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Deliverable D3.4

Definition and Development of a City-Level Co-simulation Platform for V2X

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Executive Summary

The deliverable D3.4, "Definition and Development of a City-Level Co-simulation Platform for V2X" aims to develop a co-simulation platform that should allow the joint simulation of the city traffic, the distribution network, and the vehicle-to-everything (V2X) management strategies, to ultimately help with the decision of best placement for electric vehicle supply equipment (EVSEs) at the city level. This deliverable provides a high-level overview of the platform to facilitate the use and understanding of the source code.

The methodology applied in the development of the platform is composed of four main stages:

- Stage 1 is mainly responsible for the traffic simulation of the vehicles;
- Stage 2 processes the energy requirements from the simulated electric vehicles (EVs) and defines typical recharging sites;
- Stage 3 is responsible for the integration of the grid network;
- Stage 4 processes the results of the previous stages and estimates the number of EVSEs, their locations, and the rated power of each equipment.

The co-simulation platform integrates various existing tools to achieve its objectives, including the OSMnx package and the TomTom API, as well as the EV profiling tool developed for *D1.2 of the EV4EU project: Impact of v2x in energy and power systems*, primarily for Stage 1. A critical aspect is the need for typical behaviour profiles and EV profiles. These profiles serve as input to the traffic simulator and play a key role in representing V2X management strategies, significantly affecting the simulated results. User behaviour profiles comprise each user's daily routine and individual EV charging preferences, which may differ between weekdays and weekends. On the other hand, EV profiles aim to capture the typical characteristics of popular EVs, such as weight, efficiency, and battery capacity. Consequently, these profiles should be customised for each specific case study.

Besides Stage1, the other fundamental part of the platform is Stage 3, incorporating two distinct but complementary functionalities: the first option is based on analysing data from secondary substations at the city level, while the second option consists of simulating the entire local network of the case study, accounting for all limiting factors, including substations, cable characteristics, and voltage/current constraints. This information is often difficult to obtain; Option 1 guarantees the platform's functionality with very accessible, still reduced data.

The remaining stages are dedicated to processing and extracting outcomes. In particular, Stage 2 is mainly responsible for processing the data resulting from the traffic simulator and defining the first candidate options for EVSE locations. Finally, Stage 4 incorporates all the results from the previous stages and determines the optimal EVSE location, number and rated power to minimise total installation costs.

Additionally, the platform's functionality was demonstrated using a practical example for a region of Lisbon, Portugal. By simulating 1000 EVs over seven days, the platform determined that an optimal number of 39 locations is necessary. Among these, 16 are existing EVSE locations, and 14 require capacity expansion. The remaining 23 locations are distributed among parking lots, buildings, taxi stops, restaurants, supermarkets, and one hospital.

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Acronym

API	Application Programming Interface
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GPS	Global Positioning System
POI	Point of Interest
SoC	State-of-Charge
SS	Secondary substation
V2X	vehicle-to-everything

1. Introduction

The interaction between distribution networks, urban traffic, and electric vehicles (EVs) is crucial for comprehending urban mobility, supply chain efficiency, and sustainability in modern cities [1]. This relationship holds significant implications for sustainable urban planning, as cities that successfully integrate these components can achieve substantial reductions in greenhouse gas emissions, improve traffic flow, and enhance the efficiency of urban logistics. While incorporating EVs into urban traffic and distribution networks offers opportunities to mitigate environmental impact and boost efficiency, it also introduces several challenges [1], [2]. These challenges include the necessity for substantial infrastructure investment, the potential for increased electricity demand, and the management of the transition from conventional vehicles to EVs. Addressing these issues demands coordinated efforts among city planners, policymakers, businesses, and the public [3]. Co-simulation models are well-suited to addressing the challenges associated with the interaction between EVs, urban traffic, and distribution networks. These models serve as sophisticated tools that facilitate the integration of complex systems, enabling the simultaneous simulation of multiple interacting components [4], [5]. Each system involved may operate under distinct dynamics and may necessitate different modelling approaches. Co-simulation is especially beneficial in scenarios were developing a single, unified model would be excessively complex or computationally prohibitive.

1.1 Scope and objectives

The primary objective of this document is to simulate the impact of vehicle-to-everything (V2X) technology in urban environments and distribution systems, with consideration of V2X user behaviour. To achieve this, a co-simulation platform is proposed that enables the integrated simulation of city traffic, distribution networks, and V2X management strategies. This platform is designed to assist in optimizing the placement of electric vehicle supply equipment (EVSEs) at the city level. On the other hand, the platform will identify the week points in the distribution grids supporting the increase of hosting capacity of the grid, as well as the planning of the infrastructure. Finally, the platform allows an assessment of the impact of V2X strategies in the development of the cities.

1.2 Structure

The present document is divided into 4 sections. After the introduction section (Section 1), Section 2 provides insight into the co-simulation platform. Section 3 details the main simulated results focused on the considered example for a region of Lisbon, Portugal. Finally, Section 4 outlines some overall conclusions and recommendations.

1.3 Relationship with other deliverables

This Co-simulation platform utilized both tools and definitions from work package 2 and work package 3. In specific, the EV profiling tool developed for *D1.2 of the EV4EU project: Impact of v2x in energy and power systems* [6] and utilized in *D2.4 of the EV4EU project: Optimal management of EV fleets in companies* [7] served as inspiration for one stage of this platform. Furthermore, the results of the current task will be vital for the development of *D3.5 of the EV4EU project: Simulation of V2X Management Strategies at City Level* and *D3.6 of the EV4EU project: High-Level Design of V2X Management Strategies Coordination*, since these tasks will utilize the Co-simulation platform.

2. Co-Simulation Platform Description

To achieve a fully functional co-simulation tool, the developed methodology 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 methodological approach for the proposed solution is illustrated in Figure 1.

