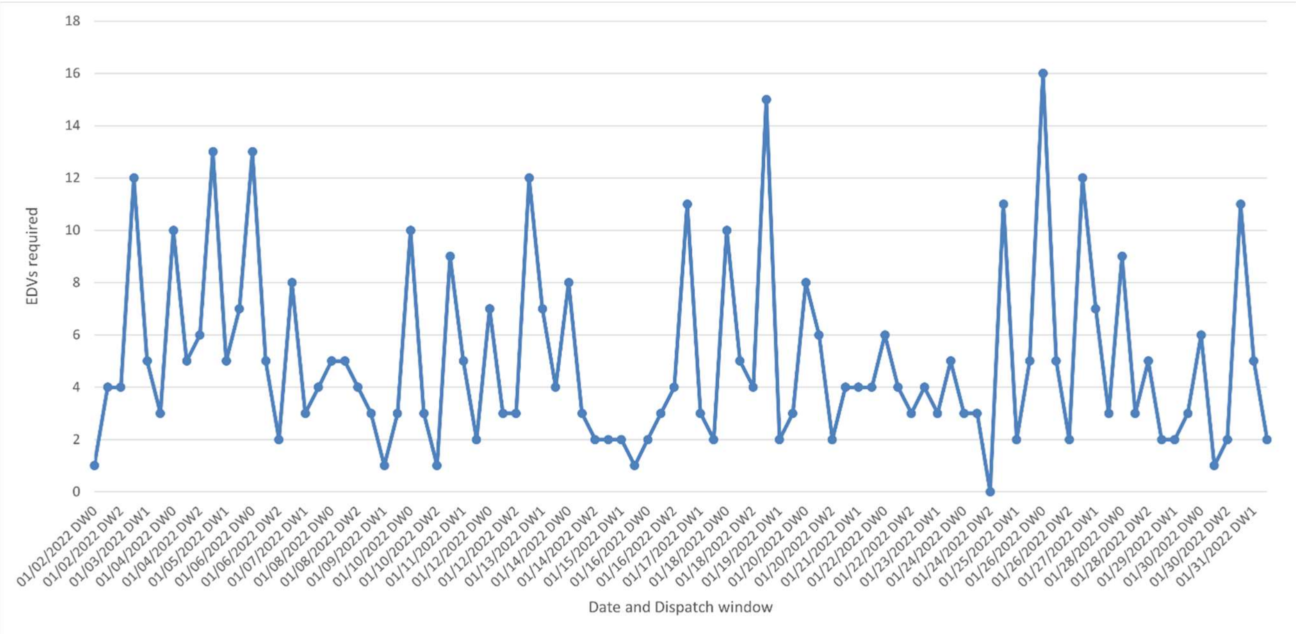

Figure 26 - Number of EDVs required to cover small orders demand in January 2022 in Arrábida store

From the results presented in Figure 26 above, it can be noticed the most demanding dispatch window is the first dispatch window, with 01/26/2022 being the most demanding day requiring 16 EDVs in order to cover demand during the dispatch window. While there have been time windows with zero customer demand (i.e., referring to small orders only), there have been only 10 dispatch windows out of the 90 examined in January, that required 11 or more EDVs to cover demand. The least demanding type of dispatch windows have been the third dispatch windows within each day, with most third dispatch window occasions requiring 3 or less EDVs to cover demand. Based on the statistical analysis on the results of the simulations, 21 dispatch windows out of the 90 consider in January required 2 or less EDVs, while 39 dispatch windows required 3 or less EDVs.

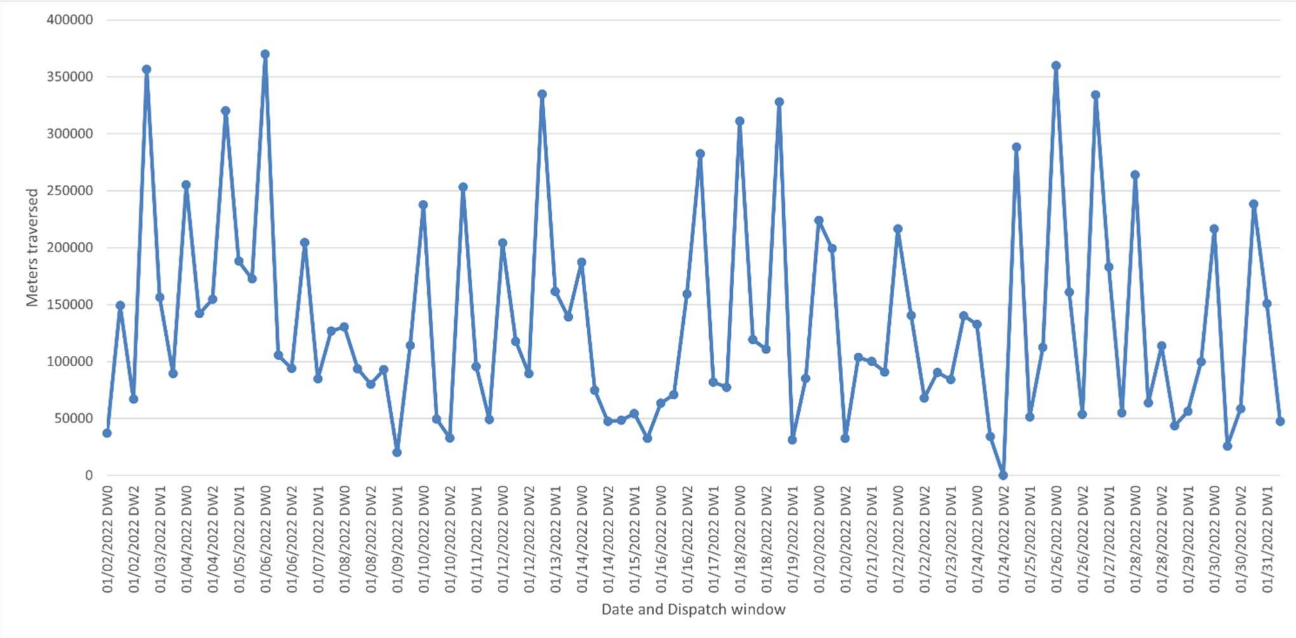

Figure 27 - Meters traversed by EDVs to cover small orders demand in January 2022 in Arrábida store

Complementary to Figure 27 that presents the EDVs required, in Figure 13, one can notice the metric distance covered by the EDVs for the same period of January 2022. The maximum distance covered has been noticed on the 6th of January 2022 with the value being 370.066 meters, when the EDVs required for that day have been estimated to be 13. From the two graphs for January one can notice that the number of EDVs required is not strongly coupled with the number of meters traversed, meaning that the distance to the customers is not strongest factor to affect EDV requirements, but time windows and volume is also correlated with the number of EDVs required. Moving on to the February case, the corresponding results are included in Figure 28 and Figure 29 below.

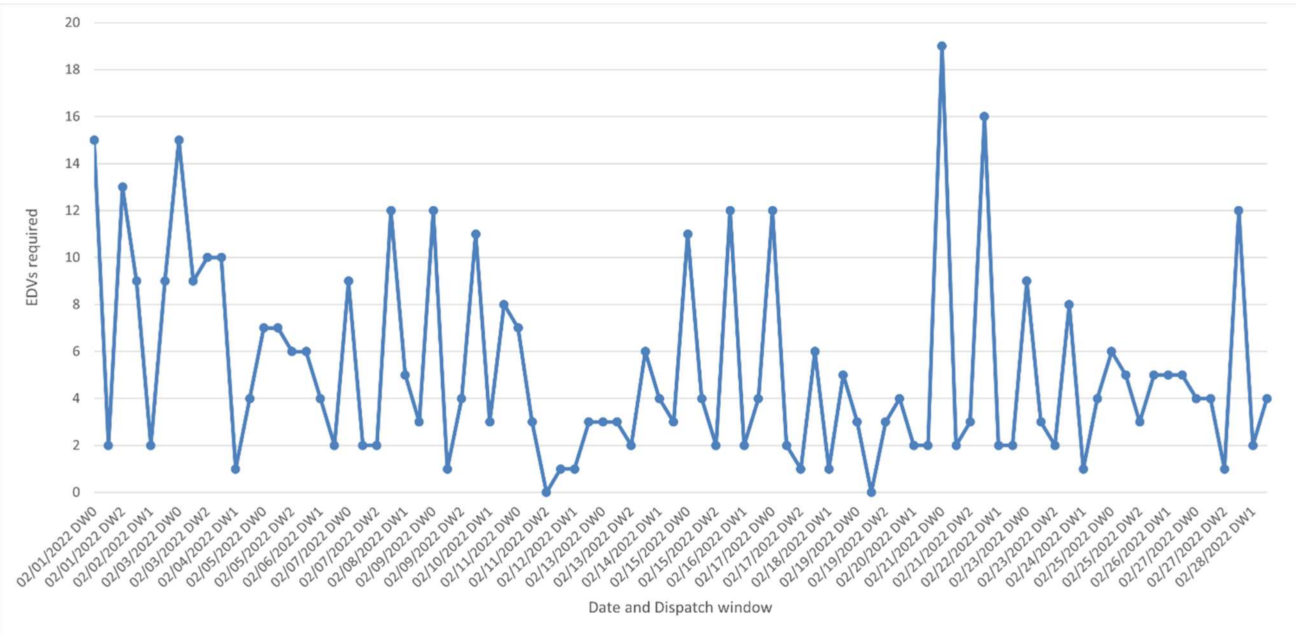

Figure 28 - Number of EDVs required to cover small orders demand in February 2022 in Arrábida store

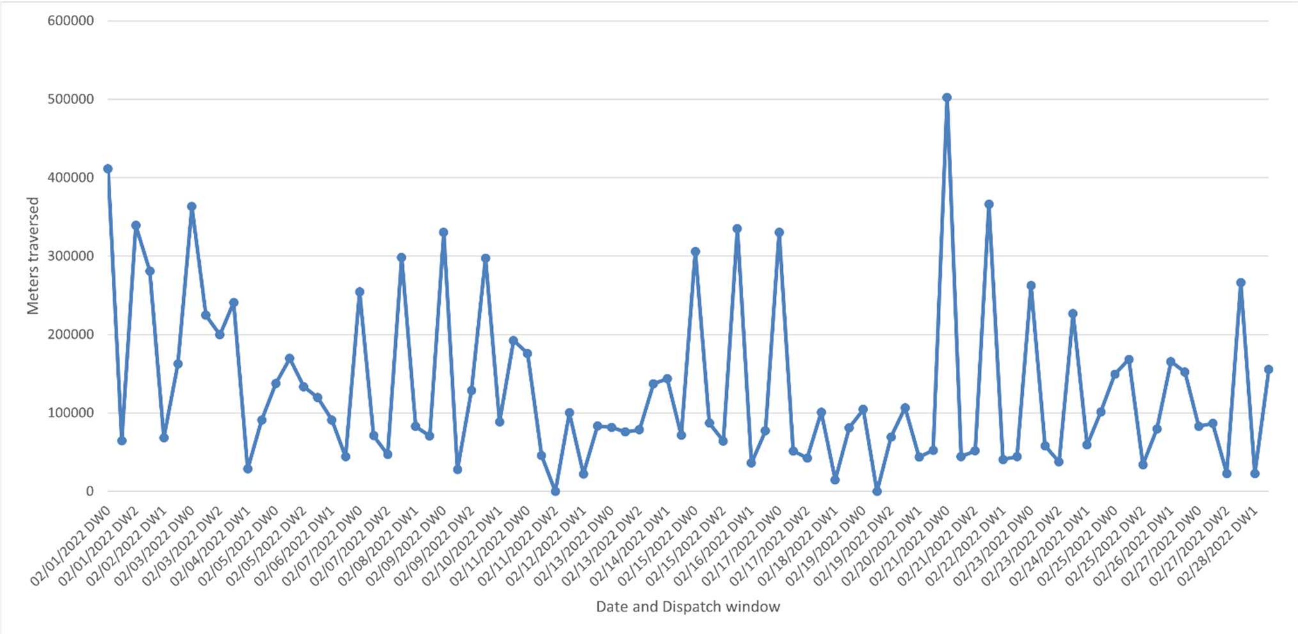

Figure 29 - Kilometers traversed by EDVs to cover small orders demand in February 2022 in Arrábida store

From Figures 28 and 29, the maximum number of EDVs for February was 19 on the first dispatch window of the 21st of February. Based on the simulations for February 2022, there have been dispatch windows with zero small orders demand, and according to analysis, there have only been 79 dispatch windows out of the 84 overall in February 2022 that can be covered with a fleet of 13 of SONAE's scooter EDVs. On the other hand, while focusing on the lower side of the demand per dispatch window, 38 out of 84 dispatch windows can be covered with 3 or less scooter EDVs, and 49 out of 84 dispatch windows can be covered with 4 EDV scooters. As in the case of January 2022, one can notice that the meters traversed by the EDVs are not strongly coupled with the number of EDVs required. Finally, let us state again that both in February and January 2022, the peaks in EDVs required for the small orders service are estimated during the first dispatch window, with dispatch windows two and three usually requiring less vehicles.

3. EDV requirements for the 6-month period under study for the small orders service

From the analysis of the small orders service to be established, the UDR model has been used to extract the number of scooters EDVs required to cover demand for 540 Dispatch windows within a 6-month period based on data provided by SONAE. Although the exact number per time window, as well the kilometers traversed, and the environmental impact have been included in Annex 1, a summary of some statistical important values is given in Table 17 and Figure 30 below.

