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Deliverable D3.5

Simulation of V2X Management Strategies at City Level

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[1] https://ev4eu.eu/

Executive Summary

The deliverable D3.5, "Simulation of V2X Management Strategies at City Level" aims to test the mass deployment of electric vehicles (EVs) in cities with different characteristics using the co-simulation platform developed in T3.4 and presented in *D3.4: Definition and Development of a City-Level Co-simulation Platform for V2X* [1]. The goal is to simulate several scenarios with different characteristics allowing to test the mass deployment of EVs in urban, industrial, and rural areas, to identify the best locations, number and rated power of the electric vehicle supply equipment (EVSEs) at the city level.

This deliverable presents the results for four use cases: Rønne (Denmark), Mesogia (Greece), Ponta Delgada (Portugal), and Krško (Slovenia). Krško is the smaller city with around 7500 customers, and Mesogia is the largest one with around 225 000 costumers. The simulation considered public and private data about the distribution network infrastructure; the consumption/generation profiles were defined based on empirical aggregated information.

As outlined in D3.4, the co-simulation platform can be employed in three distinct ways, depending on the information available. In this deliverable, the locations of the EVSEs in Rønne and Mesogia were determined exclusively using traffic data, as it was not possible to access data from the local electrical grid. For Ponta Delgada, we had access to data from the secondary substations (location and available capacity (kVA)), allowing the tool to employ Stage 3 - Option 1. For Krško, the partners provided grid measurements and topological data, enabling the tool to be fully applied with Stage 3 - Option 2.

The results obtained revealed that there is currently an insufficient number of EVSEs in all the use cases studied to meet 100% user satisfaction. Rønne has the largest charging infrastructure at the moment, requiring ten new locations and increase the capacity of eight existing locations. On the other hand, Mesogia needs twenty new locations, as there are twenty-two locations and sixteen need increased capacity. It includes a large industrial region without any charging infrastructure, which the tool has identified as being in high demand. Regarding Ponta Delgada, there are limited EVSEs compared to the estimated number of EVs in the area. The co-simulation tool suggested twenty new locations, and of the existing ten locations, eight require increased capacity. The smallest region, Krško, is characterized by single-storey houses, and the demand mostly meets the available EVSEs, requiring only eight new locations, primarily in public parking lots near residential areas and within large factories. It has been observed that the current number of EVs have a small impact on the electrical grid, which can accommodate increased demand without operational issues. To assess the region's readiness for the near future, a further study was conducted considering a scenario in which the number of EVs doubles. The findings indicated no limitations concerning the grid. Furthermore, the results obtained correspond to 100% user satisfaction in all use cases, meaning that the simulated EV drivers will have access to a public charging point when desired. This results in a kW per battery-electric vehicle (BEV) ratio that sometimes exceeds largely the AFIR guidelines, especially for Mesogia. It then becomes a political decision whether to follow strictly the AFIR regulation or to meet the population's needs by implementing the results presented in this deliverable. A study with the Ponta Delgada region revealed that following the minimum regulation of 1.3 kW/BEV would lead to a user satisfaction of only 68%.

This deliverable validates the co-simulation tool as a relevant decision-support resource for current and forthcoming scenario analysis. Its versatility allows for results to be derived regardless of the available data for each specified region. Urban managers and energy sector operators could benefit from this platform to plan the expansion of EV charging infrastructure, facilitating the adoption of vehicle-to-everything (V2X) and smart-grid solutions, ensuring an efficient transition to sustainable mobility.

Table of Contents

List of Figures

List of Tables

Acronyms

AFIR	Alternative Fuels Infrastructure Regulation
BEV	Battery Electric Vehicle
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
HEV	Hybrid Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
POI	Point of Interest
SoC	State-of-Charge
SS	Secondary Substation
V2X	Vehicle-to-Everything

1. Introduction

The electric car market in Europe has experienced unprecedented growth over the last decade, largely driven by political incentives, stricter environmental regulations, and the increasing availability of electric vehicle (EV) models across various price segments [2], [3]. This transformation has profound implications for urban mobility, energy consumption, and infrastructure planning, with cities facing the challenge of adapting their transportation systems and electrical distribution networks to support this transition [4]. The convergence of transport electrification and urbanization introduces complex dynamics into the operation and planning of city infrastructures [5]. Specifically, the temporal and spatial variability of the EV charging demand, often concentrated in high-traffic urban zones, poses particular stress on local low-voltage distribution systems [6]. The current deployment of Electric Vehicle Supply Equipment (EVSE) is often conducted inconsistently, without centralized planning or consideration of traffic behaviour or network availability [7]. This lack of coordination can lead to suboptimal outcomes, such as over/underused charging stations or unexpected grid overloads [4].

In this context, the co-simulation tool developed in T3.4 [1] supports strategic decision-making by combining real-time traffic data with grid modelling. This tool enables a comprehensive analysis, providing a pathway for optimal planning and the societal integration of EVs in modern cities. Understanding the relationship between traffic patterns and grid capacity is essential to ensure a technically and economically sustainable EV integration.

1.1 Scope and objectives

The primary objective of this document is to test the deployment of EVs in cities with different characteristics, utilizing the co-simulation tool developed in T3.4 [1]. Four use cases will be analysed, each representing different characteristics across urban, industrial, and rural areas, also with varying levels of EV penetration. Public information will be utilized whenever available, along with more comprehensive private data from electrical networks, to maximise the potential of the co-simulation tool.

1.2 Structure

This document is divided into four sections. After the introduction (Section 1), Section 2 provides an overview of the co-simulation platform, followed by a detailed description of the use cases regions. It ends with a characterisation of the inputs required for the platform. Section 3 presents the simulated results, detailing all the steps and decisions taken by the co-simulation tool to find the optimal EVSE locations. Finally, Section 4 presents some general conclusions and recommendations.

1.3 Relationship with other EV4EU deliverables

This testing of the EV deployment in different cities utilised the co-simulated tool developed for *D3.4: Definition and Development of a City-Level Co-simulation Platform for V2X* [1]. The definition of the behaviour profiles considered the insights from *Deliverable D3.1: EV Users' Needs and Concerns* [8] (critical to understand the typical requirements regarding recharging for each use case), and *D2.4: Optimal management of EV fleets in companies* [9]. Furthermore, the results of the current task will be vital for the development of *D3.6: High-Level Design of V2X Management Strategies Coordination*.

2. Methodology

Based on D3.4, the co-simulation tool comprises four main stages: **Stage 1**, mainly responsible for the vehicle's traffic simulation; **Stage 2**, where the energy requirements from the simulated EVs are processed and typical recharging sites are defined; **Stage 3**, responsible for the integration of the grid network, and finally **Stage 4**, which is responsible for processing the results of the previous stages and get estimates for the number of EVSEs, their locations, and the rated power of each one. The overview of the co-simulation tool methodological approach is illustrated in **Figure 1**.

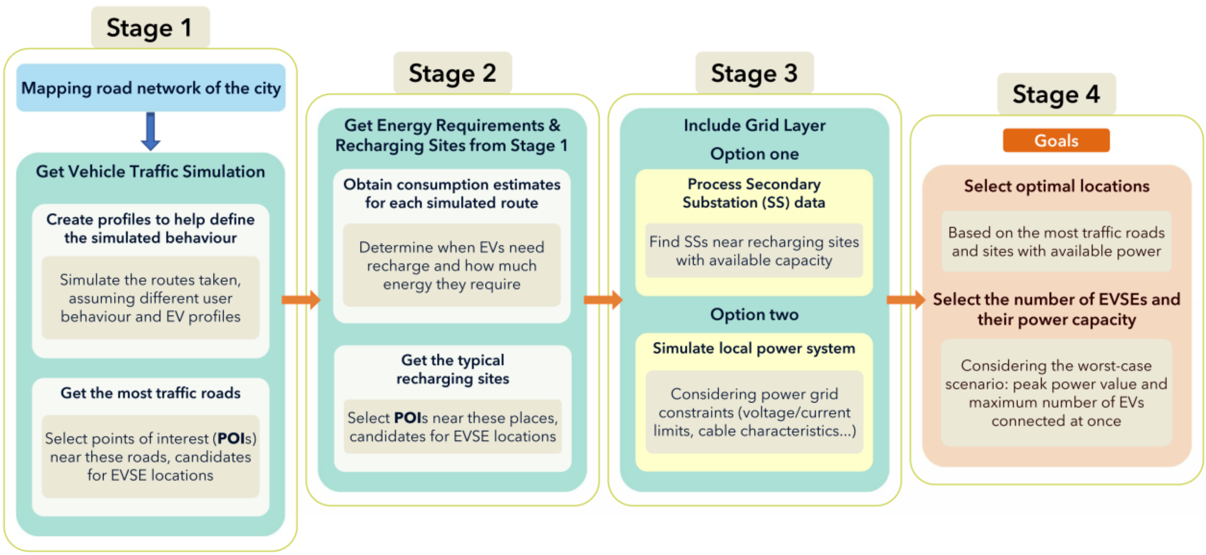

Figure 1 - Overview of the co-simulation platform, based on D3.4.

This section is divided into two subsections. Subsection 2.1 describes the main characteristics of each city selected for the use cases. Subsection 2.2 specifies the necessary inputs for the co-simulation, namely the definition of user and EV profiles, along with the available data on secondary substation or grid topology for each use case. It concludes with the constraints and EVSE options that should be tuned to improve the tool's outcomes.

2.1 Use-cases regions description

For this task, four use cases were defined to validate the co-simulation tool: Rønne City in Bornholm, Denmark; Mesogia Area in Greece; Ponta Delgada City in the Azores, Portugal; and Krško City in Slovenia. These cities have several distinct characteristics, being a set based on urban, rural, and industrial areas.

This diversity of regions provides the perfect use cases to demonstrate the robustness of the co-simulation tool in effectively validating V2X strategies and, specifically, identifying the best locations, number, and rated power of the EVSEs at the city level. Krško is the smallest city with around 7500 customers, and Mesogia is the biggest one with more than 200 000 inhabitants.

2.1.1 Rønne City, Bornholm, Denmark

Rønne is the largest town on the Danish island of Bornholm, situated in the Baltic Sea. It serves as the administrative centre of the Bornholm municipality, with 38 990 residents over 29.11 km^2, of which approximately 13 759 live in the city centre, covering 8 km^2 [10].

Regarding electric mobility for the Bornholm municipality, the passenger car stock in December 2024 reached 1216 for battery-electric vehicles (BEVs), a generous increase of 37% compared to 2023 (771 BEVs). For hybrid electric vehicles (HEVs), there were 673 units in 2024, an increase of 11% compared to 2023 (597 HEVs). The stock of EVs represents around 9.3% of the total number of vehicles in the region in December 2024 (19 549 passenger cars) [11]. It is one of the most advanced in terms of charging infrastructure, with more than 25 EVSE locations in the city centre [12]. In Denmark, the most sold BEVs in 2024 included Tesla Model Y (10471), Skoda Enyaq iV (5654), Volkswagen ID.4 (5652), Tesla Model 3 (5527), Audi Q4 e-tron (5307), and Peugeot e-208 (3036) [13].

Bornholm is recognized for its commitment to sustainability and renewable energy. The island has been designated as Denmark's first "energy island", aiming to integrate 100% renewable energies securely into the grid by 2032 [14]. Currently, local electricity production is based on biomass (16%), wind (44%), and solar (13%), covering approximately 75% of the island's electricity consumption [15].

2.1.2 Mesogia Area, Greece

Mesogia is an inland region situated in the eastern part of the Attica peninsula, Greece. It encompasses several municipalities, including Markopoulo Mesogaias, Koropi, Spata-Artemida, and Paiania. The area is characterised by a mix of urban and rural landscapes, with a rich history in viticulture and agriculture [16]. Regarding population, the municipality of Markopoulo Mesogaias, one of the prominent areas within Mesogia, has 21 722 inhabitants, while Koropi has 30 817, Spata-Artemida has 34 915, and Paiania has 28 036, according to the 2021 Greek census [16]. The international airport of Athens is located in this region, forming an important tourist centre with high demand.

Greece has seen a significant increase in EV adoption over the last 5 years. As of December 2024, there have been 21 216 BEVs and 29 547 plug-in hybrid electric vehicles (PHEVs) registered in the country, an incredible increase of 70% in BEVs (12 509 in 2023) and a 39% increase in PHEVs (21 285 in 2023), together assuming a sales share of approximately 12% in 2024 [17]. Despite this increase in sales, EVs only accounted for approximately 1% of car stock share in a universe of around 6 million cars in Greece [18]. In 2024, the most sold BEVs in Greece included the Tesla model 3 (1282 units), Volvo EX30 (985), BYD Atto 3 (729), BYD Dolphin (701), Tesla model Y (673), and Audi Q4 (299) [19].

Mesogia has been actively involved in sustainability initiatives, particularly in the energy sector. In 2023, renewable energy sources, including wind, solar, and hydroelectric power, accounted for 57% of the country's energy mix, marking a historic milestone in clean energy production [20]. The region benefits from installations of various forms of renewable energy, including wind farms and photovoltaic (PV) systems, such as net metering and rooftop PVs. Because these municipalities are characterised by a large rural area, most of the houses are single-family buildings with garages. Thus, this area becomes an interesting case study for understanding how EV users' lifestyles may or may not affect public charging needs.

2.1.3 Ponta Delgada city, Azores, Portugal

Ponta Delgada is the largest city and administrative capital of the Autonomous Region of the Azores, located on the southern coast of São Miguel Island. It serves as the main economic, cultural, and political hub of the archipelago. As of 2021, the municipality of Ponta Delgada has a resident population of 68,758 people and covers a total area of 233 km², resulting in a population density of approximately 295 inhabitants per km². The municipality is composed of 24 civil municipalities, with the city's urban core comprising São Sebastião (4050), São Pedro (7495), São José (5756) and Santa Clara (2804), around 8 km². São Roque (4590), Fajã de Cima (3293), and Fajã de Baixo (5924) are the neighbouring municipalities, mostly residential, that complete this region [21].

In recent years, there has been a notable increase in the adoption of EVs in the region. In 2023, EV (HEV + BEV) sales in the Azores archipelago surpassed ICEV sales for the first time (582 EVs, 370 HEVs, 516 ICEVs), reflecting a growing shift toward sustainable mobility in line with the rest of the country, reaching around 4% of EV stock share [22], [23]. In 2022, around 75% of Azoreans owned some type of vehicle [24]. However, despite this increase in sales throughout 2024 and 2025, Ponta Delgada city has a limited number of public EVSEs, only 10 nowadays, whose availability and locations are managed and published by the Direção Regional da Energia [25]. The most sold BEVs in Portugal for 2024 included Tesla model Y, Tesla model 3, Volvo EX30, Peugeot e-208, and BMW IX1 [26], [27], [28].