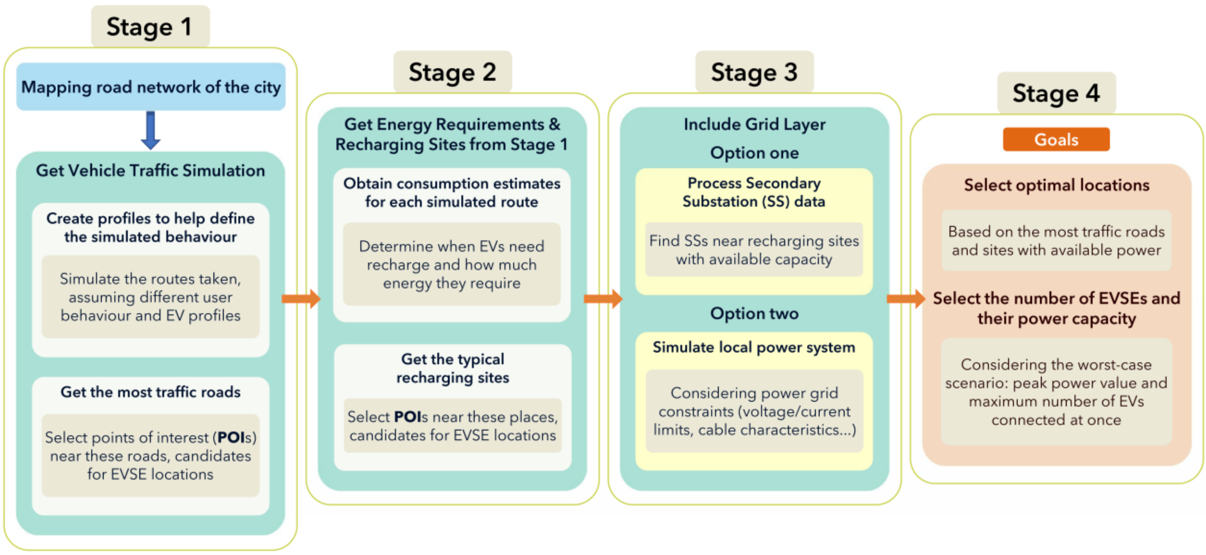


Figure 1 – Overview of the methodological approach.

Considering this structure, Section 2.1 describes Stage 1, in particular how the traffic simulator was designed, with the inputs and outputs. Section 2.2 provides context on the processing stages of Stage 2, and Section 2.2.2 describes the two possible approaches for the inclusion of the grid layer comprised in Stage 3. Finally, Stage 4's process of selecting the EVSE locations, number, and rated power is exploited in Section 2.4.

2.1 Stage 1: Traffic Layer

Stage 1 is the core of the Co-simulation platform. This stage is responsible for simulating the traffic demand at the city level, which at the same time makes possible the identification of the streets with the most traffic. This simulation is based on a group of typical profiles, which intend to represent the behaviour of different EV users and the characteristics of the EV itself [6]. The output of this stage is the identification of the city's most traffic streets and updated profiles with the characterization of each route taken. Figure 2 presents a more in-depth representation of Stage 1's architecture.

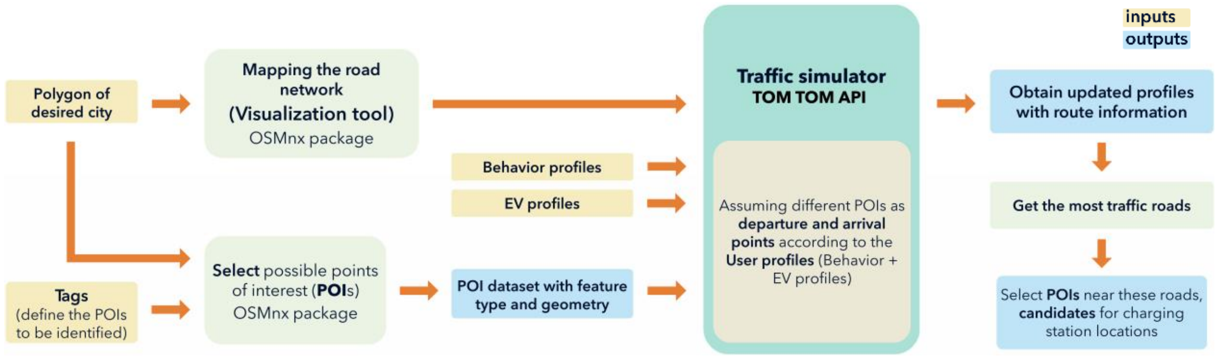


Figure 2 – Overview of Stage 1 architecture.

Since a traffic simulator is being developed, it is necessary to have visual support to display the simulation results. Therefore, a Visualisation Tool was first created based on Python's OSMnx package [8], which allows users to easily download, model, analyse, and visualise street networks and other geospatial features from OpenStreetMap [9]. By inputting the polygon of the desired city, it is possible to extract the entire road network of the area. Besides, it is also trough the OSMnx package that is possible to obtain Points of Interest (POIs). These POIs are used throughout the platform and will be also an important step for the identification of possible locations. These points represent anything normally present on any Global Positioning System (GPS) system, such as parking lots, charging stations, schools, hospitals, apartments, supermarkets, stores, etc. After defining the tags (which indicate the package which POIs to look for), the identified POIs are stored on a dataset, used throughout all stages.

For the traffic simulator, it is essential to define behaviour profiles, which are intended to represent the behaviour of different EV users over a given period. When available, validation processes can be applied, improving the reliability of the profiles (as described in section 2.1.2). Additionally, EV profiles are necessary, containing all the information needed to characterize the most popular EVs in the city.

Once all the requisite information has been created—the visualisation tool, the POI dataset, and the profiles—the simulator will be fully operational. The objective of this Stage 1 is to obtain the updated profiles with the routes information and to identify the POIs near the most traffic roads, as these will be potential locations for EV charging stations. In addition, the results of the simulator will be necessary for Stage 2.

2.1.1 Traffic simulator & TomTom API

Since the traffic simulator is the heart of the co-simulation platform, it is worth taking a closer look at it. Figure 3 displays the outline for the traffic simulator.

Firstly, it is important to understand the behaviour profiles and the EV profiles. The behaviour profiles simply consist of two parameters: mean daily departure times, and an indication of when/where the user should recharge. This indication can take various forms, namely: always charging at night, recharging every time the vehicle is parked for more than *"x"* hours, or whenever the battery reaches a certain level. On the other hand, EV profiles contain all the information needed to characterize an EV: EV consumption, EV weight, and the EV efficiencies.