Table 17 - Maximum, minimum and average values estimated for EDV requirements for test period

Month	Maximum	Minimum	Average	Median
January 2022	16	0	5,02	4

February 2022	19	0	5,26	4
March 2022	23	0	5,93	4
April 2022	20	0	4,88	4
May 2022	20	0	6,36	5
June 2022	21	0	5,24	4
Average per month	19,8	0	5,44	4,16

In Table 17, one can notice that the maximum number of EDVs in order to cover transport based on real-world network distances and SONAE's delivery demand for 2022, has been 23 EDVs while the minimum value has been zero. The latter value is based on the fact that for some of SONAE's dispatch windows within the 6-month period there was not small orders demand. On average across all time widows, six EDVs (i.e., 5.44 EDVs have been required) in the six-month period from January to June 2022. As mentioned in other parts of this document, the business value of this model and the analysis that it can provide is focused on two aspects:

1) Real-time estimation of EDVs required to satisfy daily demand within LSP's time windows (DT functionality).
2) But also, it can also be used with historical data as shown in this section to forecast number of EDVs required to cover delivery demand.

In Figure 30 below we can find one of the core results of the analysis which can enable SONAE to understand the investments requirements regarding fleet procurement if they need to realize the small orders service.

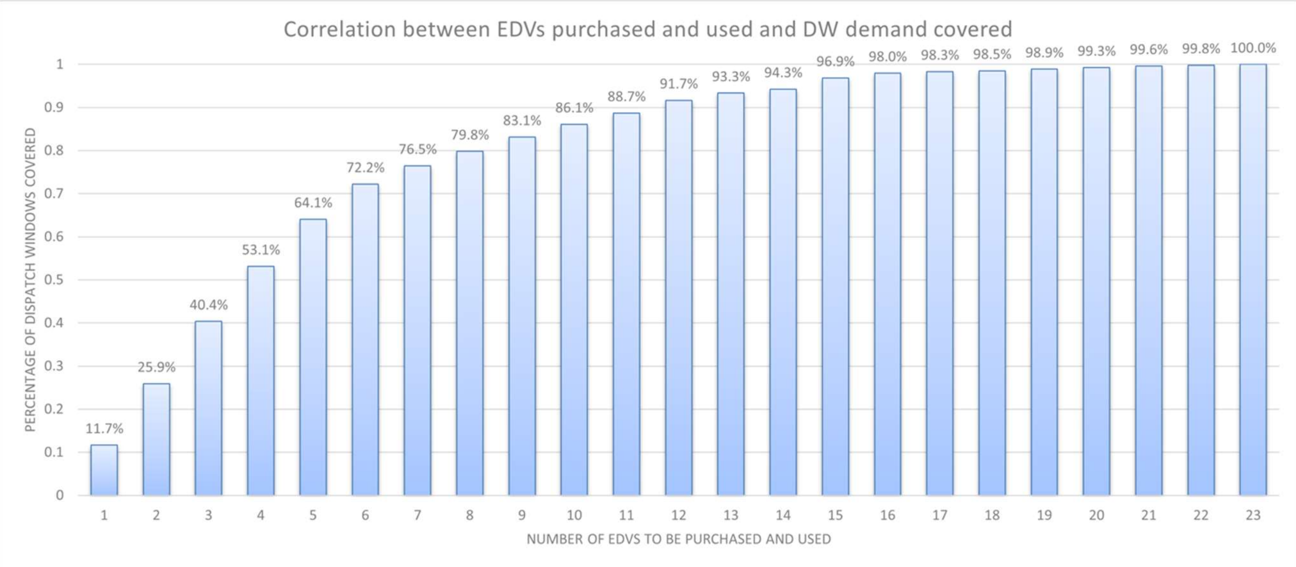

Figure 30 - Correlation between EDVs to-be-purchased and the covered demand per Dispatch Window

Based on Figure 30, one can notice the relationship between the EDVs to be purchased and the number of dispatch windows to be covered by that number of EDVs, in the case that SONAE will establish the small orders service based on them. For example, if SONAE moves on to purchase *three EDVs* and realize the small orders service based on that size of the fleet, then 40.4% (i.e., 218 out of total 540 dispatch windows) of the overall number of dispatch windows will be covered by that size of the fleet (i.e., when only referring to small orders demand). Another example from Figure 30, if SONAE moves on to purchase 8 scooter EDVs and use them for the small orders service at the Arrábida store, 79.8% of the small orders demand can be covered by the EDVs.

Based on the results of this analysis, SONAE can now move on to develop a more accurate business plan where they can more accurately estimate the investment costs for their small orders service. For the effective business planning of the small orders service SONAE would need to estimate the revenue from covering the different percentages of small orders demand at the Arrábida store, or other stores.

4. Emissions estimation for the 6-month period under study for the small orders service

The UDR model has been used in conjunction with EVCO2 in order to assess the environmental impact of SONAE's potential small order service case. To achieve that, UDR model has been utilized to calculate total kilometers run by EDVs in each case based on historical (or real-time in the case of DT), and EVCO2 has been utilized to calculate the CO_2 emissions of the vehicles. In Table 18 and Figure 31, some statistically important values for the emissions are presented.

Table 18 - Maximum, minimum and average estimated values estimated for emissions for the simulation periods (values in gCO_{2eq})

Month	Maximum	Minimum	Average	Median
January 2022	6.670.576	0	2.475.361	2.014.632
February 2022	9.055.639	0	2.395.784	1.583.745
March 2022	10.806.677	0	2.774.158	2.041.733
April 2022	11.470.606	0	2.209.126	1.671.366
May 2022	9.570.425	0	2.739.324	1.895.601
June 2022	8.236.260	0	2.130.137	1.548.586
Average per month	9.301.697	0	2.453.981	1.792. 610

As it can be seen in Table 18 and Figure 31, and as expected, March has been the month when we have the most emissions from the small orders service, while on average SONAE small orders delivery operations had on average 2.453.981 gCO_{2eq} produced. In Figure 31 below, the emissions for all dispatch windows based on the minimum number of EDVs employed for the small orders service are plotted.

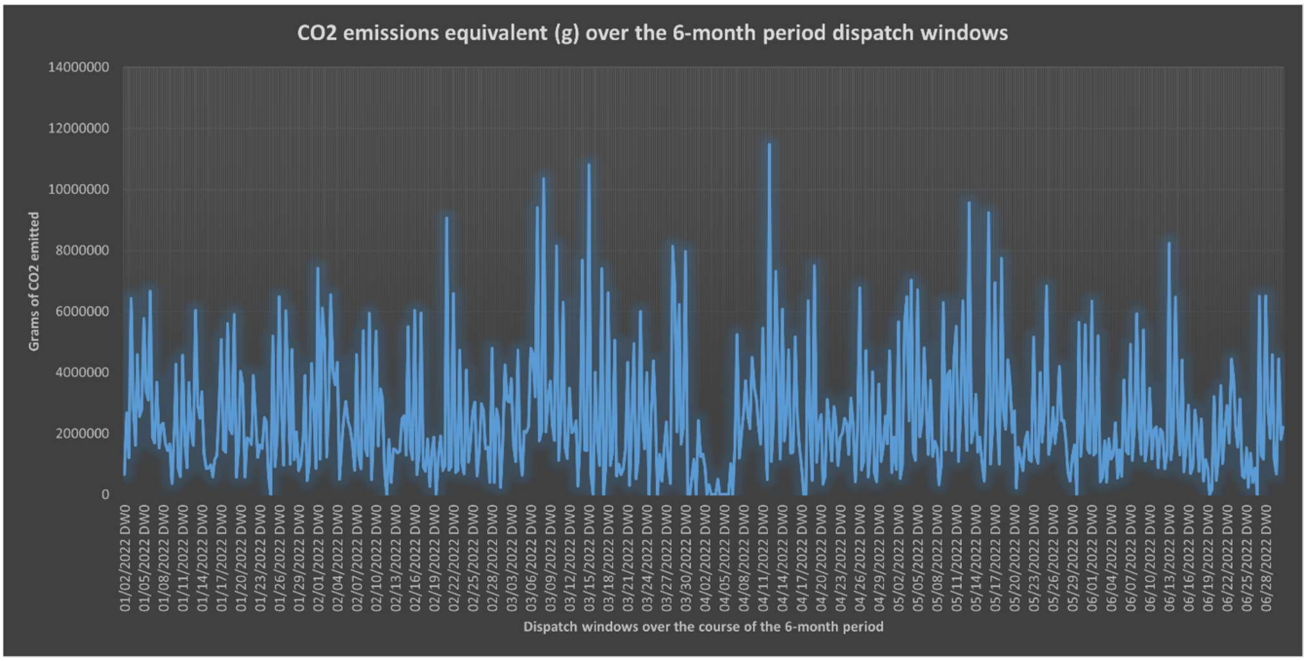

Figure 31 - Estimations about CO_2 emissions from the application of SONAE's small orders case when the minimum number of EDVs are employed based on demand

5. Results from the analysis of SONAE's potential rescheduling service

As discussed above the rescheduling service has a considerable smaller amount of demand (i.e., boxes) as compared to the small orders deliveries. Based on the statistical analysis by INLE on the deliveries data provided by SONAE:

- The number of small orders has been 24.890 entries in the initial deliveries file;
- The number of rescheduling orders has been 126 unique deliveries have been performed, out of 279 rescheduling delivery attempts to deliver the orders;
- The number of deliveries that have been both "small deliveries", as defined SONAE, but also rescheduling deliveries, have been 32;
- The total demand of rescheduling deliveries has been 842 boxes in the six-month period, and the total demand for small deliveries has been 51.455 boxes. The total delivery demand in the six-month period has been 1.877.832 boxes.

One can understand that these insights render the EDV requirements minimal as compared to the ones by the small orders service, especially if one considered that rescheduling order that are not small order (>3 boxes per order) are only 94 orders out of the 210824 overall delivery orders in the six-month period (less than 0.1%) as compared to small order which are ~12% of overall orders. For that reason, the model has been used to separately examine scooter EDV requirements for rescheduling orders that are small orders at the same time. In Figure 32 below, one can notice the correlation between EDVs to-be-purchased and the covered demand per dispatch window for a potential rescheduling service.

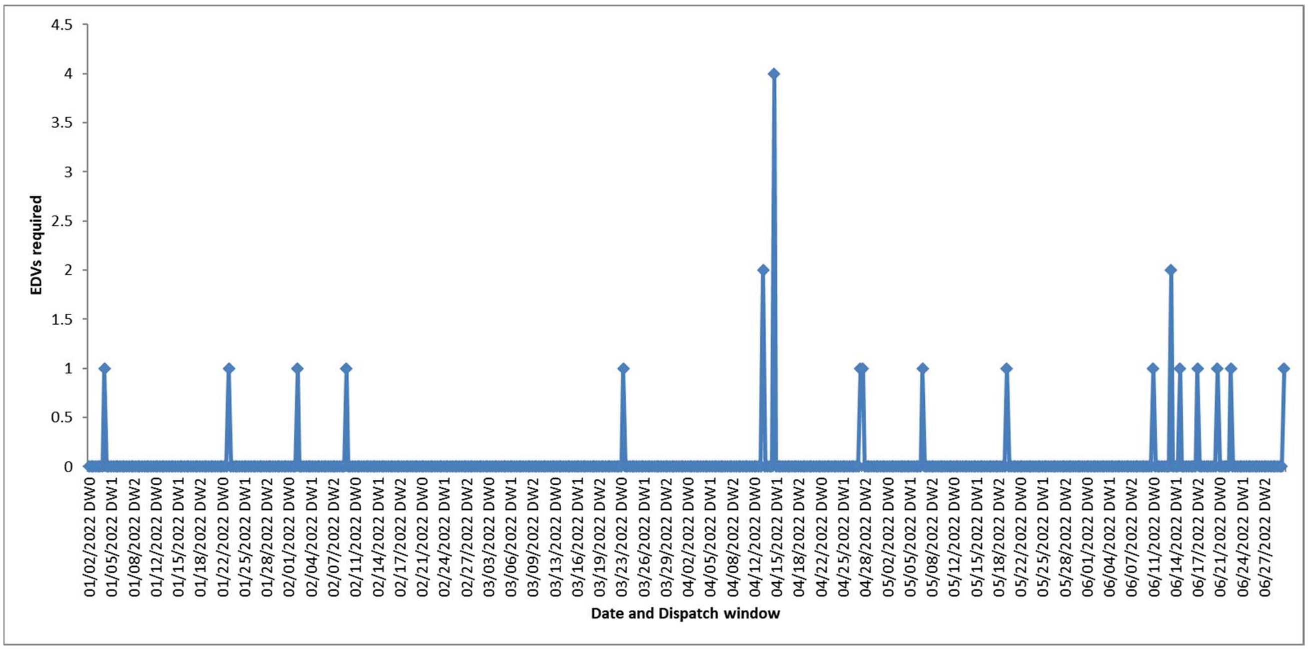

Figure 32 - Number of EDVs required to cover rescheduling orders demand in across the 6-months period Arrábida store

Based on Figure 32, above and due to limited number of rescheduled orders there are only very few dispatch windows when the EDVs would need to be utilized to deliver the orders. In more detail the dispatch windows that need require the rescheduling service are presented in Table 19:

Table 19 - Exact scooter EDV requirements for the establishment of the rescheduling service

	Date	Dispatch window	Number of EDVs required
1	01/04/2022	DW1	1
2	01/23/2022	DW0	1
3	02/02/2022	DW1	1
4	02/09/2022	DW2	1
5	03/23/2022	DW1	1
6	04/13/2022	DW1	2
7	04/15/2022	DW0	4
8	04/28/2022	DW0	1
9	04/28/2022	DW1	1
10	05/07/2022	DW1	1

	Date	Dispatch window	Number of EDVs required
11	05/20/2022	DW0	1
12	06/11/2022	DW0	1
13	06/13/2022	DW2	2
14	06/15/2022	DW0	1
15	06/17/2022	DW2	1
16	06/20/2022	DW2	1
17	06/22/2022	DW2	1
18	06/30/2022	DW2	1

Based on the analysis of the rescheduling service, it can be noticed the number of rescheduling orders (i.e., demand) is low and is not expected to support a separate investment as compared to the small order case, since the orders examined in this case are included in wider group of small order examined in the case above. Specifically, from the data presented above, two scooter EDVs can cover most of the rescheduling demand (i.e., 17 out of 18 dispatch windows) and with one EDV scooter they can support 15 out of 18 dispatch windows with rescheduling demand.