The electricity grid of Ponta Delgada, as well as the entire Azores archipelago, is managed by EDA – Electricidade dos Açores [29]. The region's electricity production relies on a mix of fossil and renewable sources. In 2023, renewable energy sources accounted for 37%, reducing to 34% in 2024 [29]. These sources include geothermal, hydro, wind, and, to a lesser extent, solar energy. Despite this advance, the share of renewables in the region is still below the national average (87.5%) and the European Union average (46.9%) [30]. Consequently, there is a strong opportunity to increase the prevalence of RES and define appropriate integration strategies when installing EVSEs.

2.1.4 Krško city, Slovenia

Krško is a town in southeastern Slovenia, located along the Sava River. It serves as the administrative centre of the Municipality of Krško and is a very industrialized region. The town is best known as the site of Slovenia's only nuclear power plant, which plays a central role in the country's energy system. As of 2024, the Krško municipality hosts about 25 992 residents and covers an area of 287 km²**.** The urban area of the town itself is approximately 6 km² in size, with around 7500 habitants [31].

Krško is making significant investments in sustainable infrastructure, particularly in the construction of cycling routes. The town has introduced a complimentary bicycle-sharing program designed to enhance cycling safety and improve access to key areas within the city. Furthermore, the Posavska statistical region (around 76 000 total residents), which includes the municipality of Krško, has revealed promising growth in electric vehicle adoption, with a total of 606 battery electric vehicles (BEVs) and 1513 hybrid electric vehicles (HEVs) registered by the end of 2024 from a total of 47 904 passenger cars, of which 16 586 existed in the municipality of Krško, and consequently a rate of 64% of vehicles/resident in Krško [32]. This indicates an EV stock share of approximately 4.4% for Posavska region.

However, in Slovenia, there has been a 27% decline in BEV sales compared to 2023, with 3156 BEVs sold in 2024, down from 4308 the previous year. In contrast, HEV sales have experienced an 18% increase, with 13 640 HEVs sold in 2024, compared to 11 140 in 2023 [33]. The top BEV models in 2024 included Tesla model 3 (446 new registrations), followed by Tesla model Y (390), Cupra Born (304), MG4 Electric (138), and Volkswagen ID.3 (138) [31], [33].

The electricity network in Krško is anchored by the Krško Nuclear Power Plant (NEK), which is co-owned by Slovenia and Croatia. Operational since 1983, the plant supplies electricity to approximately 1.5 million homes across both countries [34].

2.1.5 Summary of regions' characteristics

Table 1 summarizes the main characteristics of each area considered, including the approximate population, the type of land use, the EV stock share and the characterization of the local electrical grid.

Table 1 – Summary of main characteristics of each use case region.

Considered region	Rønne, Bornholm, Denmark	Mesogia, Greece	Ponta Delgada, Azores, Portugal	Krško, Slovenia
Population (year)	13 759 (2024) [10]	115 490 (2021) [16]	≈ 34 000 (2021) [21]	≈ 7500 (2024) [31]
Land use type	Mostly urban and residential	Mix of urban, rural and industrial	Mostly urban and residential	Mostly residential and industrial
EV stock share (%)	9.3% (for the municipality) [11]	≈ 1% (for the entire country) [18]	≈ 4% (for the Azores archipelago) [22], [23]	4.4% (for the municipality) [32]
Grid characterization	75% of renewable sources	57% of renewable sources	34% of renewable sources	Mostly from nuclear power plant

2.2 Inputs needed for Task's 3.4 co-simulation tool

The co-simulation tool requires several inputs to function effectively. One of the essential inputs, detailed in D3.4 [1], is the polygon that defines the boundaries of the desired region. Outlining these boundaries is crucial to ensure the tool accurately selects points of interest and generates the simulated routes.

The tool can reach its full potential if information about the electrical network is available, such as data from secondary substations (SSs) (Option 1, Stage 3) or complete grid topology data (Option 2, Stage 3). If this information is not available, the tool will provide optimum locations based on traffic simulations only.

2.2.1 Definition of user profiles

In addition to the polygon, various other inputs can and should be modified from the platform's default values to ensure the tool provides the best results for each region. Specifically, behaviour and EV profiles are crucial as they determine the different parameters utilized in the traffic simulator [1]. Behaviour profiles outline typical departure times and charging opportunities for users, while EV profiles detail the characteristics of the simulated EVs (consumption, weight, and efficiency). By fine-tuning these profiles, the outputs of the traffic simulator will vary, subsequently modifying the simulated needs of the drivers (Stage 2). This change will require different amounts of energy from the grid (Stage 3), ultimately affecting the number and power of each EVSE selected.

In this study, the user profiles were defined using insights from D3.1 [8] and D2.4 [9] and validated with empirical information from the TOMTOM Live traffic index report [35], to ensure that the platform operates with the most tailored profiles possible based on surveys and real online data. Regarding EV profiles, various reports were consulted, including [2], [13], [17], [27], and the characteristics of the EVs were obtained from the EV Database [36].

Deliverable D3.1 [8] revealed that drivers in Greece, Denmark, Portugal, and Slovenia prioritize vehicle range over battery care. For these drivers, it is essential to maintain their daily routines without constantly worrying about recharging their EVs. However, Denmark stands out as being more energy literate, as Danish drivers are more willing to adjust their routines to accommodate the need to charge their EVs, something less common in other countries. Consequently, it is necessary to expand the number of EVSE locations overall [8].

2.2.2 Grid topology/Secondary substation data

Stage 3 constitutes a central component of the co-simulation tool, as it integrates the electrical grid dimension into the process of identifying optimal locations. To enable this functionality, users are expected to provide input data related to the electrical infrastructure. However, such data are not always readily available online or even privately. Therefore, the tool has been designed with three operational modes to address this limitation and ensure broad applicability.

When detailed information on the grid network is available, the tool can be utilized to its full potential, either by incorporating data from secondary substations (Option 1, Stage 3) or comprehensive grid topology data and measurements (Option 2, Stage 3). In the lack of such information, the tool can still operate effectively by relying solely on traffic simulation outputs (from Stage 1) to propose suitable locations. This flexible design ensures the usability of the tool across diverse data availability scenarios, thus enhancing its practicality and adaptability. **Table 2** summarizes the minimum inputs necessary for using each Stage 3 option.

For this study, it was possible to obtain grid data for two use cases. In Ponta Delgada, we received secondary substation data, including location and available capacity (kVA), from the partner EDA - Electricidade dos Açores. On the other hand, Elektro Celje provided the EV4EU project with detailed information about the local power grid in the Krško region, via the University of Ljubljana (UL). This data contains medium voltage (MV) and low voltage (LV) feeders, secondary substations, buses, and both MV and LV lines. Additionally, this partner also supplied time series data on actual consumption at each secondary substation, allowing the tool to be utilized to its full potential.

Table 2 – Minimum inputs required for each Stage 3 option of the co-simulation tool.

Needed Features	Option 1: Hosting Capacity and Secondary Substation Data	Option 2: Hosting Capacity and Considering Low Voltage Grid
Geolocation data of grid buses (latitude, longitude)		X
Geolocation data of SSs (latitude, longitude)	X	X
Available capacity of SSs (kW)	X	
Buses/SSs timeseries consumption data		X
Geolocation data of MV and LV grid lines (latitude, longitude)		X
MV and LV grid lines' characteristics (*from_bus*, *to_bus*, resistance, reactance, length)		X

2.2.3 Constraints and EVSE options

In addition to user and EV profiles, it is advisable to specify constraints, including the maximum number of EVSEs for each location, the types of EVSEs to be installed, and their installation costs. These decisions should consider the available options for each region/platform user.

Furthermore, it is worth specifying the OSMnx tags responsible for identifying the POIs that may serve as potential locations, along with their assigned priorities [1]. The priority given to each POI plays a crucial role in influencing the outcomes, as different types retain specific characteristics that can affect the selection of final locations in Stage 4. Finally, thresholds specifying the maximum POI and SS search distances can also be adjusted to be tailored to the region under study. The tool performs a weighted selection of these parameters, but the platform users can modify them according to their preferences.

3. Simulation Results

This section presents the results for all considered use cases, demonstrating the proposed co-simulation platform's successful operation in diverse contexts. Subsection 3.1 presents the model assumptions and the main considerations common to all the use cases, followed by separate sections presenting the results for Rønne, Mesogia, Ponta Delgada, and Krško. For Krško, an additional study focusing on a near-future scenario is included.

3.1 Main considerations and common model assumptions

All simulations were performed over 7 days (5 weekdays + 2 weekend days), and the commonly chosen POI categories are presented in (1).

```
tags = {'amenity': True, 'building': True, 'shop': True, 'tourism': True, 'leisure': True}
```
(1)

The number of simulated EVs was selected according to the EV stock values presented in Section 2.1. The Clustering approach was selected, and the automatic option for choosing the number of aggregated recharging sites was also considered, with the input range varying according to the number of habitants within each region [1]. For Stage 3, obtaining grid data for the use cases in Denmark and Greece presented significant challenges, ultimately proving impossible. In Ponta Delgada, secondary substation data were employed to facilitate the analysis, while it was possible to access both grid topology data and relevant measurements for Krško. **Table 3** provides a summary of the main model assumptions for each use case.

Table 3 – Summary of the main co-simulation tool considerations for all use cases.

<table>
<tr><td rowspan="2">Stage 1</td><td>Considered region</td><td>Rønne, Bornholm, Denmark</td><td>Mesogia, Greece</td><td>Ponta Delgada, Azores, Portugal</td><td>Krško, Slovenia</td></tr>
<tr><td>Number of simulated EVs</td><td>600 EVs for 7 days</td><td>1200 EVs for 7 days</td><td>1000 EVs for 7 days</td><td>350 EVs for 7 days</td></tr>
<tr><td rowspan="2">Stage 2</td><td>Selected method</td><td colspan="4">Method 2 - Clustering approach</td></tr>
<tr><td>Selected option for determining the number of locations</td><td colspan="4">Automatic option, with range (no. of existing EVSEs, no. of EVs/10) clusters</td></tr>
<tr><td rowspan="2">Stage 3</td><td>Selected Option</td><td>Not considered</td><td>Not considered</td><td>Option 1: Hosting Capacity and Secondary Substation Data</td><td>Option 2: Hosting Capacity and Considering Low Voltage Grid</td></tr>
<tr><td>Input data</td><td>No data available</td><td>No data available</td><td>EDA CARE BT 2024 [29]</td><td>Private Elektro Celje grid topology data and measurements</td></tr>
</table>

The EVSE data were obtained by analysing the most operated EVSEs in each use case, leading to the same available options for each region. The equipment options were carefully defined for each type of POI, accounting for added constraints such as the number of EVSEs that can be installed in each site (based on typical values for all use cases – constraint #1), the opening cost for new locations (non-existing EVSEs – constraint #2), and a rule for diversifying the EVSE options, ensuring user flexibility, and future-proof infrastructure (constraint #3). **Table 4** provides a summary of the inputs for Stage 4 considered for all use cases.

Table 4 – Summary of selected inputs and constraints of Stage 4 for all use cases.

EVSE data	Constraints		
	#1	#2	#3

*# EVSE options and costs for specific POI type 	
specific_evse_options = {
'hospital', 'supermarket', 'mall', 'charging_station', 'industrial':
{ '11kW': {'power': 11, 'ports': 1, 'cost': 3000},
'22kW': {'power': 22, 'ports': 2, 'cost': 4500},
'43kW': {'power': 43, 'ports': 2, 'cost': 7000} }, }
 	
'parking', 'office':
{ '7.2kW': {'power': 7.2, 'ports': 1, 'cost': 2500},
'11kW': {'power': 11, 'ports': 1, 'cost': 3000},
'22kW': {'power': 22, 'ports': 2, 'cost': 4500},
'43kW': {'power': 43, 'ports': 2, 'cost': 7000} }, }
 	
# EVSE options and costs for remaining POI type 	
default_evse_options = {
'3.7kW': {'power': 3.7, 'ports': 1, 'cost': 1250},
'7.2kW': {'power': 7.2, 'ports': 1, 'cost': 2500} }*
	*# Define the maximum number of EVSEs for each site type
	
	max_evse_counts = {
	'parking': 20,
	'hospital': 20,
	'supermarket': 15,
	'mall': 20,
	'office': 15,
	'charging_station': 20,
	'industrial': 15
	}*
		*# Additional cost for opening a new EVSE location
		
		opening_cost = 5000*
			# For every 8 EVSEs of the same type, include 1 of higher power.

It is worth mentioning that existing EVSEs and locations were considered for all use cases. The tool assumes existing EVSEs as mandatory locations, along with each device's installed capacity. Furthermore, the results presented in the following sections correspond to 100% user satisfaction, meaning that all simulated EV drivers will have access to a public charging point when desired. This results in a kW/EV ratio that sometimes exceeds the Alternative Fuels Infrastructure Regulation (AFIR) [37] regulation. It then becomes a political decision whether to just follow the AFIR regulation or to meet the population's needs and implement the results presented in this report. Section 3.4.2 presents the effect of following AFIR's regulation of (at least) 1.3 kW/BEV.

This guarantees a practical application of the results, enabling an assessment of whether the current supply meets the needs of the estimated users or if demand exceeds the available locations and number of chargers.

3.2 Rønne City, Bornholm, Denmark

The polygon of the exact simulated area is defined in (2).

polygon = Polygon([
(55.0745346, 14.7069168),
(55.0896174, 14.7569561),
(55.1261954, 14.7487164),
(55.1276185, 14.6893215),
(55.0924663, 14.6754169),]) (2)

Starting with the selection of the POIs, the probabilities were distributed as follows: *'endpoint' - 0.05, 'building' - 0.10, 'amenity' - 0.35, 'shop' - 0.3, 'tourism' - 0.15, 'leisure' - 0.05,* with specific probabilities for *'industrial' - 0.2, 'school' – 0.25,* and *'supermarket' - 0.35.*

The identified POIs are displayed in **Figure 2** corresponding to 1701 points, of which 696 are residential homes, 592 are parking lots, 32 are sport pitches, and 17 are supermarkets. There exist 25 EVSE sites in this region, making it the most equipped of all the use cases in terms of charging infrastructure.