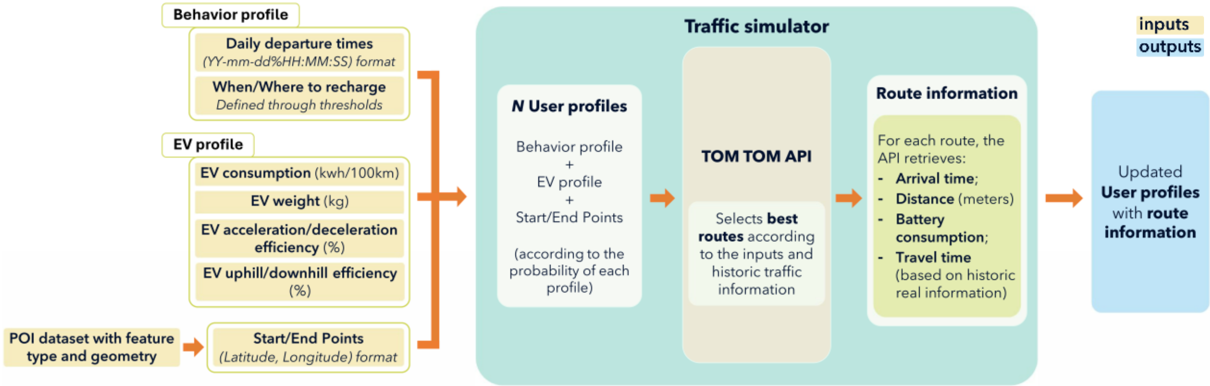


Figure 3 – Overview of the Stage 1 traffic simulator architecture.

Together with the POI dataset, the simulator creates the so-called "User Profiles". Each user profile consists of one behaviour profile plus one EV profile plus several start/end points selected from the POI dataset. These profiles are created randomly according to various individual probabilities for each of the POIs, behaviour and EV profiles. Each profile represents the behaviour of one EV for 7 days (5 weekdays and 2 weekend days). Additionally, the departure times are also adjusted by the traffic simulator based on a uniform distribution with a range of 1 hour (±30 minutes). For example, if a behaviour profile with a mean departure time of 08h00 is selected, the traffic simulator can choose departure times uniformly distributed between 07h30 and 08h30. This guarantees slightly different behaviour for each day and user profile, making the simulator more representative of real-life user behaviour.

Upon defining all N desired profiles, they are sent as input to the TomTom API [10]. This tool then proceeds to simulate the routes for each created profile. The TomTom API is developed by TomTom [11], a Dutch world leader in automotive navigation, traffic and mapping products based on GPS data. This navigation software is currently present in several new car models from global leaders, such as Volkswagen, Renault, Stellantis Group, and Toyota.

In addition to the privileged information it holds, TomTom also makes it available to developers free of charge via the API for up to 2 500 calls/day per key (at the time of writing). Depending on the number of profiles required, it is therefore possible to exceed this limit, which must be considered.

The API in question provides valuable information on desired routes, providing data such as arrival time, distance, battery consumption and driving time. Users are required to provide information such as departure and arrival points, departure time, and characteristics of the EV, i.e., the information available in each user profile. The advantage of this API is that it can retrieve precise consumption data for EVs for each route, and these results are based on real data collected anonymously by TomTom from vehicles travelling daily. It is also possible to request real-time traffic or historical data, which makes it possible to obtain results based on specific data for a given day and time. Collectively, these features make the API an optimal choice for the traffic simulator.

Following the execution of the simulator for all desired profiles, each user profile is updated to include the output of the API for each route taken, information processed and analysed in Stage 2.

2.1.2 Profile validation based on historical data

It is necessary to note that user profiles should not be selected arbitrarily. Instead, they must be carefully customised and tailored to fit each case study, particularly the behaviour profiles. The process should be based on *D3.1 of the EV4EU project: EV Users' Needs and Concerns - Preliminary Report* [12], which provides real users' needs and concerns about EV use for the participating countries of Denmark, Greece, Portugal and Slovenia. Consequently, these profiles must be validated using real data to ensure their reliability and, as a result, a more realistic simulation.

For instance, the Slovenian partners from the University of Ljubljana have access to historical data from traffic counters installed on Slovenian roads. Currently, 943 devices measure traffic flow and speed, and around 706 can also distinguish the vehicle type [13]. If an area/road that doesn't have counters is considered for simulation, the traffic can be validated based on road category nearby counters. Depending on the characteristics of the real data available for each use case, similar approaches can be considered to ensure an accurate operation of the co-simulation platform.

2.2 Stage 2: Energy Requirements & Recharging sites

The raw output from Stage 1 needs to be processed to extract useful information to be used in the subsequent stages. In particular, Stage 2 is responsible for processing the updated user profiles, finding the most typical charging sites, and determining the amount of energy that is (simulated) recharged by each user. Besides, at this stage, the POIs near these charging sites are identified and considered potential locations for installing charging stations. Figure 4 displays Stage 2 architecture with the necessary inputs and the resulting outputs.

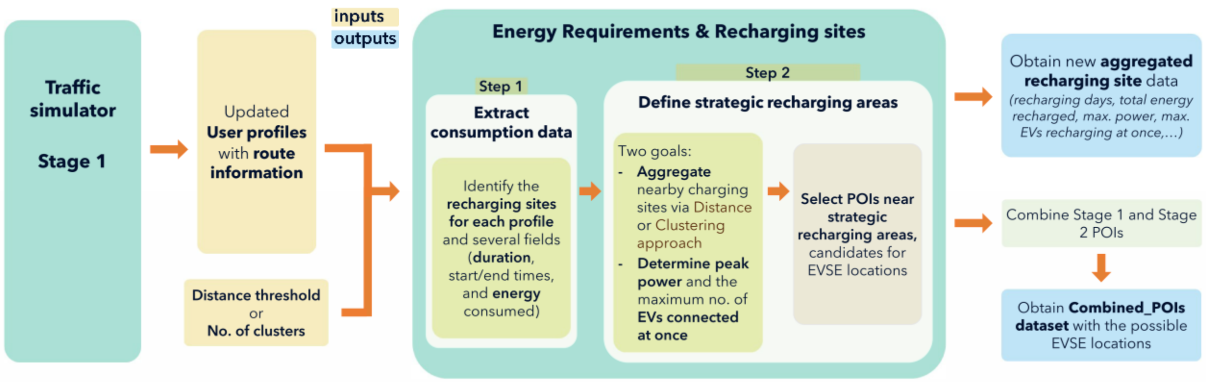


Figure 4 – Overview of Stage 2 architecture.

2.2.1 Recharging sites and requirements

According to Figure 4, Stage 2 starts with extracting consumption data from the updated user profiles. This process involves retrieving details such as the location coordinates, recharging duration, start and end times, and the energy consumed for each user's recharging activity. These unique sites are then aggregated in two possible ways, with the developer required to select only one of these methods:

- **Method 1 - Distance threshold**: This method involves randomly selecting a recharging site and then aggregating all remaining sites that are within the specified distance threshold.