3.5 LEAD Digital twin for LL6

In summary, the DT Platform has been utilized for the execution of simulations and experimentation under LL6. While three models have been used in the Porto LL for UCs 1,2 and 3, only the models for UC2 and UC3 have been integrated with the platform.

Regarding the first model, the CS-FLP for UC 1 is a model used for static analysis and needed to be run 12 times (6 preparation stores for two types of objective functions) for the computational results included in this deliverable. For that reason, it has not been deemed necessary to integrate the model with the DT platform, but potentially it could be integrated so that it is re-used by other LSPs inside LEAD or outside LEAD project after the end of the lifetime of the project.

Regarding the second model, the 2-echelon model, combined with COPERT and EVCO2, have been integrated with the platform and experiments can be run on the platform. The Porto LL has benefited regarding the second UC2 from the work of the Madrid LL, for which 2-echelon and the Porto-adapted EVCO2 have been initially developed. Since the integration took place for the Madrid LL, the same integration of models with the DT platform has been used in Porto. The experiments and results presented in this deliverable and UC2 were run on the platform.

Regarding the third model, the UDR model has been integrated with the platform, connecting with EVCO2, which has been used for emissions calculations. The model can be used there, by having platform end-users uploading all the necessary datasets and parameters as described in the model documentation. The UDR-to-EVCO2 integration enables the running of the model in pseudo-real-time, by having end-users uploading different delivery demand datasets to the platform and being able to estimate EDV requirements regarding past, current or future time horizons. LSPs (i.e., end-users) can potentially combine a demand prediction algorithm, estimating future demand, which can then be “fed” into UDR-to-EVCO2 to estimate EDV requirements for next months/seasons. Then based on a time-window they can decide on the EDV vehicles to purchase, lease or transfer from other depots/preparation stores.

4 KPIs measurements

This section of the document presents the final KPIs and compares it with the baseline and targets defined in D3.13.

Among the three scenarios defined, there were 4 experiments: 3 simulations (1 per scenario) and 1 real experimentation (for scenario 3). Although every single one of them had analyses and results, only 2 had baseline and final values to compare with: the simulation of scenario 2 and the real experimentation of scenario 3. Therefore, in this section it is only analyzed the KPIs for these scenarios. Despite this fact, during this document, in the previous sections, the results are presented for all of them.

For a matter of simplifying and avoiding duplicating content in this document, in this section it’s presented a summary of the LL6 scenarios’ analysis, by reporting the final KPIs: the time range and the full analysis is reported in Section 3 of this document and the method for its calculation was reported in D3.13.

4.1 Scenario 2 KPIs

Following, in the Table 20 to 23, it’s presented the environmental, economic, social and stakeholders KPIs for Scenario 2: Food delivery services.

Table 20 -Scenario 2 results: Environmental KPIs

Environmental KPI	Baseline value (AS IS)	Final Value (TO BE) What-if1 25% diesel 75% electric	Final Value (TO BE) What-if2 50% diesel 50% electric	Final Value (TO BE) What-if3 75% diesel 25% electric	Target	Δ (AS IS – TO BE) What-if1 25% diesel 75% electric	Δ (AS IS – TO BE) What-if2 50% diesel 50% electric	Δ (AS IS – TO BE) What-if3 75% diesel 25% electric
Energy consumption (MJ/delivery)	3,244	1,892	2,452	2,751	-10%	-42%	-24%	-15%
GHG emission (gCO_2/delivery)	150,438	84,463	116,336	135,931	-50%	-44%	-23%	-10%
Air quality (gPM2.5/delivery)	0,017	0,006	0,008	0,014	-50%	-66%	-50%	-17%
Air quality (gNO2/delivery)	0,003	0,001	0,002	0,002	-100%	-64%	-40%	-22%
Air quality (gVOC/delivery)	23,726	6,108	11,537	15,601	-10%	-74%	-51%	-34%
Noise impact (dB)	70,000	66,247	67,493	68,753	-30%	-5%	-4%	-2%

Table 21 - Scenario 2 results: Economic KPIs

Economic KPI	Baseline value (AS IS)	Final Value (TO BE) What-if1 25% diesel 75% electric	Final Value (TO BE) What-if2 50% diesel 50% electric	Final Value (TO BE) What-if3 75% diesel 25% electric	Target	Δ (AS IS – TO BE) What-if1 25% diesel 75% electric	Δ (AS IS – TO BE) What-if2 50% diesel 50% electric	Δ (AS IS – TO BE) What-if3 75% diesel 25% electric
Average delivery cost of the business model (€/delivery)	2,051	1,246	1,623	1,841	-10%	-39%	-21%	-10%
Congestion 2 (Congestion from vehicles)	610,034	189,704	333,110	471,015	-20%	-69%	-45%	-23%

Economic KPI	Baseline value (AS IS)	Final Value (TO BE) What-if1 25% diesel 75% electric	Final Value (TO BE) What-if2 50% diesel 50% electric	Final Value (TO BE) What-if3 75% diesel 25% electric	Target	Δ (AS IS – TO BE) What-if1 25% diesel 75% electric	Δ (AS IS – TO BE) What-if2 50% diesel 50% electric	Δ (AS IS – TO BE) What-if3 75% diesel 25% electric
FIRR (initial investment €)	775000	390577	547383	639791	-10%	-50%	-29%	-17%
FIRR (savings €/year)		-106085,918	-56445,725	-27712,112	Not defined in D3.13			
FIRR (number of years until compensates the scenario)		-3,624	-4,032	-4,879	Not defined in D3.13			
Delivery time (min/delivery)	6,337	6,517	6,611	6,516	-5%	3%	4%	3%

Table 22 - Scenario 2 results: Social KPIs

Social KPI	Baseline value (AS IS)	Final Value (TO BE) What-if1 25% diesel 75% electric	Final Value (TO BE) What-if2 50% diesel 50% electric	Final Value (TO BE) What-if3 75% diesel 25% electric	Target
Jobs created	-	+1	+2	+1	Not defined
Quality of the jobs	4,1	4,1	4,1	4,1	Average score >= 3.5
Neighborhoods quality of life	4,7	4,9	4,8	4,7	Average score >= 3.5
Users sustainable behaviour	3,8	Not Applied – It does not depend on the scenarios	Not Applied – It does not depend on the scenarios	Not Applied – It does not depend on the scenarios	Average score >=3
Cooperative solutions & incentive measures	3,7	Not Applied – It does not depend on the scenarios	Not Applied – It does not depend on the scenarios	Not Applied – It does not depend on the scenarios	Average score >=3

Table 23 - Scenario 2 results: Stakeholders KPIs

Stakeholders complementary KPI	Baseline value (AS IS)	Final Value (TO BE) What-if1 25% diesel 75% electric	Final Value (TO BE) What-if2 50% diesel 50% electric	Final Value (TO BE) What-if3 75% diesel 25% electric	Target	Δ (AS IS – TO BE) What-if1 25% diesel 75% electric	Δ (AS IS – TO BE) What-if2 50% diesel 50% electric	Δ (AS IS – TO BE) What-if3 75% diesel 25% electric
Distance per delivery (km)	1,007	1,153	1,213	1,152	Not defined in D3.13	14%	20%	14%

4.2 Scenario 3 KPIs

Following, in the Table 24 and 25, it has presented the economic and stakeholders KPIs for Scenario 3: Rescheduling.

Table 24 - Real Experimentation results: Economic KPIs

Economic KPI	Baseline value (AS IS)	Final Value (TO BE)	Target	Δ (AS IS – TO BE)
Average delivery cost of the business model (€/delivery)	9,00 €	6,24 €	-10%	-31%
Congestion 2 (Congestion from vehicles)	186,4	6,087	-20%	-97%
FIRR (initial investment €)	25000	7199	-10%	-71%
FIRR (savings €/year)		-179,741	Not defined in D3.13	
FIRR (number of years until compensates the scenario)		-99,037	Not defined in D3.13	
Delivery time (min/delivery)	23min08s	30min37s	-5%	32%
Delivery reliability within the time window (%)	94%	94%	+2pp	0pp

Table 25 - Real Experimentation results: Stakeholders KPIs

Stakeholders complementary KPI	Baseline value (AS IS)	Final Value (TO BE)	Target	Δ (AS IS – TO BE)
Delivery success rate (%)	86,60%	89%	Not defined in D3.13	2,4pp
Distance per delivery (km)	4,42km	9,73km	Not defined in D3.13	220%

5 Validation and user acceptance

This section reports the three workshops organised in the context of LEAD and LL6. All workshops had different goals according to the needs and therefore the results and conclusions were different between them. Each workshop complemented the previous one, therefore covering the full project life cycle. It helped LL6 to achieve the requirements of the Description of the Action (DoA) related to the user experience of the pilot and DT.

5.1 Methodology: Workshops

5.1.1 Workshop 1: Low-Emission Adaptive last mile logistics supporting on demand economy through Digital Twins

This workshop aimed to kick-off the LEAD project and LL6 (reported in D1.4) to the CoP of Porto Region and to ideate and define the 3 future scenarios with last mile deliveries stakeholders. The workshop covered:

- Roles allocation;
- Brainstorming – Virtual Sticky notes;
- Results evaluation – Assessing business value and feasibility;
- Validating the definition and representativity of the KPIs proposal;
- Description of the KPIs;
- Using Mentimeter for the participants to vote the representativity.

After a presentation of LEAD project and the Porto's Living Lab scope, discussions concluded to set as the LL's general objective not turning retail stores in EDV charging stations but turning retail stores into electrical mobility nodes, deep diving on how to cope power needs with operations: speed charging, changing batteries, type of vehicles, etc.. More information about the workshop is presented in Annex 2.

5.1.2 Workshop 2: Experimenting Green Logistics by simulating & optimizing it through Digital Twins

This workshop was organised in July 2022 (in the second LL reporting period) and established officially the CoP of LL6. The CoP of Porto Region, in which each actor had each own interests, was represented by:

Actor	Potential Interests
PA Public Administration	Reduce the negative impacts on the environment of freight transport (Air quality, GHG, noise)
	Reduce traffic congestion
	Have relevant players to demonstrate the transition in the region
R&D+i	Exchange of knowledge
	New related initiatives and approaches
	New projects and synergies with current ones
Logistics	Economic efficiency
	Improve customer satisfaction and service quality
	Contribution to social and environmental sustainability

Actor	Interests
Energy	Reduce the negative impacts on the environment of freight transport (Air quality, GHG, noise)
	New engineering solutions
	New strategy focused through the logistics
Mobility	Exchange of knowledge
	Product development or customized solutions
	New products & services
Business Models	Support some go-to-market decisions
	Improve economic efficiency, customer satisfaction and service quality
	Contribution to social and environmental sustainability

Besides this, during the workshop the following conclusions were achieved:

- Required fitting electrification and route optimization on a range of operations that include in-store picking, back store picking, dark store operation, warehouse picking and dropshipping;
- The need for automatic volumetry calculation, data-based, to feed further decision tools for type of delivery;
- The choosing of the EVs, including battery swap capabilities and an autonomy no less than 120km;
- Definition and deep dive on the scenarios (including assumptions and data required to perform it).

More information about the workshop is presented in Annex 2.

5.1.3 Workshop 3: Evaluation of Green Logistics by analyzing results obtained through Digital Twins and Real Experimentation

This workshop was organised in May 2023, representing the closing of the project for the CoP of Porto Region. It was the most important workshop (main milestone) as it helped to assess the user acceptance of LEAD outcomes and calculate social KPIs. The methodology followed in the workshop was the UPM methodology reported in D3.15 and mentioned below in this document in Figures 33 to 35 and Table 26.

The main objectives of the workshop were the presentation of the results, its assumptions and evaluation, the official closing of the project together with the CoP but also the discussion of future involvement between the CoP members.

As main conclusions of the workshop, we list the following:

- The results, both for the simulations and real experimentation are good and should be pursued for the near and long-term;
- There are further developments to be considered in order to be more effective: using a longer time range for the historical analysis, forecasting the future deliveries to act according to our business growth and be ready to at least keep the same service to our customers, etc.;
- The synergies created with the CoP should be maintained in order to reach a higher extent of the impact within the Porto Region.

More information about the workshop is presented in Annex 2.

5.2 Results

A main result of the workshops was the establishment of the CoP of Porto Region, which includes the municipality of Porto, a transportation partner, a solution provider for EV charging, an automotive industry, a solution provider of data analytics tools, a major food retailer and two scientific institutions with strong background in mobility and engineering.

The overall belief is that the approach must be systemic to deploy in the region the concept of green logistics for food delivery, in a way that could be replicated in other transportation/distribution contexts.

The project had positive results, both simulations and real experimentation, which might be fully applied in Sonae's business with a proper business case which will be conducted with all the insights of LEAD. Its implementation, although not always easy, was a success and was facilitated by managing all the work plan but also by working closely with all partners, both from the consortium but also from the CoP of Porto Region.

In this matter, the results showed the potential and the impact that can be achieved by rolling out a green network to MC Sonae. Using the same rationale, it's also possible to estimate the results throughout the region, by implementing it in every business and part of the region.

It must be highlighted that in order to keep evolving and achieve a bigger confidence to deploy it according to our business expected growth, there are a few developments that should be considered, which were referred earlier.

Despite this fact, LL6 faced a couple of challenges and barriers: lack of digitalization, complexity to access open data sources and access to some data and sharing with partners. Regarding the real experimentation, and since it is a new business model which implies running studies and testing something never made in the company, but also something that is still being developed in the world, a task force was created in order to face the following challenges: (1) to ensure the food arrives at the destinations in perfect conditions, (2) adaptation to the rescheduling service and (3) autonomy of the electric mobility. Each one of these topics involved a set of different stakeholders who helped the team to face these challenges, overcome them and get positive results and feedback.

Following in Figure 33 and Table 26, it is represented the STAR Logistics Results for the Sustainability Performance Index, which is a methodological tool that elaborates a sustainability rating of last mile logistics solutions and which will be reported in D3.15.