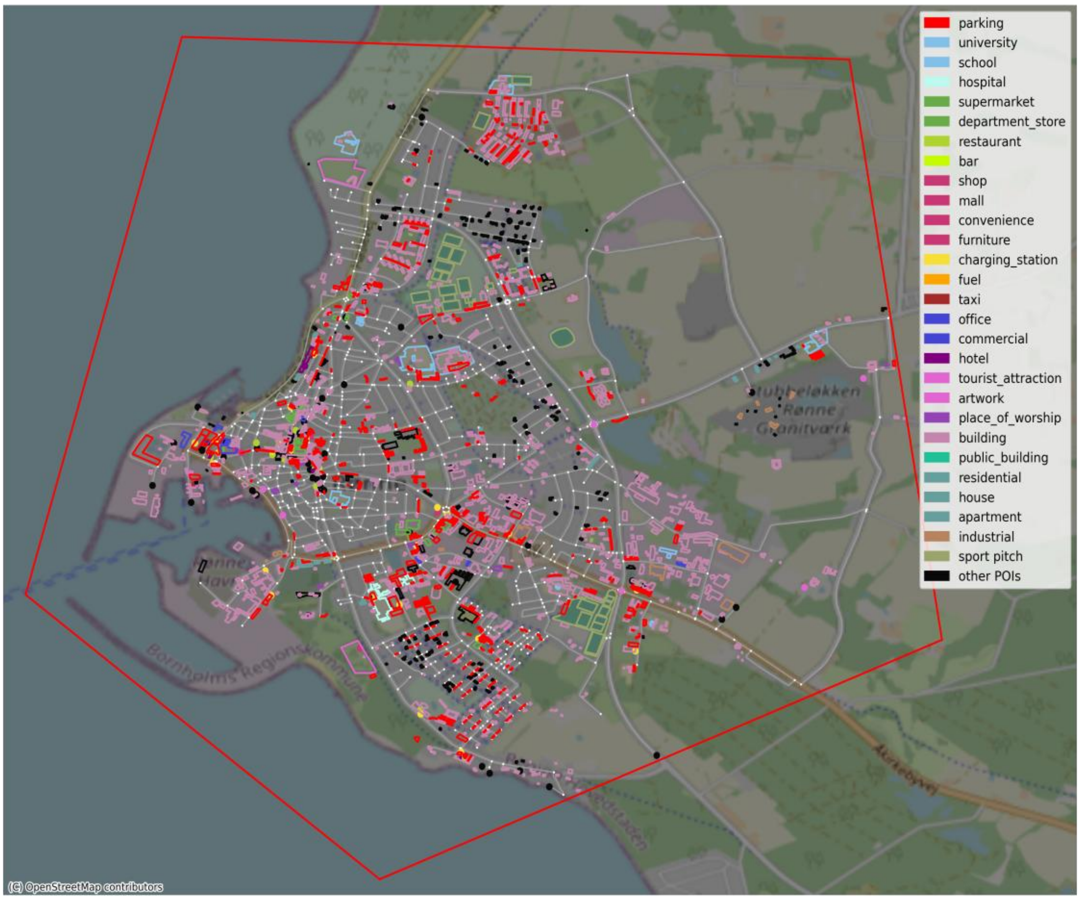

Figure 2 - Identified POIs according to the selected tags, for Rønne.

Having found the POIs, the traffic simulator also requires the user profiles. The EV profiles considered for this region are listed in **Table 5**, reflecting the most sold BEVs in the region for the year of 2024 [13]. The car characteristics were obtained from [36]. The tailored behaviour profiles are provided in **Table 6**, adjusted and updated considering the relevant information provided by [8] and [35].

Table 5 – Summary of the characteristic fields for the defined EV profiles of Rønne.

EV Profile	Tesla Model Y	Skoda Enyaq iV	Volkswagen ID4 Pro	Tesla Model 3	Audi Q4 e-tron	Peugeot e-208
Profile probability [0-1]	0.3	0.16	0.16	0.15	0.14	0.09
Battery size [kWh]	57.5	58	77	60	77	48
Vehicle weight [kg]	2456	1965	2156	2200	2145	1550
Acceleration efficiency [0-1]	0.67	0.67	0.67	0.67	0.67	0.67
Deceleration efficiency [0-1]	0.91	0.91	0.91	0.91	0.91	0.91
Uphill efficiency [0-1]	0.74	0.74	0.74	0.74	0.74	0.74
Downhill efficiency [0-1]	0.73	0.73	0.73	0.73	0.73	0.73
'Mean velocity, Consumption' [km/h, kWh/100km]	'46.5,16.4'	'46.5,17.1'	'46.5,17.3'	'46.5,13.7'	'46.5,18.3'	'46.5,15.5'
Initial SoC [kWh]	Randomly generated *([0-1] × Battery size)*					

Table 6 – Summary of the characteristic fields for the behaviour profiles of Rønne.

Behaviour Profile		Profile probability [0-1]	Mean Travel times [h] *([week], [weekend])*	Recharge home probability [0-1]	Recharge during day
Company	Fleet	0.1	[10, 12, 14, 16.5, 19, 22], [ ]	0.9	*Yes, with 50% chance when parked more than 2h*
Shift worker	Afternoon	0.12	[15, 23], [18, 20]	0.5	
	Morning	0.13	[6, 15], [10, 18]	0.6	
Typical worker	Single	0.2	[8, 16, 17], [12, 18]	0.4	
	Family	0.25	[7, 8, 17, 18], [11, 12]	0.6	
	Couple	0.2	[8, 12, 13, 17, 19], [12, 21]	0.4	

The Bornholm municipality has a population of 38 990, with 13 759 residents living in Rønne, accounting for approximately 35% of the island's population. Given the 1 216 BEVs by the end of 2024 (recall section 2.1.1), this simulation considered 600 EVs, assuming approximately 50% of the total BEVs on the island visit the Rønne region each day. Additionally, the behaviour profiles assume that around 50% of the users recharge the EV at home (as verified in **Table 6**), according to Deliverable 3.1 [8].

The output of Stage 1 (traffic routes and POIs) is depicted in **Figure 3** and **Figure 4,** having identified 650 points. It is worth mentioning that the highways were removed from the most traffic streets, ensuring that only the city/urban regions POIs were selected and identified.

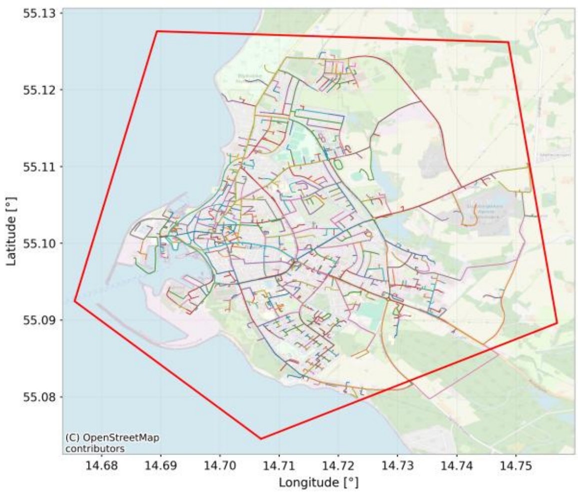

Figure 3 - Rønne resulting routes from Traffic Simulator.

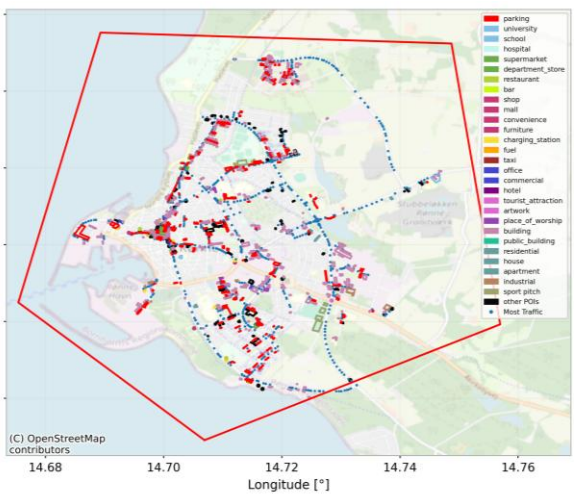

Figure 4 - Rønne most traffic streets and selected POIs.

The results from Stage 1 undergo processing and cleaning in the first step of Stage 2. Following this, Step 2 automatically identifies **33** as the optimal number of aggregated recharging sites. Subsequently, it locates 851 POIs within a 250-meter radius of these recharging sites, which are merged with the identified POIs from Stage 1, eliminating duplicates and resulting in a total of 1138 combined POIs.

Figure 5 reveals the optimal selected aggregated recharging sites and the combined POIs.

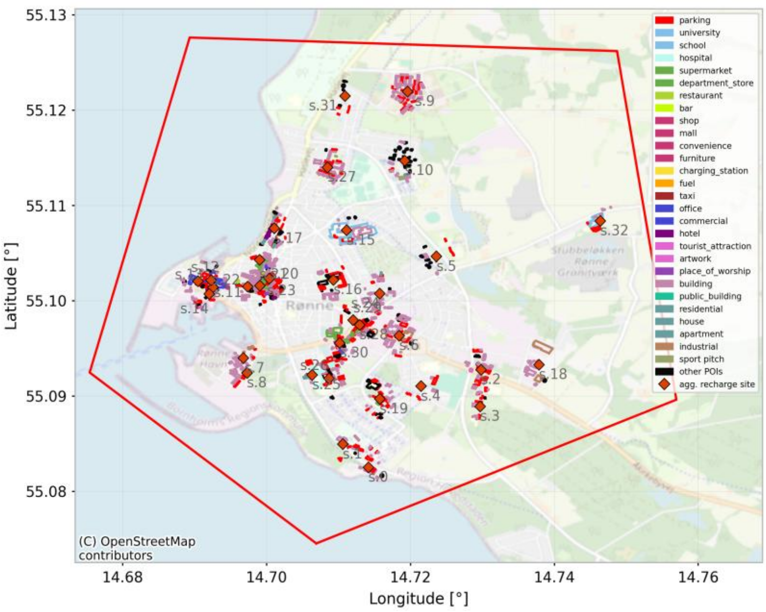

Figure 5 - Aggregated recharge sites and combined POIs for Rønne.

Since there is no Stage 3 for this use case (due to the lack of grid data), these identified POIs from traffic simulation are sent as input for Stage 4, which starts by identifying the optimal locations for each recharge site through the evaluation of the priority list defined in (3), favouring nearby EVSE installations and hospitals.

```
priority_list = ['charging_station', 'hospital', 'office', 'parking', 'taxi', 'supermarket',
'mall', 'commercial', 'industrial', 'university', 'college', 'school', 'restaurant', 'hotel',
'shop', 'convenience', 'apartment', 'sport pitch', 'building', 'home', 'residential']
```
(3)

The EVSE data was obtained by analysing the most operated EVSEs in Rønne [38]. The equipment options were carefully defined for each type of POI, accounting for added constraints such as the number of EVSEs that can be installed in each site (based on typical values for Rønne) and the opening cost for new locations (non-existing EVSEs). **Table 7** provides a summary of the inputs for Stage 4.

Figure 6 illustrates the results of Stage 4 regarding the optimal selected locations for Rønne and provides the characteristics of each recharging site, specifically the type of site, the corresponding selected combination of EVSEs and the cost of installation. The existing locations are depicted in yellow, revealing the need to open 11 new locations, among parking lots and industrial buildings.

Locations 25 and 26 are part of the parking lot of the city's main hospital and represent existing EVSEs, which explains the absence of any hospital location in the results. In addition, the findings indicated that the city already has numerous locations with sufficient EVSEs. Fourteen recharging sites do not require any increase in capacity. The most expensive locations to install would be site 16, which is the parking lot of a municipal building, and site 27, which corresponds to a parking lot in a residential area near a kindergarten. On average, users need to drive 500 m to find the nearest EVSE.

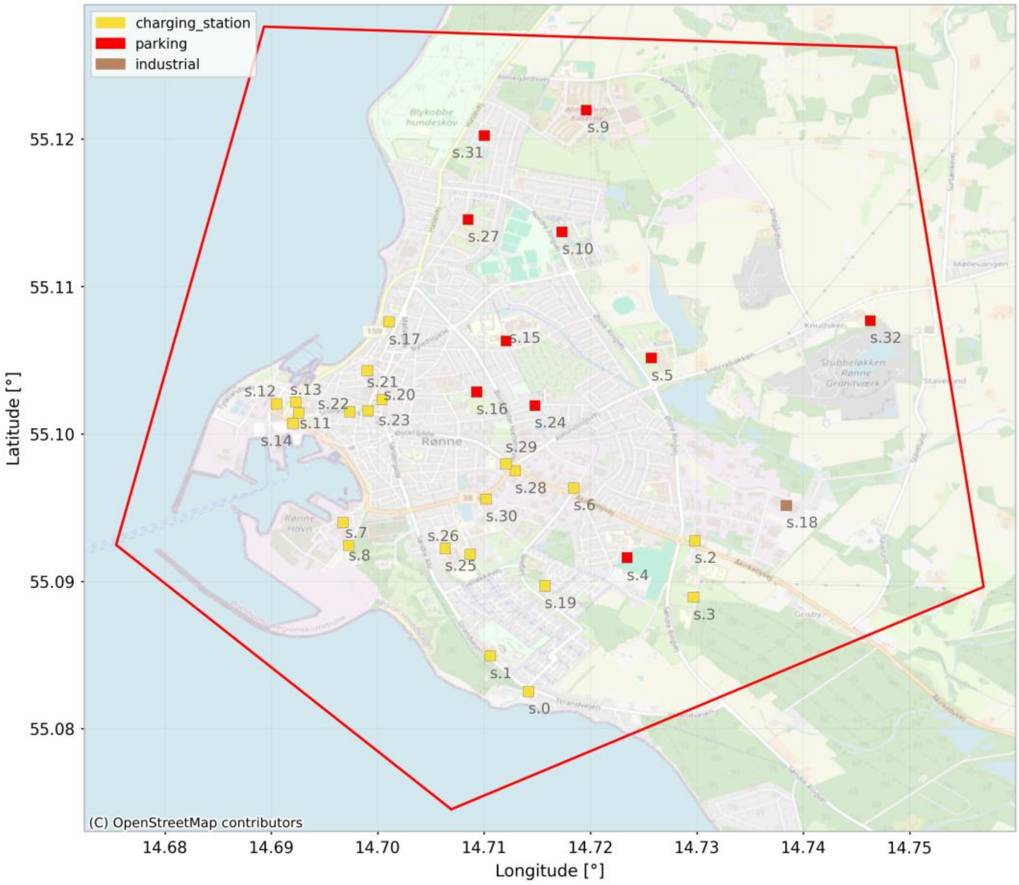

Figure 6 - Co-simulation final EVSE locations for Rønne.

Table 7 – Characteristics of the final EVSE locations for Rønne.