- **Method 2 - Clustering approach**: By defining the desired number of clusters, the K-means algorithm can accurately aggregate the recharging sites into several clusters.

The purpose of these two methods is to provide developers with enhanced flexibility. Method 1 is a fast and direct process based on distance input, although less robust than Method 2. In the second method, K-means guarantees optimal cluster selection by minimising the error between points within each cluster and their respective centroid, a significant advantage over Method 1. However, determining the optimal number of clusters in advance can be challenging without prior knowledge of suitability, thus justifying the existence of Method 1. Each method presents advantages and disadvantages, leaving the choice to the developer based on their preferences and expertise.

The new aggregated recharging sites also have characteristic attributes resulting from merging the unique charging process data. Additionally, the peak power and the maximum number of EVs simultaneously recharging are determined for each aggregated site, fields required for Stage 4. This process enables the creation of strategic recharging areas capable of serving multiple users.

Once the aggregated recharging sites are identified, the next step is to locate potential POIs near these strategic recharging areas. After selected, these POIs will be combined with those identified in Stage 1, creating a new dataset named *combined_POIs*. This dataset contains the locations with the highest potential for installing charging stations, considering the most traffic roads (Stage 1) and the recharging areas (Stage 2). The outputs of this Stage 2 are the aggregated recharging sites and the combined POIs, which will be used in Stage 3.

2.2.2 Identify the best number of locations

As previously discussed, it is challenging to identify, beforehand, either the distance or the number of clusters to select without having any perception of the simulation results. Therefore, to overcome this problem and select the optimum number of locations, an option was created to identify the *best number* of aggregated recharging sites. This number should meet all requirements and constraints while minimising total installation costs. Figure 5 provides a visual representation of this selection process.

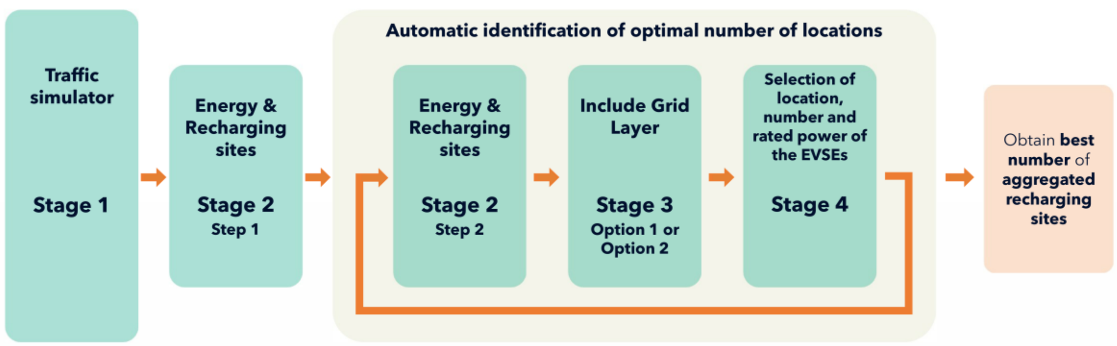


Figure 5 – Schematic for the automatic identification of the best number of aggregated recharging sites.

To use this automatic option, developers must indicate the desired Stage 3 method: for Method 1, it is necessary to specify a range of distances for the code to experiment with; if selecting Method 2, the developer needs to input a range of the desired number of clusters. Subsequently, the code will iterate through all stages from Step 2 of Stage 2 (*define strategic recharging areas*) to the final step of Stage 4, checking, at the end of each iteration, the total installation cost and ultimately selecting the number of aggregated recharging sites that meet all the requirements, constraints and yielded the lowest total installation cost among all the options tested. Consequently, the developers must choose between the manual or automatic options to select the number of aggregated sites.

2.3 Stage 3: Grid Layer

Stage 3 is assigned the crucial task of integrating the city's electricity grid into the co-simulation platform, complementing the fundamental part addressed in Stage 1. With the aggregated recharging sites data from Stage 2, it is imperative to verify if the local grid has ample capacity to meet the simulated power and energy requirements. This can be achieved through two potential approaches:

- **Option 1:** Analysing data from secondary substations (SSs) at the city level;
- **Option 2:** Simulating the local electricity network, accounting for all limiting factors, including substations, cable characteristics, and voltage/current constraints.

Figure 6 provides an overview of the Stage 3 architecture. In addition to the Stage 2 aggregated recharging sites data and combined_POIs, the SS data and grid characteristics must be input for Options 1 and 2. Regardless of the option selected, the output is the selected SSs and the ultimate POIs close to these SSs, which are fundamental for Stage 4.

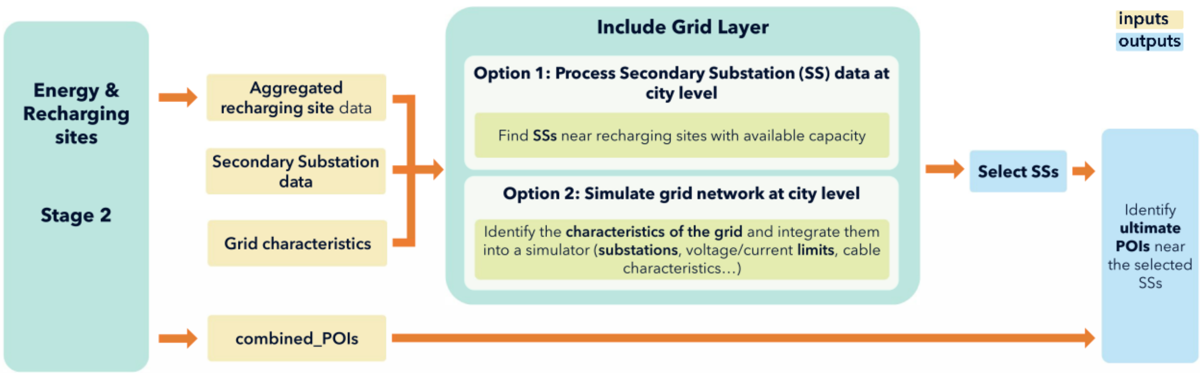


Figure 6 – Overview of Stage 3 architecture.

Considering that the platform is intended for real-world practical use, the simulations must be based on empirical data. Collecting information about the local electrical networks from different cities can be challenging for developers, as numerous characteristics may not be readily available, such as cable capacities, substation information, typical power flow, and the penetration of renewable energy systems. Therefore, two approaches were developed to address this point, which are discussed in more detail in the following sections.