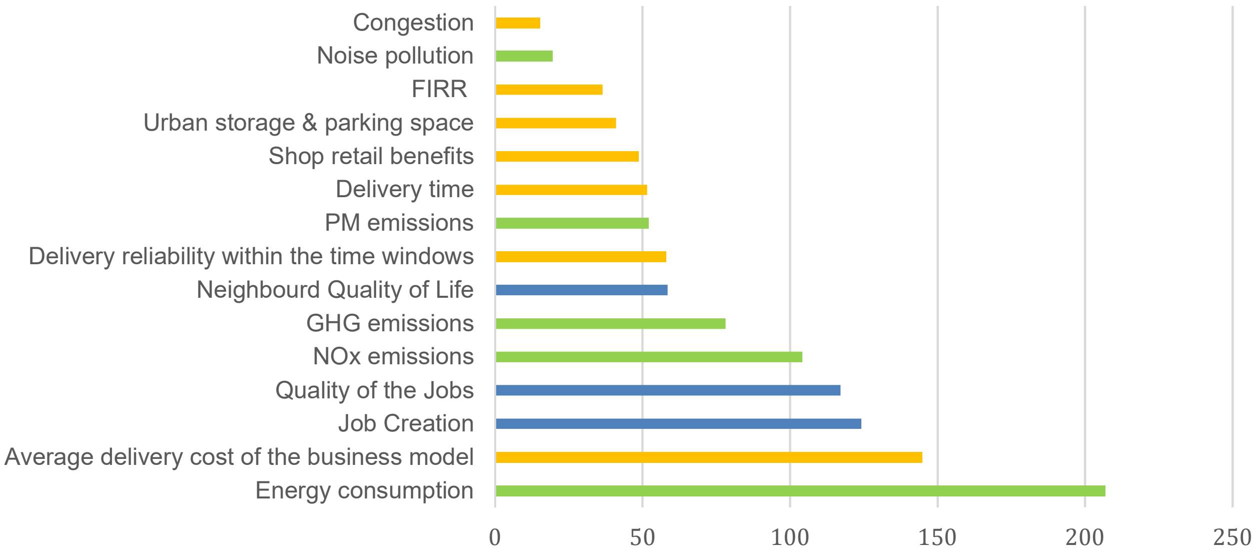

Figure 33- Weight for each criterion for Porto: STAR Logistics methodology (D3.15)

Table 26 - STAR Logistics: Sustainability rating of the scenarios proposed for last-mile logistics in Porto Living Lab (D3.15)

Scenarios	Description	Rating	Ranking
Scenario 0	BAU		
Scenario 1	Deliver with 75% electrical vehicles	283.631	1st
Scenario 2	Deliver with 50% electrical vehicles	173.808	2nd
Scenario 3	Deliver with 25% electrical vehicles	38.003	3rd

For Porto future plans is a high priority the last mile solution of Scenario 1 – delivering with 75% of electrical vehicles: the energy consumption savings per delivery is 1.4MJ/delivery and 57gCO_{2e}/delivery. In a 10 years horizon, and forecasting our deliveries for the same period, we can expect savings of 131.425kWh/year and 20tCO_{2e}/year as presented in the following Figure 34 and 35.

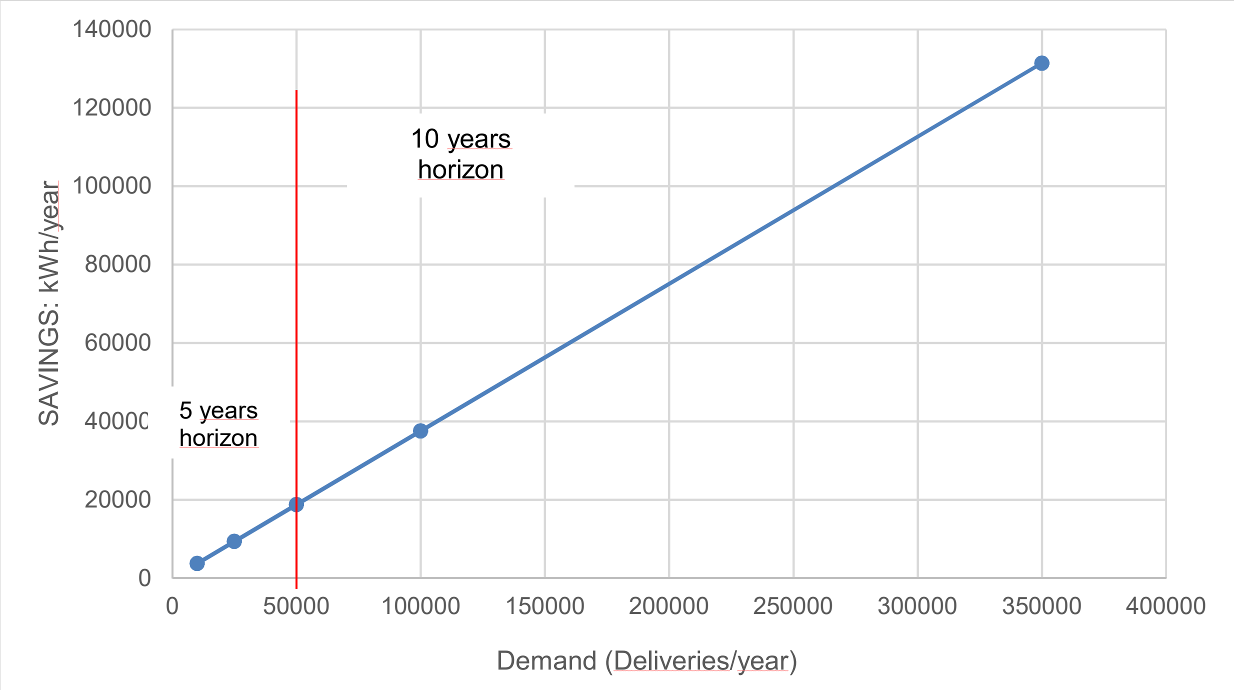

Figure 34 - Medium and Long-Term Impact Assessment: Annual energy savings if Scenario 1 is implemented in a 5 years horizon and 10 years horizon (D3.15)

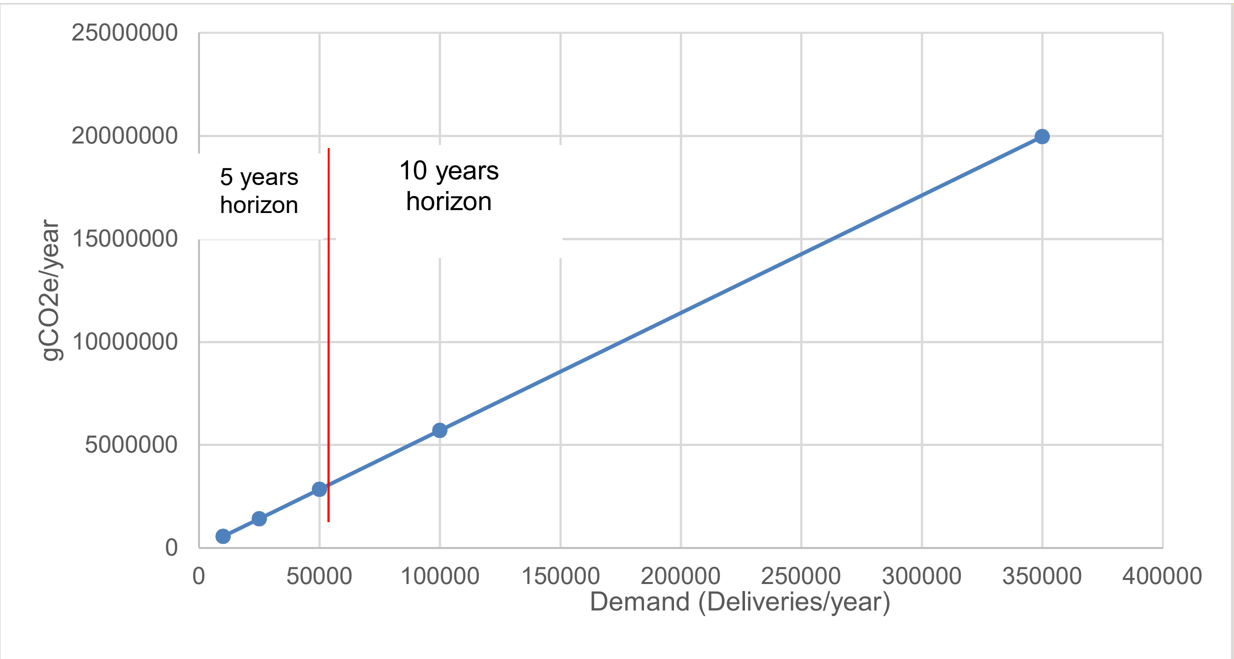

Figure 35 - Medium and Long-Term Impact Assessment: Annual GHG emissions savings if Scenario 1 is implemented in a 5 years horizon and 10 years horizon (D3.15)

6 Learnings and recommendations

During LEAD project a lot have been learned, both from a positive but also from a negative perspective. At this stage, and after analysing the project end-to-end, some lessons and recommendations could be enumerated to guide future implementations. For a better reading, three different areas can be highlighted:

- Stakeholders: a close collaboration with the governance/authorities (in this case the CoP of Porto Region) is crucial to ensure the successful implementation. Each one of them (individual person or entity) helps the team to identify different points of views and balance requirements depending on their area/sector. They will also be engaged in these topics and the rollout for other environments will likely happen;
- Data: even though collecting data remains a challenge, to mitigate it we should manage it earlier in order to avoid delays in the project but even to ensure all data is included and trustful;
- Real operations: with the goal to act in every single product, there are different requirements that need to be studied. A list of categories and requirements should be created as early as possible.

7 Summary and outlook

The ambitioned electric transition is clearly aligned with MC Sonae's commitment to anticipate its carbon neutrality by ten years, leveraging its value proposition as well as preparing the internal teams to this new mindset of mobility.

Thus, three scenarios were defined in the context of LEAD together with our internal and external partners and CoP of Porto Region:

- Scenario 1: Electric transition - necessity to place EDV chargers in all preparation stores;
- Scenario 2: Food delivery services - investigate if EDVs can be used in the instant food deliveries services;
- Scenario 3: Rescheduling - test if a specific electric motorbike type can be used for the small orders and/or rescheduling services.

The work performed within LL6 contributed with important results and insights, always based on an economic feasibility and potential replication post-project, including the social and environmental dimensions to leverage the related final value propositions. As mentioned earlier, these results were positive, both from a simulations and real experimentation perspective.

To conclude, LL6 accomplished all the milestones and the objectives initially planned and defined for the project. The results will now serve as base for the next steps. Together with the partners involved and the CoP of Porto Region, deep synergies were created which will be maintained in the future in order to maximise positive impacts within the CoP.

It’s also important to highlight that LEAD helped to reach a new level of maturity on the PI ambition. Sonae had a context working with such topics in projects such as ICONET (“New ICT infrastructure and reference architecture to support Operations in future PI Logistics NETworks”) and a step forward was given in with LEAD by improving understanding on the PI and introducing Digital Twins in last mile delivery operations.

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[3] International Energy Agency (IEA), “Portugal 2021: Energy Policy Review,” 2021.

[4] Entidade Reguladora dos Serviços Energéticos (ERSE), “Annual Report on the Electricity and Natural Gas Markets in 2021.”

[5] Royo, B., Ciprés, C., Lekkakos, S. (2021). LEAD D1.4 Innovation Agenda - Value case scenarios and validation KPIs, LEAD Project

[6] Gouveia, N., Silva, M., Germano, S., Politaki, D (2022). LEAD D3.13 Porto Value Case (v1), LEAD Project

[7] Vazquez, N. (2023). LEAD D3.15 Impact Assessment, Solutions Validation and Learning Conclusions, LEAD Project

Annexe 1: "What if" scenarios details

"What if" Scenario 2

Table 27 - Total delivery time per dispatch window for all scenarios

Scenario	DW0	DW0_total	DW1	DW1_total	DW2	DW2_total
AS IS	13,6342	13,6342	11,2053	11,2053	13,2876	13,2876
What-if 1 (diesel)	3,7333	13,982	3,0987	11,6887	3,5526	13,5395
What-if 1 (electric)	10,2487		8,59		9,9869	
What-if2 (diesel)	7,0993	14,1986	5,7771	11,7316	6,9229	13,8458
What-if2 (electric)	7,0993		5,9545		6,9229	
What-if3 (diesel)	10,3359	13,9789	8,59	11,6887	9,9869	13,5389

Table 28 - Total distance traversed per dispatch window for all scenarios

Scenario	DW0	DW0_total	DW1	DW1_total	DW2	DW2_total
AS IS	127,9905	127,9905	108,3288	108,3288	127,3306	127,3306
What-if 1 (diesel)	44,7424	143,6371	42,3327	130,0844	44,0824	142,4041
What-if 1 (electric)	98,8947		87,7517		98,3217	
What-if2 (diesel)	76,693	153,386	65,7494	132,0116	76,2264	152,4528

What-if2 (electric)	76,693		66,2622		76,2264	
What-if3 (diesel)	99,0837	143,4987	87,7517	130,0844	98,3217	142,4041
What-if3 (electric)	44,415		42,3327		44,0824	

Table 29 - Number of vehicles per dispatch windows for all scenarios

Scenario	DW0	DW0_total	DW1	DW1_total	DW2	DW2_total
AS IS	11	11	9	9	11	11
What-if 1 (diesel)	3	11	3	10	3	11
What-if 1 (electric)	8		7		8	
What-if2 (diesel)	6	12	5	10	6	12
What-if2 (electric)	6		5		6	
What-if3 (diesel)	8	11	7	10	8	11
What-if3 (electric)	3		3		3	