Recharge site	Best Combination	Cost [€]	Recharge site	Best Combination	Cost [€]
0 - charging_station	1 '11kW'	3000	17 - charging_station	EVSE with sufficient capacity	0
1 - charging_station	EVSE with sufficient capacity	0	18 - industrial	1 '11kW', 3 '22kW'	21500
2 - charging_station	1 '11kW', 1 '22kW'	7500	19 - charging_station	2 '22kW'	9000
3 - charging_station	1 '11kW', 3 '22kW'	16500	20 - charging_station	1 '11kW', 1 '22kW'	7500
4 - parking	2 '22kW'	14000	21 - charging_station	EVSE with sufficient capacity	0
5 - parking	3 '22kW'	18500	22 - charging_station	EVSE with sufficient capacity	0
6 - charging_station	3 '22kW'	13500	23 - charging_station	EVSE with sufficient capacity	0
7 - charging_station	2 '22kW'	9000	24 - parking	3 '22kW'	18500
8 - charging_station	EVSE with sufficient capacity	0	25 - charging_station	EVSE with sufficient capacity	0
9 - parking	3 '22kW'	18500	26 - charging_station	EVSE with sufficient capacity	0
10 - parking	3 '22kW'	18500	27 - parking	1 '7.2kW', 4 '22kW'	25500
11 - charging_station	EVSE with sufficient capacity	0	28 - charging_station	EVSE with sufficient capacity	0
12 - charging_station	EVSE with sufficient capacity	0	29 - charging_station	EVSE with sufficient capacity	0
13 - charging_station	EVSE with sufficient capacity	0	30 - charging_station	1 '11kW'	3000
14 - charging_station	EVSE with sufficient capacity	0	31 - parking	1 '22kW'	9500
15 - parking	1 '7.2kW', 1 '22kW'	12000	32 - parking	1 '7.2kW', 1 '22kW'	12000
16 - parking	1 '7.2kW', 4 '22kW'	25500	-	-	-

3.3 Mesogia Area, Greece

The polygon of the exact simulated area is defined in (4).

polygon = Polygon([
(38.0026557, 24.0361977),
(38.0053610, 23.9685631),
(37.9875044, 23.9012718),
(37.9612526, 23.8350105),
(37.8709237, 23.8549232),
(37.8527633, 24.0636635),]) (4)

Starting with the selection of the POIs, the categories chosen are presented in (1), with the probabilities distributed as follows: *'endpoint' - 0.05, 'building' - 0.10, 'amenity' - 0.35, 'shop' - 0.3, 'tourism' - 0.15, and 'leisure' - 0.05.*

The identified POIs are displayed in **Figure 7** corresponding to 2810 points, of which 376 are residential homes, 234 are industrial buildings, 207 are parking lots, 127 are sport pitches, 57 are tourist attractions, and 34 are supermarkets. There already exists 22 EVSE locations in this region.

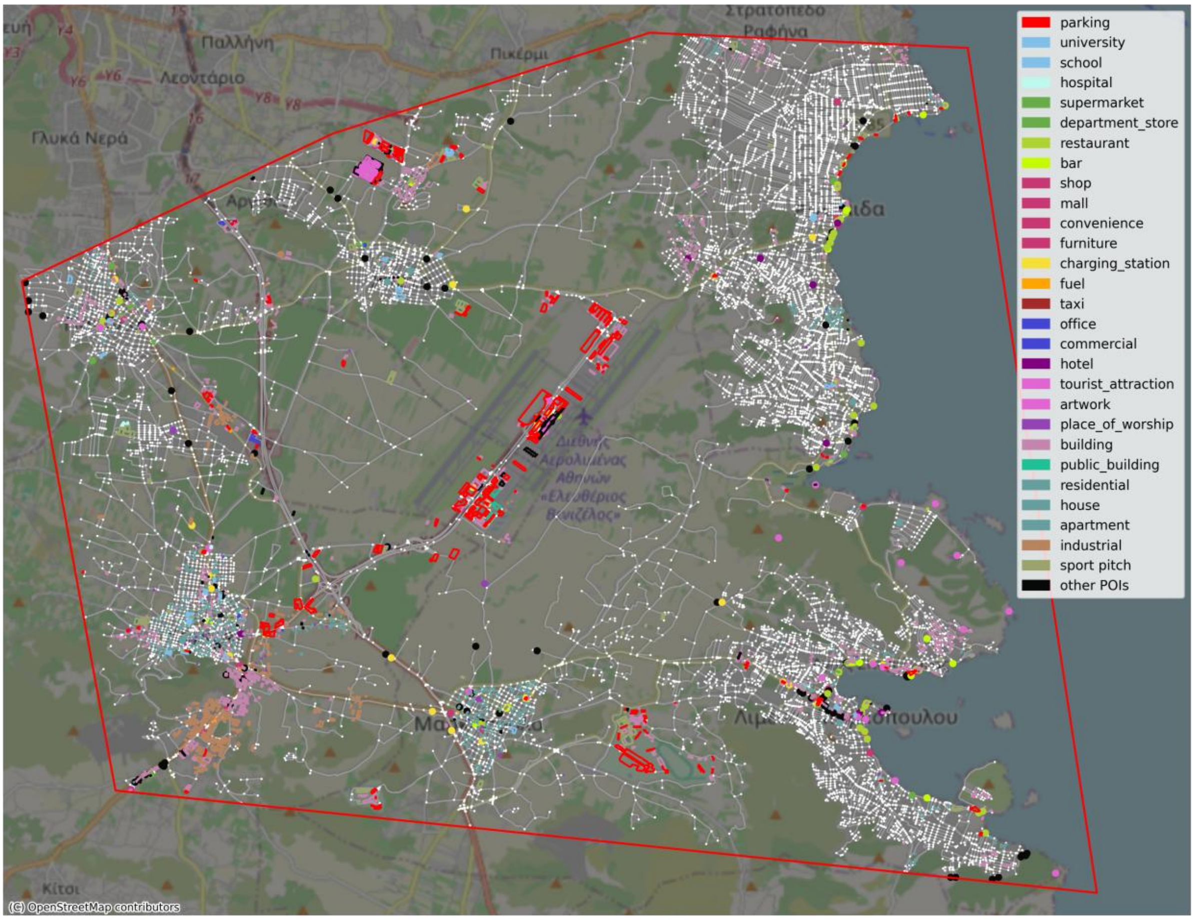

Figure 7 - Identified POIs according to the selected tags, for Mesogia.

The EV profiles considered for this region are listed in **Table 8**, corresponding to the 2024 best-selling models in Greece, as previously reported (recall subsection 2.1.2). The characteristics of the EVs were obtained from [36]. The tailored behaviour profiles are provided in **Table 9**, adjusted and updated considering the relevant information provided by [8] and [35].

Table 8 – Summary of the characteristic fields for the defined EV profiles.

EV Profile	Tesla Model 3	Volvo EX30	BYD Atto 3	BYD Dolphin	Tesla Model Y	Audi Q4
Profile probability [0-1]	0.29	0.21	0.16	0.15	0.14	0.06
Battery size [kWh]	58	49	60.5	60.5	57.5	77
Vehicle weight [kg]	2200	2200	1825	1733	2456	2145
Acceleration efficiency [0-1]	0.67	0.67	0.67	0.67	0.67	0.67
Deceleration efficiency [0-1]	0.91	0.91	0.91	0.91	0.91	0.91
Uphill efficiency [0-1]	0.74	0.74	0.74	0.74	0.74	0.74
Downhill efficiency [0-1]	0.73	0.73	0.73	0.73	0.73	0.73
'Mean velocity, Consumption' [km/h, kWh/100km]	'46.5,13.7'	'46.5,18.0'	'46.5,18.3'	'46.5,17.3'	'46.5,16.4'	'46.5,18.3'
Initial SoC [kWh]	Randomly generated *([0-1] × Battery size)*					

Table 9 – Summary of the characteristic fields for the defined Behaviour profiles.

Behaviour Profile		Profile probability [0-1]	Mean travel times [h] *([week], [weekend])*	Recharge home probability [0-1]	Recharge during day
Company	Fleet	0.12	[10, 12, 14, 16.5, 19, 22], [ ]	0.9	*Yes, with 50% chance when parked more than 2h*
Shift worker	Afternoon	0.12	[15, 23], [18, 20]	0.5	
	Morning	0.12	[6, 15], [11, 18]	0.6	
Typical worker	Single	0.19	[8, 17, 18], [12, 17]	0.3	
	Family	0.26	[7, 8, 17, 18], [9, 12]	0.6	
	Couple	0.19	[8, 12, 13, 17, 19], [12, 23]	0.1	

A population density analysis of the simulated area revealed an approximate population of 115 490 inhabitants within the region. Given an estimated electric vehicle (EV) stock share of approximately 1%, this results in approximately 1200 EVs in this area for the year 2024. Given its status as a suburb of Athens, the location of most EVs, this number emerges as reasonable. Similar to Rønne, we estimated that approximately 50% of users recharge at home, thus not utilizing public infrastructure (as verified in **Table 9**), according to Deliverable 3.1 [8].

The output of Stage 1 (traffic routes and POIs) is depicted in **Figure 8** and **Figure 9**, having identified 1063 points. It is worth mentioning that the highways were removed from the most traffic streets, ensuring that only the city/urban regions POIs were selected and identified.

The results from Stage 1 undergo processing and cleaning in the first step of Stage 2. Following this, Step 2 automatically identifies **49** as the optimal number of aggregated recharging sites. Subsequently, it locates 1284 POIs within a 400-meter radius of these recharging sites, which are merged with the identified POIs from Stage 1, eliminating duplicates and resulting in a total of 2147 combined POIs. **Figure 10** displays the determined aggregated recharging sites and the near identified POIs.

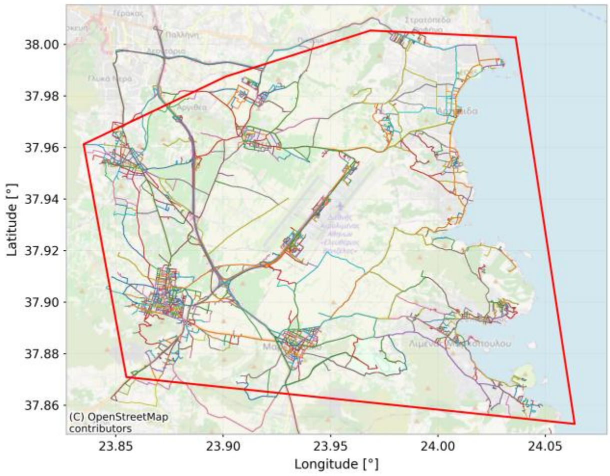

Figure 8 - Mesogia resulting routes from Traffic Simulator.

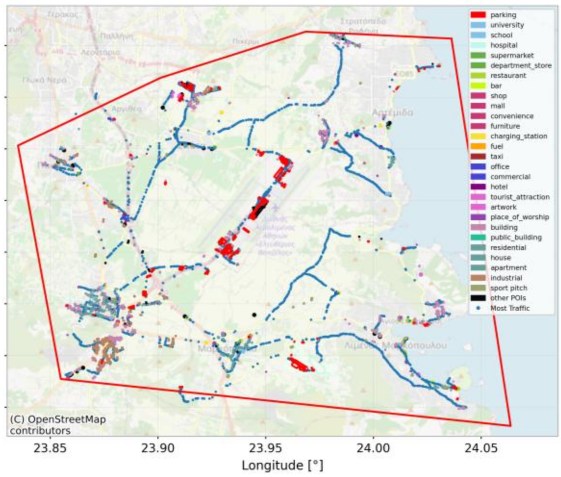

Figure 9 - Mesogia most traffic streets and selected POIs.

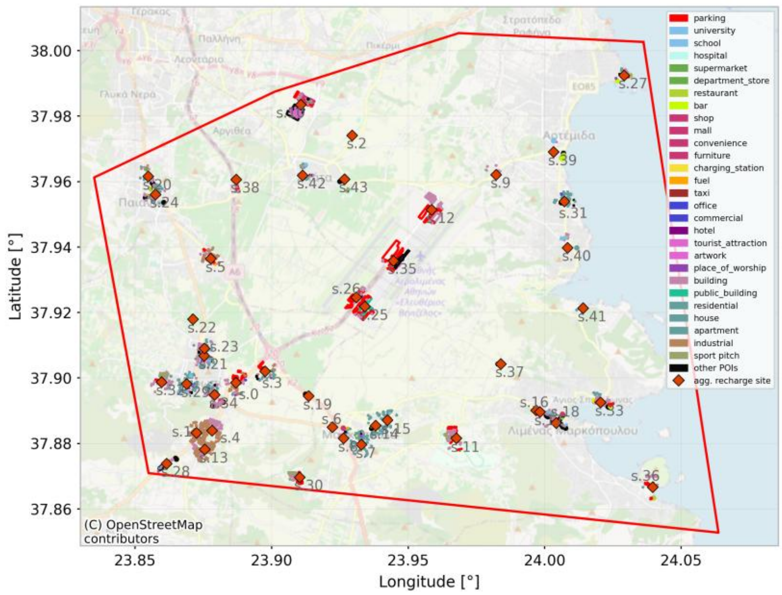

Figure 10 - Aggregated recharge sites and combined POIs for Mesogia.

Since there is no Stage 3 for this use case, these identified POIs from traffic simulation are the ones sent as input for Stage 4, which starts by identifying the optimal locations for each recharge site through the evaluation of the priority list defined in (5), favouring nearby EVSE installations, hospitals, and office spaces.

```
priority_list = ['charging_station', 'hospital', 'office', 'parking', 'taxi', 'supermarket',
'mall', 'commercial', 'industrial', 'university', 'college', 'school', 'restaurant', 'hotel',
'shop', 'convenience', 'apartment', 'sport pitch', 'building', 'home', 'residential']
```
(5)

The EVSE data was obtained by analysing the most operated EVSEs in Greece [12]. The equipment options were carefully defined for each type of POI, accounting for added constraints such as the number of EVSEs that can be installed in each site, based on typical values for Greece and the opening cost for new locations (non-existing EVSEs). Table 4 provides a summary of the inputs for Stage 4.

Figure 11 illustrates the results of Stage 4 regarding the optimal selected locations and **Table 10** provides the characteristics of each recharging site, specifically the type of site, the corresponding selected combination of EVSEs and the cost of installation.