2.3.1 Option 1: Hosting Capacity and Secondary Substation Data

One of the most common and readily available sources of information about the local electricity network is data on secondary substations. Option 1 employs this data, significantly simplifying the interpretation of results and ensuring the functionality of the co-simulation tool with access to limited but essential data.

For the simulator to function correctly, the data from the SS must include three essential characteristics: the SS coordinates (in latitude and longitude format), the SS installed power (in kVA or kW), and the SS available capacity (in percentage, kVA or kW). With those fields, the process starts with identifying the nearest SS to each aggregated recharging site identified in Stage 2, based on a threshold distance (typically less than 300 meters). Subsequently, the co-simulation tool identifies the near SSs with available capacity to meet the power requirements of each aggregated recharging site, incorporating a 10% safety margin on the available capacity of each substation. The output of Option 1 is the selected SSs, ordered according to the shortest distance to each aggregated recharging site, which is fundamental for Stage 4.

Despite being a straightforward approach to interpret and operate, Option 1 has some limitations. It does not consider other typical power grid constraints beyond the capacity of the secondary substations, such as cables, variable loads, lines, and voltage/current limits. Therefore, Option 2 was developed precisely to address these points.

2.3.2 Option 2: Hosting Capacity and Considering Low Voltage Grid

The second option is to use a power grid simulation tool to analyse and simulate the behaviour of the local distribution network. Our research has shown that the Python library Panda Power is the most suitable solution. Panda Power [14] is an easy-to-use open-source tool for modelling, analysing and optimising power systems with a high degree of authenticity. Therefore, this tool is responsible for simulating the conditions of the power grid and modelling the production, distribution and consumption of electricity for this option 2. As input, it integrates historical measurements of voltage, active and reactive power from specific SSs, as well as photovoltaic data and cable characteristics.

The ultimate goal of this development is to represent the conditions of the network elements and their simulation results for active and reactive power, voltage, load utilisation, etc. Additionally, the aim is to analyse the impact of EVSEs while assessing the flexibility potential of EVs based on historical data and simulated distribution network conditions.

The core of this second approach is a matrix that manages information, operates on interconnected traffic and electrical grid layers and on which mathematical operations are applied. EVSEs serve as a bridge between these layers, with the number of EVs influencing network utilisation. However, before inputting the data into the matrix, it needs to be cleaned by removing extraneous data/outliers and adding missing values. The data needs to be at the same time intervals and linked to other related information to provide more in-depth insights. Figure 7 presents an overview of this second option simulation procedure.

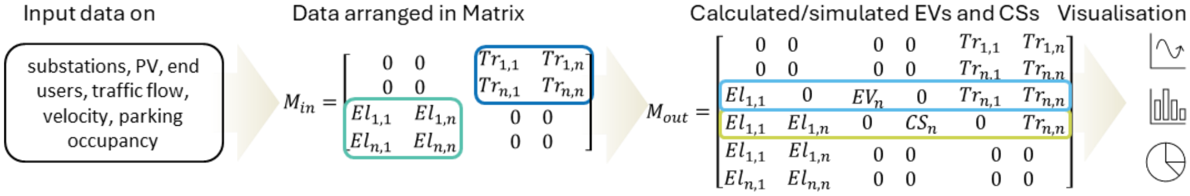


Figure 7 – Overview of Stage 3's Option 2 simulation procedure.

This matrix consists of 3 dimensions, where the rows represent each element of the simulation: from the point of view of the distribution network, these can be substations, installed photovoltaic systems and end users, for example; from the point of view of the traffic layer, these can be roads and parking lots. The variables describing the state of these elements are organised in columns. These variables can be power, voltage, and traffic flow, among others. Consequently, the number of rows and columns is not fixed but depends on the characteristics of each use case. Finally, the third dimension of the matrix (depth) represents the time axis. Each depth level represents a new time interval, and the number of levels depends on this interval and the simulation's sampling time. For instance, if an entire week were simulated in 15-minute intervals, this matrix would have 672 levels. Therefore, it is crucial to wisely decide which Stage 3 option to adopt, considering the characteristics of each alternative.

2.4 Stage 4: Selection of EVSE's location, number and rated power

Upon obtaining the results from Stages 1, 2, and 3, the tool progresses to Stage 4, tasked with selecting the optimal location, the number, and the rated power of each EVSE to be installed. For this, it is essential to input the aggregated recharging sites data from Stage 2 (consisting of aggregated locations, their corresponding peak power values, and the maximum number of EVs recharging simultaneously), as well as the selected SSs and ultimate POIs from Stage 3. Additionally, information about available EVSEs on the market for installation, including their maximum power, number of connectors, and cost, must be provided. It is also possible to introduce constraints such as general infrastructure installation costs, the maximum number of EVSEs per location type, and other relevant factors. Figure 8 presents the schematic for Stage 4 architecture.

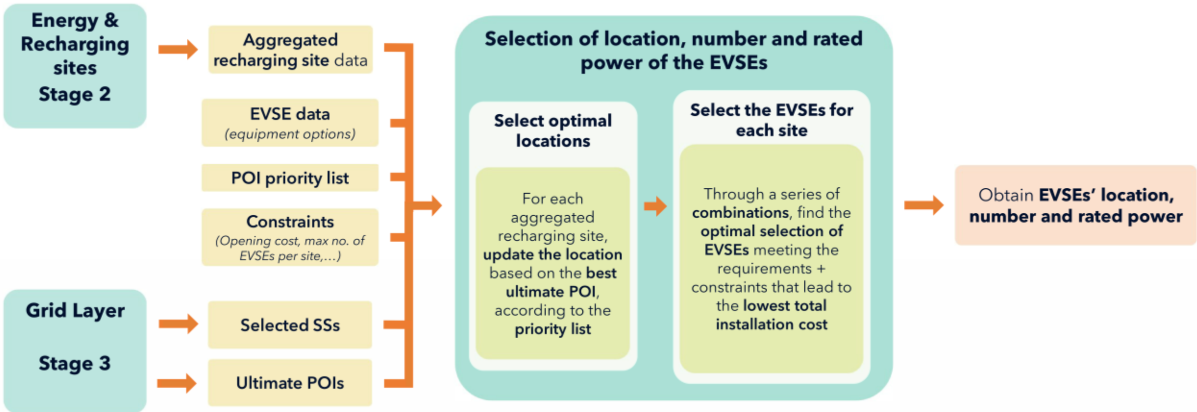


Figure 8 – Overview of Stage 4 architecture.