Table 30 - Total NO2 in tonne per dispatch window for all scenarios

Scenario	DW0	DW1	DW2
AS-IS	3,418552e-07	2,893399e-07	3,400926e-07
What-if1	1,195043e-07	1,130682e-07	1,177415e-07
What-if2	2,048425e-07	1,756128e-07	2,048425e-07
What-if3	2,646468e-07	2,343797e-07	2,626115e-07

Table 31 - Total VOC2 in tonne per dispatch window for all scenarios

Scenario	DW0	DW1	DW2
AS-IS	0,002693	0,003179	0,002693
What-if1	0,000735	0,000735	0,000735
What-if2	0,00147	0,001225	0,00147
What-if2	0,001959	0,001714	0,001959

Table 32 - Total PM2.5 in tonne per dispatch window for all scenarios

Scenario	DW0	DW1	DW2
AS-IS	0,000002	0,000002	0,000002
What-if1	6,953533e-07	6,579035e-07	6,850960e-07
What-if2	0,000001	0,000001	0,000001
What-if2	0,000002	0,000001	0,000002

Table 33 - Total CO_2 emissions in tonne per dispatch windows for orders delivered by both diesel and electric fleet for all scenarios

Scenario	DW0	DW1	DW2
AS-IS	0,019114	0,016178	0,019016
What-if1	0,011584	0,010123	0,008784
What-if2	0,015255	0,013103	0,013639
What-if3	0,016999	0,015203	0,016869

Table 34 - Total CO_2 emissions in tonne for orders delivered by diesel fleet for all scenarios

Scenario	DW0	DW1	DW2
AS-IS	0,019114	0,016178	0,019016
What-if 1	0,006682	0,006322	0,006583
What-if2	0,011454	0,009819	0,011454
What-if3	0,014797	0,013105	0,014684

Table 35 - Total CO_2 emissions in tonne for orders delivered by electric fleet for all scenarios

Scenario	DW0	DW1	DW2
What-if1	0,004902	0,003801	0,002201
What-if2	0,003802	0,003284	0,002185
What-if3	0,002202	0,002098	0,002185

Table 36 - Energy Consumption in TJ per dispatch window for all scenarios

Scenario	DW0	DW1	DW2
AS-IS	0,000412	0,000371	0,000388
What-if1	0,000234	0,000217	0,000232
What-if2	0,00031	0,000265	0,00031
What-if3	0,000344	0,000307	0,000342

Table 37 - Energy Consumption in TJ per dispatch window for orders delivered by diesel fleet per what if scenarios

Scenario	DW0	DW1	DW2
AS-IS	0,000412	0,000371	0,000388
What-if1	0,000126	0,000122	0,000125
What-if2	0,000227	0,000193	0,000227
What-if3	0,000295	0,000261	0,000294

Table 38 - Energy Consumption in TJ per dispatch window for orders delivered by electric fleet per what if scenarios

Scenario	DW0	DW1	DW2
What-if1	0,000108	0,000096	0,000107
What-if2	0,000084	0,000072	0,000083
What-if3	0,000048	0,000046	0,000048

“What if” Scenario 3

1. January 2022: Estimated EDVs required, meters traversed and emissions

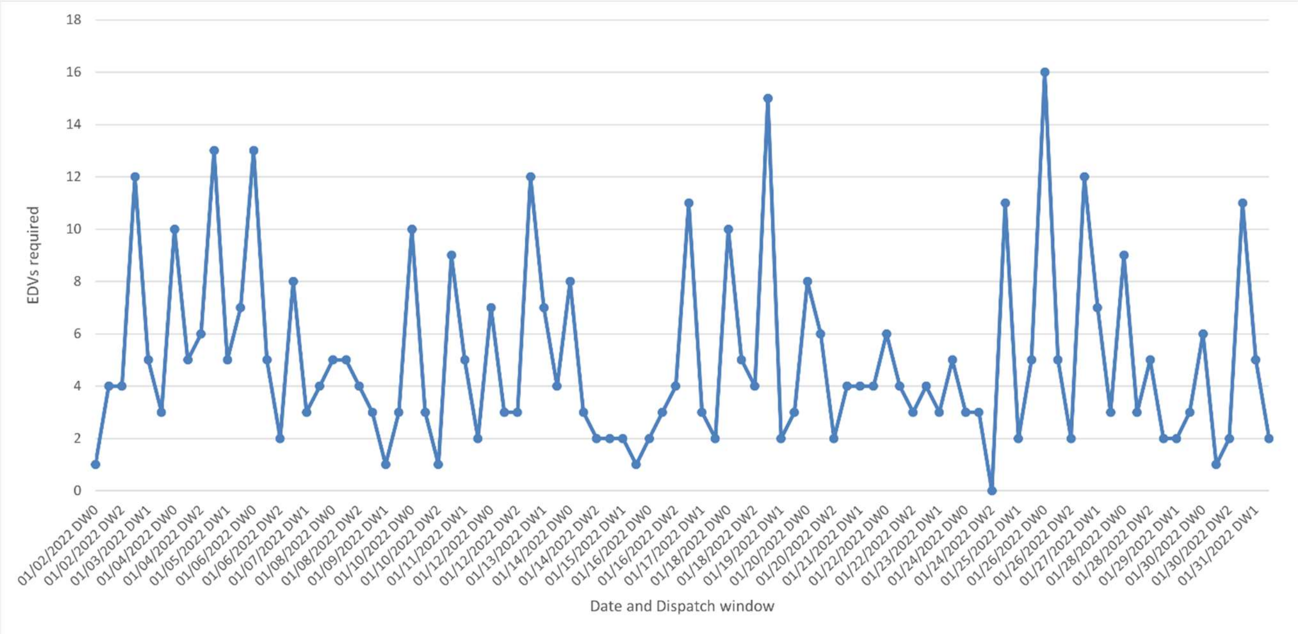

Figure 36 - Number of EDVs required to satisfy demand (per Dispatch window in January 2022)

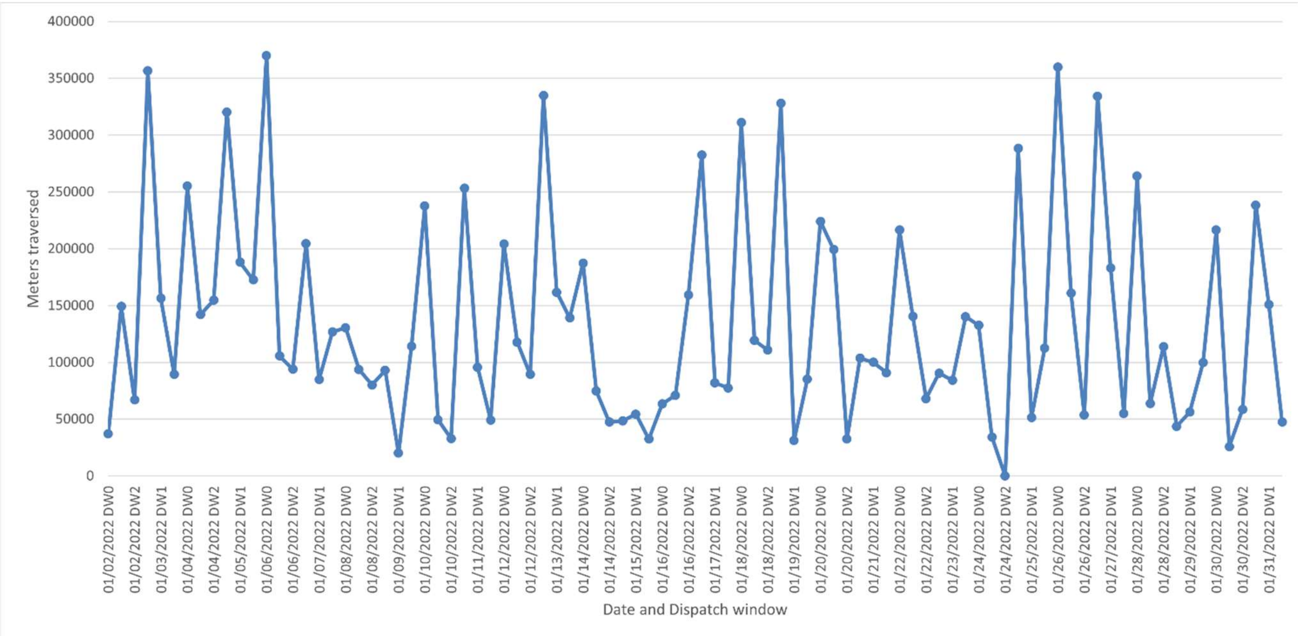

Figure 37 - Meters traversed by required EDVs to satisfy demand (per Dispatch window in January 2022)

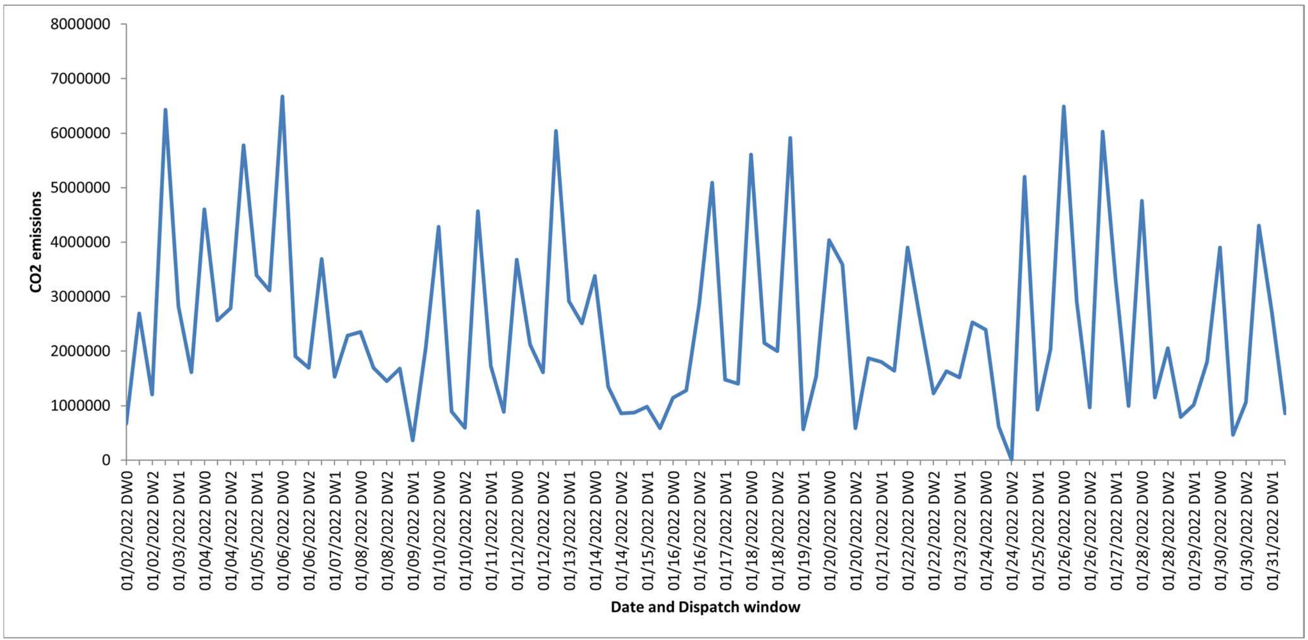

Figure 38 - CO_2 produced by the EDVs to satisfy demand (per Dispatch window in January 2022)

2. February 2022: Estimated EDVs required, meters traversed and emissions

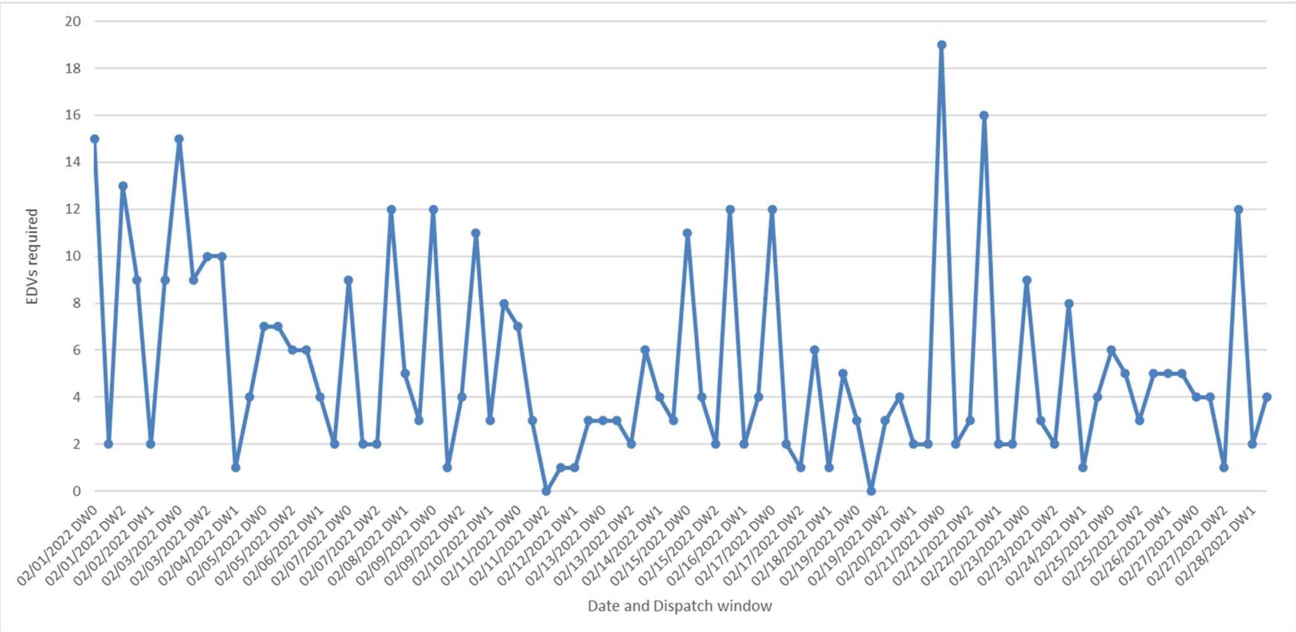

Figure 39 - Number of EDVs required to satisfy demand (per Dispatch window in February 2022)