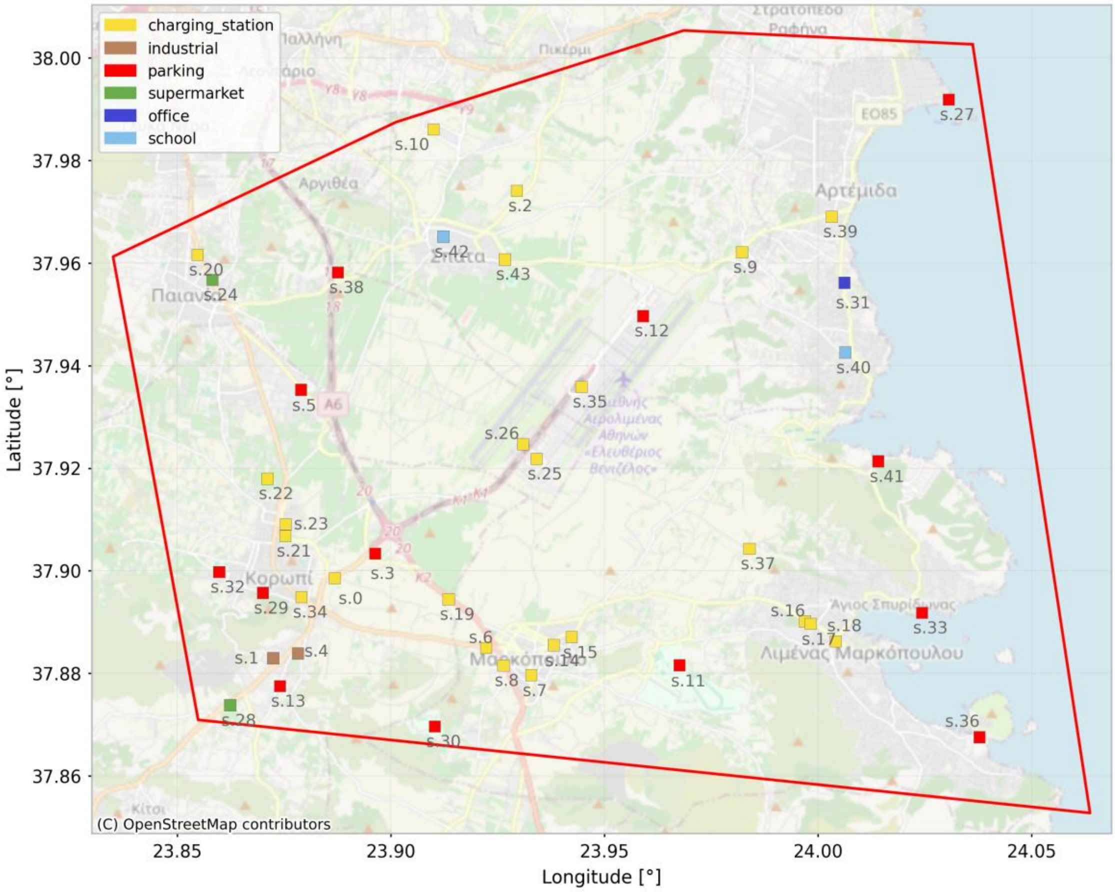

Figure 11 - Co-simulation final EVSE locations for Mesogia.

Table 10 – Characteristics of the final EVSE locations for Mesogia.

Recharge site	Best Combination	Cost [€]	Recharge site	Best Combination	Cost [€]
0 - charging_station	1 '11kW', 4 '22kW'	21000	22 - charging_station	EVSE with sufficient capacity	0
1 - industrial	1 '11kW', 8 '22kW'	39000	23 - charging_station	EVSE with sufficient capacity	0
2 - charging_station	3 '22kW'	13500	24 - supermarket	4 '22kW'	23000
3 - parking	7 '22kW'	36500	25 - charging_station	4 '22kW'	18000
4 - industrial	8 '22kW', 1 '43kW'	48000	26 - charging_station	1 '11kW', 1 '22kW'	7500
5 - parking	6 '22kW'	32000	27 - parking	2 '22kW'	14000
6 - charging_station	EVSE with sufficient capacity	0	28 - supermarket	2 '22kW'	14000
7 - charging_station	1 '22kW'	4500	29 - parking	5 '22kW'	27500
8 - charging_station	1 '22kW'	4500	30 - parking	2 '22kW'	14000
9 - charging_station	2 '22kW'	9000	31 - office	4 '22kW'	23000
10 - charging_station	1 '11kW', 5 '22kW'	25500	32 - parking	1 '7.2kW', 3 '22kW'	21000
11 - parking	4 '22kW'	23000	33 - parking	1 '7.2kW', 3 '22kW'	21000
12 - parking	4 '22kW'	23000	34 - charging_station	2 '22kW'	9000
13 - parking	1 '7.2kW', 6 '22kW'	34500	35 - charging_station	EVSE with sufficient capacity	0

14 - charging_station	1 '11kW', 2 '22kW'	12000	36 - parking	1 '7.2kW', 4 '22kW'	25500
15 - charging_station	EVSE with sufficient capacity	0	37 - charging_station	1 '43kW'	7000
16 - charging_station	EVSE with sufficient capacity	0	38 - parking	3 '22kW'	18500
17 - charging_station	2 '22kW'	9000	39 - charging_station	2 '22kW'	9000
18 - charging_station	EVSE with sufficient capacity	0	40 - school	3 '11kW'	14000
19 - charging_station	2 '22kW'	9000	41 - parking	1 '7.2kW', 1 '22kW'	12000
20 - charging_station	5 '22kW'	22500	42 - school	4 '7.2kW'	15000
21 - charging_station	2 '22kW'	9000	43 - charging_station	EVSE with sufficient capacity	0

To the south of Koropi, in Viomichaniki Periochi, lies a large industrial region with high levels of car traffic. According to the results, this area is of great interest for EVSE infrastructure, as they serve not only industrial workers but also the companies' vehicles that are located nearby. Site 1 is the most expensive to install, with 8 EVSEs of 22 kW and 1 of 11 kW needed to meet all the demand. Similarly, sites 4 and 13, which are found within this industrial area, indicate a substantial need for EVSE installations. On average, users travel 1.2 km to the nearest EVSE, with the longest distance near the site 27, approximately 3 km. This area is primarily residential, where users typically recharge their vehicles at home.

3.4 Ponta Delgada city, Azores, Portugal

This section presents two options for results. Subsection 3.4.1 presents the results obtained following the constraints and inputs indicated in **Table 3** and **Table 4**, similar to those discussed previously for Ronne and Mesogia, assuming 100% user satisfaction, i.e., each user has EVSEs available to recharge according to their simulated behaviour. Subsection 3.4.2 provides the results following the AFIR guideline of at least 1.3 kW/BEV, aiming to demonstrate how this recommendation would affect the number of EVSEs suggested by the co-simulation tool to install and how user satisfaction would be affected.

3.4.1 100% user satisfaction

The polygon of the exact simulated area is defined in (6).

```
polygon = Polygon([
    (37.7491364, -25.7073215),
(37.7405169, -25.6961650),
(37.7320322, -25.6850046),
(37.7357656, -25.6647491),
(37.7490686, -25.6268120),
(37.7480336, -25.6180787),
(37.7729536, -25.6135082),                                   (6)
(37.7800091, -25.6242371),
(37.7728179, -25.6596851),
(37.7678312, -25.6729031),
(37.7651511, -25.6826878),
(37.7652190, -25.6894255),
(37.7659993, -25.6974936),
(37.7613853, -25.7078791) ])
```

Starting with the selection of the POIs, the probabilities were distributed as follows: *'endpoint' - 0.05, 'building' - 0.10, 'amenity' - 0.35, 'shop' - 0.3, 'tourism' - 0.15, 'leisure' - 0.05,* with specific probabilities for *'industrial' - 0.2, 'school' – 0.25,* and *'supermarket' - 0.35.*

The identified POIs are displayed in **Figure 12** corresponding to 1338 points, of which 512 are residential homes, 312 are parking lots, 59 are restaurants, 37 are hotels, and 22 are supermarkets. There are already 10 EVSE sites in this region, making it second worst equipped of all the use cases in terms of charging infrastructure.

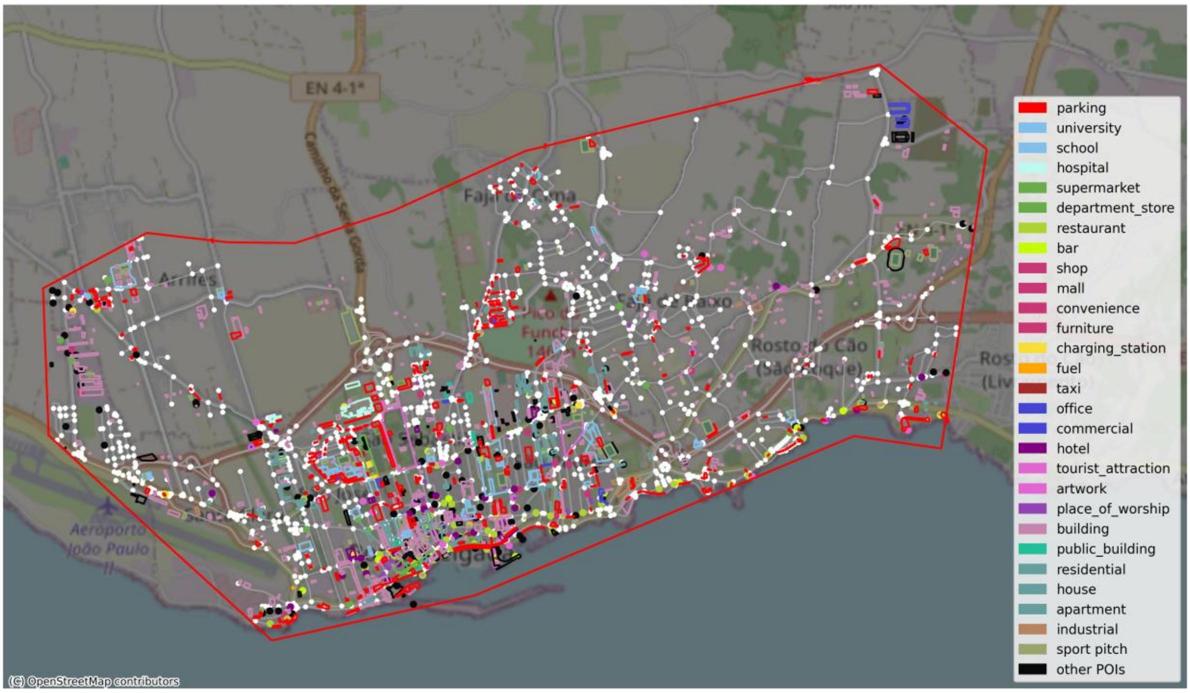

Figure 12 - Identified POIs according to the selected tags, for Ponta Delgada.

Having found the POIs, the traffic simulator also requires the user profiles. The EV profiles considered for this example are listed in **Table 11**, and the behaviour profiles are provided in **Table 12**.

Table 11 – Summary of the characteristic fields for the defined EV profiles for Ponta Delgada.

EV Profile	Tesla Model Y	Tesla Model 3	Peugeot e-208	Volvo EX30	BMW IX1
Profile probability [0-1]	0.3	0.25	0.2	0.15	0.1
Battery size [kWh]	57.5	58	48.1	49	77
Vehicle weight [kg]	2456	2200	1550	2200	2145
Acceleration efficiency [0-1]	0.67	0.67	0.67	0.67	0.67
Deceleration efficiency [0-1]	0.91	0.91	0.91	0.91	0.91
Uphill efficiency [0-1]	0.74	0.74	0.74	0.74	0.74
Downhill efficiency [0-1]	0.73	0.73	0.73	0.73	0.73
'Mean velocity, Consumption' [km/h, kWh/100km]	'46.5,16.4'	'46.5,13.7'	'46.5,15.5'	'46.5,18.0'	'46.5,18.3'
Initial SoC [kWh]	Randomly generated *([0-1] × Battery size)*				

Table 12 – Summary of the characteristic fields for the defined behaviour profiles for Ponta Delgada.

Behaviour Profile		Profile probability [0-1]	Mean travel times [h] *([week], [weekend])*	Recharge home probability [0-1]	Recharge during day
Company	Fleet	0.1	[10, 12, 14, 16.5, 19, 22], [ ]	0.9	*Yes, with 50% chance when parked more than 2h*
Shift worker	Afternoon	0.1	[15, 23], [17, 20]	0.5	
	Morning	0.15	[7, 15], [11, 17]	0.6	
Typical worker	Single	0.2	[8, 17, 18], [12, 17]	0.3	
	Family	0.25	[8, 9, 17, 18], [9, 12]	0.6	
	Couple	0.2	[8, 12, 13, 17, 19], [12, 23]	0.2	

A population density analysis of the simulated area revealed an approximate population of 34 000 inhabitants within the simulated region (São Sebastião, São Pedro, Santa Clara, São Roque, Fajã de Cima, and Fajã de Baixo). Given an estimated EV stock share of approximately 4% and around 75% of vehicles/resident in Azores, this use case considered 1000 EVs in this area for 2024, resulting in the routes depicted in **Figure 13**. We assumed that around 50% of the users recharge the EV at home.

Then, the identification of the heaviest traffic streets takes place, followed by the identification of the POIs near those roads. **Figure 14** displays the most traffic streets, identified in blue, with the nearest POIs corresponding to 575 points. It is worth mentioning that the highways were removed from the most traffic streets, ensuring that only the city/urban regions POIs were selected and identified.

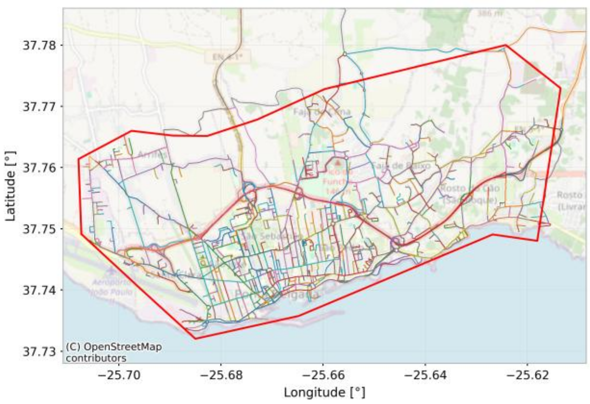

Figure 13 - Ponta Delgada resulting routes from Traffic Simulator.

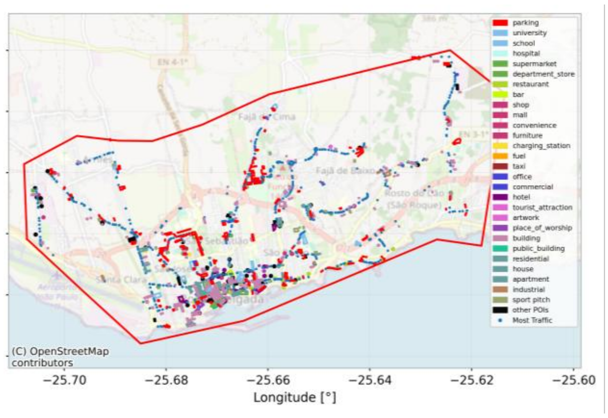

Figure 14 - Ponta Delgada most traffic streets and selected POIs.

The results from Stage 1 undergo processing and cleaning in the first step of Stage 2. Following this, Step 2 automatically identifies **31** as the optimal number of aggregated recharging sites. Subsequently, it locates 732 POIs within a 300-meter radius of these recharging sites, which are merged with the identified POIs from Stage 1, eliminating duplicates and resulting in a total of 1096 combined POIs.

Ponta Delgada had access to secondary substation data. Therefore, Stage 3 - Option 1 is the next step. In this stage, the tool analyses the combined POIs, the aggregated recharging sites data, and the SS data. The process begins by identifying the SSs close to the aggregated recharge sites with available capacity, as displayed in **Figure 15**, along with the existing EVSE locations. It then locates the ultimate POIs within 300 metres of the selected SS, as shown in **Figure 16**, resulting in 689 potential POIs for installing EVSEs. One can verify that there are numerous SSs in the simulated region with the necessary power availability, without any obstacles at the grid level of the secondary substations.