Following the architecture presented in Figure 8, one can see that Stage 4 starts with selecting the optimal locations according to the priority list. This list indicates the sequence for choosing the optimal locations from the ultimate POIs. For example, city administrations may stipulate that EVSEs should be placed in parking lots first and only then in office buildings rather than in other areas such as super-markets or shopping centres. This list is a crucial input and should be adjusted to reflect the unique characteristics of each city.

Having defined all the locations, the most complex step of the process begins: choosing the best combination of EVSEs for each location. That is a complex task as various requirements need to be considered, namely the worst-case scenario (defined by the peak power value and the maximum number of EVs simultaneously recharging), as well as the constraints that can be applied, such as the maximum number of EVSEs per location type. Generally, there are physical limitations on sites that prevent or facilitate the installation of EVSEs, which is why it is essential to consider this information in the co-simulation tool. The selection is performed by creating a series of potential *combinations* of different EVSEs per location to identify the option that offers the lowest total installation cost while meeting all the requirements and constraints. Additionally, if any optimal location corresponds to an existing charging station, the correspondent resources are accounted for in this Stage 4 selection process.

Consider a practical example: Suppose there are three EVSE options: 11kW - 1 connector, 22kW - 2 connectors and 43kW - 2 connectors, and a charging site that requires 55kW peak power and 4 EVs recharging at once. In this example, the best options would be two 22kW EVSEs + one 11kW EVSE (55kW and five connectors total), one 22kW EVSE + one 43kW EVSE (65kW and four connectors total), or even five 11kW EVSEs (55kW and five connectors total). All of these options meet the requirements, and assuming no other constraint is added, the ultimate choice would fall on the option with the lowest installation cost.

3. Simulation Example: Lisbon, Portugal case

This section presents a simulation example to illustrate the successful operation of the proposed co-simulation platform. Subsection 3.1 presents the model assumptions and the main considerations taken, while subsection 3.2 provides the input data along with the results obtained, following the co-simulation platform's stages.

3.1 Main considerations and model assumptions

For this example, it was considered an area within the city of Lisbon, Portugal, defined by the polygon presented in Equation (1). It was chosen for its familiarity with the INESC-ID team and for having all the necessary input information for this demonstration.

polygon = Polygon([
(38.69928634117295, -9.178085361403708),
(38.72164442859689, -9.17580833377256),
(38.73718732140661, -9.161134155437464),
(38.74379819328395, -9.137478368041014),
(38.7413315216153, -9.0970611275881),
(38.71374833136723, -9.114455088659387),
(38.70279105095467, -9.139628895038078),]) (1)

The simulation involved 1000 EVs over seven days. The Clustering approach was selected, and the automatic option for choosing the number of aggregated recharging sites was also considered, with the input range set at (0, 100). For Stage 3 inputs, option one was utilised, with the SS data obtained from [15]. Table 1 provides a summary of the main model assumptions.

Table 1 – Summary of main considerations for the present example.

Stage 1 choices and inputs	Considered region	Lisbon, Portugal
	Number of simulated EVs	1000 EVs for 7 days
Stage 2 choices and inputs	Selected method	Method 2 - Clustering approach
	Selected option for determining the number of locations	Automatic option, with *range (0,100)* clusters
Stage 3 choices and inputs	Selected Option	Option 1: Hosting Capacity and Secondary Substation Data
	Input data	E-REDES Open Data [15]

3.2 Considered inputs and obtained results

Starting with the selection of the POIs, the categories chosen are presented in Equation (2), with the probabilities distributed as follows: *'endpoint' - 0.1, 'building' - 0.25, 'amenity' - 0.25, 'shop' - 0.3, and 'tourism' - 0.1.*

```
tags = {'amenity': ['restaurant', 'university', 'school', 'parking', 'taxi', 'veterinary',
'cinema', 'casino', 'charging_station'], 'building': True, 'shop': True, 'tourism':True}
```
(2)

The identified POIs are displayed in Figure 9, corresponding to 4036 points, of which 710 are buildings, 708 are restaurants, 351 are parking lots, 108 are charging stations, and 90 are supermarkets.

Figure 9 – Identified POIs according to the selected tags, for the desired region.

Having found the POIs, the traffic simulator also requires the user profiles. The EV profiles considered for this example are listed in Table 2, and the behaviour profiles are provided in Table 3. It should be noted that the characteristics of both profiles are based on Deliverable D2.4 [7], but adjusted and updated for the case of Lisbon, considering the relevant information provided in [16], [17] and [18].

Table 2 – Summary of the characteristic fields for the defined EV profiles.

EV Profile	Tesla Model 3	Renault Zoe	BMW IX1	Volvo EX30
Profile probability [0-1]	0.4	0.2	0.2	0.2
Battery size [kWh]	58	52	65	49
Vehicle weight [kg]	2200	2000	2400	2200
Acceleration efficiency [0-1]	0.67	0.67	0.67	0.67
Deceleration efficiency [0-1]	0.91	0.91	0.91	0.91
Uphill efficiency [0-1]	0.74	0.74	0.74	0.74
Downhill efficiency [0-1]	0.73	0.73	0.73	0.73
'Mean velocity, Consumption' [km/h, kWh/100km]	'46.5,14.0'	'46.5,17.0'	'46.5,17.0'	'46.5,18.0'
Initial SoC [kWh]	Randomly generated *([0-1] × Battery size)*			

Table 3 – 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	0.14	[10, 12, 16.5, 22], [ ]	0	*Yes, with 50% chance when parked more than 4h*
	Employer	0.14	[8, 12, 14, 18.5], [ ]	0.1	
Shift	Worker	0.12	[15, 23], [18, 20]	0.8	
Typical worker	Single	0.18	[8, 17, 18], [12, 18]	0.4	
	Family	0.22	[8, 9, 17, 18], [9, 12]	0.7	
	Couple	0.2	[8, 12, 13, 17, 19], [12, 23]	0.1	

An interesting point is the simplicity of defining travel times for the different simulated days. For example, the behaviour profile *Company - Fleet* is characterised by *travel_time = ([10, 12, 16.5, 22], […])*, indicating that it exclusively engages in travel during the week. Another point is that the initial State-of-Charge (SoC) field is updated randomly upon creating user profiles, thus ensuring greater diversity in the combined profiles. For this example, 1000 EV users were simulated over seven days, resulting in the routes depicted in Figure 10.

After having the routes, the identification of the most traffic streets takes place, followed by the identification of the POIs near those roads. Figure 11 displays the most traffic streets, identified in blue, with the nearest POIs corresponding to 1230 points.