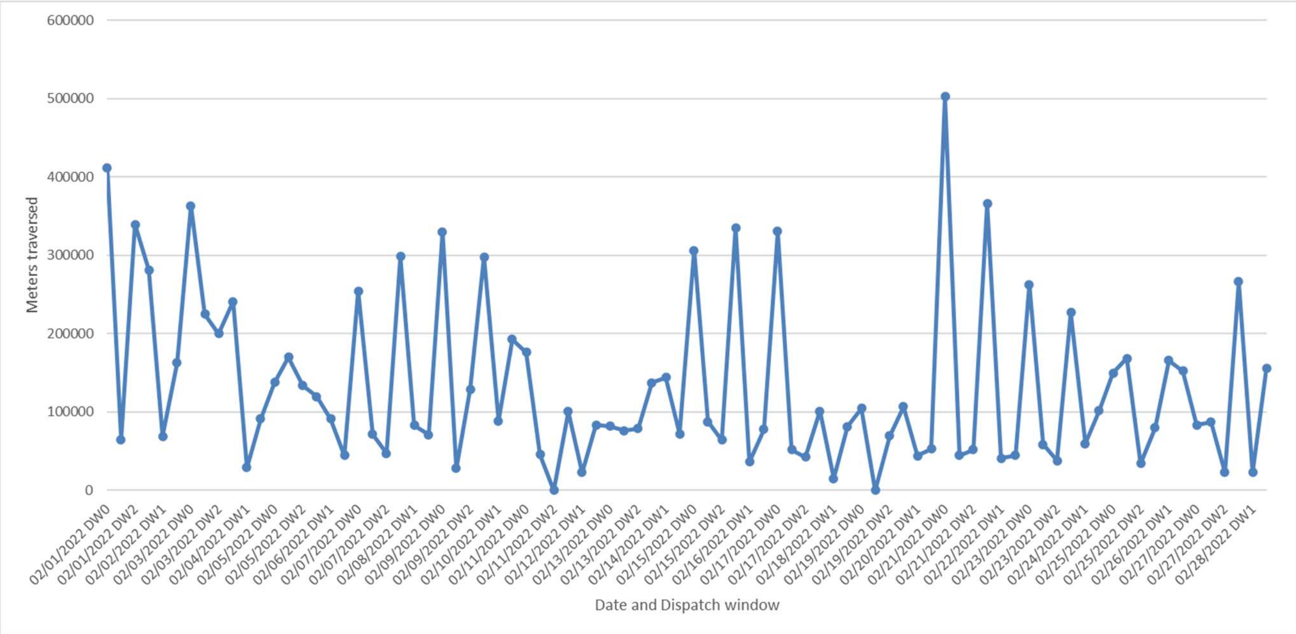

Figure 40 - Meters traversed by required EDVs to satisfy demand (per Dispatch window in February 2022)

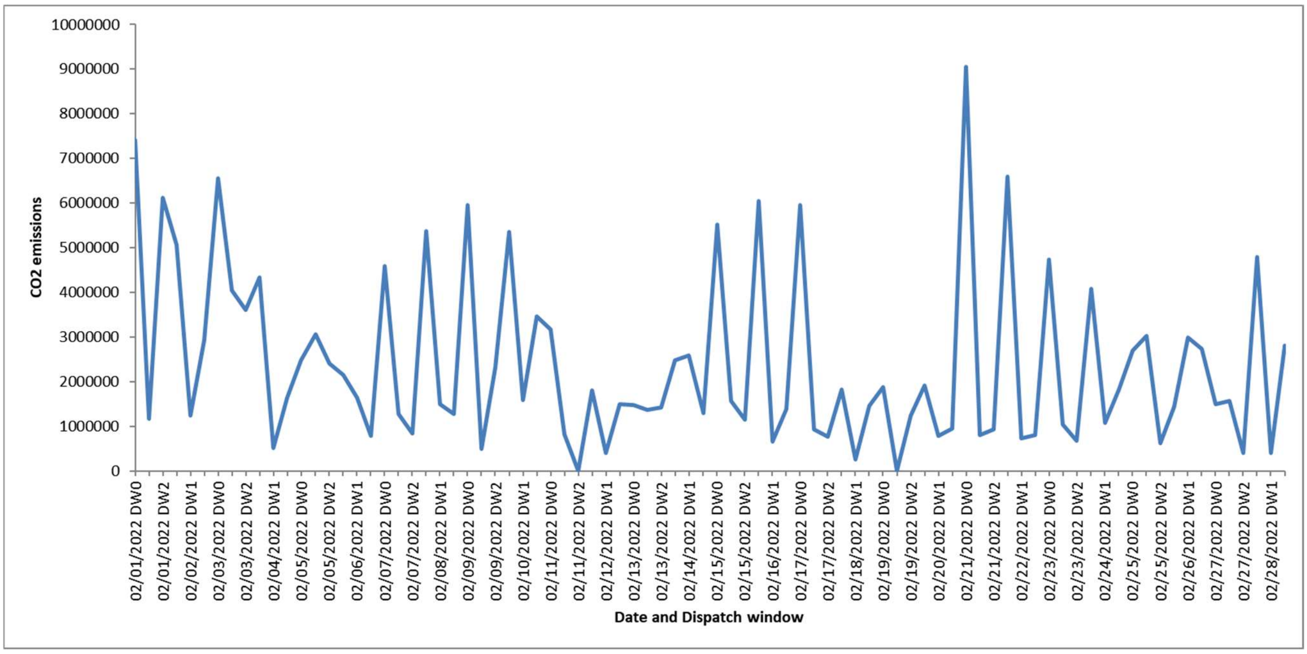

Figure 41 - CO_2 produced by the EDVs to satisfy demand (per Dispatch window in February 2022)

3. March 2022: Estimated EDVs required, meters traversed and emissions

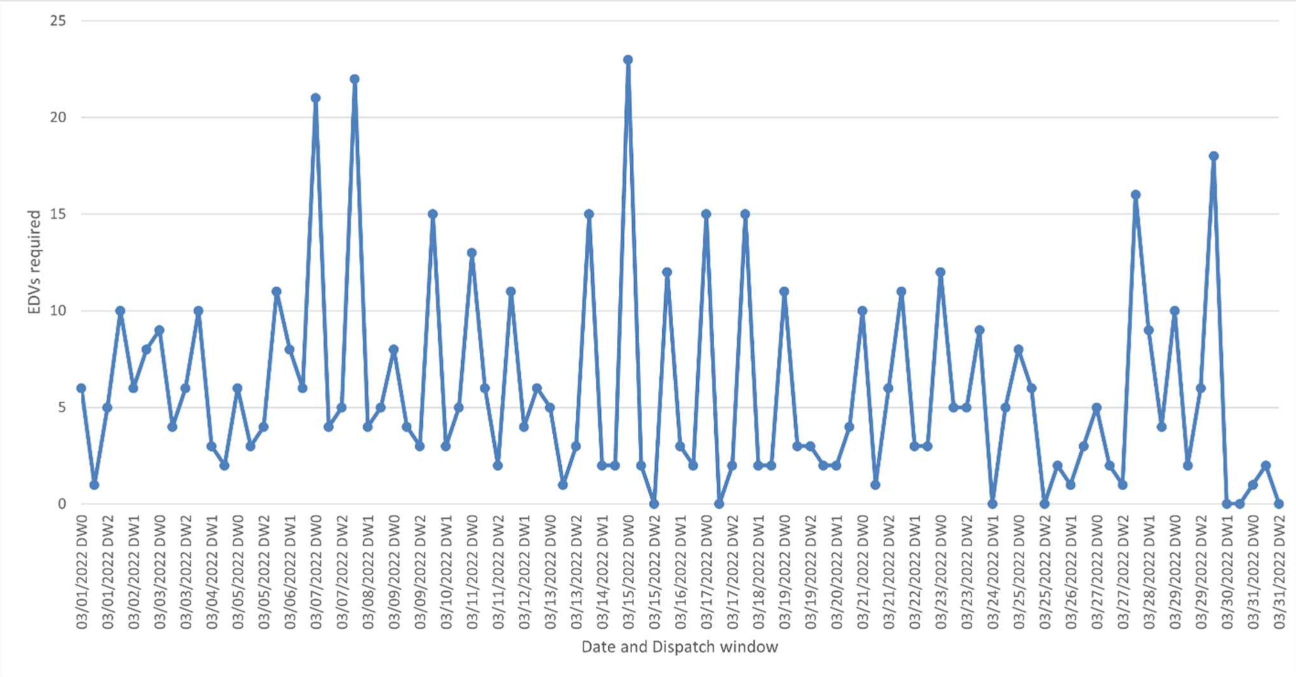

Figure 42 - Number of EDVs required to satisfy demand (per Dispatch window in March 2022)

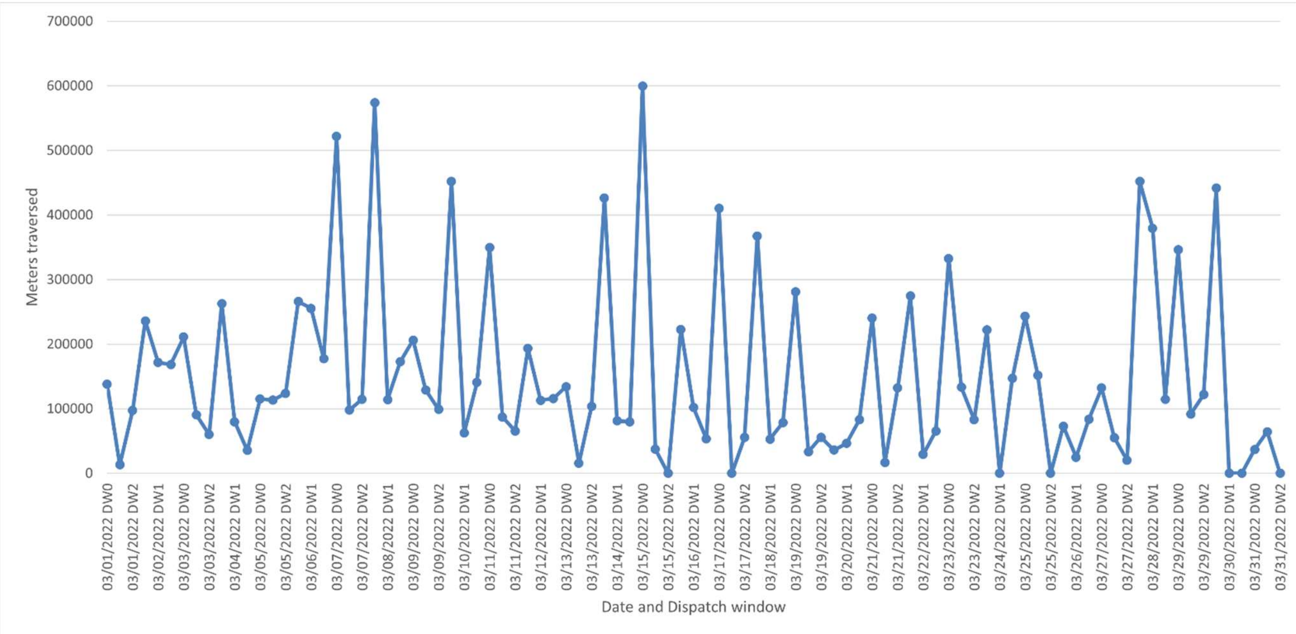

Figure 43 - Meters traversed by required EDVs to satisfy demand (per Dispatch window in March 2022)

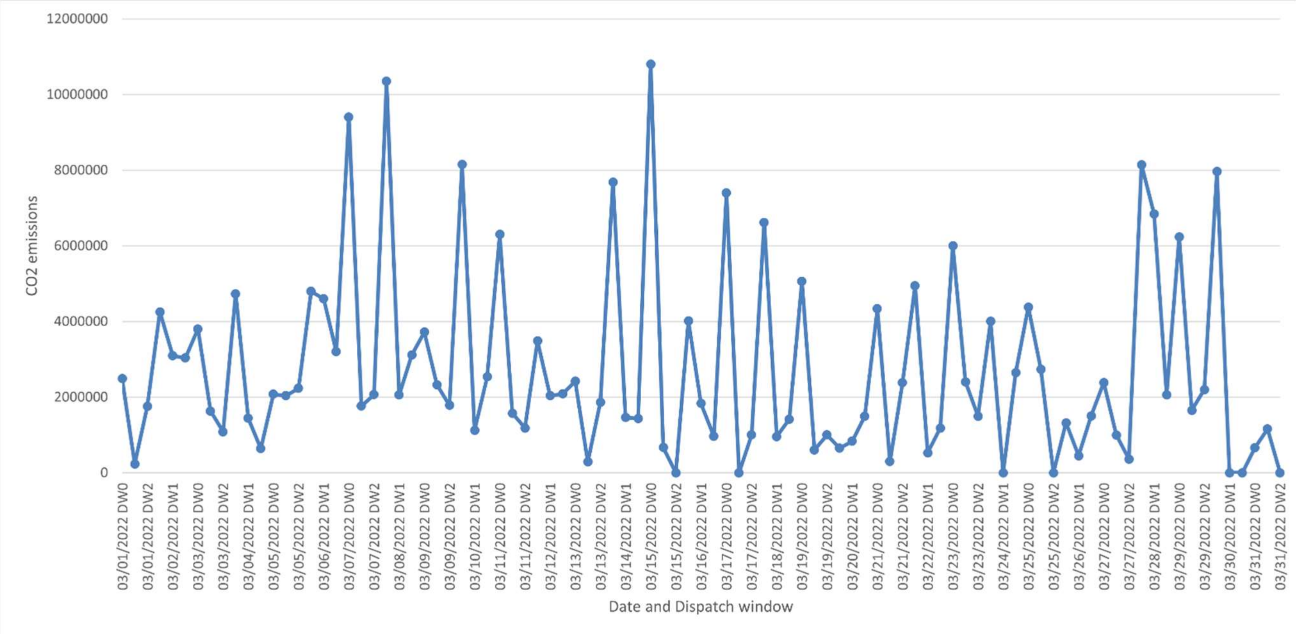

Figure 44 - CO_2 produced by the EDVs to satisfy demand (per Dispatch window in March 2022)