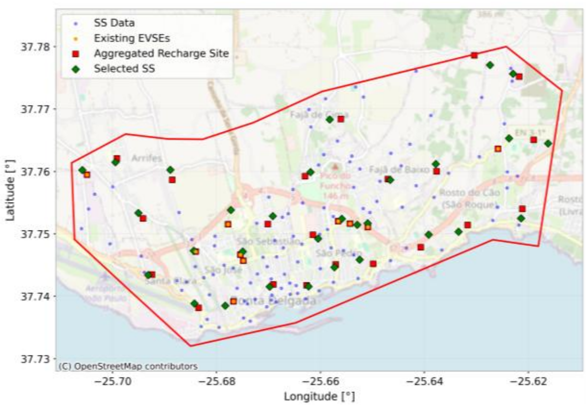

Figure 15 - Aggregated recharge sites from Stage 2 and selected SSs from Stage 3 for Ponta Delgada.

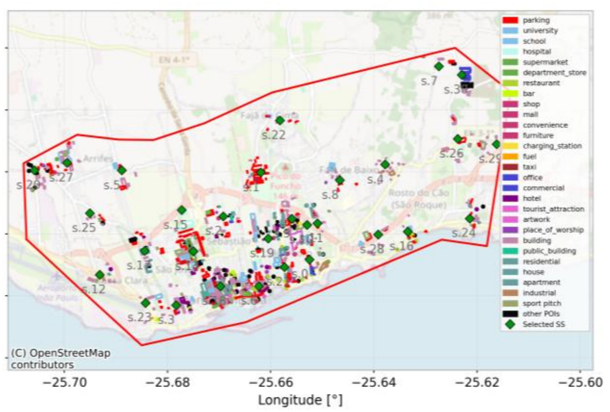

Figure 16 – Selected SSs and ultimate POIs from Stage 3 for Ponta Delgada.

Finally, Stage 4 start by identifying the optimal locations for each recharge site through the evaluation of the priority list defined in (7), favouring nearby EVSE installations, hospitals, and office spaces.

```
priority_list = ['charging_station', 'hospital', 'office', 'parking', 'taxi', 'supermarket',
'mall', 'commercial', 'industrial', 'university', 'college', 'school', 'restaurant', 'hotel',
'shop', 'convenience', 'greenhouse', 'apartment', 'sport pitch', 'building', 'home', 'residen-
tial']                                                                                     (7)
```

Figure 17 illustrates the results of Stage 4 regarding the optimal selected locations and **Table 13** provides the characteristics of each recharging site, specifically the type of site, the corresponding selected combination of EVSEs and the cost of installation.

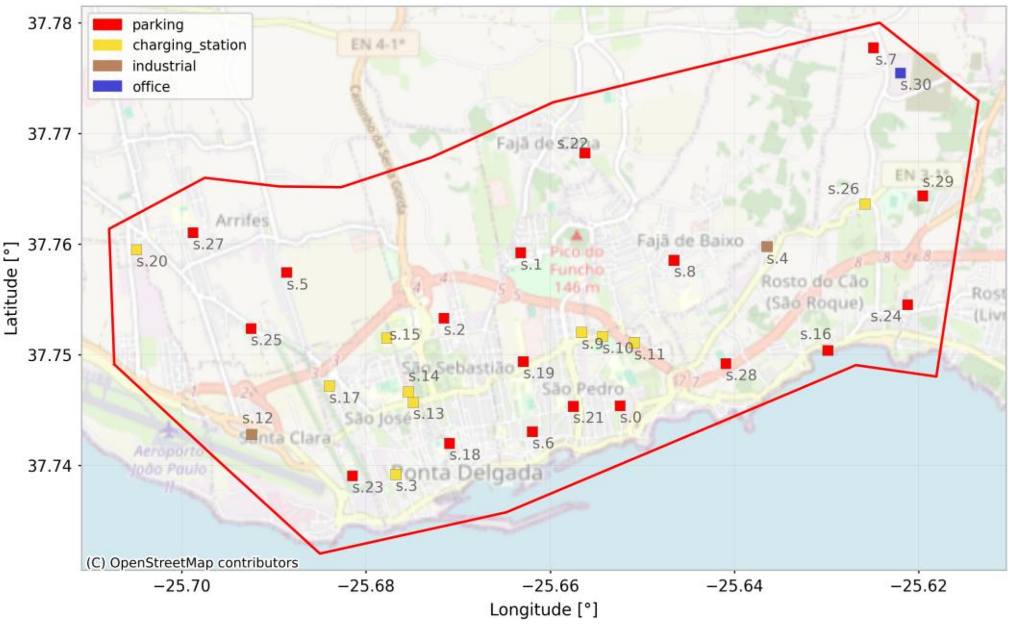

Figure 17 - Co-simulation final EVSE locations for Ponta Delgada.

An analysis of the results indicates that, similarly to the findings in Rønne and Mesogia, the existing EV charging infrastructure in this area has insufficient capacity to meet the needs of EV drivers, requiring additional charging equipment. Site 0 would require the most investment due to 8 EVSEs of varying capacities. This location is near residential neighbourhoods and the São Pedro parish council. Site 18 is a multi-story parking lot in the city centre, close to several local businesses. Due to the limited parking space in the narrow streets, this location is very popular with the public. Site 14, on the other hand, is an existing charging station located in the parking lot of a fuel station and does not require additional EVSEs, similar to site 13. On average, users need to travel 600 m to reach the nearest EVSE.

Table 13 – Characteristics of the final EVSE locations for Ponta Delgada.

Recharge site	Best Combination	Cost [€]	Recharge site	Best Combination	Cost [€]
0 - parking	1 '7.2kW', 7 '22kW'	39000	16 - parking	3 '22kW'	18500
1 - parking	3 '22kW'	18500	17 - charging_station	1 '11kW', 2 '22kW'	12000
2 - parking	4 '22kW'	23000	18 - parking	1 '7.2kW', 7 '22kW'	39000
3 - charging_station	1 '11kW', 3 '22kW'	16500	19 - parking	1 '7.2kW', 3 '22kW'	21000
4 - industrial	1 '11kW', 5 '22kW'	30500	20 - charging_station	1 '11kW', 2 '22kW'	12000
5 - parking	2 '22kW'	14000	21 - parking	1 '7.2kW', 3 '22kW'	21000
6 - parking	1 '7.2kW', 4 '22kW'	25500	22 - parking	1 '7.2kW', 3 '22kW'	21000
7 - parking	3 '22kW'	18500	23 - parking	4 '22kW'	23000
8 - parking	1 '7.2kW', 3 '22kW'	21000	24 - parking	3 '22kW'	18500
9 - charging_station	1 '22kW'	4500	25 - parking	1 '7.2kW', 1 '22kW'	12000
10 - charging_station	1 '11kW'	3000	26 - charging_station	1 '11kW', 2 '22kW'	12000
11 - charging_station	1 '11kW', 2 '22kW'	12000	27 - parking	1 '7.2kW', 2 '22kW'	16500
12 - industrial	1 '11kW', 3 '22kW'	21500	28 - parking	1 '7.2kW', 2 '22kW'	16500
13 - charging_station	EVSE with sufficient capacity	0	29 - parking	3 '22kW'	18500
14 - charging_station	EVSE with sufficient capacity	0	30 - office	2 '22kW'	14000
15 - charging_station	2 '22kW'	9000	-	-	-

3.4.2 Assuming AFIR regulation

A constraint was incorporated into the tool to ensure that only the most in-demand EVSEs are selected until meeting the target ratio, to align with the AFIR regulation that imposes a minimum of 1.3 kW of charging capacity in public EVSEs per BEV and 0.8 kW per PHEV [37]. The POIs, most traffic streets, and locations have been maintained, with only the number of EVSEs being adjusted, as listed in **Table 14**.

Table 14 – Characteristics of the final EVSE locations for Ponta Delgada, following AFIR regulation.

Recharge site	Best Combination	Cost [€]	Recharge site	Best Combination	Cost [€]
0 - parking	1 '7.2kW', 4 '22kW'	25500	16 - parking	1 '22kW'	9500
1 - parking	2 '22kW'	14000	17 - charging_station	1 '11kW', 2 '22kW'	12000
2 - parking	2 '22kW'	14000	18 - parking	1 '7.2kW', 4 '22kW'	25500
3 - charging_station	1 '11kW', 4 '22kW'	21000	19 - parking	1 '7.2kW', 3 '22kW'	21000
4 - industrial	1 '11kW', 2 '22kW'	17000	20 - charging_station	1 '11kW', 3 '22kW'	16500
5 - parking	1 '22kW'	9500	21 - parking	1 '7.2kW', 2 '22kW'	16500
6 - parking	1 '7.2kW', 4 '22kW'	25500	22 - parking	1 '7.2kW', 2 '22kW'	16500
7 - parking	1 '22kW'	9500	23 - parking	2 '22kW'	14000
8 - parking	1 '7.2kW', 1 '22kW'	12500	24 - parking	1 '22kW'	9500
9 - charging_station	1 '22kW'	4500	25 - parking	1 '22kW'	9500
10 - charging_station	1 '11kW'	3000	26 - charging_station	1 '11kW', 1 '22kW'	7500

11 - charging_station	1 '11kW', 1 '22kW'	7500	27 - parking	1 '7.2kW', 1 '22kW'	12000
12 - industrial	1 '11kW', 1 '22kW'	7500	28 - parking	1 '7.2kW', 1 '22kW'	12000
13 - charging_station	EVSE with sufficient capacity	0	29 - parking	1 '22kW'	9500
14 - charging_station	EVSE with sufficient capacity	0	30 - office	1 '22kW'	9500
15 - charging_station	2 '22kW'	9000	-	-	-

Sites 0 and 18 are the most significantly impacted by the reduction in EVSEs. Conversely, only nine sites retained the previously proposed EVSEs. Among these, site 6 demonstrates the highest demand for chargers, as it features a large free parking lot (Rua do Peru). This reduction in EVSEs leads to a **drop in user satisfaction to around 68%**, i.e., only approximately 68% of users have access to a charging station when desired. As a result, users may be forced to search for an EVSE that is further away or recharge later, increasing range anxiety and compromising users' routines. This situation can be mitigated using smart charging approaches already proposed in EV4EU such as the ones presented in [39], [40].

3.5 Krško city, Slovenia

This section presents two simulated results for the Krško region: one reflecting the current number of EVs and another projecting the expected number for the near future. As the only region with access to grid topology and measurement data, Krško can fully leverage the co-simulation platform, demonstrating its effectiveness as a decision-support tool for the present and the future. This analysis provides valuable insights into the impacts of EVs on the local power grid.

3.5.1 Current scenario of the region

The polygon of the exact simulated area is defined in (8).

$$
\begin{array}{ll}
\textit{polygon = Polygon([} & (15.4750156, 45.9445551), \\
(15.5188751, 45.9337217), & (15.4667759, 45.9410337), \\
(15.5201626, 45.9483747), & (15.4685354, 45.9358706), \\
(15.5055714, 45.9529399), & (15.4778481, 45.9353782), \\
(15.5053139, 45.9583700), & (15.4824829, 45.9342589), \\
(15.5018806, 45.9617411), & (15.4850149, 45.9336023), \\
(15.4928255, 45.9652313), & (15.4959154, 45.9329456), \\
(15.4877186, 45.9703917), & (15.4983187, 45.9362288), \\
(15.4811311, 45.9693776), & (15.5033827, 45.9355423), \\
(15.4810667, 45.9633222), & (15.5056143, 45.9353334), \\
(15.4810238, 45.9565202), & (15.5078888, 45.9351543), \\
(15.4801655, 45.9513884), & (15.5188751, 45.9337217)\ ])
\end{array}
\tag{8}
$$

Starting with the selection of the POIs, the probabilities were distributed as follows: *'endpoint' - 0.05, 'building' - 0.10, 'amenity' - 0.35, 'shop' - 0.3, 'tourism' - 0.15, 'leisure' - 0.05,* with specific probabilities for *'industrial' - 0.2, 'school' – 0.25,* and *'supermarket' - 0.35.*

The identified POIs are displayed in **Figure 18** corresponding to 1090 points, of which 512 are residential homes, 312 are parking lots, 59 are restaurants, 37 are hotels, and 22 are supermarkets. There are already 10 EVSE sites in this region, making it second worst equipped of all the use cases in terms of charging infrastructure.

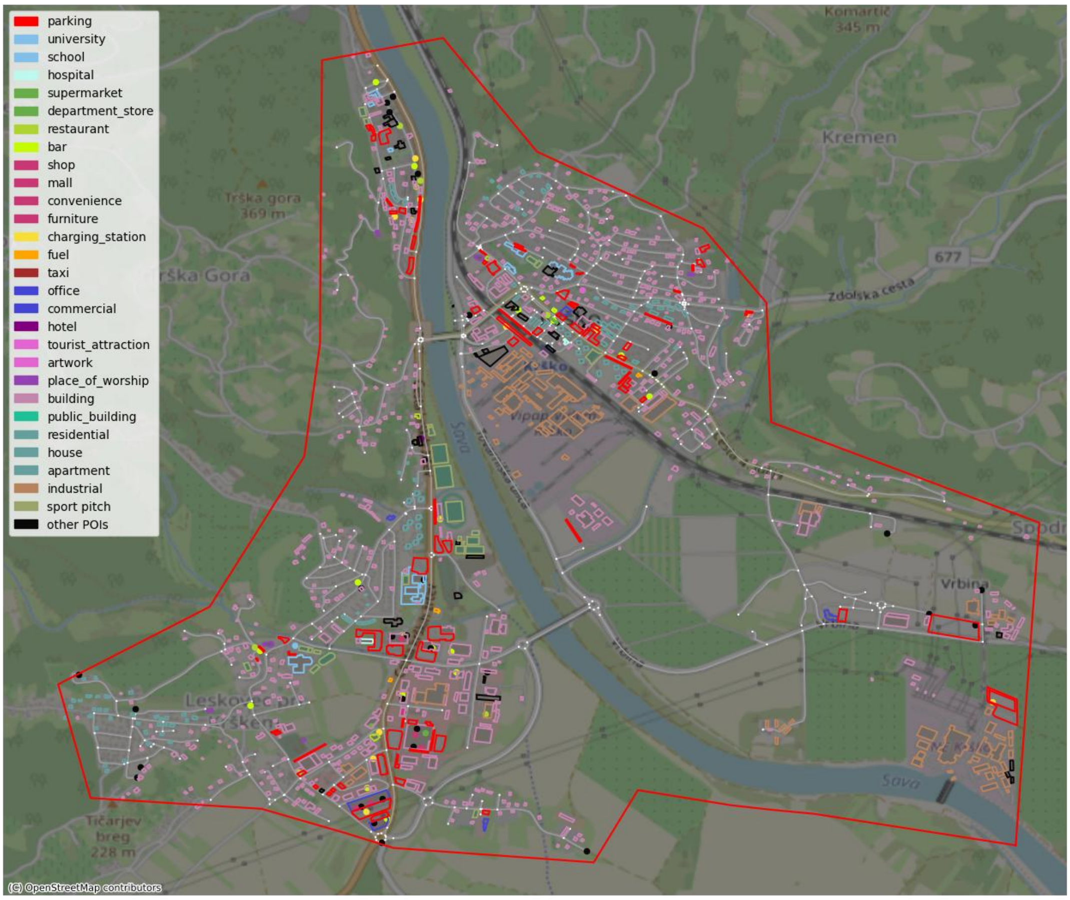

Figure 18 - Identified POIs according to the selected tags, for Krško.