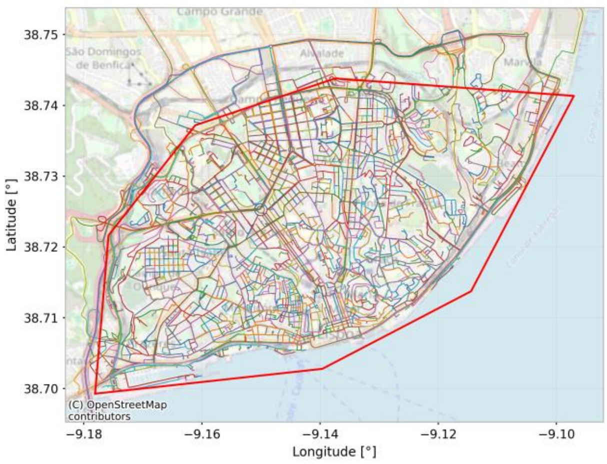


Figure 10 – Resulting routes from Traffic Simulator.

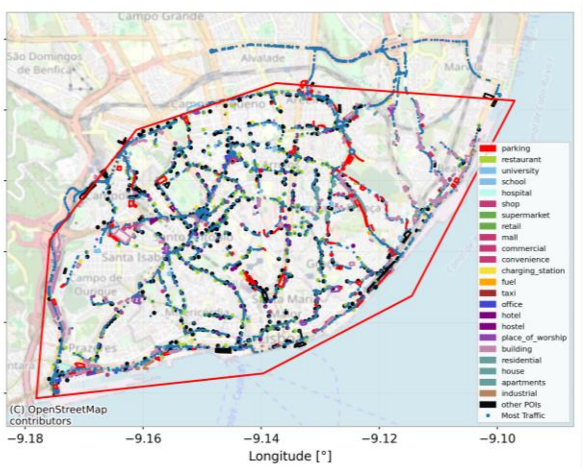
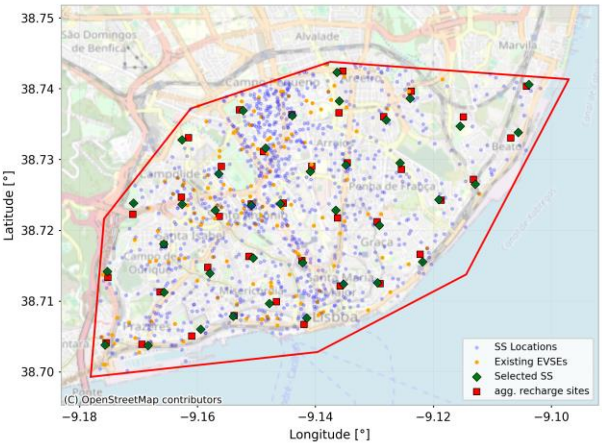


Figure 11 – Most traffic streets and selected POIs.

The results from Stage 1 undergo processing and cleaning in the first step of Stage 2. Following this, Step 2 automatically identifies **39** as the **optimal number of aggregated recharging sites**. Subsequently, it locates 622 POIs within a 150-meter radius of these recharging sites, which are merged with the identified POIs from Stage 1, eliminating duplicates and resulting in a total of 1852 combined POIs.

Having the combined POIs, the aggregated recharging sites data and the SS data, Stage 3 starts by looking for the SSs that are close to the aggregated recharge sites and that have available capacity, as displayed in Figure 12 along with the existing EVSE locations. It then finds the ultimate POIs within 200 metres of the selected SS, as shown in Figure 13, resulting in 781 points as options for installing EVSEs.



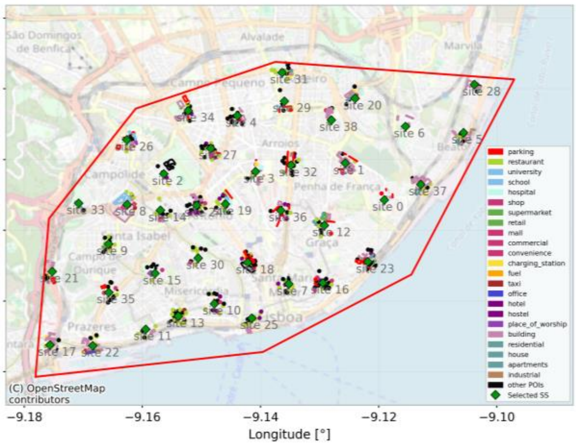


Figure 12 – Aggregated recharge sites from Stage 2 and selected SSs from Stage 3.

Figure 13 – Selected SSs and ultimate POIs from Stage 3.

Finally, Stage 4 start by identifying the optimal locations for each recharge site through the evaluation of the priority list defined in Equation (3), favouring nearby EVSE installations.

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

The EVSE data was obtained by analysing the most commonly operated EVSEs in Portugal [19]. 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 a given site (based on typical values for Portugal [19]) and the opening cost for new locations (non-existing EVSEs). Table 4 provides a summary of the inputs for Stage 4.

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

EVSE data	**Constraints**	
	#1	**#2**
# Define EVSE options and costs for specific POI type *specific_evse_options = {* ***'parking', 'supermarket', 'mall', 'office', 'charging_station', 'industrial':*** *{* *'11kW': {'power': 11, 'ports': 1, 'cost': 3000},* *'22kW': {'power': 22, 'ports': 2, 'cost': 5000},* *'43kW': {'power': 43, 'ports': 2, 'cost': 8000}* *},* *}* *# Define EVSE options and costs for remaining POI type* *default_evse_options = {* *'3.7kW': {'power': 3.7, 'ports': 1, 'cost': 1000},* *'7.2kW': {'power': 7.2, 'ports': 1, 'cost': 2000}* *}*	*# Define the maximum number of EVSEs for each site type* *max_evse_counts = {* *'parking': 15,* *'hospital': 20,* *'supermarket': 10,* *'mall': 12,* *'office': 8,* *'charging_station': 20,* *'industrial': 5* *}*	*# Additional cost for opening a new EVSE location* *opening_cost = 2000*

Figure 14 illustrates the results of Stage 4 regarding the optimal selected locations and Table 5 provides the characteristics of each recharging site, specifically the type of site, the corresponding selected combination of EVSEs and the cost of installation.