4. April 2022: Estimated EDVs required, meters traversed and emissions

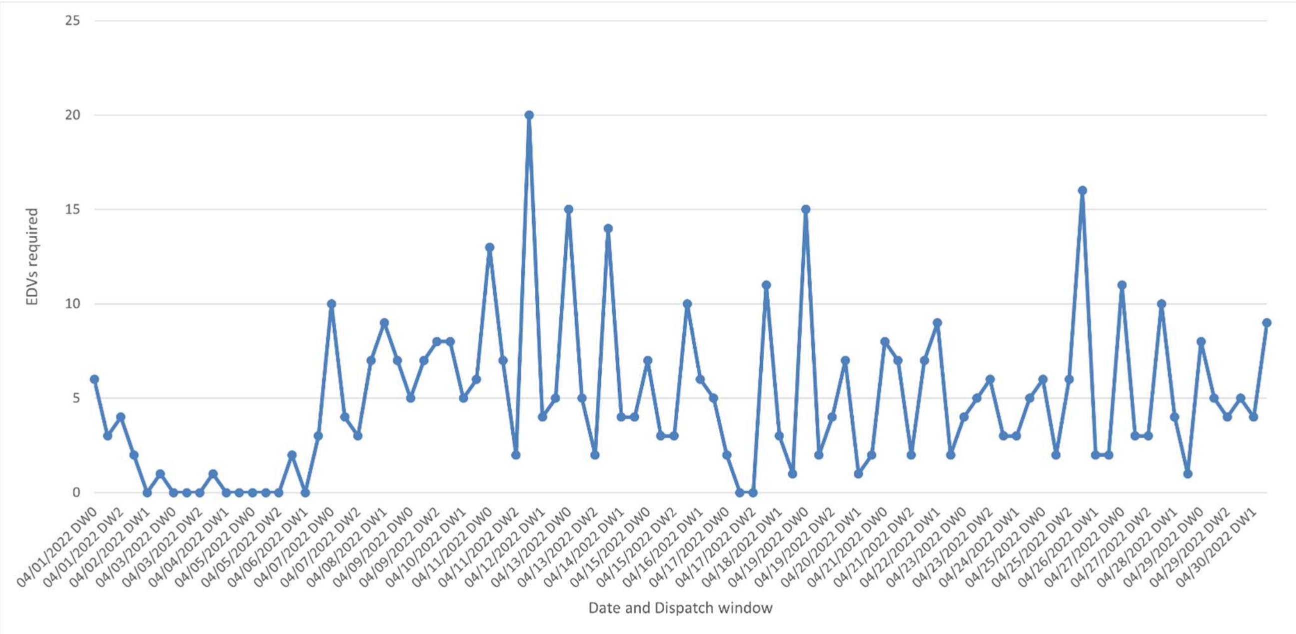

Figure 45 - Number of EDVs required to satisfy demand (per Dispatch window in April 2022)

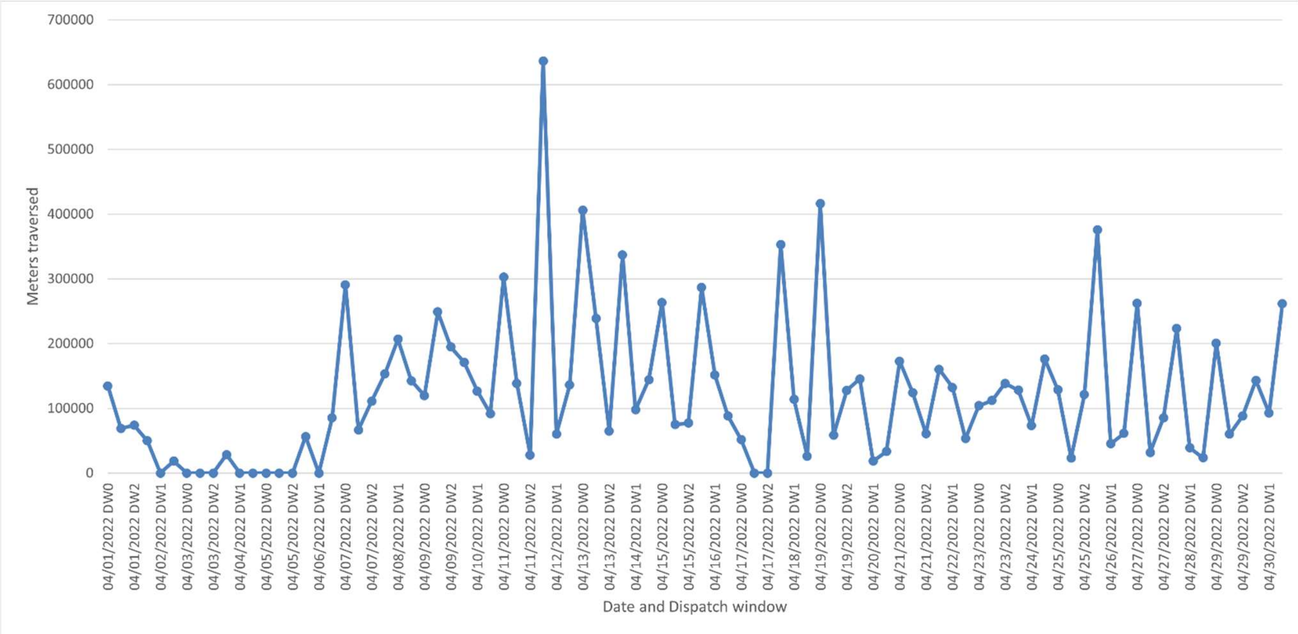

Figure 46 - Meters traversed by required EDVs to satisfy demand (per Dispatch window in April 2022)

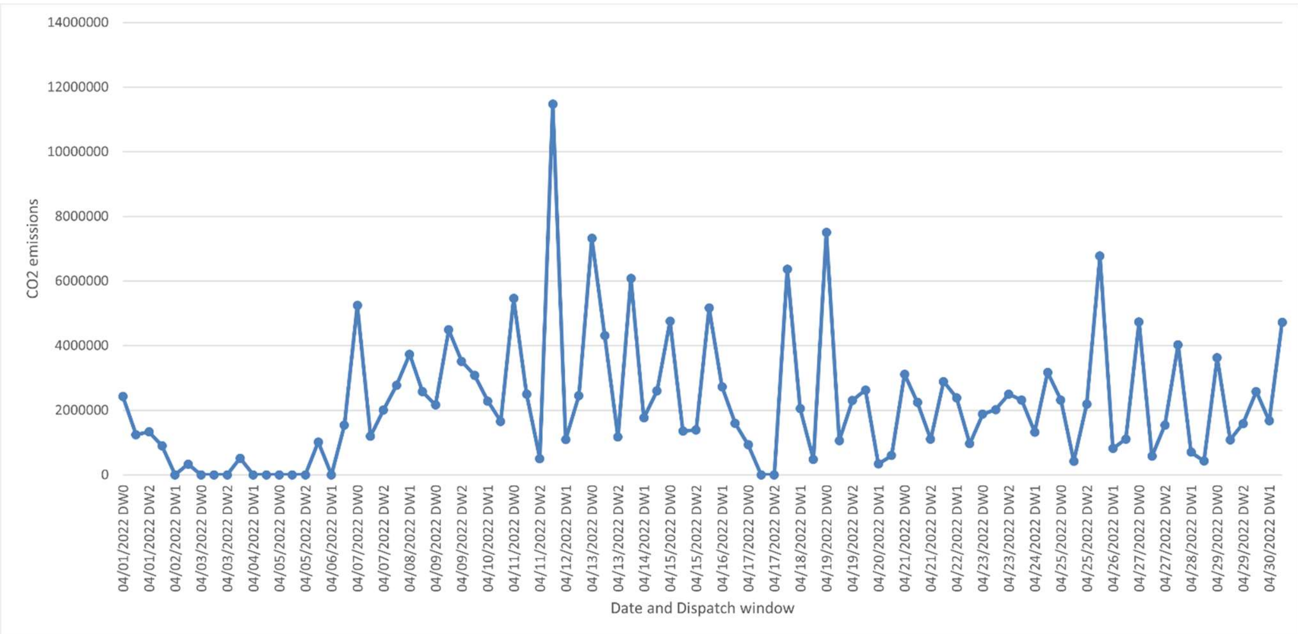

Figure 47 - CO_2 produced by the EDVs to satisfy demand (per Dispatch window in April 2022)

5. May 2022: Estimated EDVs required, meters traversed and emissions

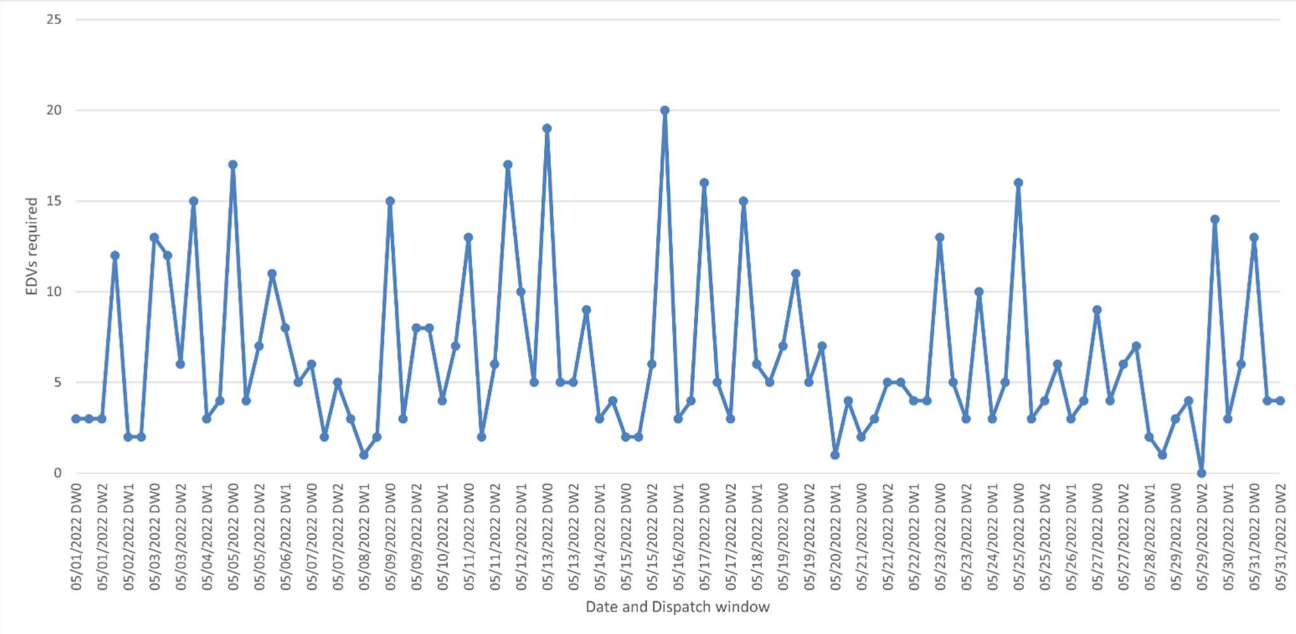

Figure 48 - Number of EDVs required to satisfy demand (per Dispatch window in May 2022)

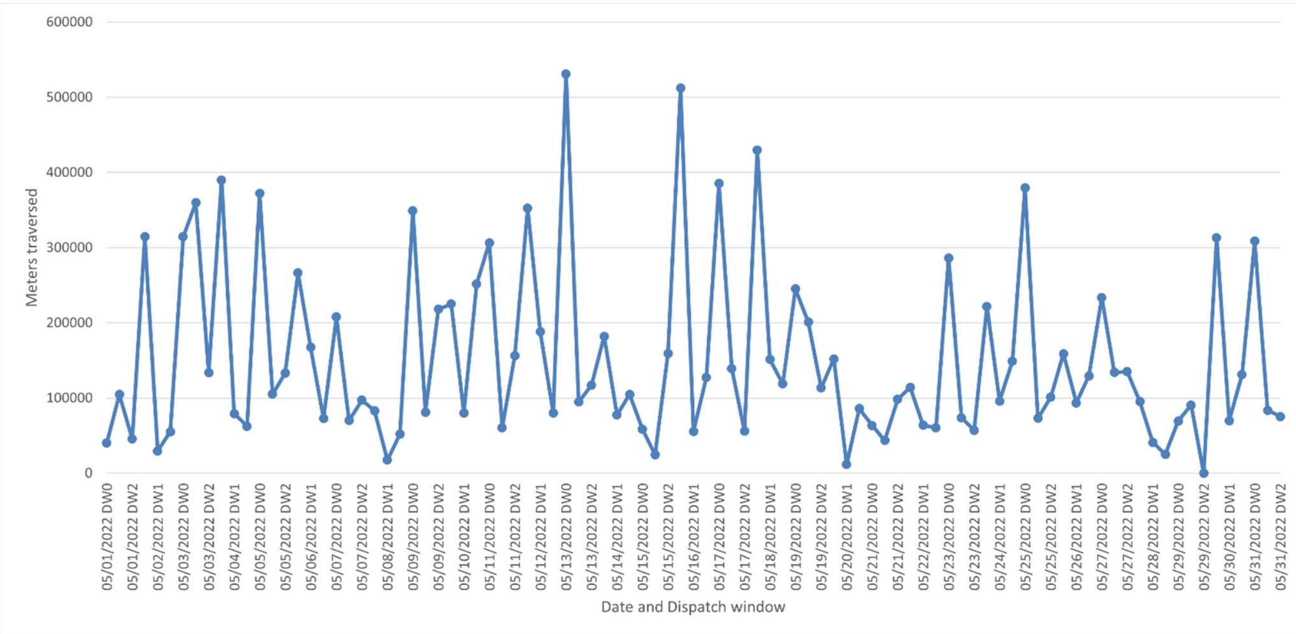

Figure 49 - Meters traversed by required EDVs to satisfy demand (per Dispatch window in May 2022)