The EV profiles considered for this example are listed in **Table 15**, and the behaviour profiles are provided in **Table 16**. The characteristics of both profiles were adjusted and updated for the case of Krško, considering the relevant information provided in [8] and [35].

Table 15 – Summary of the characteristic fields for the defined EV profiles.

EV Profile	Tesla Model 3	Tesla Model Y	Cupra Born	MG MG4	Volkswagen ID.3
Profile probability [0-1]	0.32	0.27	0.21	0.1	0.1
Battery size [kWh]	58	57.5	59	50.8	52
Vehicle weight [kg]	2200	2456	1841	1710	1787
Acceleration efficiency [0-1]	0.67	0.67	0.67	0.67	0.67
Deceleration efficiency [0-1]	0.91	0.91	0.91	0.91	0.91
Uphill efficiency [0-1]	0.74	0.74	0.74	0.74	0.74
Downhill efficiency [0-1]	0.73	0.73	0.73	0.73	0.73
'Mean velocity, Consumption' [km/h, kWh/100km]	'46.5,13.7'	'46.5,16.4'	'46.5,16.4'	'46.5,16.9'	'46.5,16.3'
Initial SoC [kWh]	Randomly generated *([0-1] × Battery size)*				

There is no precise data on the number of EVs for the simulated urban centre of Krško, except for the statistical region of Posavska, which has a stock share of EVs of approximately 4.4%. With 16586 passenger cars in the entire Krško municipality at the end of 2024, it is assumed that roughly 50% of these vehicles travel to the centre of the region (simulated area) every day. Thus, this results in approximately 350 EVs travelling through Krško daily, making this the number of EVs considered for this use case, resulting in the routes depicted in **Figure 19**. From these, we also assumed that approximately 50% of the users recharge the EVs at home (recall **Table 16**), according to Deliverable 3.1 [8].

Table 16 – Summary of the characteristic fields for the defined behaviour profiles for Krško.

Behaviour Profile		Profile probability [0-1]	Mean travel times [h] *([week], [weekend])*	Recharge home probability [0-1]	Recharge during day
Company	Fleet	0.1	[10, 12, 14, 16.5, 19, 22], [ ]	0.9	*Yes, with 50% chance when parked more than 2h*
Shift worker	Afternoon	0.1	[15, 23], [17, 20]	0.5	
	Morning	0.15	[7, 15], [11, 17]	0.6	
Typical worker	Single	0.2	[8, 17, 18], [12, 17]	0.3	
	Family	0.25	[8, 9, 17, 18], [9, 12]	0.6	
	Couple	0.2	[8, 12, 13, 17, 19], [12, 23]	0.2	

After having the routes, the identification of the most traffic streets takes place, followed by the identification of the POIs near those roads. **Figure 20** displays the most traffic streets, identified in blue, with the nearest POIs corresponding to 594 points. It is worth mentioning that the highways were removed from the most traffic streets, ensuring that only the city/urban regions POIs were selected and identified.

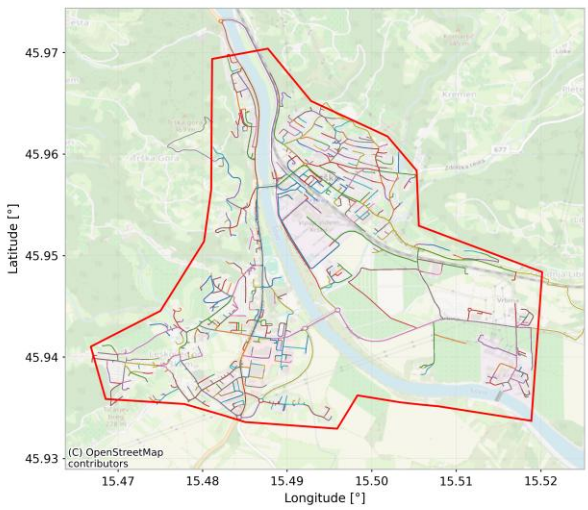

Figure 19 - Krško resulting routes from Traffic Simulator.

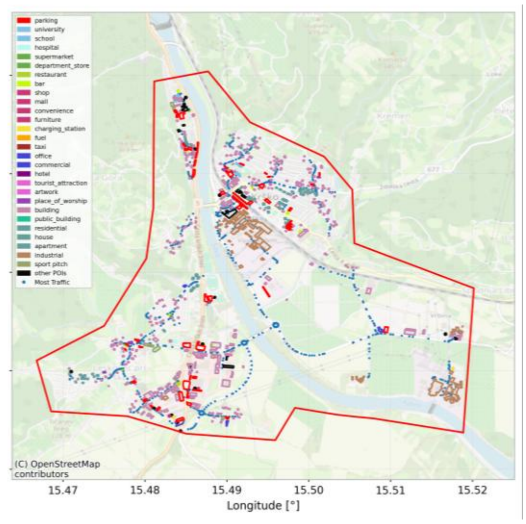

Figure 20 - Krško most traffic streets and selected POIs.

The results from Stage 1 undergo processing and cleaning in the first step of Stage 2. Subsequently, Step 2 automatically identifies **19** as the optimal number of aggregated recharging sites and determines each site's energy and power requirements. Additionally, it locates 501 POIs within a 250-meter radius of these recharging sites, which are merged with the identified POIs from Stage 1, eliminating duplicates and resulting in a total of 784 combined POIs.

Krško use case had access to grid topology and measurements data. Therefore, Stage 3 - Option 2 is the next step. In this stage, the tool analyzes the combined POIs, the aggregated recharging sites data, and the grid data. The process begins by inputting the grid topology data into the grid simulator, including information about MV and LV feeders, secondary substations, buses, and MV and LV lines. **Figure 21** depicts a visual representation of the entire simulated grid.

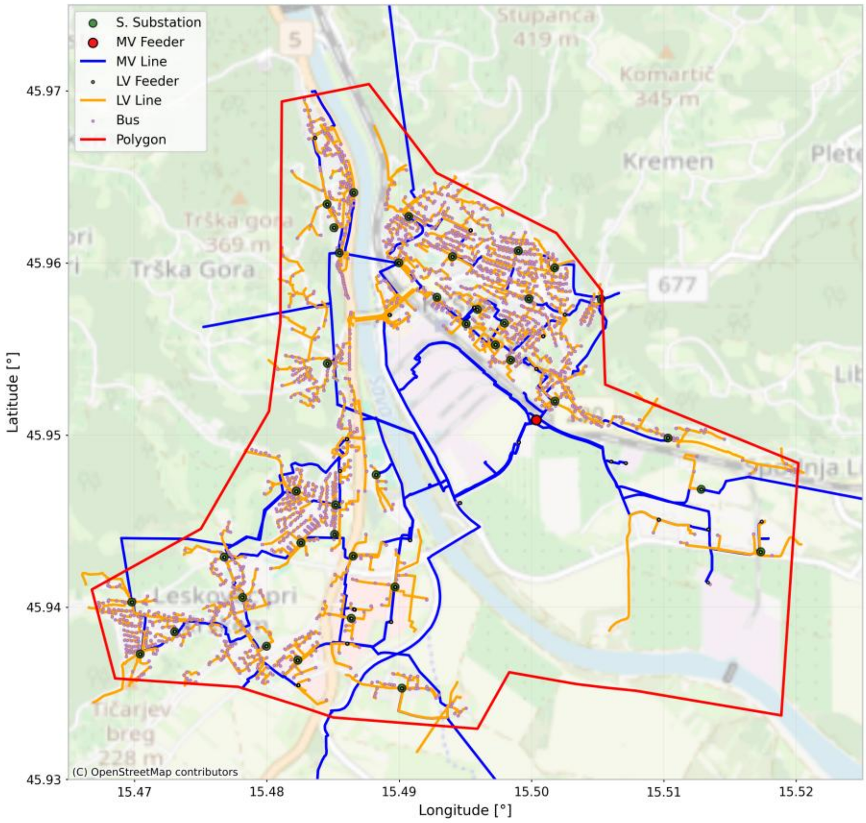

Figure 21 - Grid topology data considered for simulation for Krško.

Similar to the process used in Stage 3 - Option 1 of the Azorean use case (recall section 3.4), this method first identifies the nearest bus to each aggregated recharge site. It then simulates the installation of Electric Vehicle Supply Equipment (EVSEs) using *pandapower* to account for the increased power demand resulting from EV charging. With access to power measurements at each SS, it was possible to utilize the tool at its highest potential by conducting a time-series simulation. This involved analysing Krško's grid measurements and selecting a typical week of consumption for the region.

After conducting the simulation, it was determined that the demand induced by EV charging does not exceed any physical limits of the local electricity network. Specifically, line 46 near site 16, which operates at medium voltage, experienced the highest demand, reaching 49.2%. Additionally, bus 11, associated with a secondary substation near site 14, exhibited the most significant voltage variation, with a decrease of 0.04 per unit (p.u).

Figure 22, **Figure 23**, **Figure 24**, and **Figure 25** provide a comparative analysis of electricity consumption before and after integrating the new EVSEs into the Krško grid regarding the line loadings and the voltage magnitude, respectively. It is crucial to emphasize that the original consumption data already encompasses the recharging needs of existing EVs at the selected typical week. This simulation further enhances robustness by incorporating the potential impact of an additional 350 EVs.

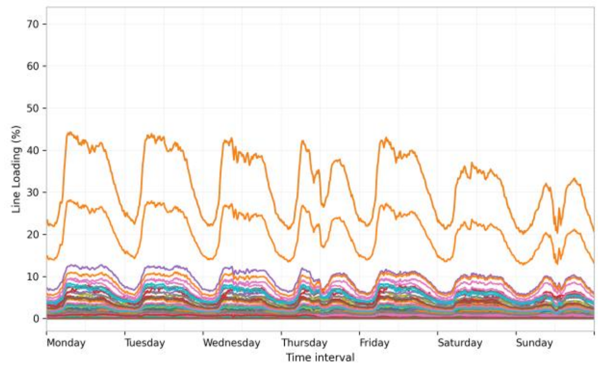

Figure 22 - Line loadings before the insertion of 350 EVs in Krško**.**

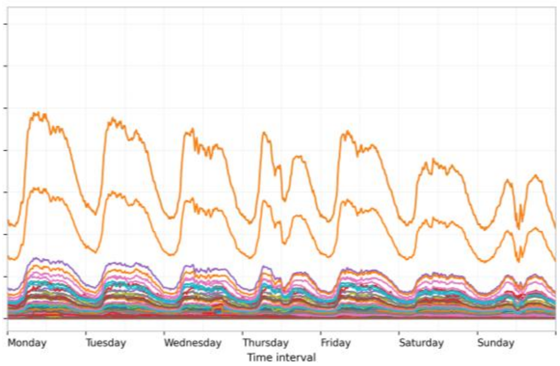

Figure 23 - Line loadings after the insertion of 350 EVs in Krško.

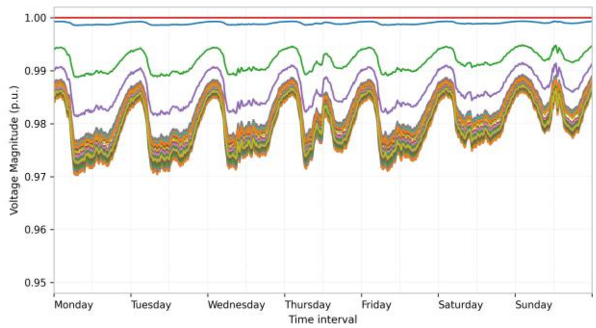

Figure 24 - Voltage magnitudes at buses before the insertion of 350 EVs in Krško.

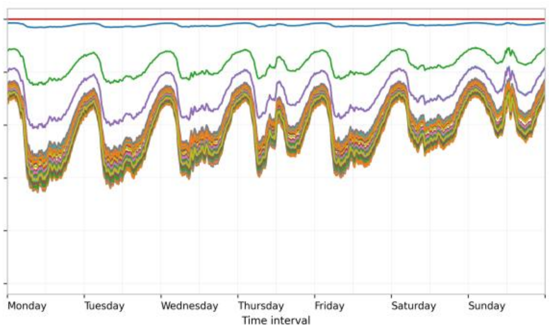

Figure 25 - Voltage magnitudes at buses after the insertion of 350 EVs in Krško.

Since there are no restrictions at the grid level, the closest buses to each aggregated site were selected. Next, it identifies the ultimate POIs within 300 meters of the selected buses, as displayed in **Figure 26**, resulting in 689 POIs as options for installing EVSEs.

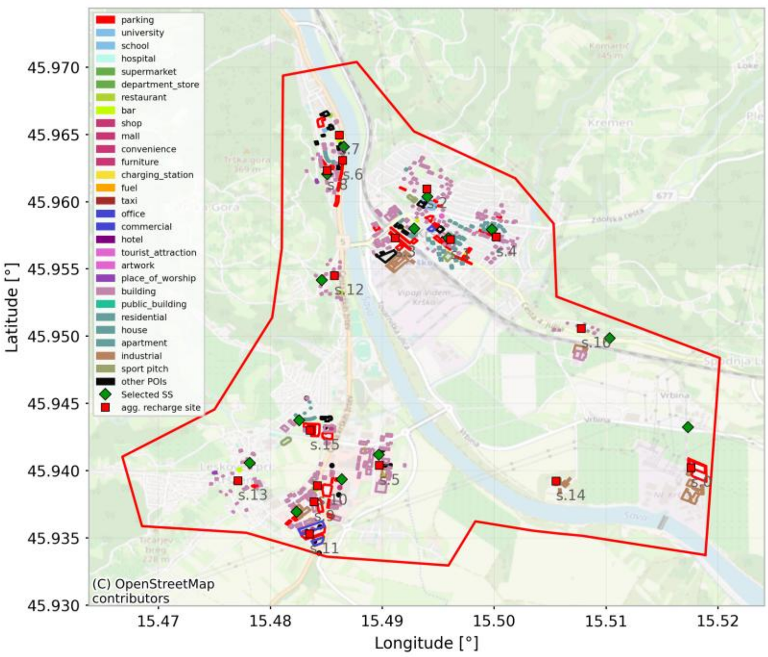

Figure 26 - Selected SSs and ultimate POIs from Stage 3 for 350 EVs in Krško.