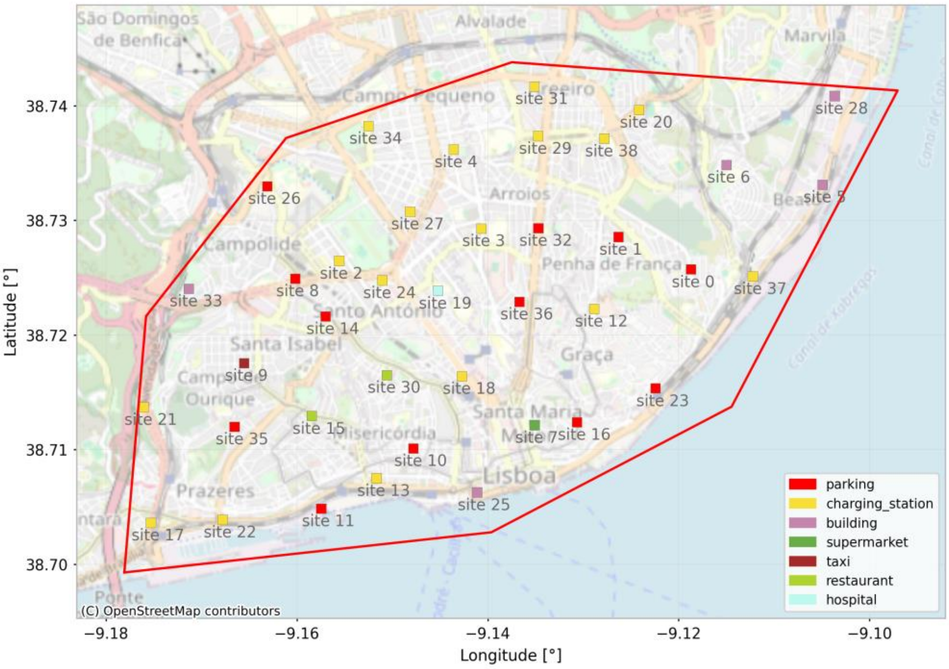


Figure 14 – Co-simulation final EVSE locations.

Table 5 – Characteristics of the final EVSE locations.

Recharge site	Best Combination	Cost [€]	Recharge site	Best Combination	Cost [€]
0 - parking	1 '11kW', 5 '22kW'	30000	20 - charging_station	5 '22kW'	25000
1 - parking	1 '11kW', 7 '22kW'	40000	21 - charging_station	2 '22kW'	10000
2 - charging_station	3 '22kW'	15000	22 - charging_station	1 '11kW', 2 '22kW'	13000
3 - charging_station	6 '22kW'	30000	23 - parking	6 '22kW'	32000
4 - charging_station	5 '22kW'	25000	24 - charging_station	1 '11kW', 2 '22kW'	13000
5 - building	15 '3.7kW'	17000	25 - building	12 '3.7kW'	14000
6 - building	16 '3.7kW'	18000	26 - parking	5 '22kW'	27000
7 - supermarket	3 '22kW'	17000	27 - charging_station	8 '22kW'	40000
8 - taxi	6 '3.7kW'	8000	28 - building	11 '3.7kW'	13000
9 - taxi	10 '3.7kW'	12000	29 - charging_station	Nearby EVSE with sufficient capacity	0
10 - parking	1 '11kW', 3 '22kW'	20000	30 - restaurant	11 '3.7kW'	13000
11 - building	9 '3.7kW', 2 '7.2kW'	15000	31 - charging_station	4 '22kW'	20000
12 - charging_station	1 '11kW', 3 '22kW'	18000	32 - parking	1 '11kW', 6 '43kW'	53000
13 - taxi	9 '3.7kW'	11000	33 - building	4 '3.7kW'	6000
14 - parking	1 '11kW', 5 '22kW'	30000	34 - charging_station	1 '11kW', 4 '22kW'	23000
15 - restaurant	3 '3.7kW', 4 '7.2kW'	13000	35 - parking	5 '22kW'	27000
16 - parking	7 '22kW'	37000	36 - parking	5 '22kW'	27000
17 - charging_station	Nearby EVSE with sufficient capacity	0	37 - charging_station	5 '22kW'	25000
18 - charging_station	1 '11kW'	3000	38 - charging_station	4 '22kW'	20000
19 - hospital	12 '3.7kW'	14000	-	-	-

4. Conclusions

This deliverable D3.4 provides a high-level overview of the definition and development of a City-Level Co-simulation platform for vehicle-to-everything (V2X). The methodology applied comprises four main stages: Stage 1 is primarily responsible for the traffic simulation of the electric vehicles (EVs), while Stage 2 processes the energy requirements from the simulated vehicles and defines typical recharging sites. Stage 3, on the other hand, is responsible for integrating the grid network, and Stage 4 processes the results of the previous stages and estimates the number of electric vehicle supply equipment (EVSEs), their optimal locations, and the rated power of each equipment.

One general conclusion is the importance of carefully selecting Stages' options and providing essential input information to utilise the platform effectively. Specifically:

- For Stage 1, it is crucial to specify the application area for the platform by defining its coordinate boundary (polygon). Additionally, it is necessary to select and tailor the number of EVs to be simulated according to each case study. Moreover, it is essential to input typical behaviour and EV profiles, as these serve as the foundation for the traffic simulator based on the TomTom API.
- For Stage 2, it is necessary to select the most appropriate recharging site aggregation method for the case study, from method 1 - distance threshold or method 2 - clustering approach. Furthermore, it needs to be decided whether a fixed number of EVSE locations is preferred or whether the platform should determine the optimal number of stations to minimise installation costs. The first option was developed to address the potential administrative constraints of each city.
- For Stage 3, it is crucial to select one of two options for integrating the grid layer. The options are as follows: Option 1 involves hosting capacity and secondary substation data, while Option 2 entails hosting capacity and considering low voltage grid. Option 1 guarantees the platform's functionality with access to accessible, still reduced data; Option 2 simulates the local network in detail, accounting for all limiting factors, such as substations, cable characteristics, and voltage/current constraints.
- Finally, Stage 4 needs the input of the characteristic data of the EVSEs to be installed, along with the priority list that defines the order in which the locations should be chosen. Furthermore, it is possible to include constraints related to the locations, such as the maximum number of EVSEs allowed in each location type or the extra cost of opening a new EVSE location.

The practical example provided for a region of Lisbon, Portugal, demonstrated the applicability of the co-simulation platform in a real-world context. In particular, the simulation revealed that 39 locations would be required to meet the demand of 1000 EV users. However, of these 39 locations, only 23 would be new, as the remainder correspond to existing locations in the region. Yet the simulation recommended increasing the capacity of 21 of these already existing locations, maintaining two unaltered.

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