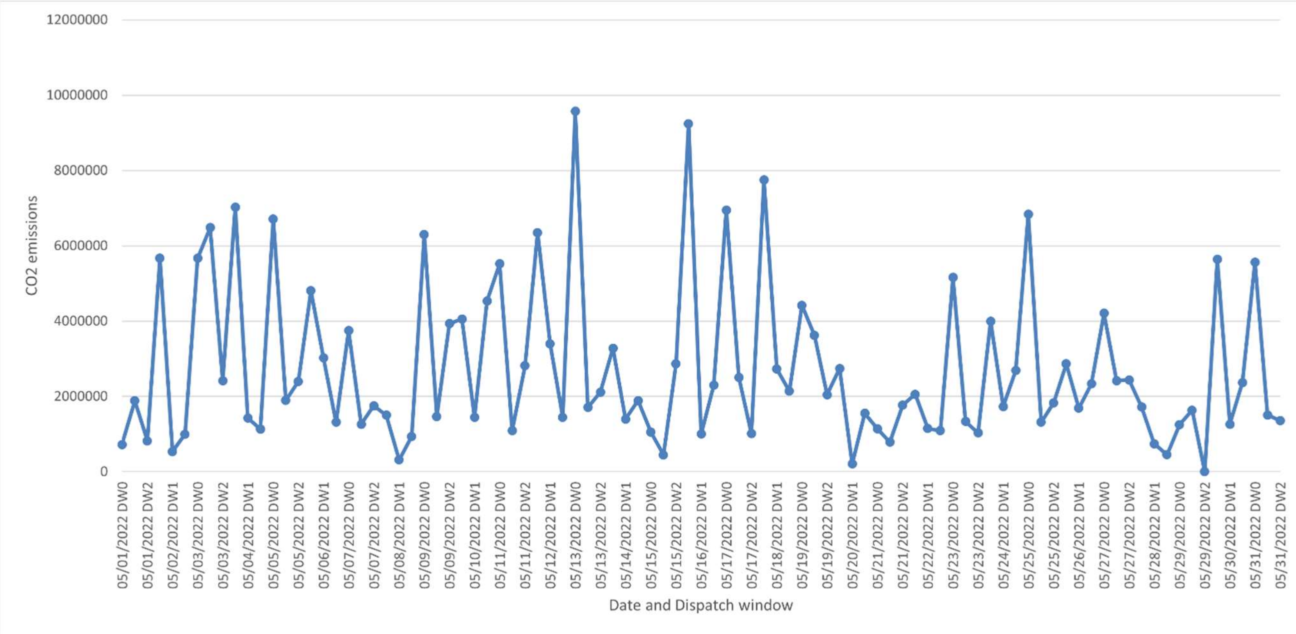

Figure 50 - CO_2 produced by the EDVs to satisfy demand (per Dispatch window in May 2022)

6. June 2022: Estimated EDVs required, meters traversed and emissions

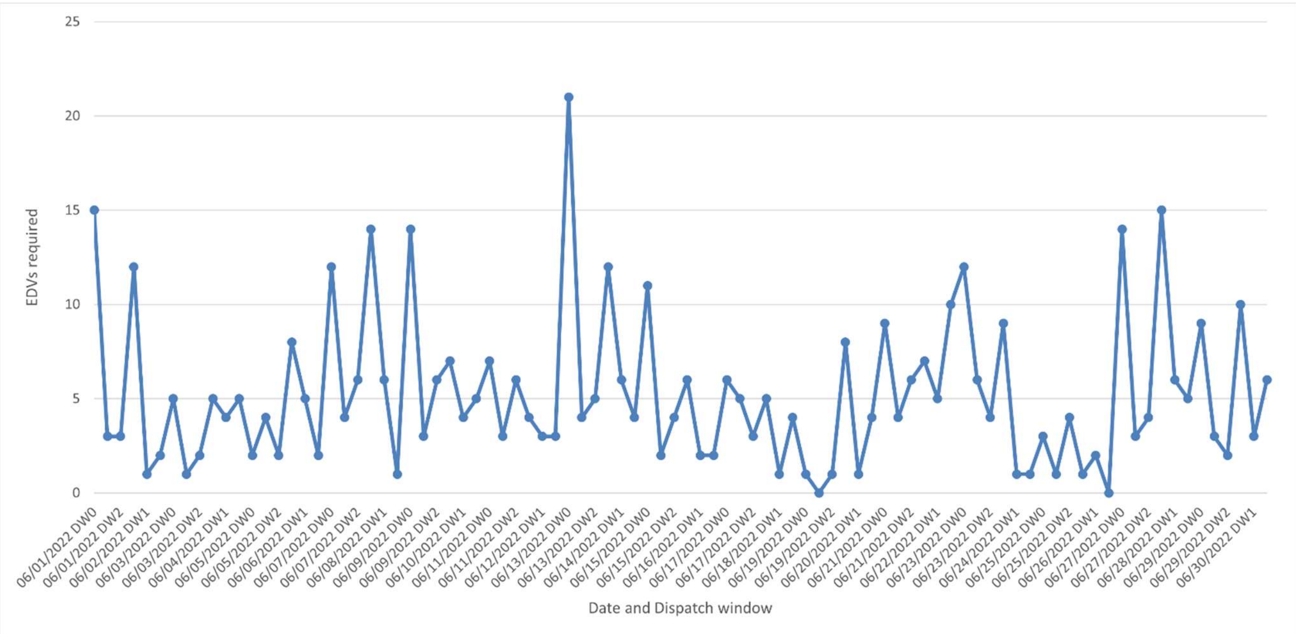

Figure 51 - Number of EDVs required to satisfy demand (per Dispatch window in June 2022)

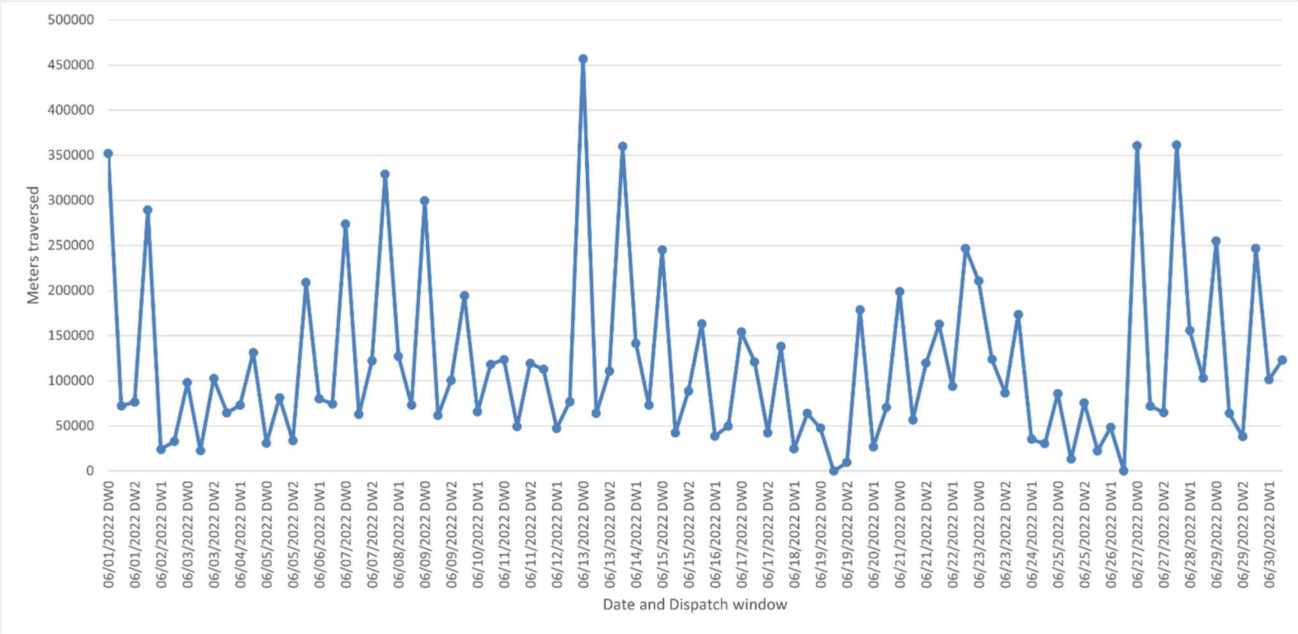

Figure 52 - Meters traversed by required EDVs to satisfy demand (per Dispatch window in June 2022)

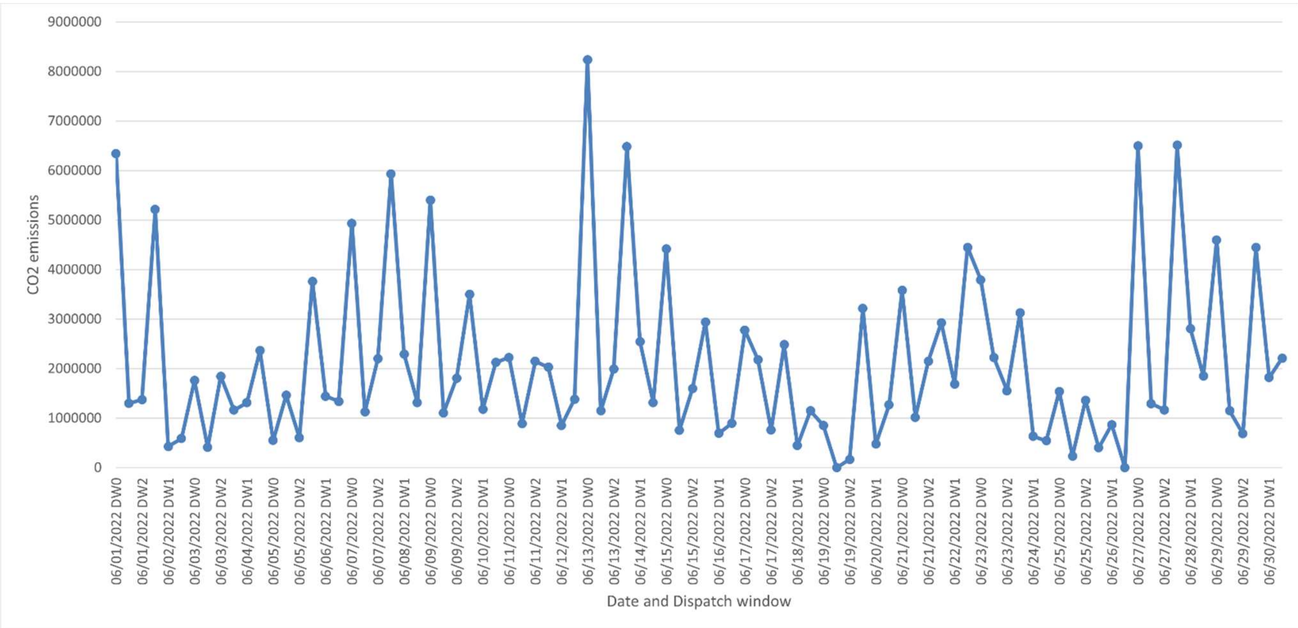

Figure 53 - CO_2 produced by the EDVs to satisfy demand (per Dispatch window in June 2022)

Annex 2: Workshops

Workshop 1

Date: 16th December 2020

Context:

- Rise on-demand logistics: stress last mile delivery systems;
- Customer: responsive system for customized products;
- Industry: instant delivery;
- Cities: possible negative consequences.
  Urban planner + city authorities + stakeholder = prediction, evaluation, new business models.

Agenda:

- Presentation of the LEAD project and the Porto Living Lab
- Workshop objective and activities description
- Activity 1:
    - Description of the 3 scenarios
    - Description of ideasCloud
        - Part 1: Brainstorming (icloud step1)
- [Break]
        - Part 2: Briefing (icloud step2)
- Activity 2:
    - KPIs definition and voting (Mentimeter)
- Close-up

Participants:

AMP (Municipality)
Delivery Express (Transportation company)
EFACEC (Energy Equipment Industry)
INEGI (RTO)
INESCTEC (RTO)
LTP Labs (Data Management company)
MSG Automotive /Soares Gonçalves (Automotive industry)
MC Sonae (Retailer)

Workshop 2

Date: 20th July 2022

Context:

- Rise on-demand logistics: stress last mile delivery systems;
- Customer: responsive system for customized products;
- Industry: instant delivery;
- Cities: possible negative consequences.
  Urban planner + city authorities + stakeholder = prediction, evaluation, new business models.

Agenda:

- Delivery strategy overview
- LEAD project, Porto Living Lab presentation and updates
- Tour within the Preparation store, focusing on the rescheduling value-case
- Discussion, suggestions and feedback
- Social KPIs, LEAD`s methodology
- Other topics

Participants:

AMP (Municipality)
Delivery Express (Transportation company)
EFACEC (Energy Equipment Industry)
INEGI (RTO)
INESCTEC (RTO)
LTP Labs (Data Management company)
MSG Automotive /Soares Gonçalves (Automotive industry)
MC Sonae (Retailer)

Workshop 3

Date: 2nd May 2023

Context:

- Rise on-demand logistics: stress last mile delivery systems;
- Customer: responsive system for customized products;
- Industry: instant delivery;
- Cities: possible negative consequences.
  Urban planner + city authorities + stakeholder = prediction, evaluation, new business models.

Agenda:

- LEAD project
- Porto Living Lab
- Scenarios and its results – presentation and evaluation
- Discussion
- CoP validation surveys
- Closing

Participants:

Delivery Express (Transportation company)
EFACEC (Energy Equipment Industry)
INEGI (RTO)
INESCTEC (RTO)
MSG Automotive /Soares Gonçalves (Automotive industry)
MC Sonae (Retailer)