If any issues arise during Stage 3 - Option 2, the tool will search for alternative buses until the limiting factor is resolved, even adjusting the chosen EVSEs to find the optimal balance between available power and grid safety.

Finally, Stage 4 start by identifying the optimal locations for each recharge site through the evaluation of the priority list defined in (9), favouring nearby EVSE installations, hospitals, and parking spaces.

```
priority_list = ['charging_station', 'hospital', 'parking', 'office', 'supermarket', 'mall',
'commercial', 'industrial', 'university', 'school', 'restaurant', 'shop', 'convenience', 'ho-
tel', 'sport pitch', 'building', 'home', 'residential', 'apartment']
```
(9)

Figure 27 illustrates the results of Stage 4 regarding the optimal selected locations and **Table 17** provides the characteristics of each recharging site, specifically the type of site, the corresponding selected combination of EVSEs and the cost of installation.

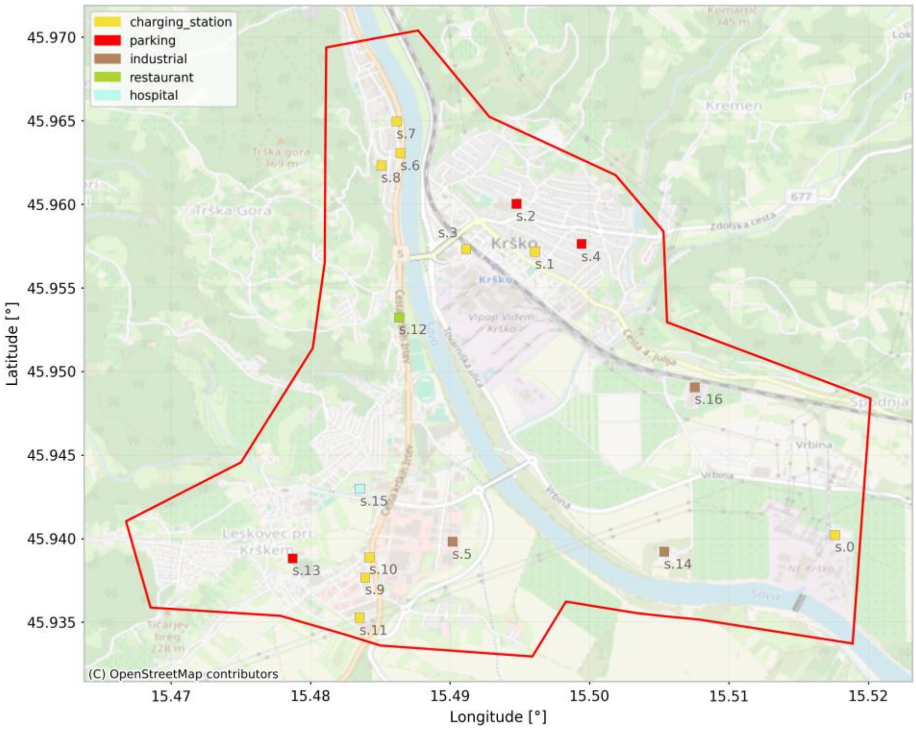

Figure 27 - Co-simulation final EVSE locations for 350 EVs in Krško.

The obtained results align with the findings in Rønne and Mesogia in that the existing infrastructure is already reasonably well positioned, missing only key sites and an increase in the number of EVSEs. The southern part of the region, near Leskovec pri Krškem, characterised by commercial and industrial areas, is currently well supplied since sites 6, 7, 9, 10, and 11 do not need any reinforcement in power or number of EVSEs. Conversely, the simulated southeastern region is primarily industrial, including the Krško Nuclear Power Plant, which has a dedicated EVSE location mainly for its employees (according to OpenStreetMap and OSMnx). The extensive parking lot at this site indicates a large workforce, suggesting a considerable need for EVSEs. Similarly, the EVSEs at locations 5, 14, and 16 are primarily intended to serve local staff. It is also important to note that the main hospital does not include EVSEs. Consequently, the co-simulation tool identified this location as vital for EVSE infrastructure. On average, users need to travel 750 m to reach the nearest EVSE, excluding the southeastern industrial sites, since they are only for employees and are located outside the city center.

Table 17 – Characteristics of the final EVSE locations for 350 EVs in Krško.

Recharge site	Best Combination	Cost [€]	Recharge site	Best Combination	Cost [€]
0 - charging_station	4 '22kW'	18000	9 - charging_station	EVSE with sufficient capacity	0
1 - charging_station	3 '22kW'	13500	10 - charging_station	EVSE with sufficient capacity	0
2 - parking	4 '22kW'	23000	11 - charging_station	EVSE with sufficient capacity	0
3 - charging_station	3 '22kW'	13500	12 - restaurant	3 '3.7kW'	8750
4 - parking	1 '7.2kW', 3 '22kW'	21000	13 - parking	1 '7.2kW', 3 '22kW'	21000
5 - industrial	1 '11kW', 2 '22kW'	17000	14 - industrial	2 '22kW'	14000
6 - charging_station	EVSE with sufficient capacity	0	15 - hospital	2 '22kW'	14000
7 - charging_station	EVSE with sufficient capacity	0	16 - industrial	1 '22kW'	9500
8 - charging_station	1 '11kW'	3000	-	-	-

3.5.2 Near future scenario

It is essential to evaluate the future demand for EVs and to determine necessary reinforcements for the electricity grid. Over the next three years, by 2028, the share of EVs in Europe is expected to roughly double from its current level [22]. Therefore, it is worth demonstrating how the co-simulation platform can serve as a decision-support tool for this future scenario. The Krško region was utilized to simulate the impact of 700 EVs, which is twice the current number. This increase would result in two new locations, site 17 and site 18, parking lots for an industrial site and a company office, respectively. **Figure 28** depicts these new locations needed for 700 EVs.

Table 18 outlines the additional EVSEs needed for each location. The selected sites will require an increase in capacity and number of EVSEs to accommodate the growing number of EVs. The most significant growth is at site 9, which needs six additional EVSEs, and sites 0, 1, 4, 5, and 6 require four more EVSEs.

Table 18 – Characteristics of the final EVSE locations for 700 EVs in Krško.

Recharge site	Best Combination	Cost [€]	Recharge site	Best Combination	Cost [€]
0 - charging_station	1 '11kW', 5 '22kW'	25500	10 - charging_station	EVSE with sufficient capacity	0
1 - charging_station	1 '11kW', 5 '22kW'	25500	11 - charging_station	EVSE with sufficient capacity	0
2 - parking	6 '22kW'	32000	12 - restaurant	6 '3.7kW'	12500
3 - charging_station	1 '11kW', 6 '22kW'	30000	13 - parking	4 '22kW'	23000
4 - parking	6 '22kW'	32000	14 - industrial	1 '11kW', 2 '22kW'	17000
5 - parking	1 '7.2kW', 5 '22kW'	30000	15 - hospital	4 '22kW'	23000
6 - charging_station	3 '22kW'	13500	16 - industrial	1 '11kW', 1 '22kW'	12500
7 - charging_station	1 '22kW'	4500	17 - parking	1 '7.2kW', 2 '22kW'	16500
8 - charging_station	EVSE with sufficient capacity	0	18 - parking	1 '7.2kW', 5 '22kW'	30000
9 - charging_station	1 '11kW'	3000	-	-	-

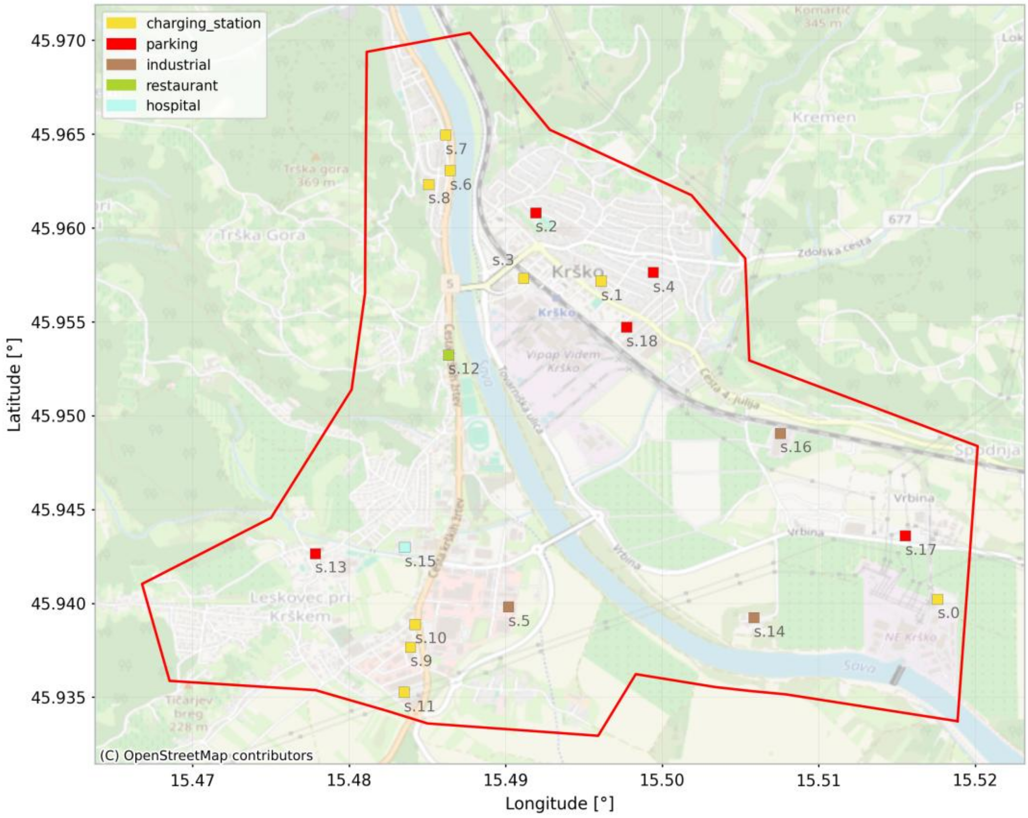

Figure 28 - Co-simulation final EVSE locations for 700 EVs in Krško.

This increase in the demand for energy and power to recharge EVs translates into higher overall consumption on the electrical grid. However, during Stage 3, no issues were detected with the grid given the combination of EVSEs detailed in **Table 18**. Line 46 remains the most loaded, now reaching a utilization rate of 57.6%, while bus 11 exhibits a decrease of 0.08 p.u. compared to the original data (refer to **Figure 24**). Monday becomes the most requested day for recharging. **Figure 29** presents the lines loadings for the 700 EVs and **Figure 30** the voltage magnitude variation for each day.

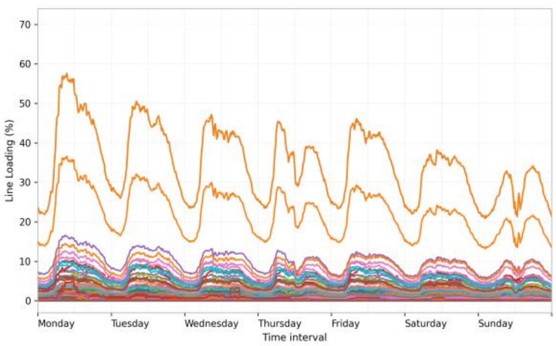

Figure 29 - Line loading after the insertion of 700 EVs in Krško.

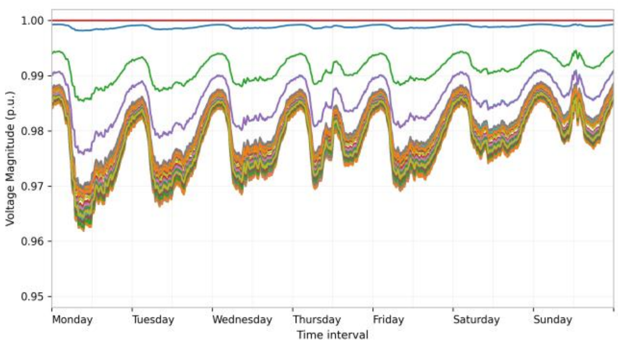

Figure 30 - Voltage magnitudes at buses before the insertion of 700 EVs in Krško.

4. Conclusions

This Deliverable D3.5 - Simulation of V2X Management Strategies at City Level aims to test the mass deployment of electric vehicles (EVs) in different cities, using the co-simulation platform developed in T3.4. The objective is to simulate various scenarios to determine the best locations for charging infrastructure, the ideal number of Electric Vehicle Supply Equipment (EVSE) and the power required for each one.

The study analysed four different use cases, including Rønne city, in Denmark, Mesogia area, in Greece, Ponta Delgada city, in Portugal, and Krško, in Slovenia. Each of these regions has unique characteristics that influence the charging demand.

- Rønne presents the largest existing infrastructure in its urban centre, but the study showed that its capacity should be expanded in key locations more to the north of the city, near apartments, schools and office spaces.
- Mesogia is the largest region being considered and includes several smaller cities that already have some well-placed EVSE, although requiring an increase in the number of charging ports. Additionally, the co-simulation tool identified a significant industrial area lacking charging infrastructure, with high demand.
- Ponta Delgada, despite the increasing number of EVs, lacks sufficient infrastructure to meet its residents' current needs. To meet 100% of the users' satisfaction, there should be installed more 102 EVSEs in the region, not causing any problems on the electrical grid, based on findings from Stage 3. However, to meet the AFIR regulation of at least 1.3 kW/BEV, the number of EVSEs would drop to 69, resulting in a user satisfaction of around 68%.
- In Krško, the smallest town characterized by single-family homes, the current demand for EV charging satisfies the existing infrastructure. Minimal expansion is needed, primarily in industrial areas, to meet the recharging needs of industrial workers. A thorough analysis of the local power grid conducted in Stage 3 indicated no issues with load growth, even when projecting a near future with twice the number of present EVs.

Based on the results obtained, this study confirms the importance of charging infrastructure for the mass adoption of EVs in the regions analysed. In each one, the number of EVSEs available is insufficient to meet current and future demand, making it necessary to expand the infrastructure to ensure the efficient and sustainable operation of electric mobility.

Besides, the co-simulation platform proved an effective tool for supporting decision-making in the charging infrastructure implementation. It can determine strategic locations for new EVSEs and the capacity of existing ones to be optimized. Its flexibility made it possible to analyse different urban, industrial, and rural use cases, even without data from the electrical grid.

Given these findings, urban managers, energy sector operators, and political entities should use this approach to plan the expansion of EV charging infrastructure, ensuring an efficient transition to sustainable mobility. The tool's ability to integrate traffic and power grid data demonstrates its potential to guide public policies and investments in the area, facilitating the adoption of vehicle-to-everything (V2X) and smart-grid solutions, promoting the sustainable growth of electromobility.

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